Table of Contents - ESD

6. Earth Science Division (ESD)

6.a. Demographics

6.a.i. Principal Investigators (PIs)

6.a.i.1. Limitations of the data – ESD PIs

26,043 submitted proposals are included in the ROSES 2016-2021 database. Please see Appendix Table 1 to see which programs are included. The total number of proposals submitted and selected for each ROSES year and the total number of proposals submitted to each SMD Division cannot be reported due to the Office of the Chief Scientist's suppression guidelines. See *Yearbook Introduction Section 1.a.ii.1 Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information. The number of proposals rounded to the nearest hundred are included for these two circumstances to provide context. For the Earth Science Division, there are ~8,800 submitted proposals over all ROSES years: ~7,800 for ROSES 2016-2020 and ~1,000 for ROSES 2021.

Proposals with PIs who took the survey but selected "prefer not to answer" for all demographic survey questions:

- Submitted proposals: ESD 2016 - 2020: 8% | ESD 2021: 6%
- Selected proposals: ESD 2016 - 2020: 6% | ESD 2021: 5%

Unique identifiers in the dataset are not completely unique. Less than 1% of PIs of submitted ROSES 2016-2021 proposals have more than 1 unique ID in the NSPIRES system.

6.a.i.2. Gender – ESD PIs

ESD PIs: Submitted Gender - Plot

PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

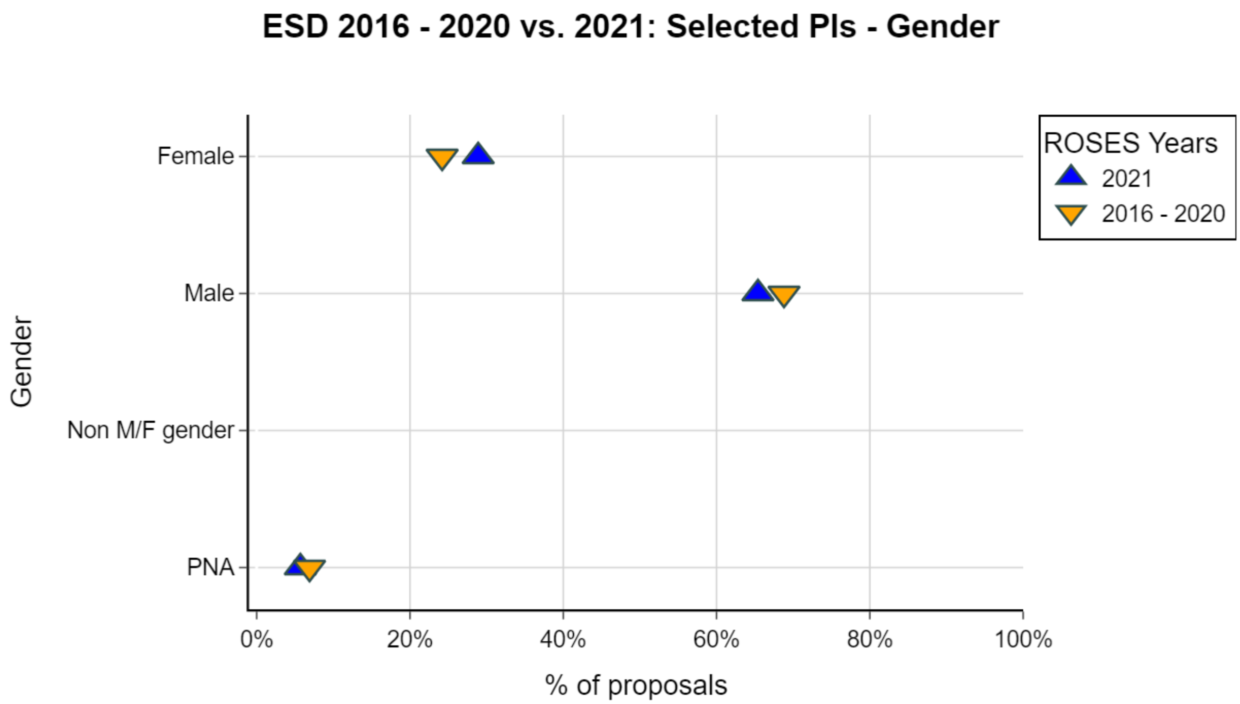
ESD PIs: Submitted Gender - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Gender

Gender	ESD 2016 - 2020	ESD 2021
Female	23%	26%
Male	69%	67%
Non M/F gender	NR	NR
PNA	8%	6%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

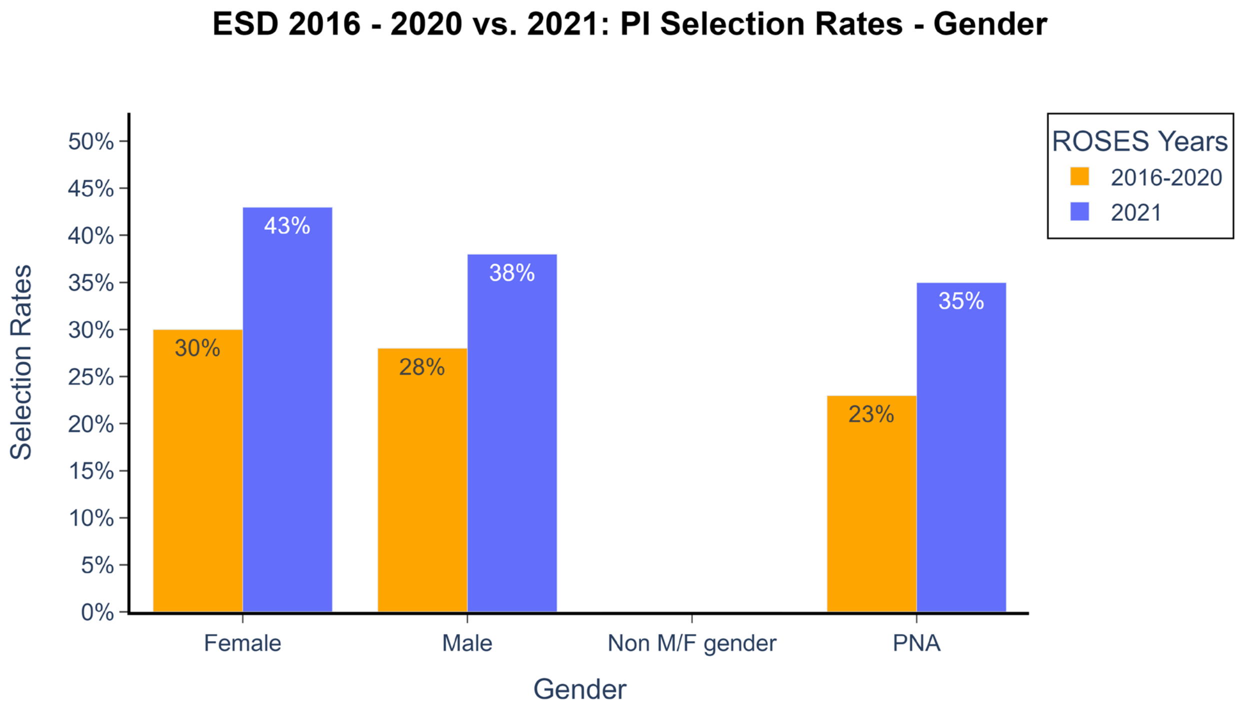
ESD PIs: Selected Gender - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Gender

Gender	ESD 2016 - 2020	ESD 2021
Female	24%	29%
Male	69%	65%
Non M/F gender	NR	NR
PNA	7%	6%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Gender Selection Rate - Bar Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: Non M/F gender (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Gender Selection Rate - Data Table

ESD 2016 - 2020 vs. 2021: PI Selection Rates - Gender

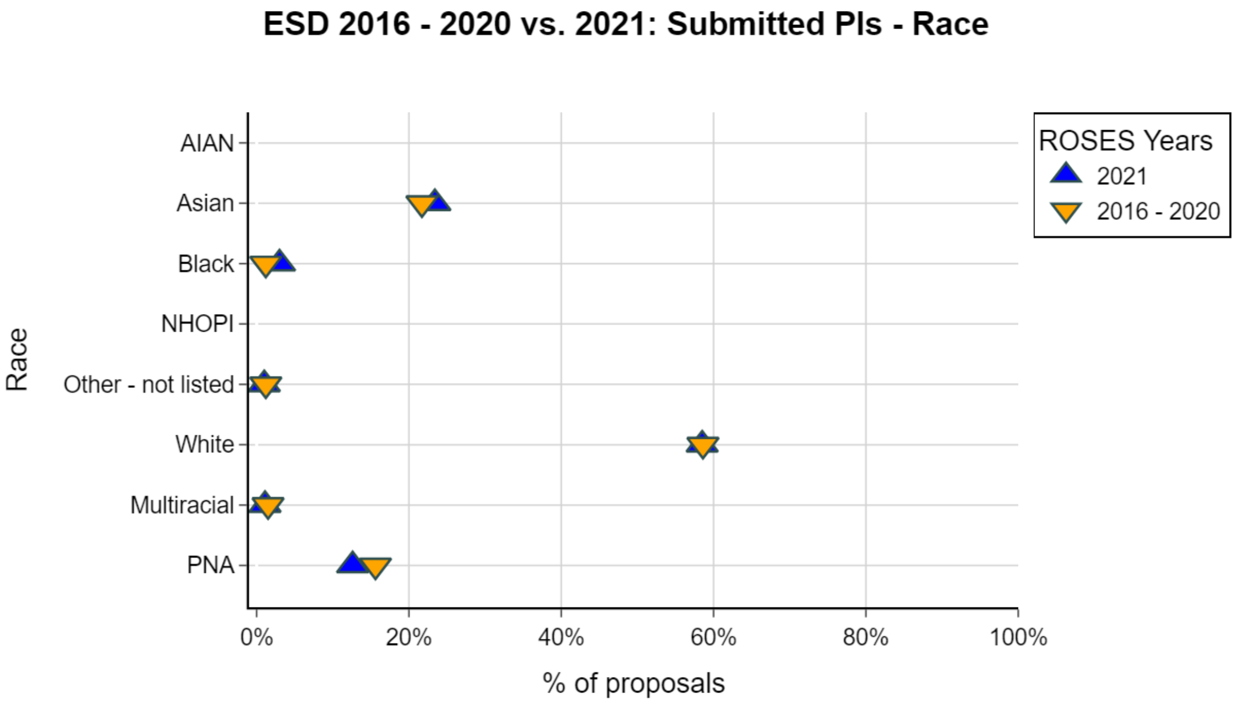
Gender	ESD 2016-2020	ESD 2016-2020 Response/All Genders	ESD 2021	ESD 2021 Response/All Genders
Female	30%	1.07	43%	1.1
Male	28%	1	38%	0.97
Non M/F gender	NR	NR	NR	NR
PNA	23%	0.82	35%	0.9
All Genders	28%	1	39%	1

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.3. Race – ESD PIs

6.a.i.2. Race – ESD PIs

ESD PIs: Submitted Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (All years), NHOPI (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

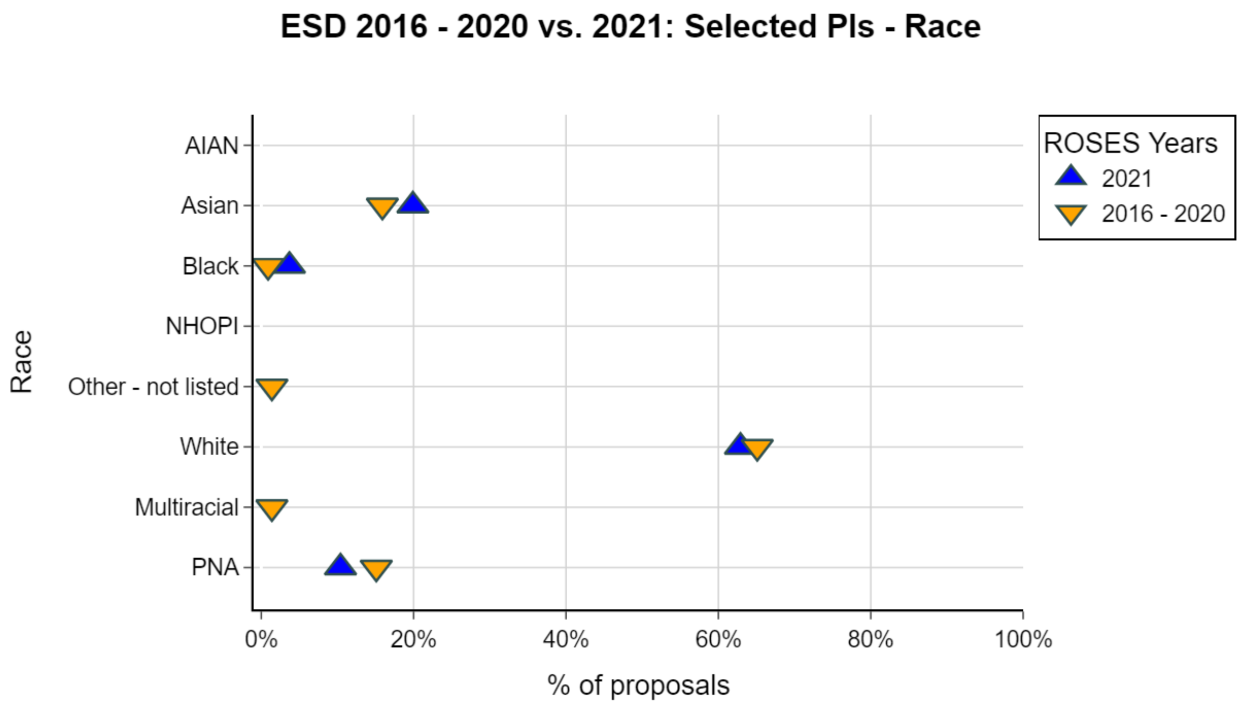
ESD PIs: Submitted Race - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Race

Race	ESD 2016 - 2020	ESD 2021
AIAN	NR	NR
Asian	22%	23%
Black	1%	3%
NHOPI	NR	NR
Other - not listed	1%	1%
White	59%	58%
Multiracial	2%	1%
PNA	16%	13%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (All years), NHOPI (All years), Other – not listed (ROSES 2021), Multiracial (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

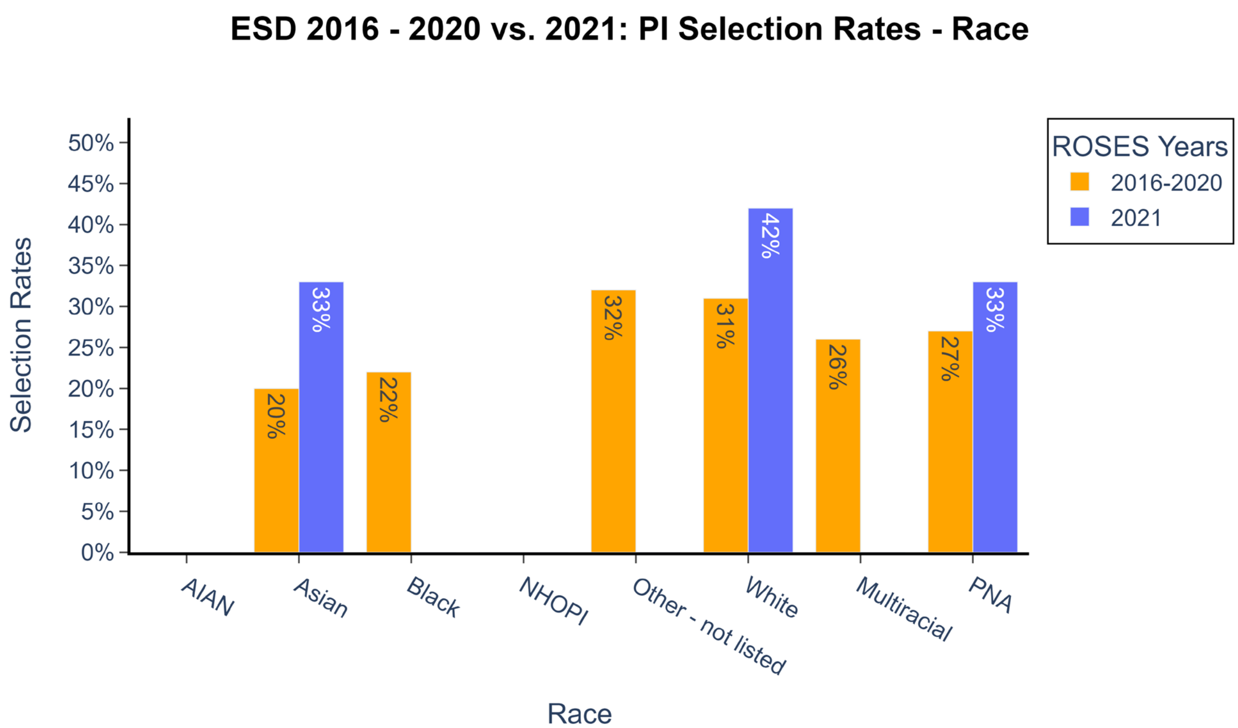
ESD PIs: Selected Race - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Race

Race	ESD 2016 - 2020	ESD 2021
AIAN	NR	NR
Asian	16%	20%
Black	< 1%	4%
NHOPI	NR	NR
Other - not listed	1%	NR
White	65%	63%
Multiracial	1%	NR
PNA	15%	10%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Race Selection Rate - Bar Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: AIAN (All years), Black (ROSES 2021), NHOPI (All years), Other – not listed (ROSES 2021), Multiracial (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Race Selection Rate - Data Table

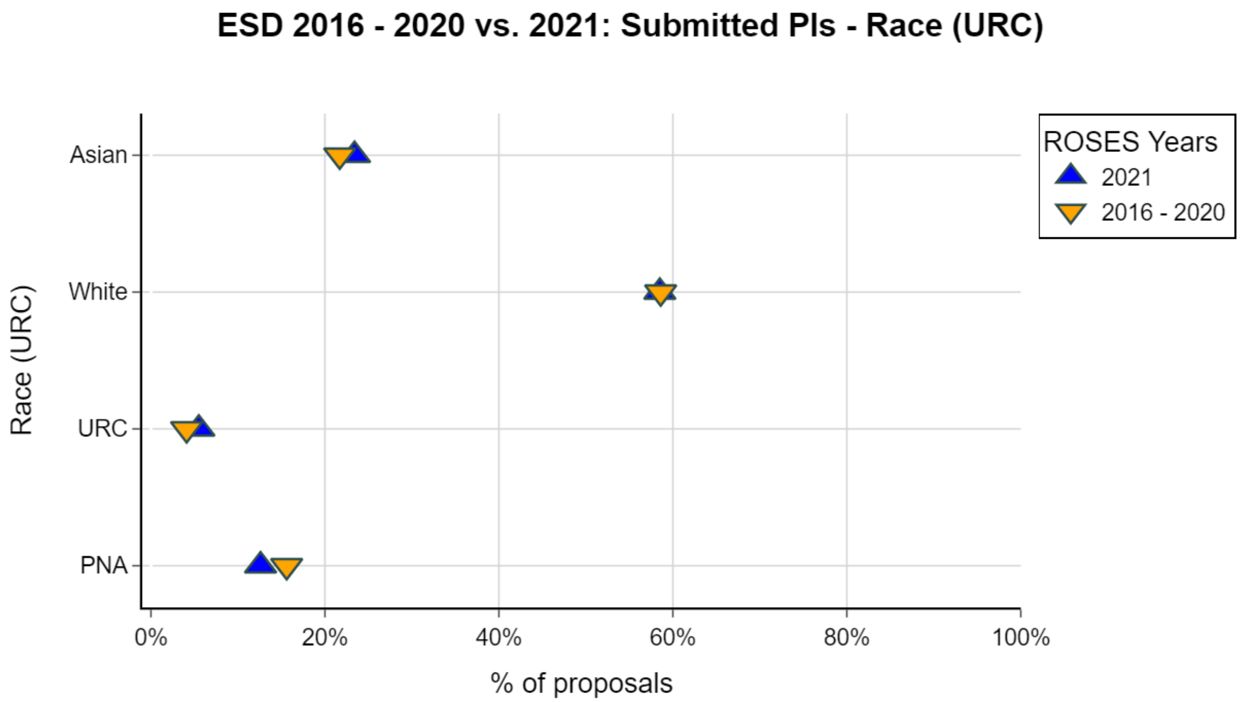
ESD 2016 - 2020 vs. 2021: PI Selection Rates - Race

Race	ESD 2016-2020	ESD 2016-2020 Response/All Races	ESD 2021	ESD 2021 Response/All Races
AIAN	NR	NR	NR	NR
Asian	20%	0.71	33%	0.85
Black	22%	0.79	NR	NR
NHOPI	NR	NR	NR	NR
Other - not listed	32%	1.14	NR	NR
White	31%	1.11	42%	1.08
Multiracial	26%	0.93	NR	NR
PNA	27%	0.96	33%	0.85
All Races	28%	1	39%	1

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.4. Race using Under-Represented Community (URC) – ESD PIs

ESD PIs: Submitted Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

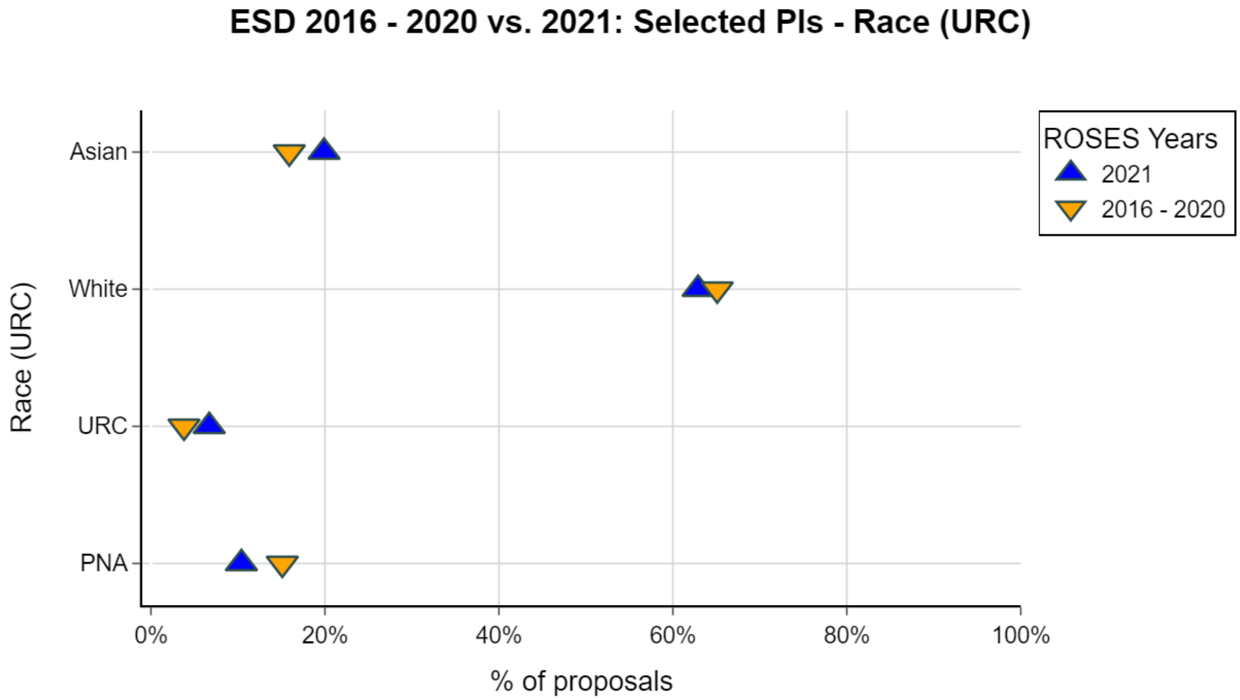
ESD PIs: Submitted Race (URC) - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Race (URC)

Race (URC)	ESD 2016 - 2020	ESD 2021
Asian	22%	23%
White	59%	58%
URC	4%	6%
PNA	16%	13%

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

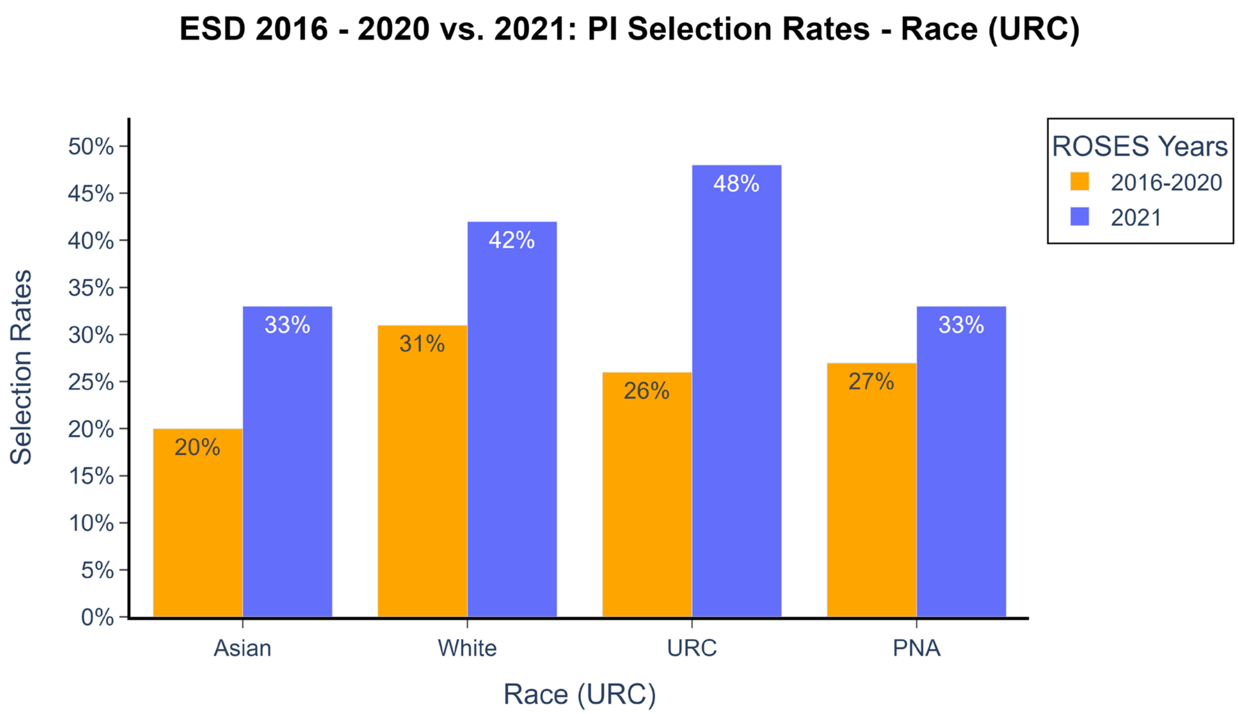
ESD PIs: Selected Race (URC) - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Race (URC)

Race (URC)	ESD 2016 - 2020	ESD 2021
Asian	16%	20%
White	65%	63%
URC	4%	7%
PNA	15%	10%

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Race (URC) Selection Rate - Bar Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

ESD PIs: Race (URC) Selection Rate - Data Table

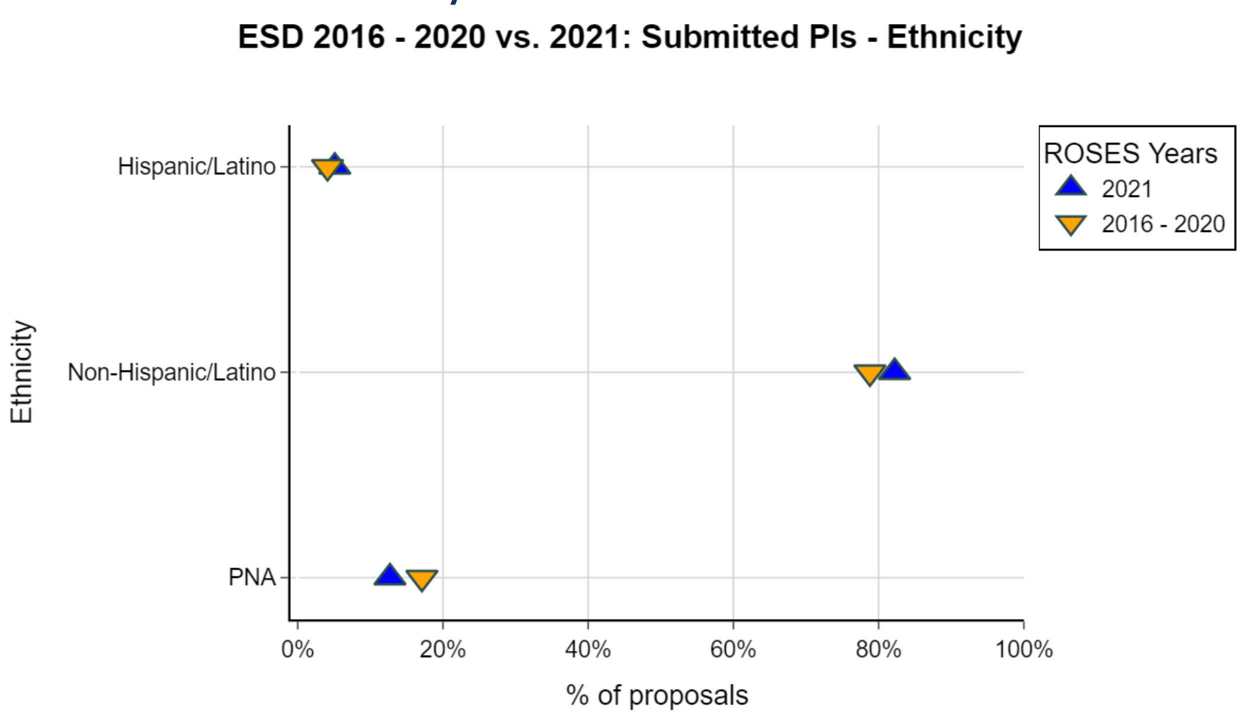
ESD 2016 - 2020 vs. 2021: PI Selection Rates - Race (URC)

Race (URC)	ESD 2016-2020	ESD 2016-2020 Response/All Races (URC)	ESD 2021	ESD 2021 Response/All Races (URC)
Asian	20%	0.71	33%	0.85
White	31%	1.11	42%	1.08
URC	26%	0.93	48%	1.23
PNA	27%	0.96	33%	0.85
All Races (URC)	28%	1	39%	1

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.5. Ethnicity – ESD PIs

ESD PIs: Submitted Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

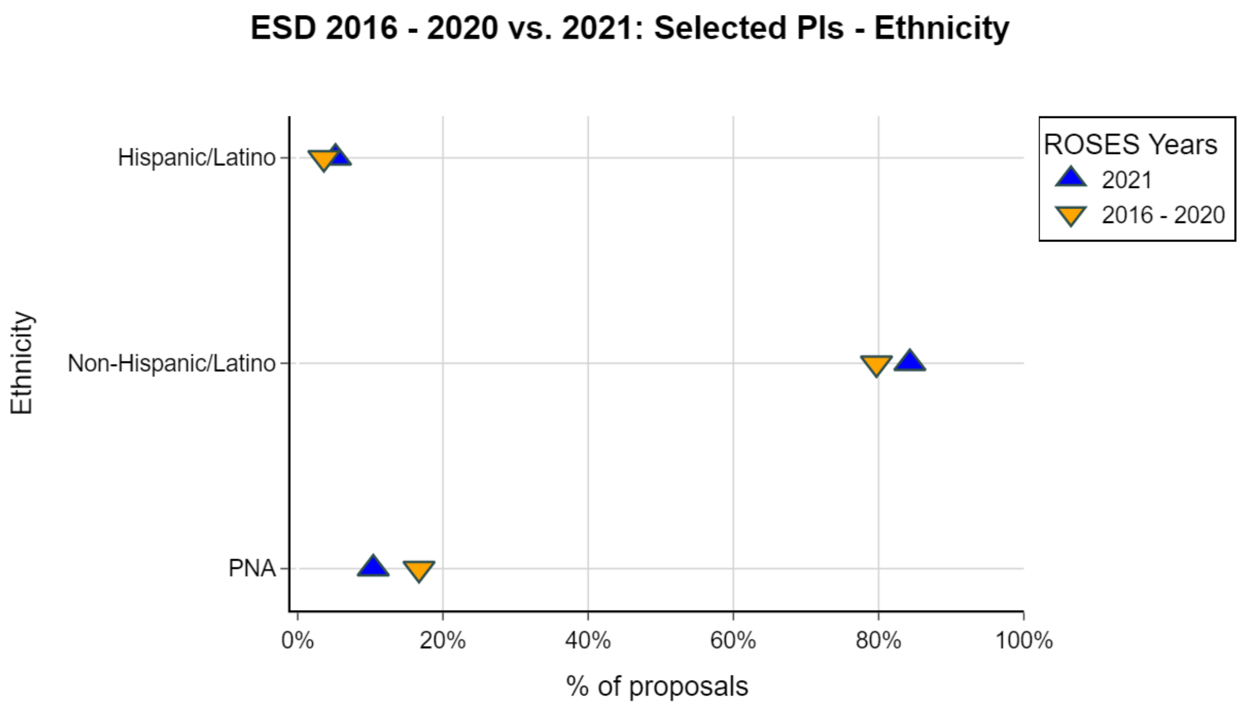
ESD PIs: Submitted Ethnicity - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Ethnicity

Ethnicity	ESD 2016 - 2020	ESD 2021
Hispanic/Latino	4%	5%
Non-Hispanic/Latino	79%	82%
PNA	17%	13%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Ethnicity - Data Table

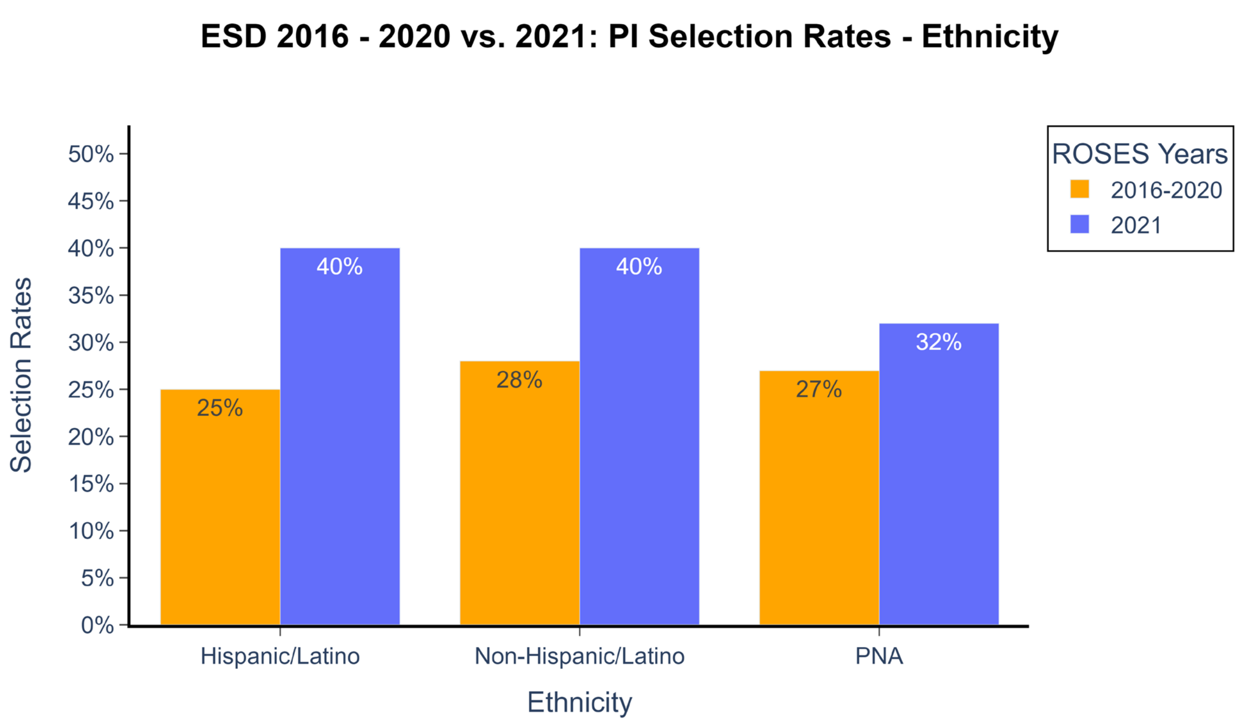
d

ESD 2016 - 2020 vs. 2021: Selected PIs - Ethnicity

Ethnicity	ESD 2016 - 2020	ESD 2021
Hispanic/Latino	4%	5%
Non-Hispanic/Latino	80%	84%
PNA	17%	10%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Ethnicity Selection Rate - Bar Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

ESD PIs: Ethnicity Selection Rate - Data Table

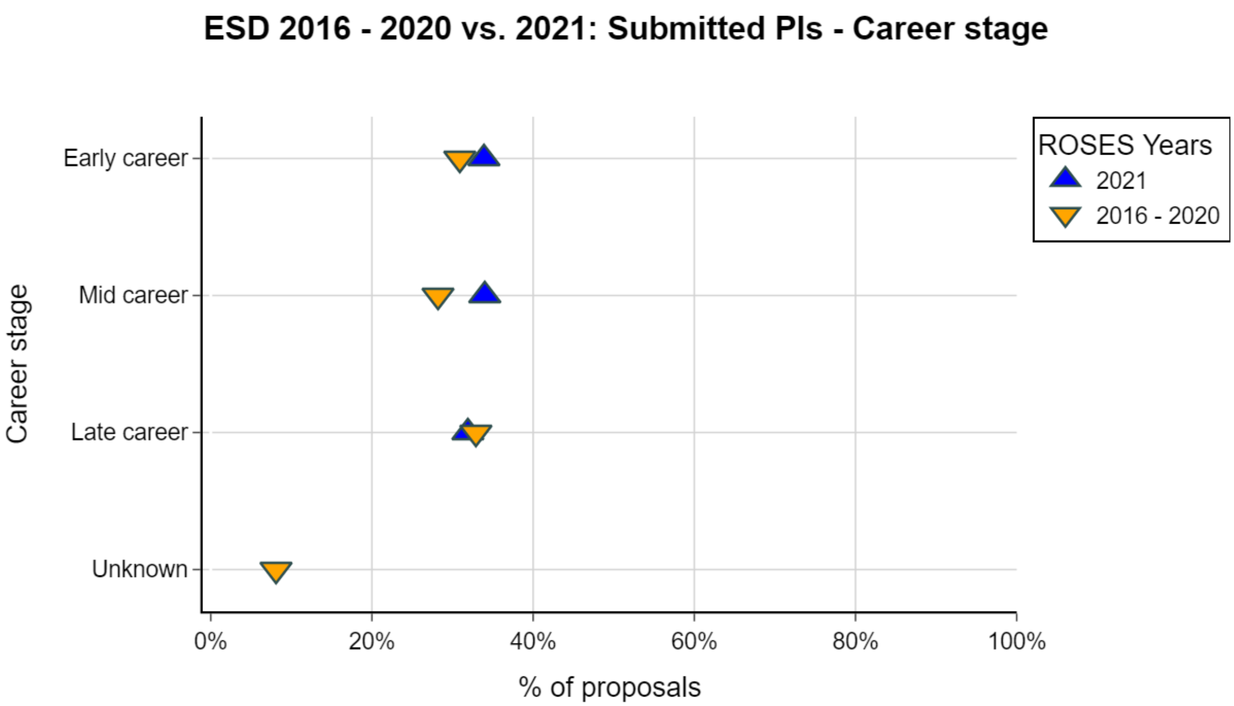
ESD 2016 - 2020 vs. 2021: PI Selection Rates - Ethnicity

Ethnicity	ESD 2016-2020	ESD 2016-2020 Response/All Ethnicities	ESD 2021	ESD 2021 Response/All Ethnicities
Hispanic/Latino	25%	0.89	40%	1.03
Non-Hispanic/Latino	28%	1	40%	1.03
PNA	27%	0.96	32%	0.82
All Ethnicities	28%	1	39%	1

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.6. Career Stage – ESD PIs

ESD PIs: Submitted Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Unknown (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

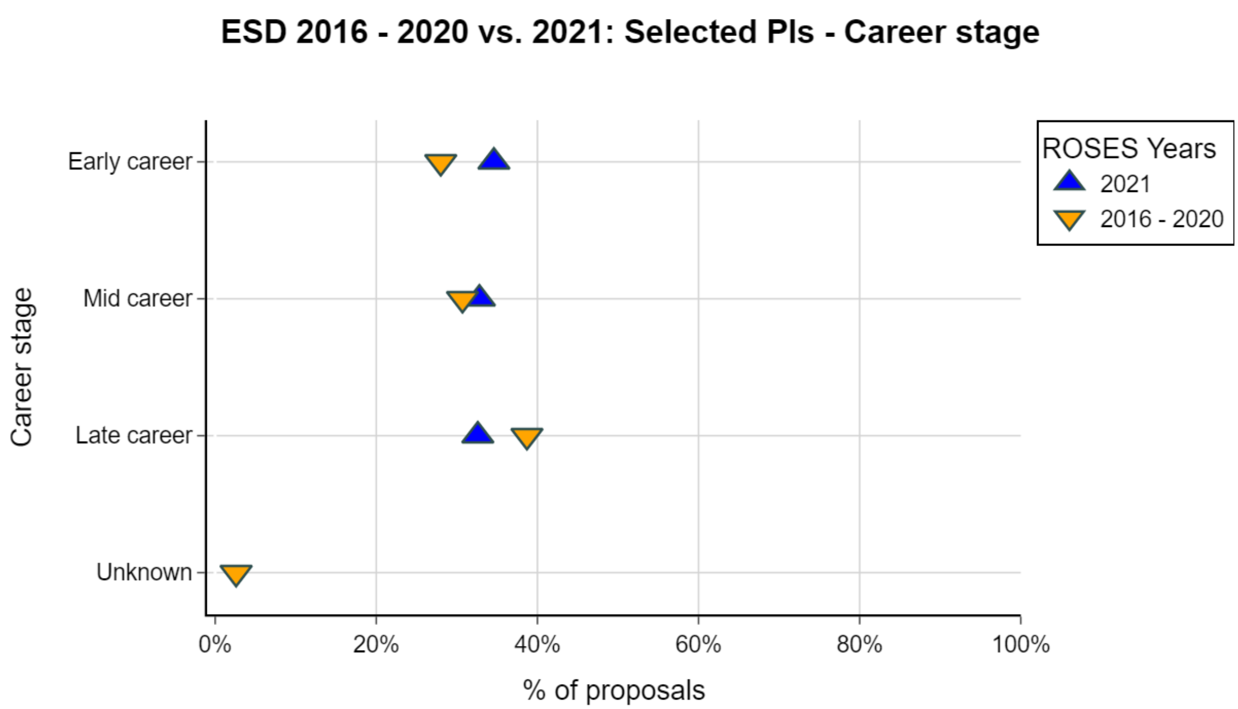
ESD PIs: Submitted Career Stage – Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Career stage

Career stage	ESD 2016 - 2020	ESD 2021
Early career	31%	34%
Mid career	28%	34%
Late career	33%	32%
Unknown	8%	NR

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Unknown (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

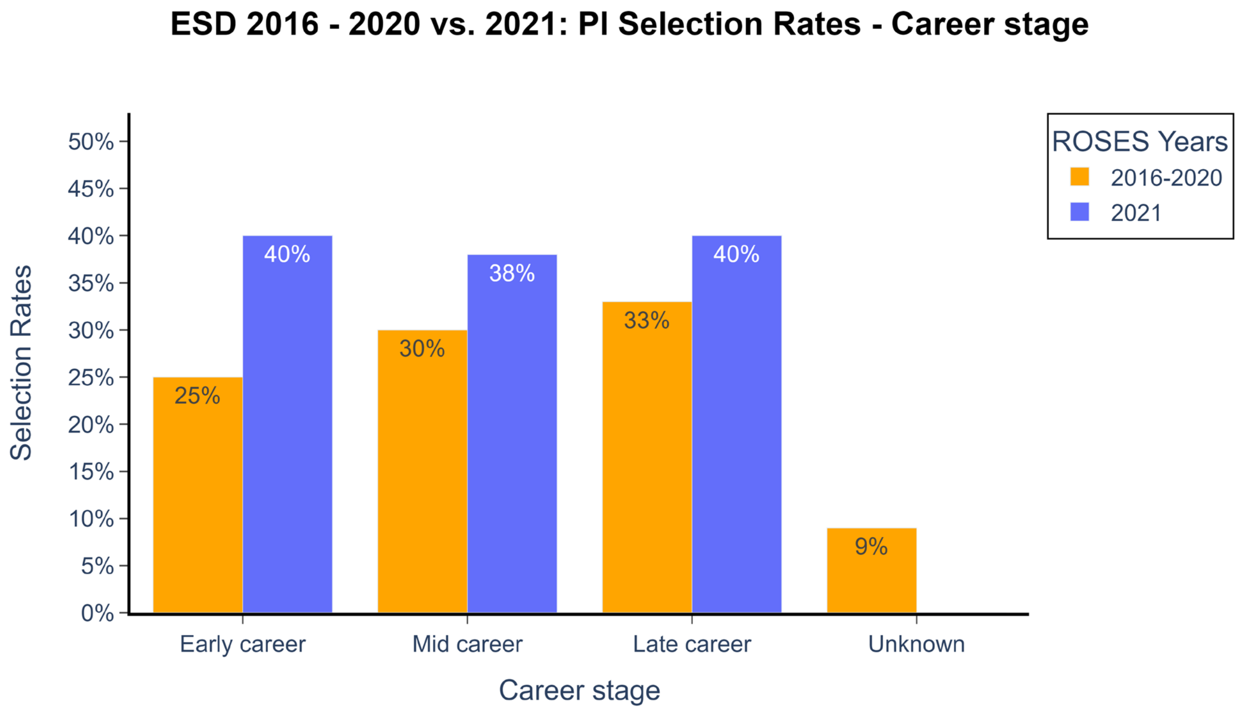
ESD PIs: Selected Career Stage - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Career stage

Career stage	ESD 2016 - 2020	ESD 2021
Early career	28%	35%
Mid career	31%	33%
Late career	39%	33%
Unknown	3%	NR

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Career Stage Selection Rate - Bar Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: Unknown (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Career Stage Selection Rate – Data Table

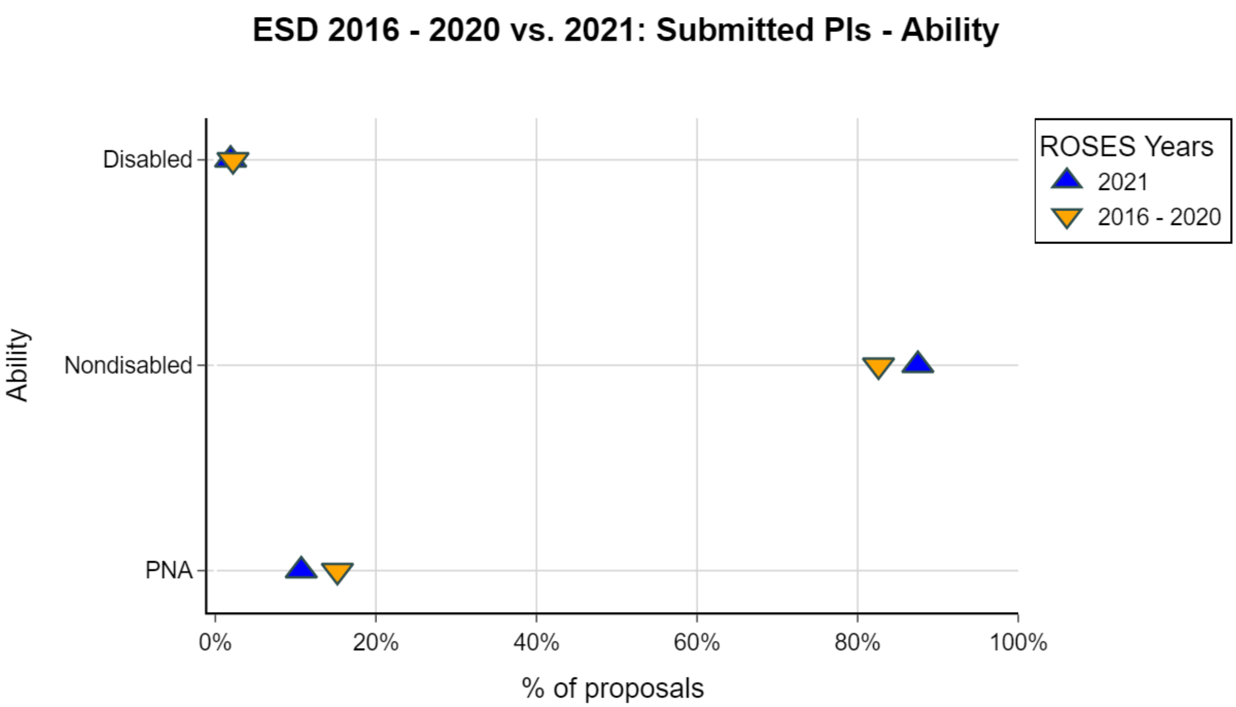
ESD 2016 - 2020 vs. 2021: PI Selection Rates - Career stage

Career stage	ESD 2016-2020	ESD 2016-2020 Response/All Career stages	ESD 2021	ESD 2021 Response/All Career stages
Early career	25%	0.89	40%	1.03
Mid career	30%	1.07	38%	0.97
Late career	33%	1.18	40%	1.03
Unknown	9%	0.32	NR	NR
All Career stages	28%	1	39%	1

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.7. Disability Status – ESD PIs

ESD PIs: Submitted Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

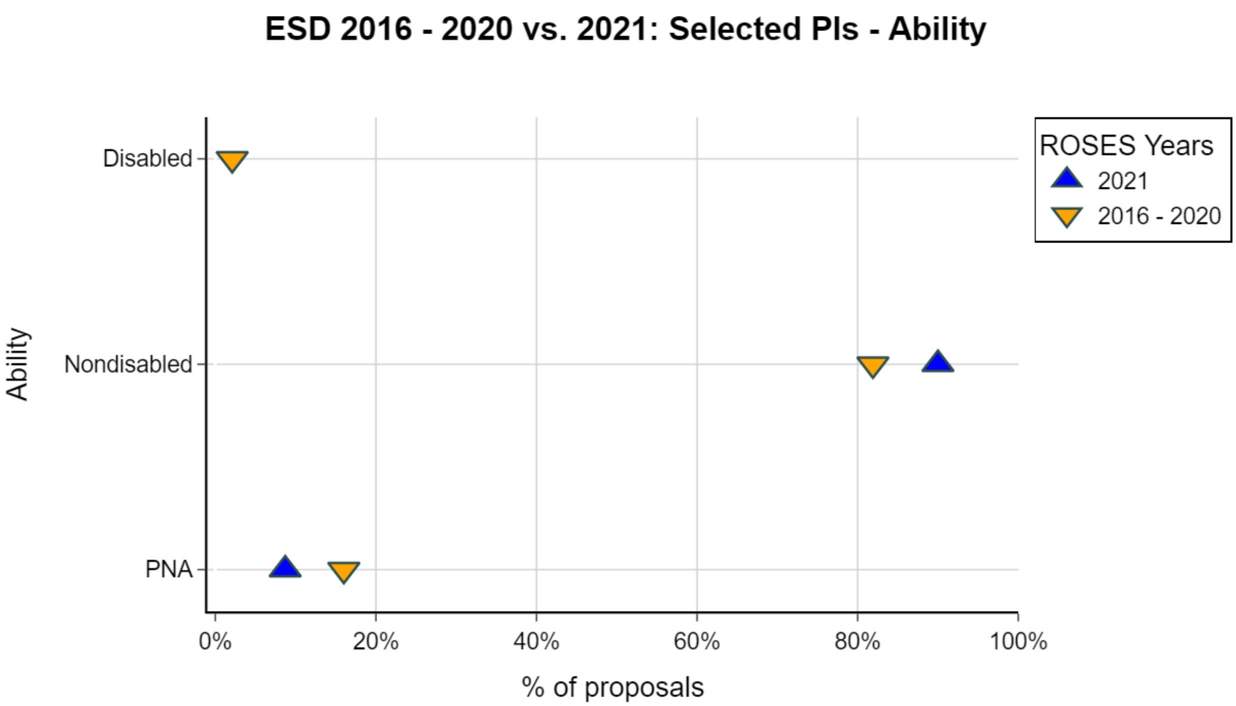
ESD PIs: Submitted Ability - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Ability

Ability	ESD 2016 - 2020	ESD 2021
Disabled	2%	2%
Nondisabled	83%	88%
PNA	15%	11%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Disabled (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

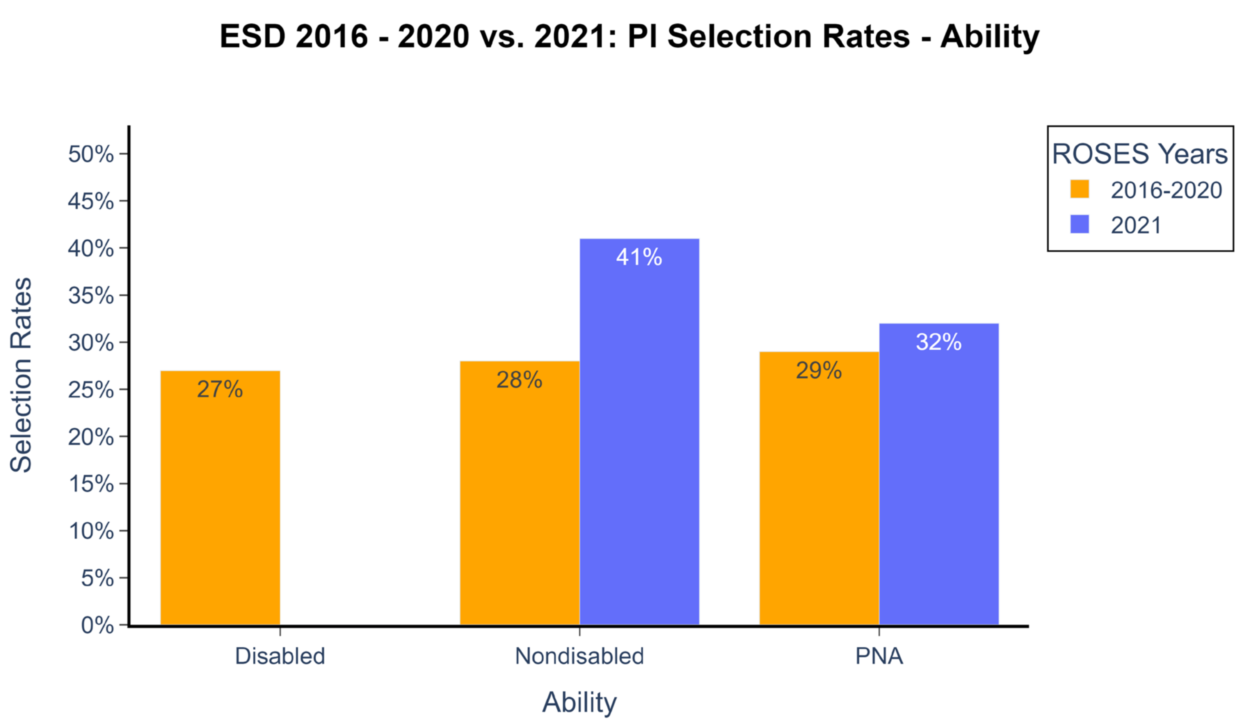
ESD PIs: Selected Ability - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Ability

Ability	ESD 2016 - 2020	ESD 2021
Disabled	2%	NR
Nondisabled	82%	90%
PNA	16%	9%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Ability Selection Rate - Bar Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group.

Suppressed categories: Disabled (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Ability Selection Rate - Data Table

ESD 2016 - 2020 vs. 2021: PI Selection Rates - Ability

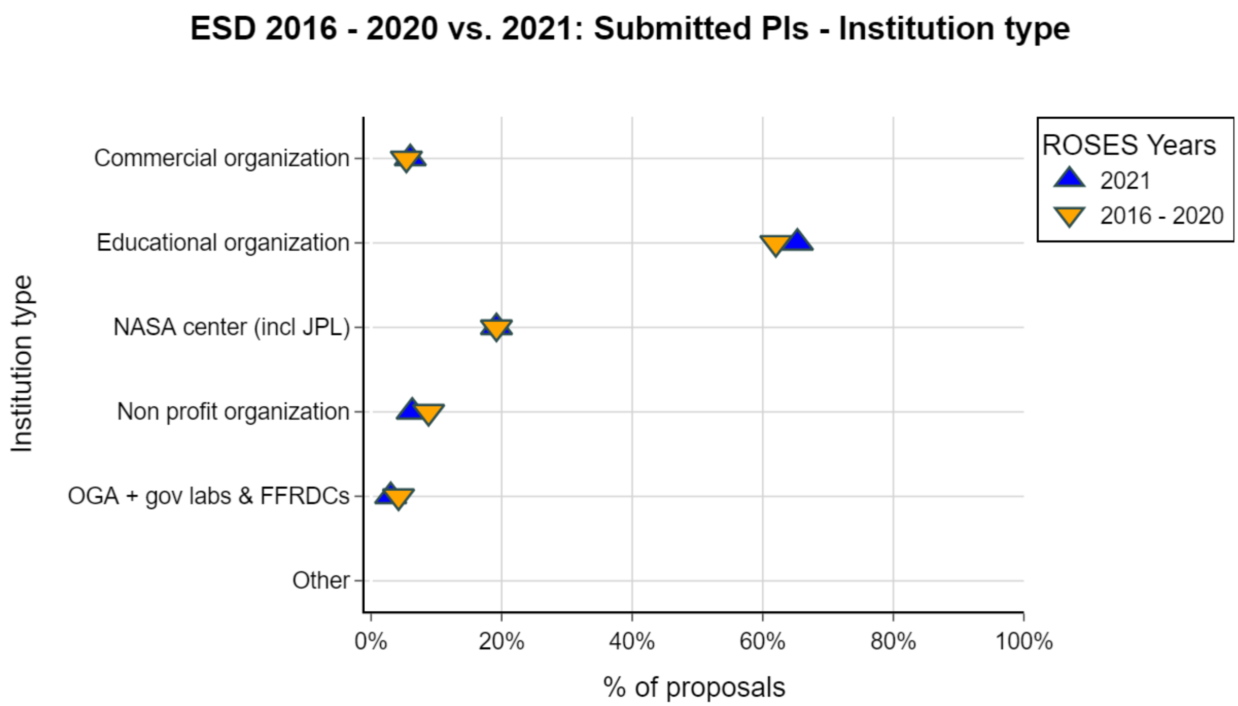
Ability	ESD 2016-2020	ESD 2016-2020 Response/All Abilities	ESD 2021	ESD 2021 Response/All Abilities
Disabled	27%	0.96	NR	NR
Nondisabled	28%	1	41%	1.05
PNA	29%	1.04	32%	0.82
All Abilities	28%	1	39%	1

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group.

6.a.i.8. Institutional Analysis

6.a.i.8.a. Institution Type – ESD PIs

ESD PIs: Submitted Institution Type - Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Other (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

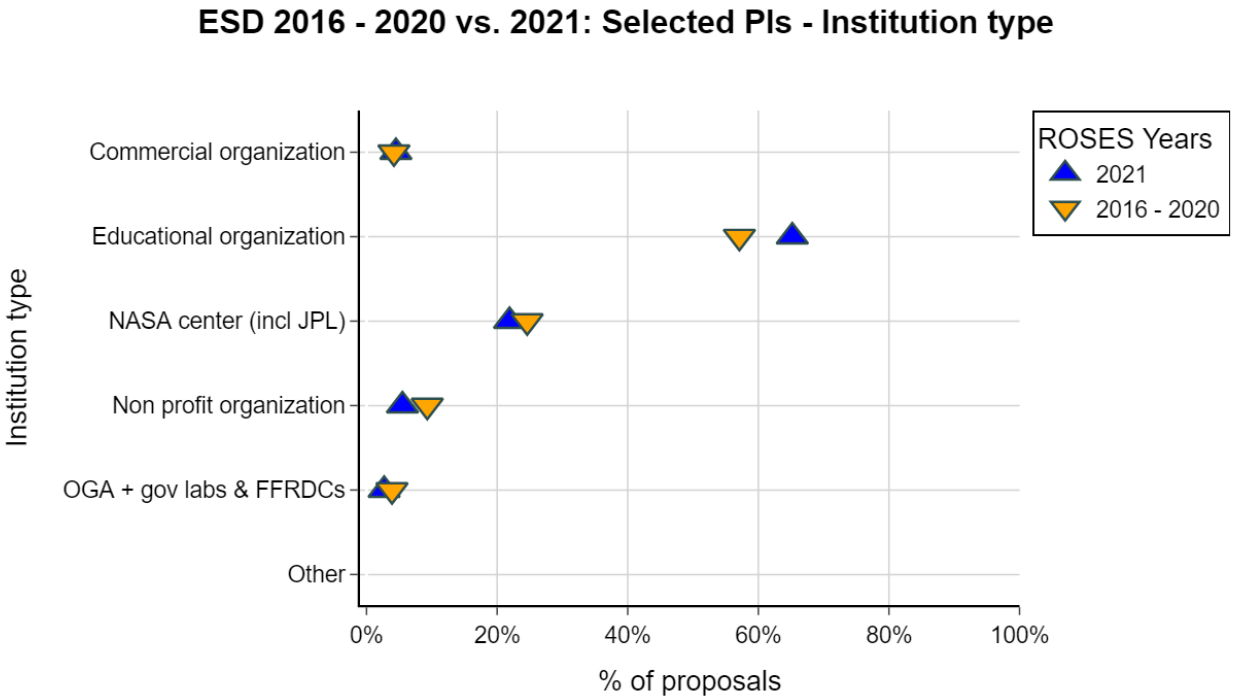
ESD PIs: Submitted Institution Type - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Institution type

Institution type	ESD 2016 - 2020	ESD 2021
Commercial organization	5%	6%
Educational organization	62%	65%
NASA center (incl JPL)	19%	19%
Non profit organization	9%	6%
OGA + gov labs & FFRDCs	4%	3%
Other	NR	NR

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Institution Type - Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Other (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

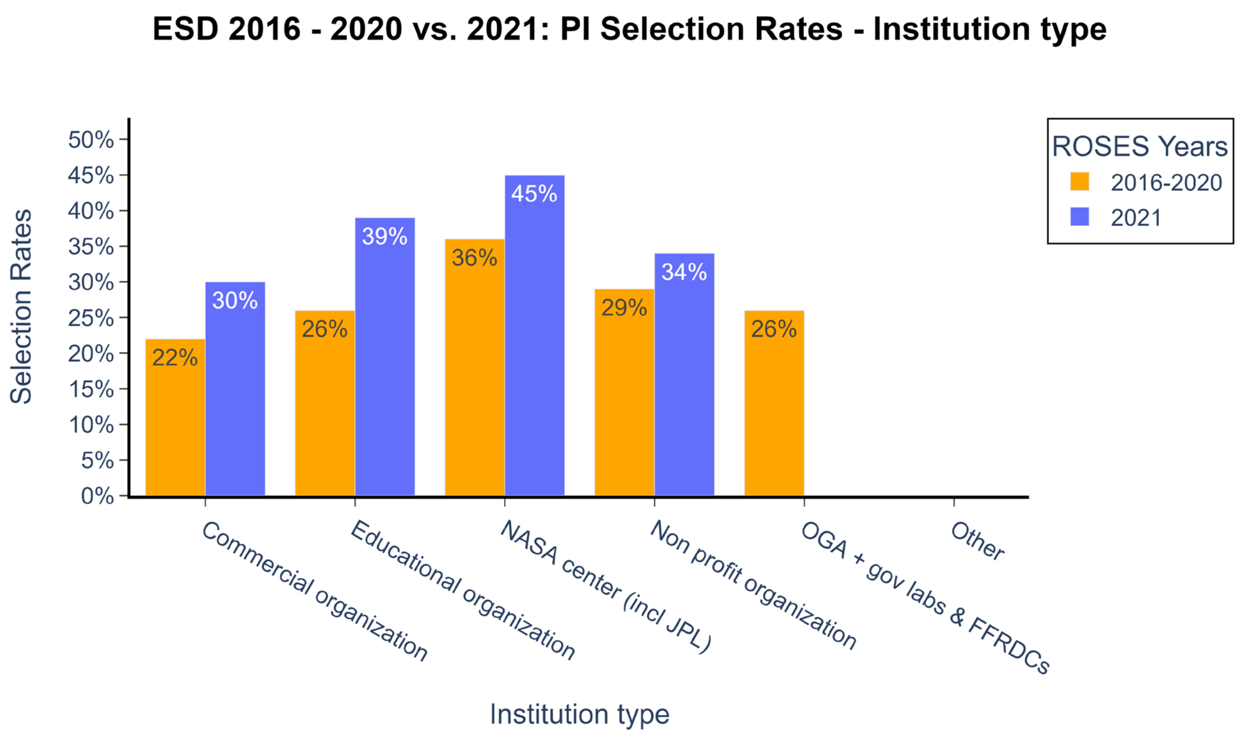
ESD PIs: Selected Institution Type - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Institution type

Institution type	ESD 2016 - 2020	ESD 2021
Commercial organization	4%	4%
Educational organization	57%	65%
NASA center (incl JPL)	25%	22%
Non profit organization	9%	6%
OGA + gov labs & FFRDCs	4%	3%
Other	NR	NR

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Institution Type Selection Rate - Bar Plot



OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: OGA + gov labs & FFRDCs (ROSES 2021), Other (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Institution Type Selection Rate - Data Table

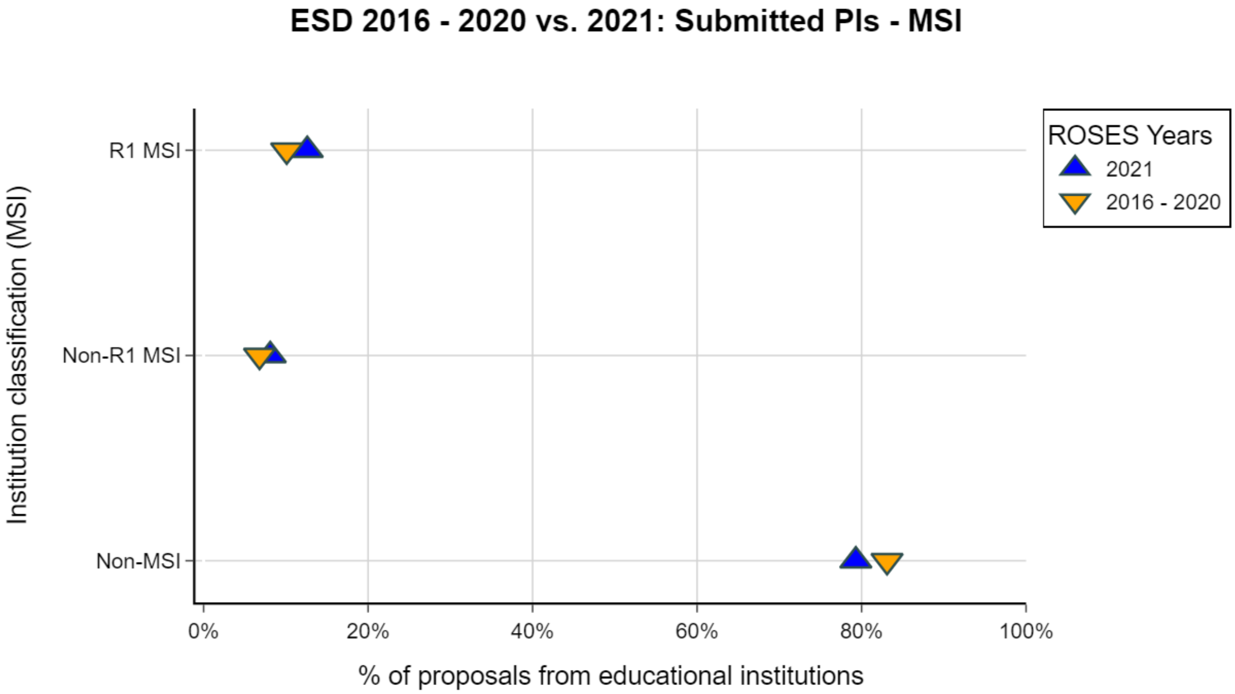
ESD 2016 - 2020 vs. 2021: PI Selection Rates - Institution type

Institution type	ESD 2016-2020	ESD 2016-2020 Response/All Institution types	ESD 2021	ESD 2021 Response/All Institution types
Commercial organization	22%	0.79	30%	0.77
Educational organization	26%	0.93	39%	1
NASA center (incl JPL)	36%	1.29	45%	1.15
Non profit organization	29%	1.04	34%	0.87
OGA + gov labs & FFRDCs	26%	0.93	NR	NR
Other	NR	NR	NR	NR
All Institution types	28%	1	39%	1

OGA: Other Government Agency | FFRDCs: Federally Funded Research and Development Centers | Other: State, Local or Federally Recognized Tribal Government Agency & Unaffiliated Individuals | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.8.a. Minority Serving Institutions (MSIs) – ESD PIs

ESD PIs: Submitted MSI - Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated.

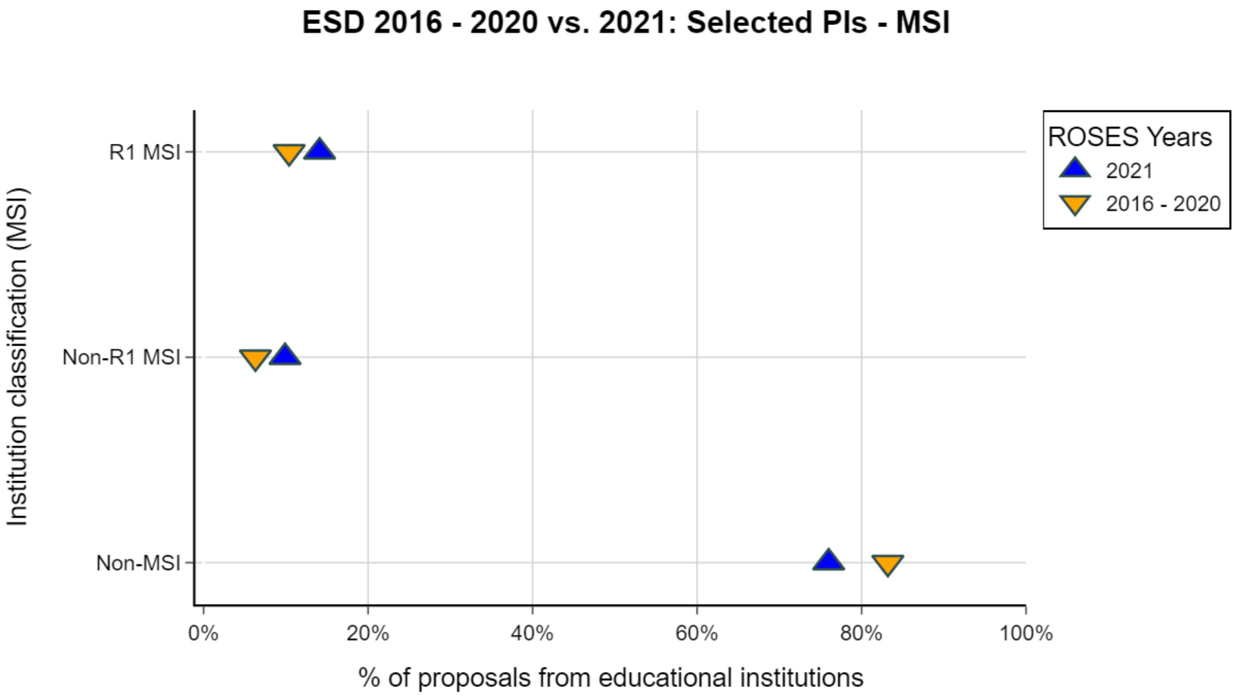
ESD PIs: Submitted MSI - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - MSI

MSI	ESD 2016 - 2020	ESD 2021
R1 MSI	10%	13%
Non-R1 MSI	7%	8%
Non-MSI	83%	79%

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected MSI - Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated.

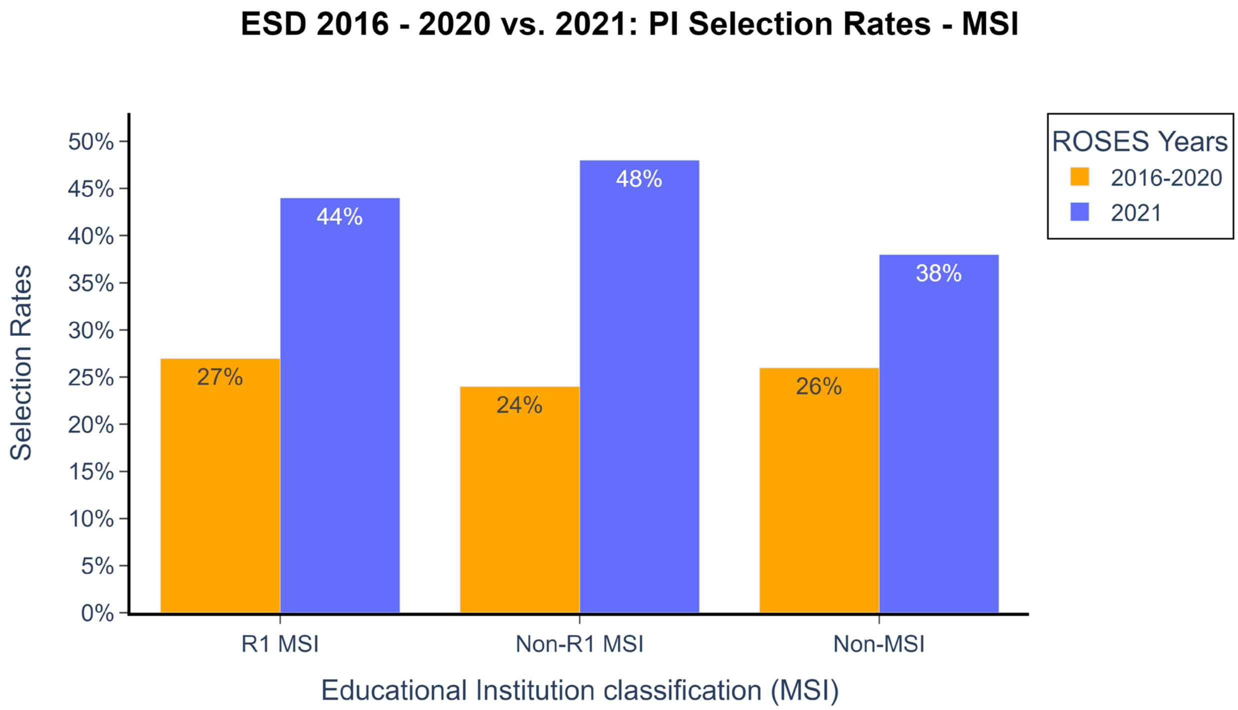
ESD PIs: Selected MSI - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - MSI

MSI	ESD 2016 - 2020	ESD 2021
R1 MSI	10%	14%
Non-R1 MSI	6%	10%
Non-MSI	83%	76%

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: MSI Selection Rate - Bar Plot



MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group.

ESD PIs: MSI Selection Rate - Data Table

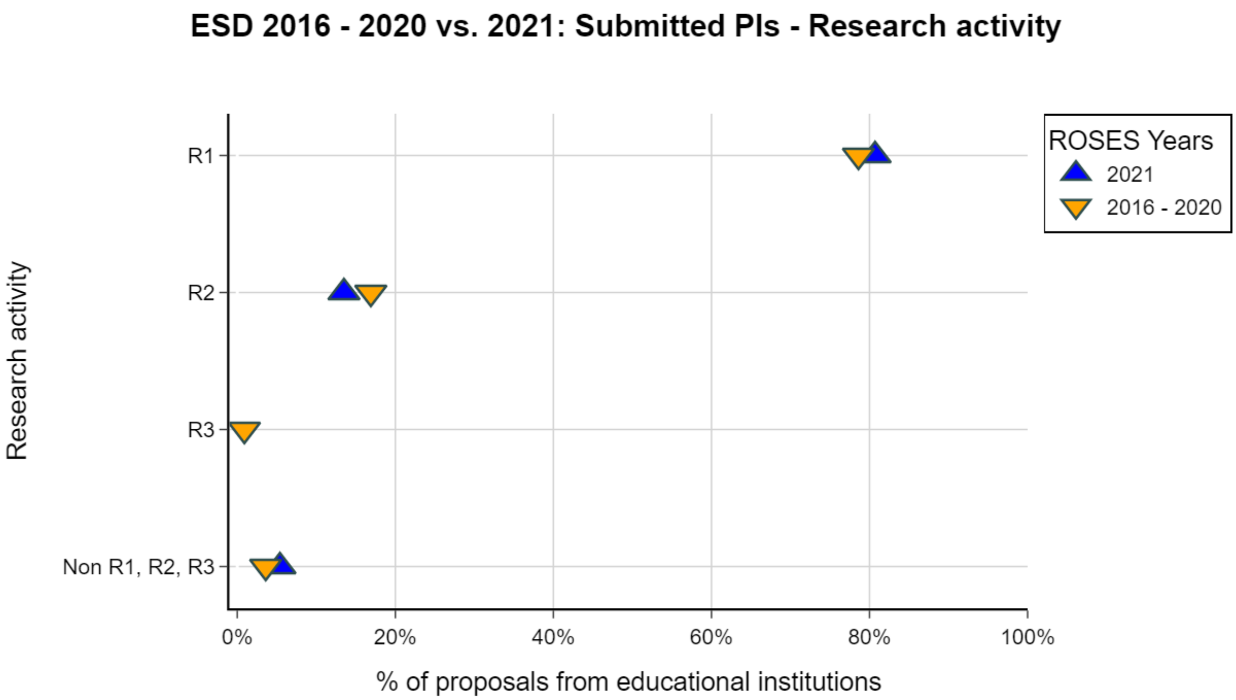
ESD 2016 - 2020 vs. 2021: PI Selection Rates - MSI

MSI	ESD 2016-2020	ESD 2016-2020 Response/All Educational Institutions	ESD 2021	ESD 2021 Response/All Educational Institutions
R1 MSI	27%	1.04	44%	1.13
Non-R1 MSI	24%	0.92	48%	1.23
Non-MSI	26%	1	38%	0.97
All Educational Institutions	26%	1	39%	1

MSI: Minority Serving Institution | R1: Doctoral university - Very high research activity | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.i.8.c. Carnegie Classification of Research Activity – ESD PIs

ESD PIs: Submitted Research Activity - Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: R3 (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

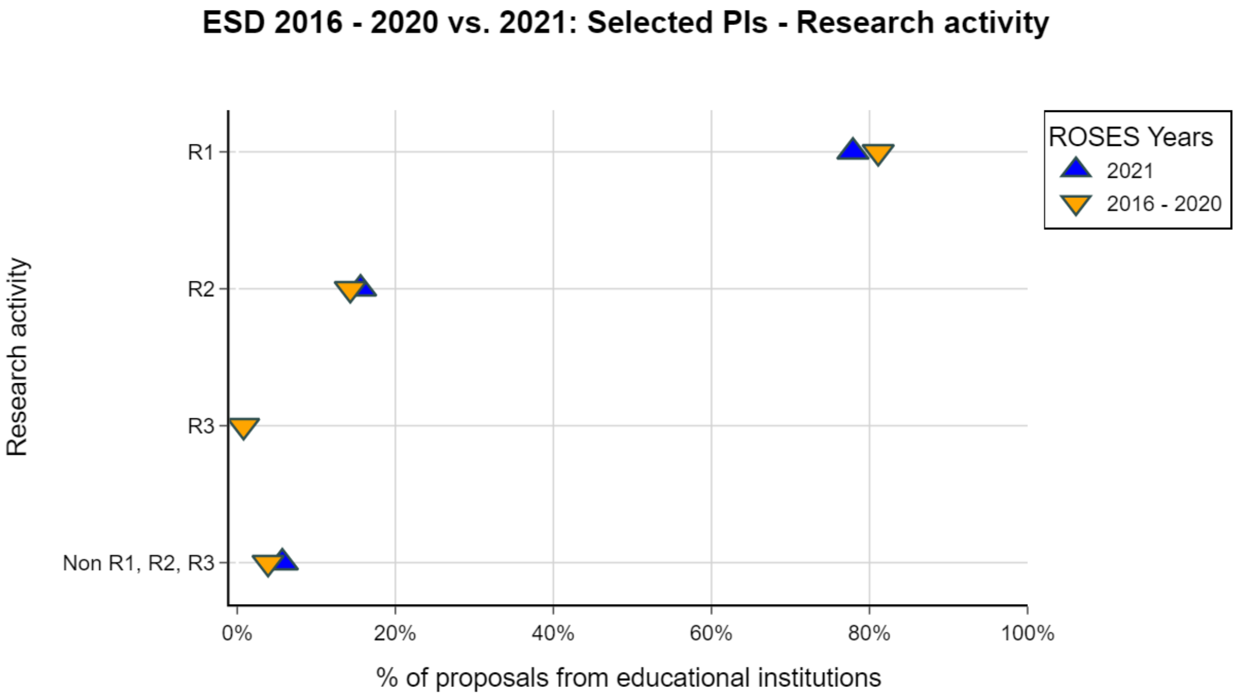
ESD PIs: Submitted Research Activity - Data Table

ESD 2016 - 2020 vs. 2021: Submitted PIs - Research activity

Research activity	ESD 2016 - 2020	ESD 2021
R1	79%	81%
R2	17%	14%
R3	< 1%	NR
Non R1, R2, R3	4%	5%

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Selected Research Activity - Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: R3 (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

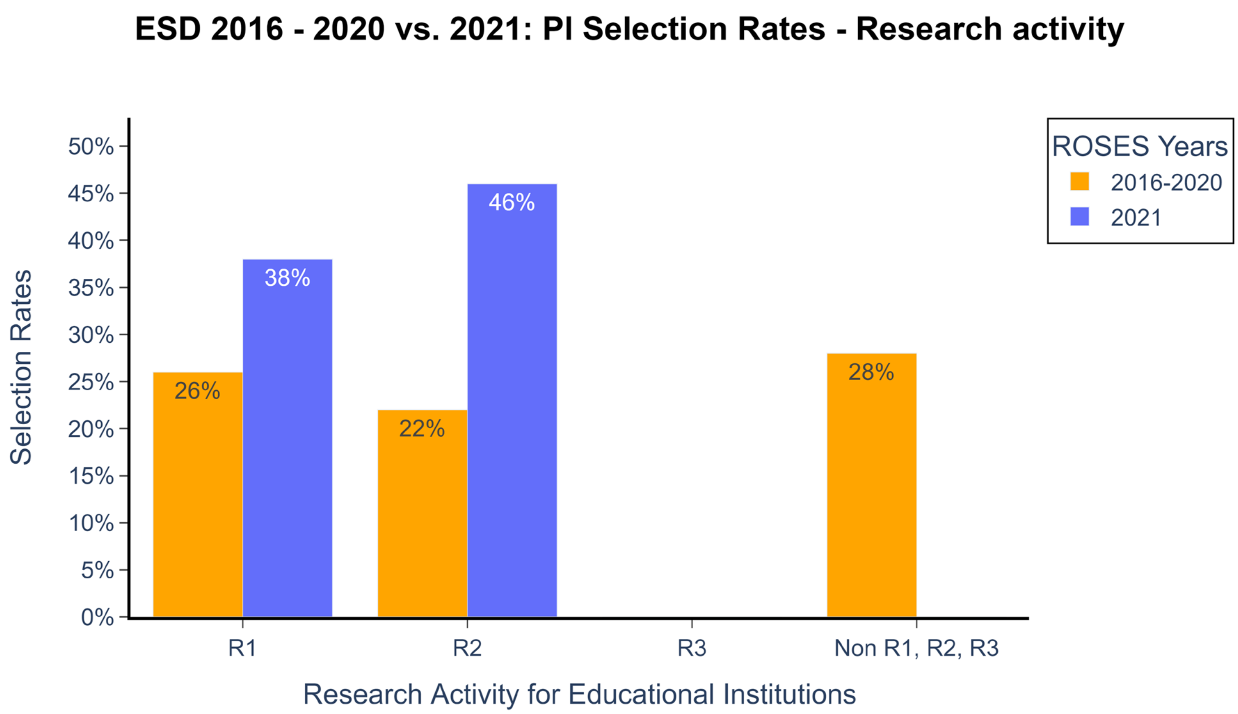
ESD PIs: Selected Research Activity - Data Table

ESD 2016 - 2020 vs. 2021: Selected PIs - Research activity

Research activity	ESD 2016 - 2020	ESD 2021
R1	81%	78%
R2	14%	16%
R3	< 1%	NR
Non R1, R2, R3	4%	6%

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD PIs: Research Activity Selection Rate - Bar Plot



R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

Suppressed categories: R3 (All years), Non R1, R2, R3 (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD PIs: Research Activity Selection Rate – Data Table

ESD 2016 - 2020 vs. 2021: PI Selection Rates - Research activity

Research activity	ESD 2016-2020	ESD 2016-2020 Response/All Educational Institutions	ESD 2021	ESD 2021 Response/All Educational Institutions
R1	26%	1	38%	0.97
R2	22%	0.85	46%	1.18
R3	NR	NR	NR	NR
Non R1, R2, R3	28%	1.08	NR	NR
All Educational Institutions	26%	1	39%	1

R1: Doctoral university - Very high research activity | R2: Doctoral university - High research activity | R3: Doctoral/professional university | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated. | Selection rate = # of selected proposals with PIs from a demographic response group/ # of submitted proposals with PIs from the same demographic response group

6.a.ii. Science Team

6.a.ii.1. Limitations of the data – ESD Science team

26,043 submitted proposals are included in the ROSES 2016-2021 database. Please see Appendix Table 1 to see which programs are included. The total number of proposals submitted and selected for each ROSES year and the total number of proposals submitted to each SMD Division cannot be reported due to the Office of the Chief Scientist's suppression guidelines. See *Yearbook Introduction Section 1.a.ii.1* *Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics* for more information. The number of proposals rounded to the nearest hundred are included for these two circumstances to provide context. For the Earth Science Division, there are ~8,800 submitted proposals over all ROSES years: ~7,800 for ROSES 2016-2020 and ~1,000 for ROSES 2021.

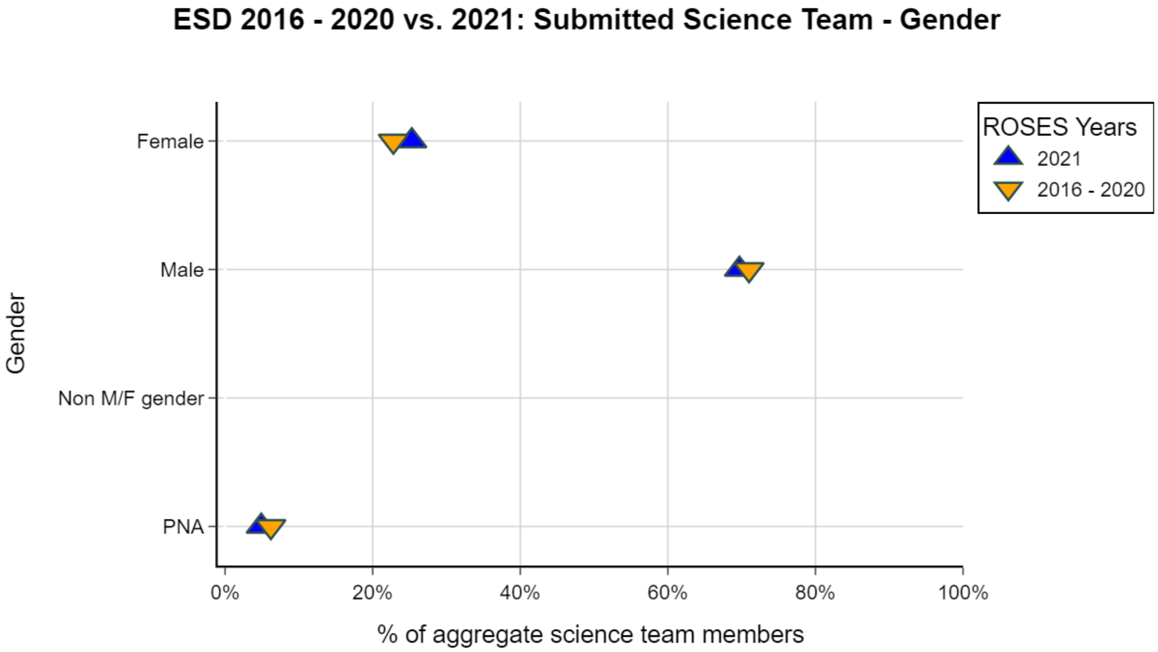
Instances in the science team member dataset where a science team member took the survey but selected "prefer not to answer" for all demographic survey questions:

- Submitted proposals: ESD 2016 - 2020: 6% | ESD 2021: 4%
- Selected proposals: ESD 2016 - 2020: 5% | ESD 2021: 4%

Demographic data responses for one collaborator and one Co-I participating in ESD proposals in ROSES 2016 and 2017, respectively, are missing and have been removed from the dataset.

6.a.ii.2. Gender - ESD Science Team

ESD Science Team: Submitted Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

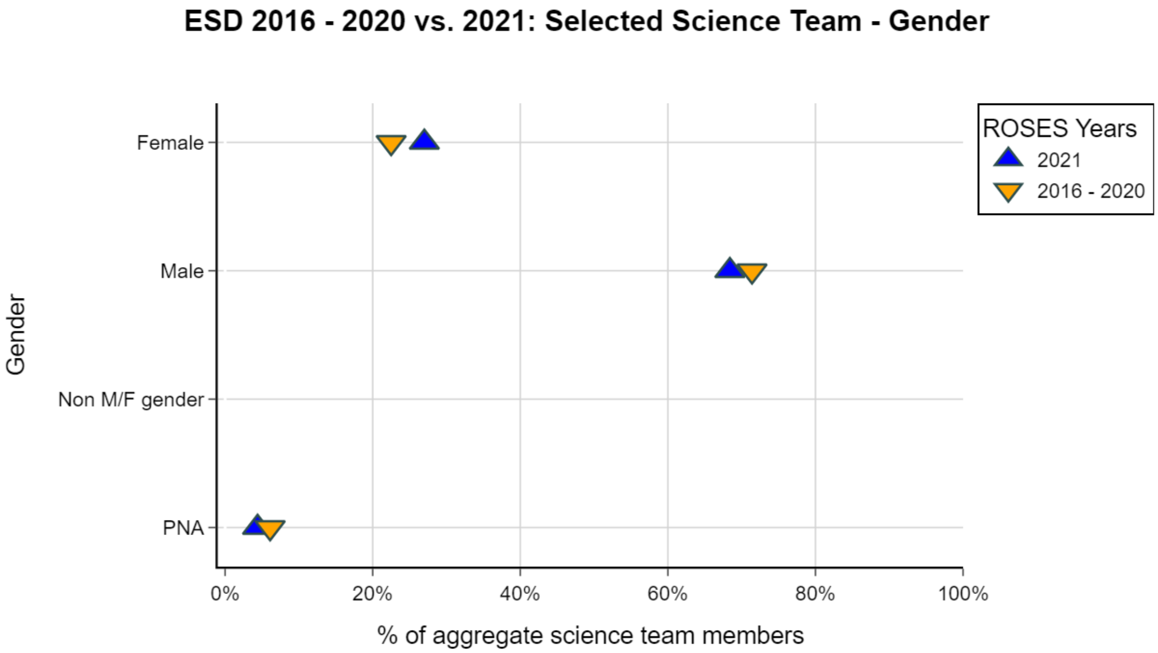
ESD Science Team: Submitted Gender - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Gender

Gender	ESD 2016 - 2020	ESD 2021
Female	23%	25%
Male	71%	70%
Non M/F gender	NR	NR
PNA	6%	5%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Gender - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: Non M/F gender (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

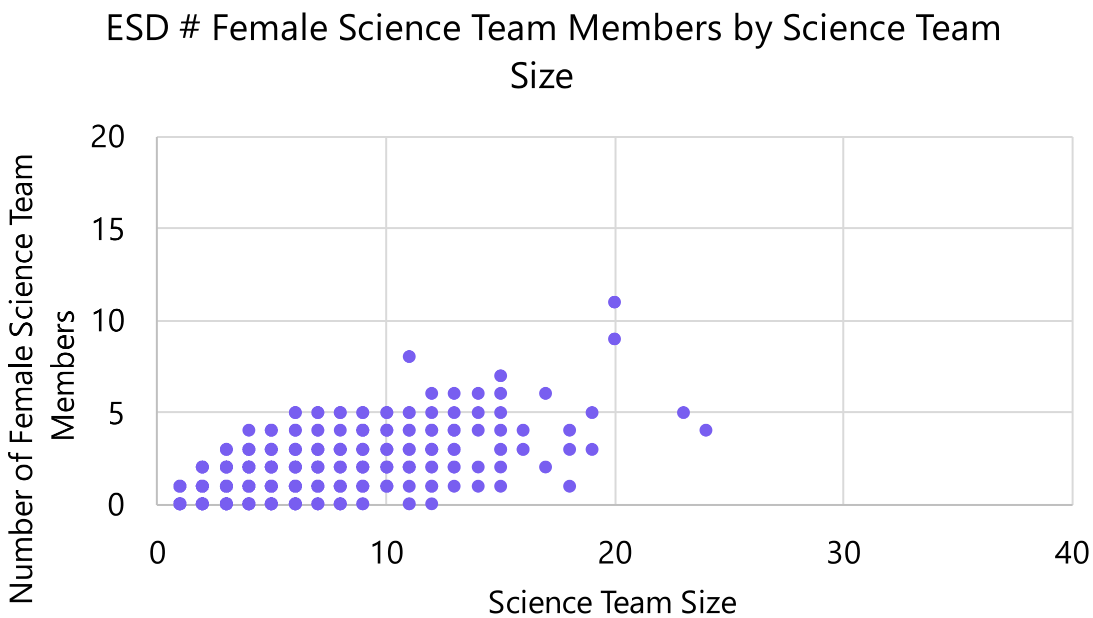
ESD Science Team: Selected Gender - Data Table

ESD 2016 - 2020 vs. 2021: Selected Science Team - Gender

Gender	ESD 2016 - 2020	ESD 2021
Female	22%	27%
Male	71%	68%
Non M/F gender	NR	NR
PNA	6%	4%

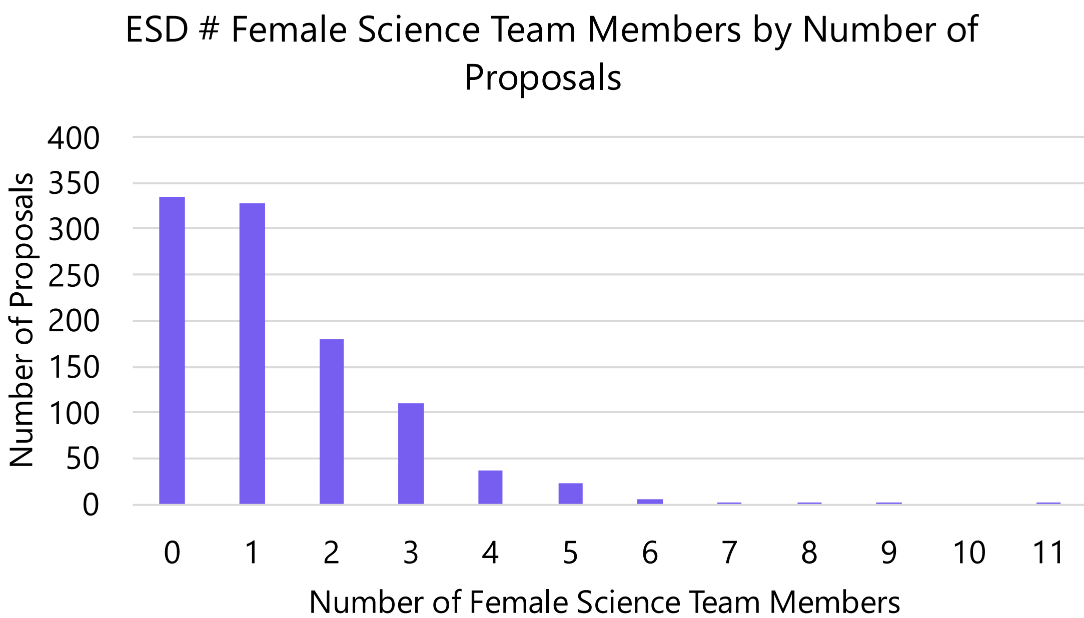
PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD ROSES 2021 Science Teams: Female Science Team Members by Science Team Size – Scatter Plot



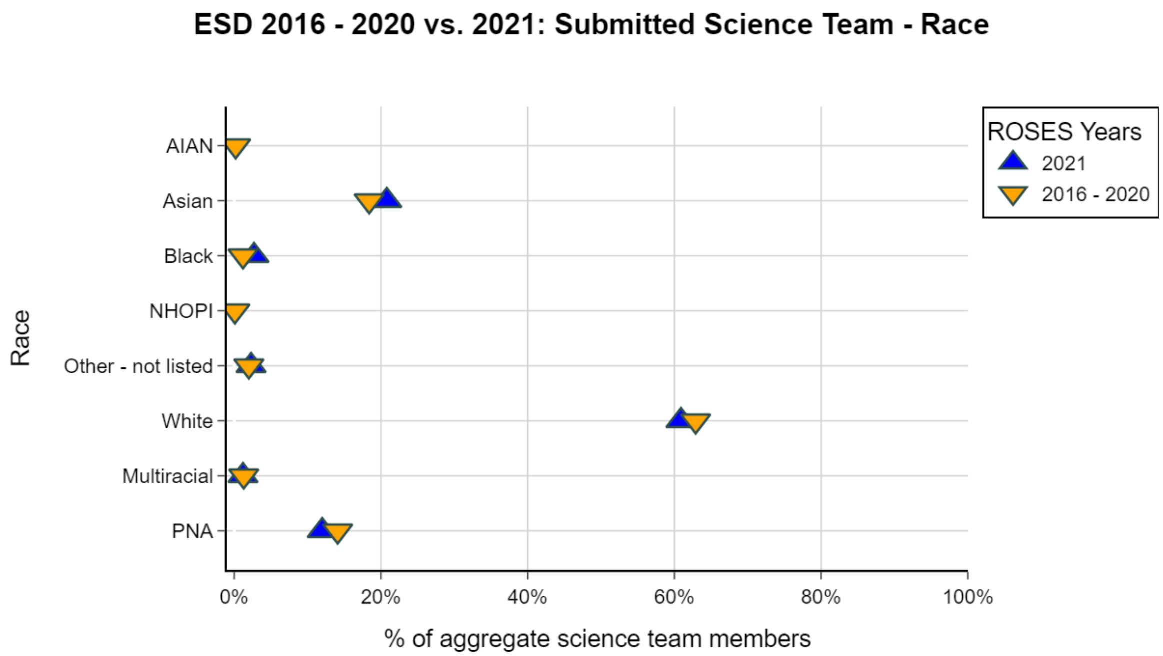
Note: 33% of proposals submitted to ROSES 2021 Earth Science programs did not include female researchers in their science team. 7% of proposals submitted to ROSES 2021 Earth Science programs only included the PI as the science team.

ESD ROSES 2021 Science Teams: Female Science Team Members by Number of Proposals – Bar Plot



6.a.ii.3. Race – ESD Science Team

ESD Science Team: Submitted Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (ROSES 2021), NHOPI (ROSES 2021).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

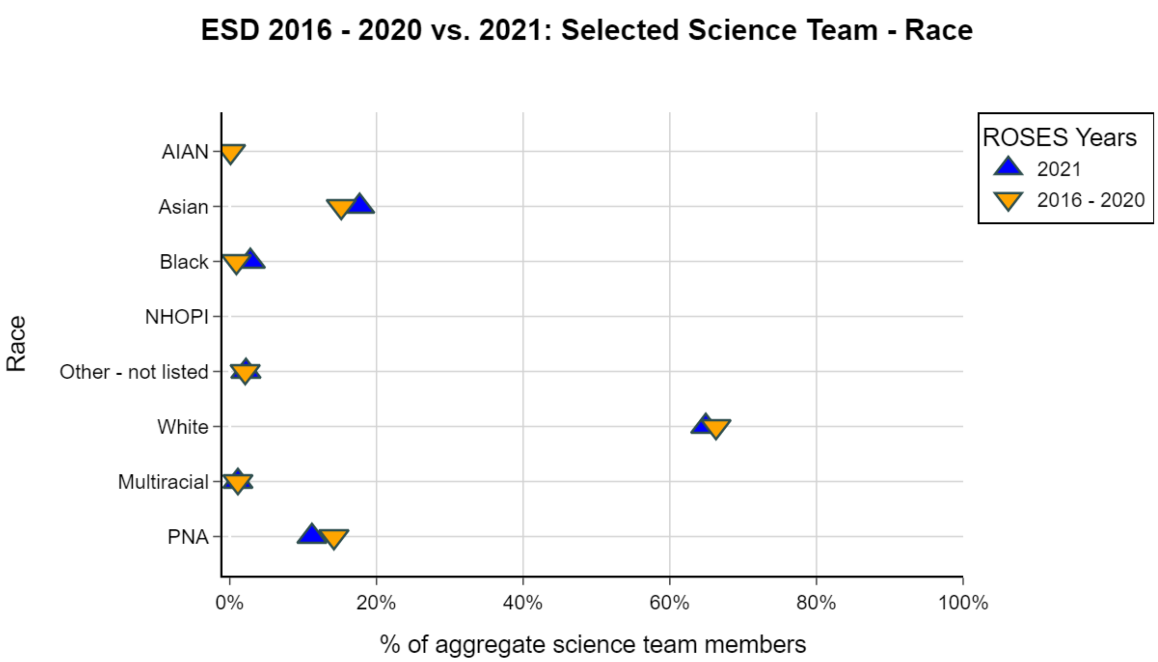
ESD Science Team: Submitted Race - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Race

Race	ESD 2016 - 2020	ESD 2021
AIAN	< 1%	NR
Asian	18%	21%
Black	1%	3%
NHOPI	< 1%	NR
Other - not listed	2%	2%
White	63%	61%
Multiracial	1%	1%
PNA	14%	12%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Race - Plot



AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

Suppressed categories: AIAN (ROSES 2021), NHOPI (All years).
See Yearbook introduction Section 1.a.ii.i Office of the Chief Scientist (OCS) Suppression Guidelines for self-reported demographics for more information.

ESD Science Team: Selected Race - Data Table

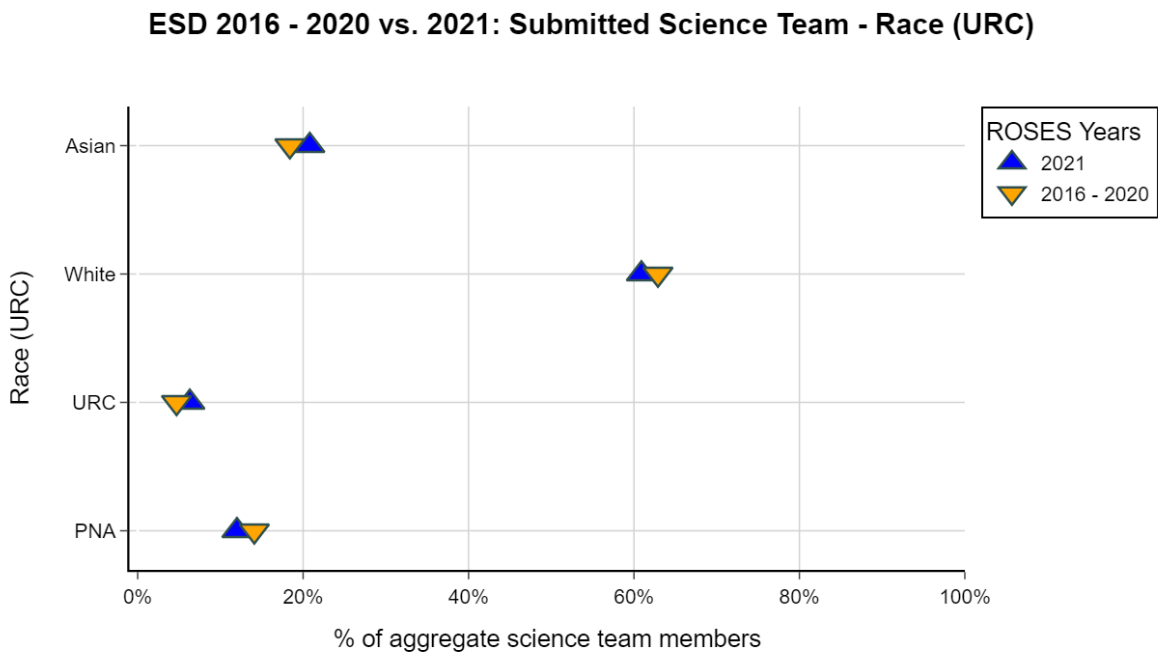
ESD 2016 - 2020 vs. 2021: Selected Science Team - Race

Race	ESD 2016 - 2020	ESD 2021
AIAN	< 1%	NR
Asian	15%	18%
Black	< 1%	3%
NHOPI	NR	NR
Other - not listed	2%	2%
White	66%	65%
Multiracial	1%	1%
PNA	14%	11%

AIAN: American Indian and Alaska Native | NHOPI: Native Hawaiian and Other Pacific Islander | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

6.a.ii.4. Race using Under-Represented Community (URC) – ESD Science Team

ESD Science Team: Submitted Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

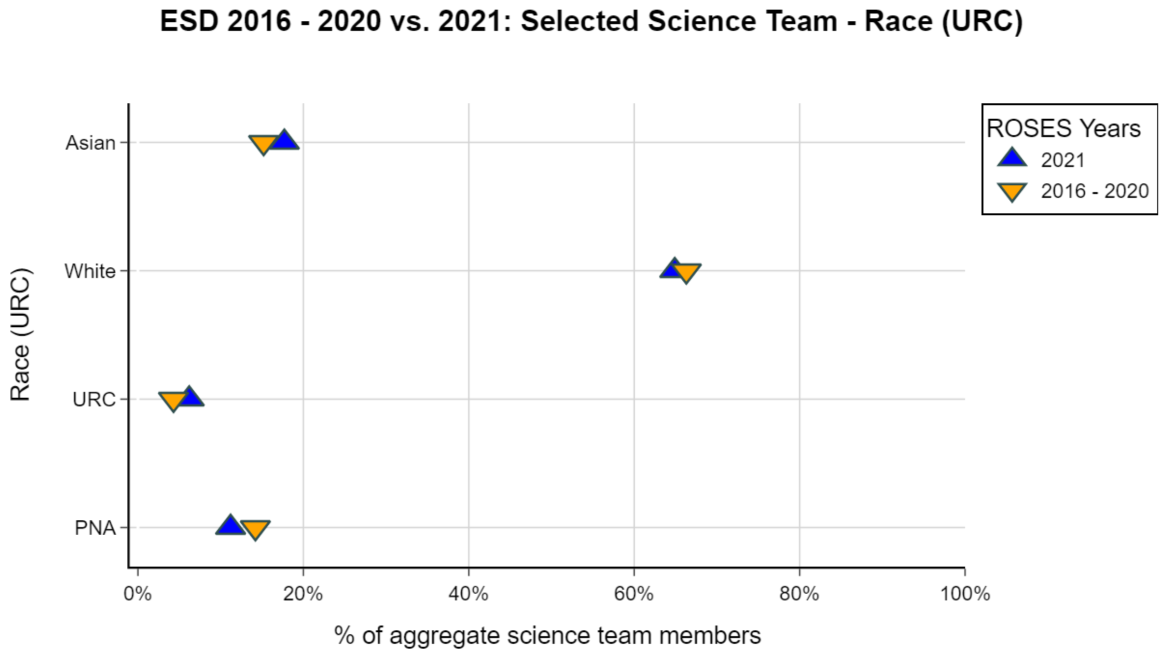
ESD Science Team: Submitted Race (URC) - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Race (URC)

Race (URC)	ESD 2016 - 2020	ESD 2021
Asian	18%	21%
White	63%	61%
URC	5%	6%
PNA	14%	12%

Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Race (URC) - Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

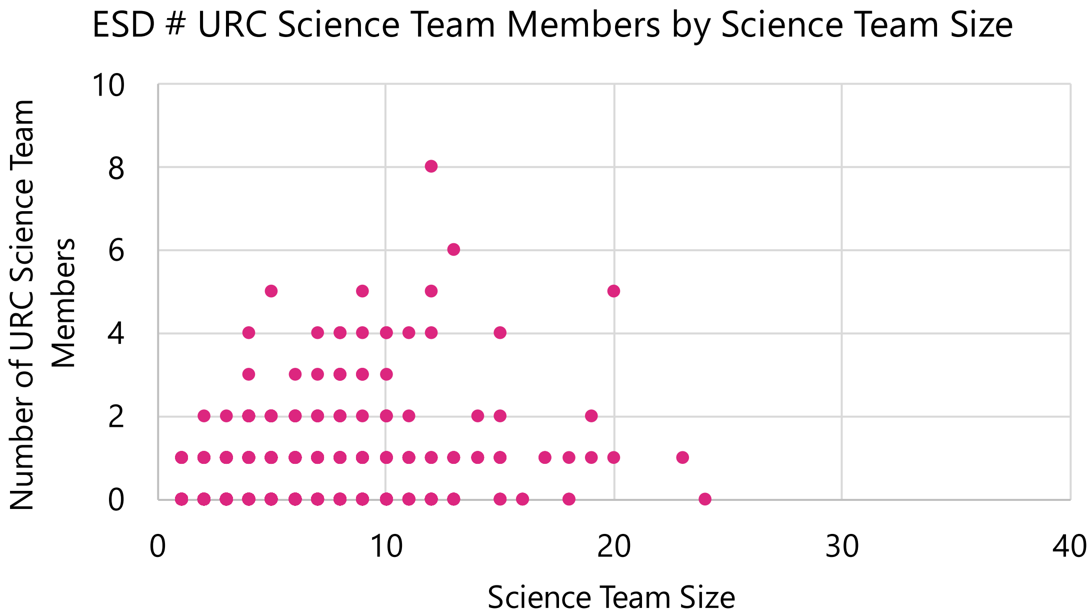
ESD Science Team: Selected Race (URC) - Data Table

ESD 2016 - 2020 vs. 2021: Selected Science Team - Race (URC)

Race (URC)	ESD 2016 - 2020	ESD 2021
Asian	15%	18%
White	66%	65%
URC	4%	6%
PNA	14%	11%

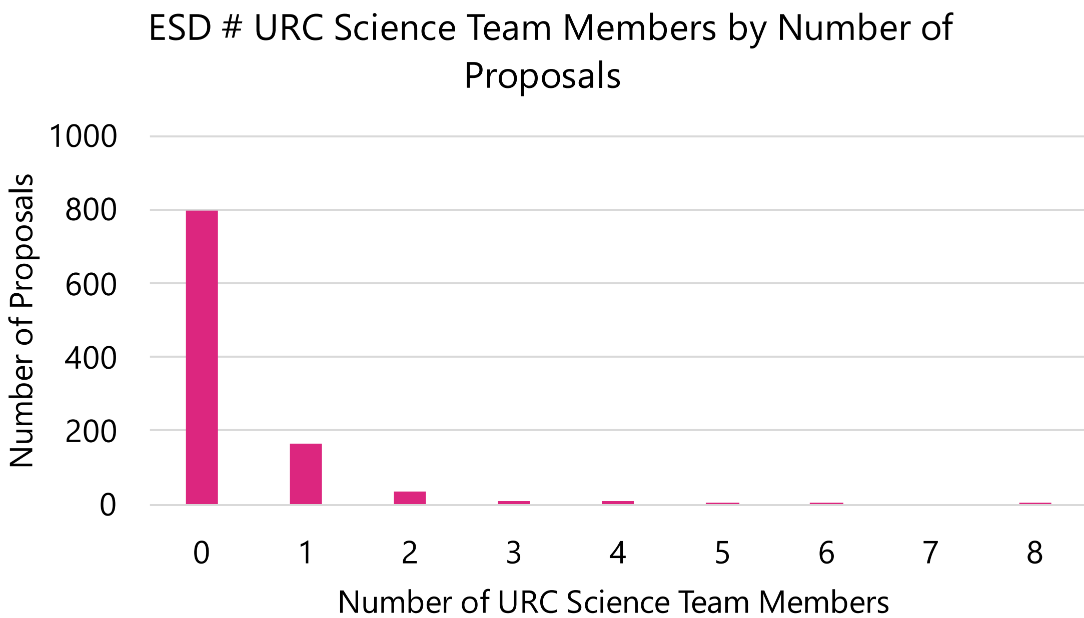
Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD ROSES 2021 Science Teams: URC Science Team Members by Science Team Size – Scatter Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other. | Note: 78% of proposals submitted to ROSES 2021 Earth Science programs did not include URC researchers in their science team. 7% of proposals submitted to ROSES 2021 Earth Science programs only included the PI as the science team.

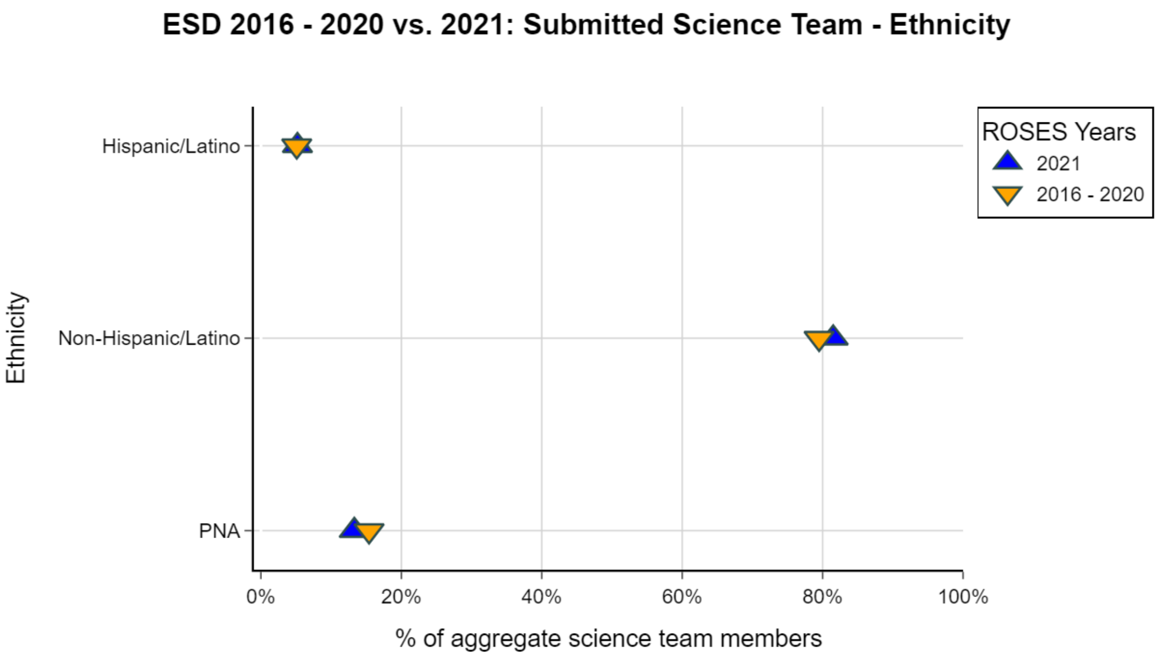
ESD ROSES 2021 Science Teams: URC Science Team Members by Number of Proposals – Bar Plot



Under-Represented Community (URC) includes American Indian & Alaska Native, Black, Native Hawaiian & Other Pacific Islander, Multiracial, and Other.

6.a.ii.5. Ethnicity - ESD Science Team

ESD Science Team: Submitted Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

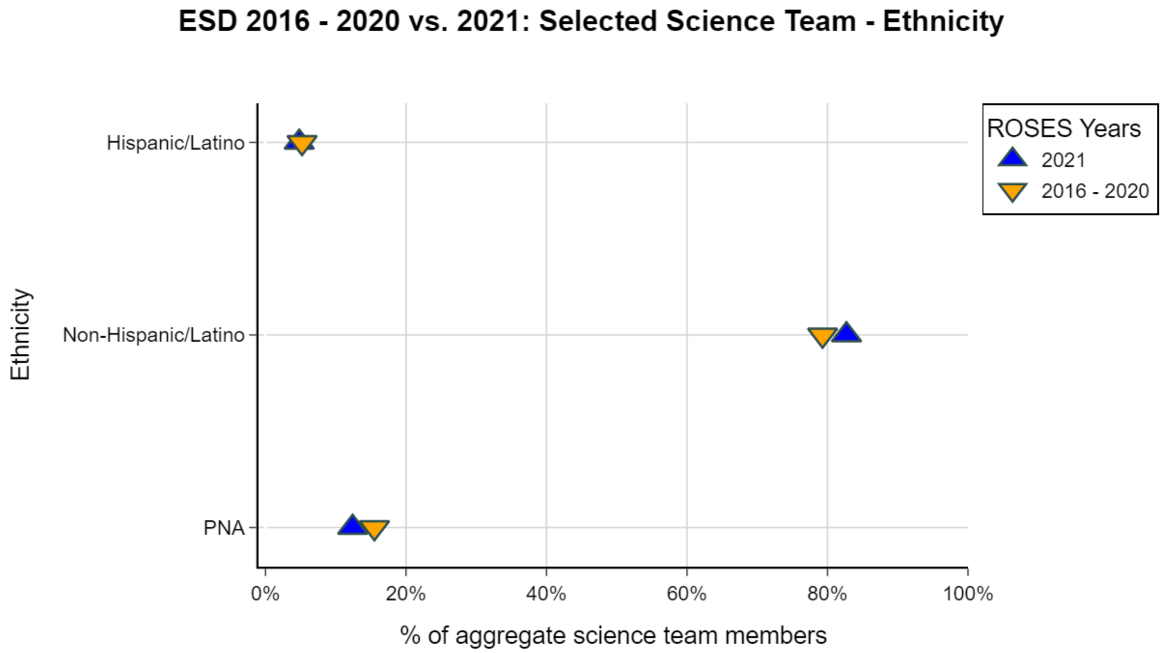
ESD Science Team: Submitted Ethnicity - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Ethnicity

Ethnicity	ESD 2016 - 2020	ESD 2021
Hispanic/Latino	5%	5%
Non-Hispanic/Latino	80%	82%
PNA	15%	13%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Ethnicity - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Ethnicity - Data Table

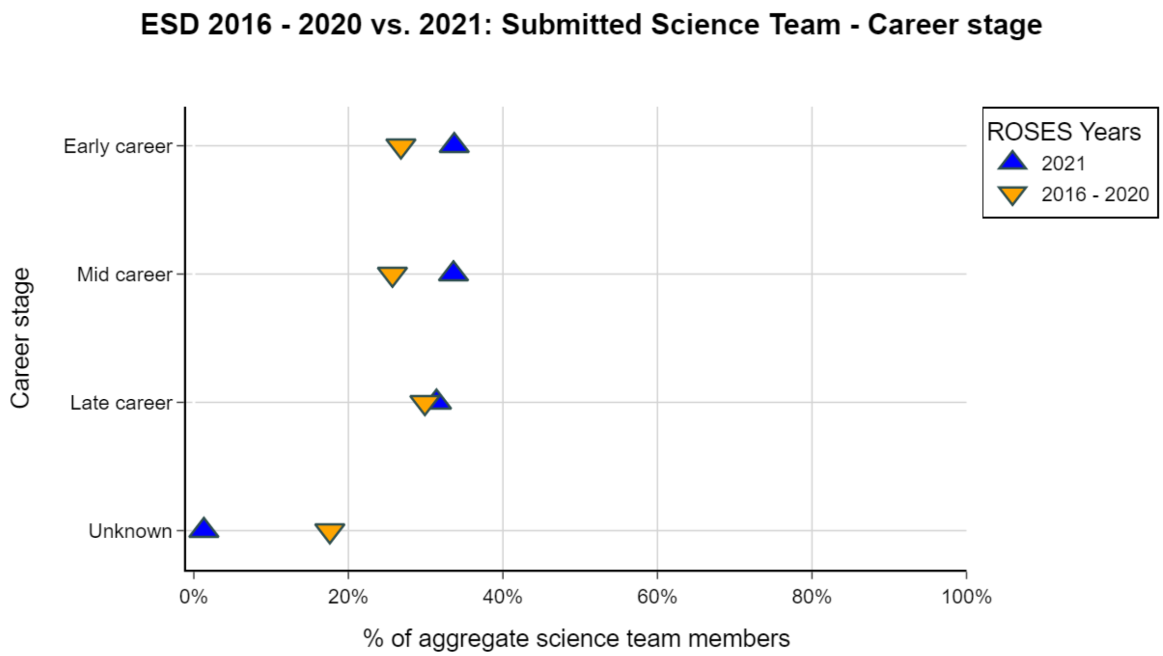
ESD 2016 - 2020 vs. 2021: Selected Science Team - Ethnicity

Ethnicity	ESD 2016 - 2020	ESD 2021
Hispanic/Latino	5%	5%
Non-Hispanic/Latino	79%	83%
PNA	16%	12%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

6.a.ii.6. Career Stage - ESD Science Team

ESD Science Team: Submitted Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

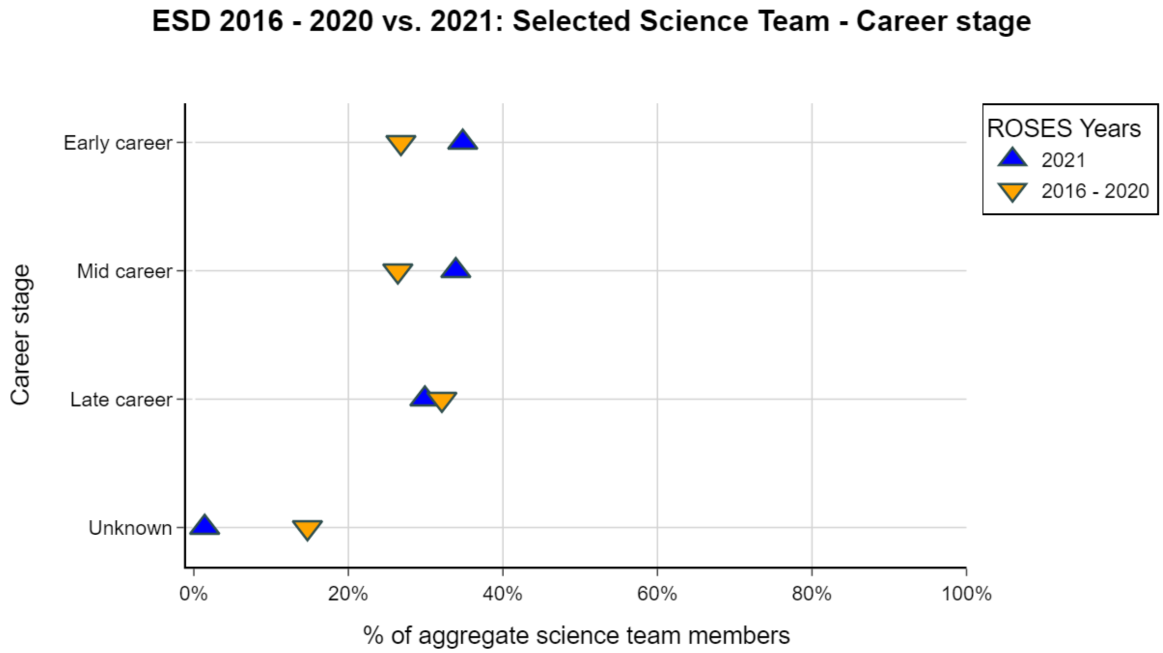
ESD Science Team: Submitted Career Stage - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Career stage

Career stage	ESD 2016 - 2020	ESD 2021
Early career	27%	34%
Mid career	26%	34%
Late career	30%	31%
Unknown	18%	1%

Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Career Stage - Plot



Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | ROSES 2016-2020 proposal data are aggregated.

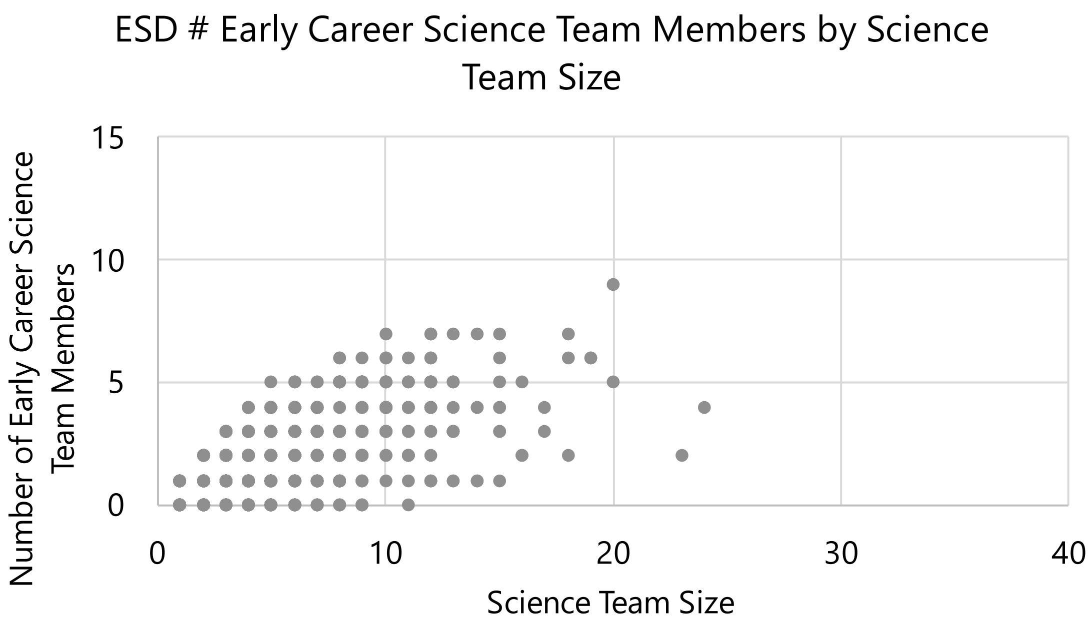
ESD Science Team: Selected Career Stage - Data Table

ESD 2016 - 2020 vs. 2021: Selected Science Team - Career stage

Career stage	ESD 2016 - 2020	ESD 2021
Early career	27%	35%
Mid career	26%	34%
Late career	32%	30%
Unknown	15%	1%

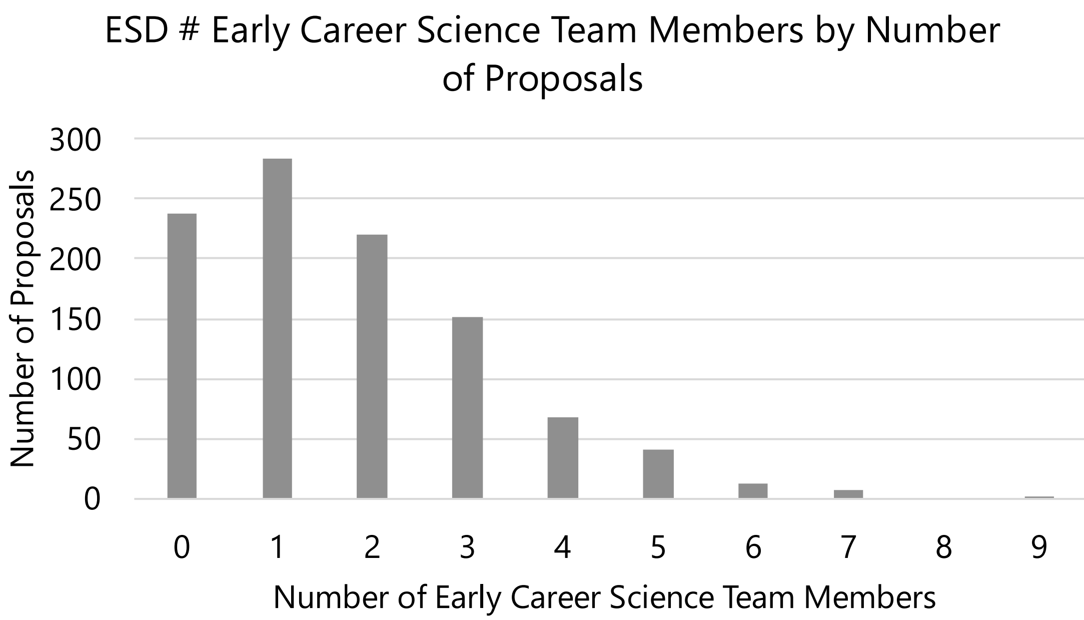
Early career: < 10 years since earning final degree | Mid career: 10 - 19 years since earning final degree | Late career: 20+ years since earning final degree | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD ROSES 2021 Science Teams: Early Career Science Team Members by Science Team Size – Scatter Plot



Early career: < 10 years since earning final degree | Note: 23% of proposals submitted to ROSES 2021 Earth Science programs did not include early career researchers in their science team. 7% of proposals submitted to ROSES 2021 Earth Science programs only included the PI as the science team.

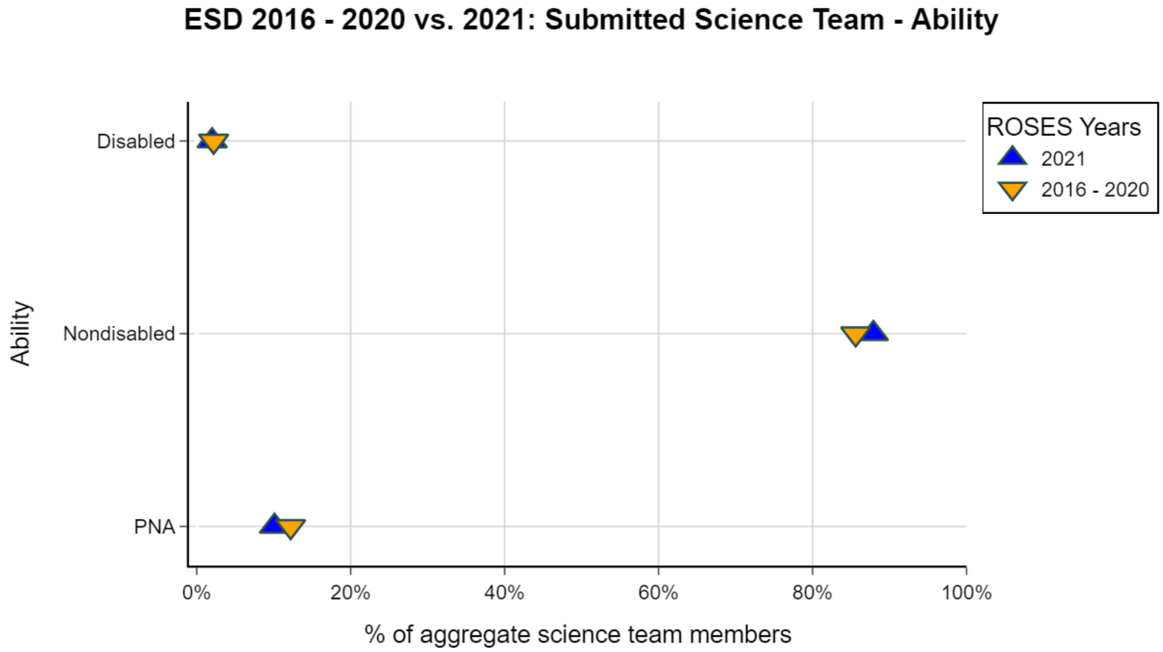
ESD ROSES 2021 Science Teams: Early Career Science Team Members by Number of Proposals – Bar Plot



Early career: < 10 years since earning final degree

6.a.ii.7. Disability Status - ESD Science Team

ESD Science Team: Submitted Ability - Plot



Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

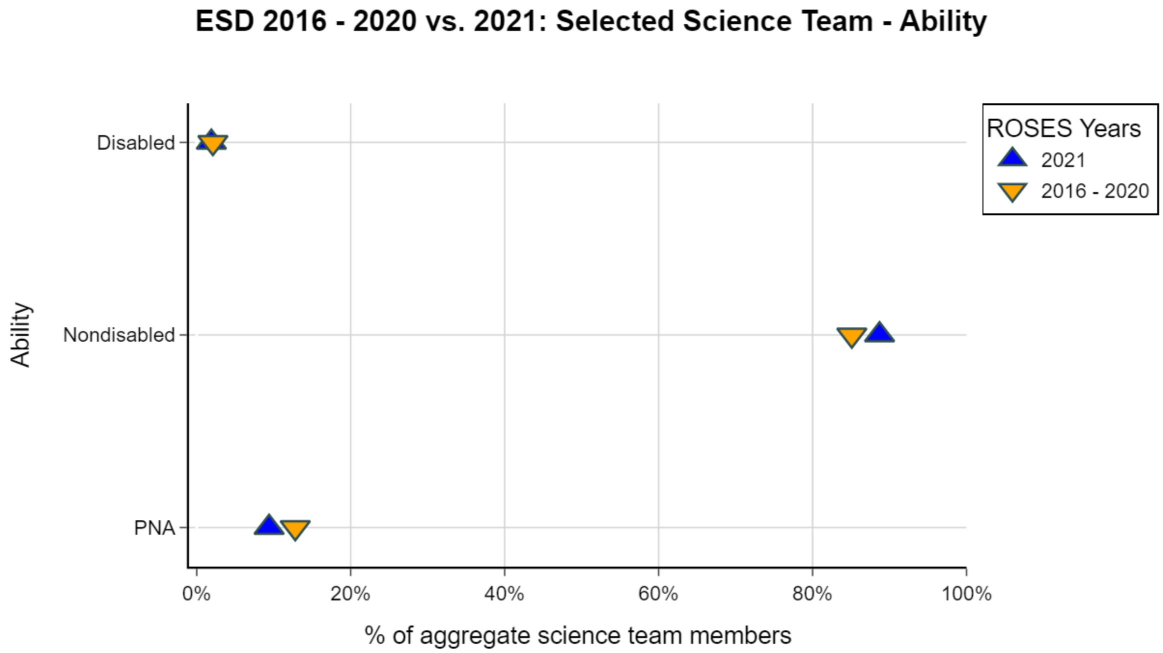
ESD Science Team: Submitted Ability - Data Table

ESD 2016 - 2020 vs. 2021: Submitted Science Team - Ability

Ability	ESD 2016 - 2020	ESD 2021
Disabled	2%	2%
Nondisabled	86%	88%
PNA	12%	10%

Disabled includes hearing, visual, mobility/orthopedic, and other impairment. | PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Ability - Plot



PNA: Prefer not to answer | ROSES 2016-2020 proposal data are aggregated.

ESD Science Team: Selected Ability - Data Table

ESD 2016 - 2020 vs. 2021: Selected Science Team - Ability

Ability	ESD 2016 - 2020	ESD 2021
Disabled	2%	2%
Nondisabled	85%	89%
PNA	13%	9%

PNA: Prefer not to answer | NR: Not reportable | ROSES 2016-2020 proposal data are aggregated.

6.b. Proposal Data

6.b.i New PI

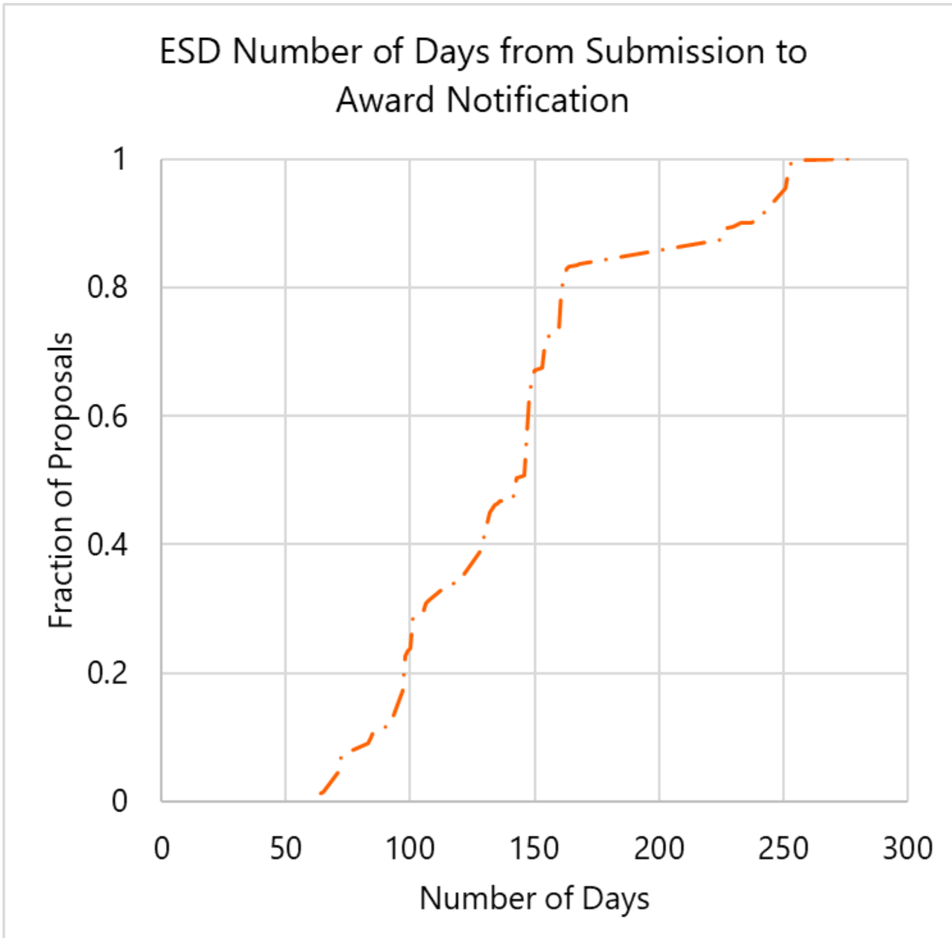
Comparison of Proposal Statistics of New PIs and Unique PIs for ROSES 2021

ESD 2021	New PIs	Unique PIs	New PI %
Selected	196	384	51%
Submitted	513	890	58%
Selection Rate	38%	43%	

New PI (Division): A PI that was selected by any program in the given SMD Division in ROSES 2021 but was not selected by any program in that SMD Division in the previous five ROSES years.
New PIs Submitted: an individual submitting a proposal that would be a new PI if the submitted proposal were selected.
Unique PIs: participation of individuals and not proposals.

6.b.ii. Time from Proposal Submission to Award Notification for ROSES 2021

Number of Days from Proposal Submission to Award Notification for ESD - Empirical Distribution Function



Notes: Number of days from proposal submission to 80% of award notifications for ESD is 162 days. SMD Policy Document SPD-22A applied to proposals submitted to ROSES 2016-2021 and included this statement: "Proposers shall receive a status notification from the Program Officer concerning their proposal no later than 150 days after the proposal due date, if selections have not yet already been made and announced."

Rapid Response and Novel Research in Earth Science program is not included since it does not have a due date

6.c. ROSES 2021 Selection Announcements

Appendix A. Earth Science Division

Appendix	Program Element Name
A.2	Land-Cover/Land-Use Change
A.4	Terrestrial Ecology
A.7	Biodiversity: Marine, Freshwater, and Terrestrial Biodiversity Survey of the Cape (BioSCape) Airborne Campaign Science Team
A.9	Ocean Salinity Science Team
A.15	Cryospheric Science
A.17	Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment
A.21	Remote Sensing of Water Quality
A.23	Earth Surface and Interior
A.24	Precipitation Measurement Missions Science Team
A.25	DSCOVR Science Team
A.26	CloudSat and CALIPSO Science Team Recompete
A.34	Earth Science Applications: Water Resources
A.35	SERVIR Applied Sciences Team
A.37	Earth Science Applications: Health and Air Quality
A.41	Instrument Incubator Program
A.45	Decadal Survey Incubation
A.46	Advanced Information Systems Technology
A.47	Land-Cover/Land-Use Change: SARI Synthesis

A.48	Earth Science Applications: Socioeconomic Assessments
A.49	Earth Science Applications: Equity and Environmental Justice
A.50	Subseasonal-to-Seasonal Hydrometeorological Prediction
A.51	Increasing Participation of Minority Serving Institutions in Earth Science Division Surface-Based Measurement Networks

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences -2021
NNH21ZDA001N
A.2 NASA Land-Cover/Land-Use Change

This synopsis is for the Land-Cover and Land-Use Change (LCLUC) part of the NASA Research Announcement (NRA) ROSES-2021 NNH21ZDA001N-LCLUC. This NRA offered opportunities for research by early career scientists to develop and use multi-source remote sensing technologies to improve understanding of human interaction with the environment, and thus provide a scientific foundation for understanding the sustainability, vulnerability and resilience of land-cover and land-use systems. NASA LCLUC research contributes toward the goals of the U.S. Global Climate Research Program (USGCRP) by providing critical scientific information about LCLUC-climate interactions and the consequences of land-cover and land-use change on environmental goods and services, the carbon and water cycles and the management of natural resources. NASA received 19 proposals and selected 8 proposals for a total funding of $3.7 Million for three years. More details are available at: http://nspires.nasaprs.com.

Latha Baskaran/Jet Propulsion Laboratory
Analyzing the Land-Use Change Impacts of Oil and Gas Exploration Related Infrastructure Changes on Arctic Communities
21-LCLUC21_2-0025

The Arctic is a hotspot of land-cover and land-use change (LCLUC) due to polar amplification of global warming, thawing permafrost, human activity, and greening/browning of tundra vegetation. Arctic ecosystems are susceptible to disturbances such as energy exploration, fires, and construction, changing the structure, composition, and function of natural plant communities, and causing permafrost degradation. Further, regions in the Arctic are susceptible to infrastructure failure due to relatively high ground-ice content and thick deposits of frost-susceptible sediments, increasing the potential for thaw. Changes in infrastructure and land use related to oil and gas exploration, opening of the Northern Sea Route and the Northwest Passage (roads, new routes, construction codes, pipelines, deepwater ports, settlements), associated environmental impacts, and the human adaptations to climate change are critical research priorities for the Arctic. Our goal in this proposal is to identify land disturbances and societal vulnerabilities associated with expanding the human footprint of oil and gas exploration concomitant to thawing permafrost around two Arctic regions with an extensive history of oil and gas exploration – the Prudhoe Bay in North Slope Borough (NSB), Alaska, and the Yamal Peninsula in Russia.

Microtopography is a defining feature of Arctic landscapes, driving variability in permafrost state and other important ecological processes at the 1-10 m scale. Accurate characterization of Arctic LCLUC will thus require a multiscale approach capable of both the regional spatial extent to capture a regional study area and sensitivity to governing biophysical dynamics that occur well below the scale of Landsat pixels. We thus propose to base our image analysis on an analytic framework explicitly designed to accommodate such “sub-pixel” processes: spectral and temporal mixture models. Understanding the impact of LCLUC in the Arctic will necessarily involve the characterization of change at these scales. Our approach would extend an image analysis methodology that has been shown to produce time series of accurate, scalable estimates of sub-pixel processes at both decameter and hectometer resolutions in diverse, challenging environments. Here, we will leverage satellite and airborne imagery spanning two orders of magnitude in spatial and spectral resolution to track anthropogenic Arctic LCLUC (roads, pipelines, structures). The availability of data from AVIRIS-NG, a rigorously calibrated airborne Imaging Spectrometer, in the NSB study area allows us to significantly extend our multispectral analysis, establishing a baseline and set of best practices for the integration of future global IS datasets into the LCLUC program's framework and potentially becoming an early example of the power of the next generation of land imaging to quantify LCLUC dynamics in hotspots of global significance.

Along with the remote-sensing based time-series analysis, our research will identify vulnerabilities of communities in the NSB due to LCLUC. Communities already impacted by climate change may see further vulnerabilities arise from infrastructure expansion. Previous research in the Yamal Peninsula has shown that the indigenous Nenet communities in Yamal have been resilient to land-use changes from increasing oil and gas fields in the region. However, the ongoing development of oil reserves requires constant adaptation and puts communities at risk. To evaluate human impacts in the NSB region, we will utilize a framework to assess vulnerability based on previous research at Yamal, adapted for Northern Alaska. Resource development and oil and gas exploration are also part of plans in NSB, specifically in the National Petroleum Reserve-Alaska. The parallel nature of this proposed research to previous work in Yamal will help understand the drivers of vulnerability in both study regions and differences in vulnerability and exposure for communities to LCLUC.

Nina Brooks/University of Connecticut, Storrs
A Remote Sensing Analysis of Heat Stress, LCLUC, and Women's Health in Sub Saharan Africa
21-LCLUC21_2-0021

Extreme heat in combination with land-cover/land-use change (LCLUC) pose significant challenges for sub-Saharan Africa (SSA). Climate change is increasing the duration, intensity, and frequency of extreme heat events throughout the region. In tandem, human activity is driving rapid LCLUC, putting pressure on agricultural production, threatening food security, and challenging livelihood strategies. Extreme heat and LCLUC disproportionately impact women through complex biological, social, economic, and cultural pathways. While numerous studies have leveraged NASA remote sensing (RS) platforms and datasets to study extreme heat exposure and LCLUC processes, we lack a nuanced understanding of extreme heat, interactions with LCLUC, and the acute and differential effects on women in SSA. Practitioners and decision makers require tools and information to direct resources and implement interventions to address these urgent issues.

Our overarching objective is to provide timely, policy relevant, and evidence-based information that can help support adaptation responses to extreme heat and LCLUC, particularly among women in SSA. We propose to leverage a suite of RS-derived datasets that are underpinned by multiple NASA space-borne platforms and the gold standard of georeferenced demographic survey data to study the relationships between extreme heat, land-cover and land-use change, and maternal reproductive and child health (MRCH) in sub-Saharan Africa. Our research will produce the first fine-grained (0.05°) and longitudinal (1986 - 2016) synthesis of how dynamic interactions between the changing characteristics of extreme heat events, extreme heat exposure, and LCLUC directly and indirectly impact maternal health outcomes across the diverse geography of SSA. Our interdisciplinary team of early career researchers brings complementary skills of RS, earth system science, social science, and data science to address the core RS and social and economic sciences components of this solicitation. By examining these critical relationships, we will directly advance NASA LCLUC Program priorities to solve human-environmental challenges in the age of climate change.

We will achieve this by accomplishing four research objectives:

1. Measure and map changes in extreme heat event characteristics and exposure: We will produce a region-wide, fine-grained, thirty-year analysis of the changing characteristics of extreme heat events and population exposure to extreme heat across SSA using the most accurate, newly produced daily minimum and maximum temperatures (Tmin and Tmax) and relative humidity (RH) for SSA.

2. Identify interactions hotspots between extreme heat events characteristics exposure, and LCLUC: We will integrate numerous RS-derived datasets that address different components of LCLUC, including vegetation change, settlement typologies that delineate how populations are distributed across the rural-urban continuum, and livelihood zones, with the output from Objective 1 to assess how interactions between the changing characteristics of extreme heat events and LCLUC drive changes in extreme heat exposure across SSA's diverse geography.

3. Quantify the impacts of heat-stress and LCUC on maternal reproductive and child health: We will conduct an individual-level, econometric analysis of the complex impacts of heat-stress and LCLUC on MRCH. To accomplish this, we will combine the outputs from Objectives 1 and 2 with the best standardized, nationally representative, georeferenced demographic survey data in SSA: the Demographic and Health Surveys (DHS).

4. Conduct a High-Resolution Case Study for Nigeria: We will conduct a moderate- and high-resolution replication of Objectives 1-3 in Nigeria. We will partner with International Food Policy Research Institute Nigeria Strategy Support Program (IFPRI NSSP) to ensure the research is responsive to local needs, engage stakeholders, and support policy integration.

Nimrod Carmon/Jet Propulsion Laboratory
Early Estimation of Fire-Risk in the Eastern Mediterranean and Socioeconomic Informed Communications of Actionable Strategies
21-LCLUC21_2-0004

We will use 20-year time series of land surface imagery, precipitation, and fire history to develop a statistical model correlating vegetation traits to fire risk for ~20,000 sq. km of Israel. We will incorporate an innovative precipitation forecasting model to deliver accurate seasonal fire-risk assessment maps 3-4 months before the start of the fire season. We will work with collaborators from Tel-Aviv University and the MEDRIN GOFC-GOLD consortium, and the Jewish National Fund (JNF-KKL) in Israel, to deliver end-user-oriented risk mitigation strategies tailored to the socioeconomic needs and capacity of people living on these at-risk lands.

We will develop novel data-fusion and trait retrieval algorithms to map water-stress and fire-risk indicators in vegetation. We will model the relationship between vegetation traits and seasonal rainfall with a time-series analysis to predict the traits given a seasonal precipitation prediction from a meteorological model. With an extensive record of forest fire events and expert knowledge from our collaborators, we will develop a fire-risk index calculated from the vegetation trait maps. With these elements, we will be able to produce a very early prediction of fire-risk. The methodology in this work will be developed on well-surveyed and managed Israeli forests and then applied to the entire Eastern Mediterranean to provide early fire-risk maps of the region.

The Eastern Mediterranean is home to many communities that vary in their social structures, economic activities, and relationships with the environment. Many under-developed communities rely heavily on the provision of ecological services to sustain their livelihoods. These at-risk communities may not have the capacity to translate an objective fire-risk map to actionable strategies and may lack the resources and infrastructure to react promptly. We will develop a translation and transfer framework based on socioeconomic and demographic surveys and interviews with end-users, coupled with our early fire-risk assessment. This system will provide a user-oriented fire-risk mitigation strategy adjusted by the socioeconomic analysis.

The technical merit of the proposed work, both in the socioeconomic and remote-sensing elements, differ from existing work in this field. First, fire-risk maps are usually with coarse resolution and given as a weekly forecast. In our case, we will develop 30m resolution maps months in advance of the fire season, providing enough time and enough spatial fidelity for smaller communities to react to upcoming threats. Second, coupling the socioeconomic elements to a fire-risk assessment ensures the usefulness and value of this work to end-users, as it communicates the risk in transferable terms.

Qiongyu Huang/Smithsonian Institution

Untangling the Interactions Between Rural Outmigration, Grassland Degradation, and Sustainable Land Use in Mongolia
21-LCLUC21_2-0006

Pastoral herding is the most prevalent land use type in Mongolia and is a way of life rooted in the country's long history of nomadism. Traditional herding families are increasingly facing economic hardship and are at risk of losing livelihoods. Many of them are moving away to seek non-herding jobs or have become hired labor to care for livestock of other households. These changes may affect land use practices as well as rural herders' opportunities for sustainable livelihood and eventually drive grassland degradation in the steppe ecosystems. However, so far, little attention has been paid to the interaction between this changing social-environmental system and its impact on rural communities.

There is a need to utilize medium-resolution satellite data to quantify fractional cover of vegetation functional type in grassland ecosystem as it can more adequately provide information for herding-related decision-making processes, and it can be linked readily with expansive vegetation functional type information collected by unmanned aerial vehicle (UAV). There is also a knowledge gap in utilizing state-of-the-art remote sensing methods to quantify resilience, a comprehensive measure of grassland health in social science literature that is closely related to vegetation functional type composition. Such products can help to evaluate the impact of land use practices and household dynamics on grassland conditions and untangle the complex interplay of changing rural population, household dynamics, herding practices, and rapidly evolving grassland systems.

As such, the objectives of the proposal are to: 1. Assess changes in household demographics, livestock management practices, and opportunities of sustainable livelihoods related to rural outmigration; 2. Develop and assess novel algorithms for quantifying fractional grass cover, fractional vegetational functional types, and a synthetic grassland resilience index by leveraging medium-resolution satellite imagery and UAV data, and 3. Use statistical matching method to systematically assess the differences of fractional grass cover and resilience at the district level as a function of changing human and social capital.

We will evaluate changes to rural demographics and livelihoods associated with rural outmigration through a household survey administered across multiple districts in three Mongolian provinces. Survey questions will focus on the rural herding labor force, finances, and associated decisions, and potential impact on opportunities for a sustainable livelihood. We will use Landsat-8 data to model fractional grass cover in two periods between 2013 and 2022. The model will be trained using UAV-derived vegetation functional type information based on object-based segmentation and classification algorithm. We will use the Harmonized Landsat and Sentinel-2 (HLS) data to create a fractional vegetation functional types product circa 2020 and, subsequently, a synthetic grassland resilience index map. The resulting metrics will be compared between regions using a statistical matching method to systematically assess the social drivers of degradation.

We have incorporated feedback received from our 2019 LCLUC submission and modified the previous version significantly. The proposed research, grounded in the sustainable livelihood framework, will improve the understanding of land cover and land use impact of changing demographics in Mongolia. Working with multiple Mongolian collaborators (Mongolian Geo-spatial Association, WCS Mongolia, Zoological Society Luujin), this project will build remote sensing capacity in Central Asia and examine the synergies between mid-resolution satellite data and high-resolution UAV data. It will also improve our understanding of the comparative advantages of Landsat and HLS products in mapping fractional cover of major vegetation functional types in grassland ecosystems.

McKenzie Johnson/University of Illinois, Urbana-Champaign
Land Cover Change, Conflict, and Peacebuilding in Colombia
21-LCLUC21_2-0010

In Colombia's "post-conflict" period, there is an urgent need to disentangle causal relationships between land cover land use change (LCLUC), conflict, and peacebuilding. Since the 2016 Peace Agreement between the Government of Colombia and the Revolutionary Armed Forces of Colombia (FARC), Colombia has experienced significant deforestation and environmental degradation, especially in the Amazon. Environmental change, in turn, is perceived to be heightening the risk of conflict relapse. Existing scholarship argues that FARC's demobilization, in conjunction with weak state presence, is driving LCLUC. However, much of this research has focused on measuring LCLUC after 2016 to gauge the effect of the peace process. This is problematic because it fails to consider historical patterns of LCLUC and thus risks drawing inaccurate conclusions about long-term LCLUC drivers, as well as the factors shaping opportunities for building durable peace. To address these gaps, we start with the proposition that conflict-peace transitions, where they reinforce patterns of conflict-driven LCLUC, produce destabilizing processes of political and economic transformation that undermine peacebuilding. In Colombia, we expect such patterns include land consolidation and conversion to large-scale extractive development; however, there is a lack of empirical data linking social drivers to observed LCLUC, especially before 2016. This has hindered efforts to understand the relationship between LCLUC and peacebuilding. There is thus a critical and unmet need to integrate remote sensing with social science research to elucidate LCLUC-conflict-peacebuilding causal relationships that currently remain theoretical and contested.

We address this need by drawing on a socio-ecological concept model that employs LCLUC as a lens to examine conflict and peacebuilding dynamics, focusing specifically on 1) how the socio-political and economic drivers of conflict produce LCLUC and 2) how LCLUC in turn shapes conflict-peace transitions. Our approach combines NASA satellite remote sensing data, advanced image processing, and geospatial analysis with multiscalar socio-political and economic analyses across two regions in Colombia (Montes de Maria and Caquetá) from 2000 to the present. Our analysis centers on three time periods: (1) Plan Colombia (2000-onward); (2) the demobilization of paramilitary groups (2005-onward); and (3) the Demobilization of FARC/peace process (2016-onward). We thus attempt to account for both the spatial and temporal complexity of the Colombian conflict to show how LCLUC-conflict dynamics have shaped possible peacebuilding trajectories across Colombia.

Using this integrated approach, we respond to three key science questions:
(1) How have land cover and land use changed in the targeted study period/regions?
(2) What are the socio-political drivers of LCLUC over time and across regions, and how has LCLUC in turn shaped conflict dynamics?
(3) How have Colombia's LCLUC-conflict dynamics shaped peacebuilding dynamics, and with what implications for building durable peace in Colombia?

This project directly responds to this NASA LCLUC solicitation by focusing on a mega-diverse country in Latin America, a NASA LCLUC priority region (RedLaTIF network region), to shed new light on LCLUC-peacebuilding dynamics, a critical and understudied topic. The project team is composed of three early-career scientists as PI/Co-I/Collaborator from interdisciplinary domains with complementary strengths and strong international collaborations. This project is thus expected to contribute to the NASA LCLUC’s goal of identifying high-impact LCLUC ""hotspot"" areas and combining ground data collection, NASA/non-NASA satellite data (MODIS, Landsat, Sentinel-2, Planet Labs and DigitalGlobe/MAXAR) and social science research to advance our understanding regarding “sustainability, vulnerability, and resilience of human land-use and terrestrial ecosystems.""

Alexey Shiklomanov/Goddard Space Flight Center
Assessing the Impact of Urban Land Conversion on Local and Regional Surface Climate and Its Socioeconomic Consequences in Western North Africa
21-LCLUC21_2-0001

Urbanization represents a small areal fraction of global land transformation; however, it occupies earth's most fertile and productive lands, and its ecological impact is significant and long lasting on the landscape. Over the last few decades, urban expansion has been rapid and significant, especially in developing countries where the population is becoming increasingly urban and where changing land rights and ownership have led to expansion of suburban areas. Morocco, a developing country in Northwest Africa, is emblematic of these trends. Moroccan cities have high growth potential, particularly in terms of land use and verticality. However, urban policies in Morocco need improvement to accommodate the growing number of households forced to live in urban outskirts because of housing prices, and more generally to address environmental, economic, and social issues and regulate urban development as defined by the United Nations framework. Research on the specific physical processes associated with urbanization is needed to assess the impact of urban land conversion on local and regional surface climate and its impact on society. This research will help us understand the interactions between urban landscapes and surface climate and the relationships between urban land use and societies, and will provide managers and policymakers a knowledge platform to consider in urban planning.

Urban land conversion affects surface climate through four mechanisms: reduction of transpiration from a reduction in vegetation fraction; a reduction in water infiltration capacity and consequent increase in surface runoff; the alteration of surface albedo through choice of building material and color; and the modification of surface roughness and consequent impacts on surface heat and moisture convergence. The proposed research will use satellite data and models to address a core theme of this solicitation, namely that urban expansion has been rapid and significant over the last few decades, as populations in developing countries become increasingly urban. Specifically, the study comprises four major tasks:

First, we will use moderate-resolution optical imagery (Landsat, Sentinel-2) to map urbanization through time for the densely populated and rapidly urbanizing cities of Morocco. Specifically, we will generate maps for 10 large cities for two time periods -- 2008 and 2018 -- where data are available and where the urban signature is remotely measurable on the landscape. These products will serve as baseline boundary conditions for the modeling tasks. Second, we will run land surface models available through the NASA Land Information System (LIS) offline over the selected cities to assess the diurnal variation of the land surface temperature (LST) and evaluate the interactions between LST variability, city characteristics, and ambient climate. This modeling work will show which urban characteristics and related landscape arrangements are best for mitigating the UHI in cities with different climate settings. Third, we will use the fully coupled Weather Research and Forecasting (WRF) model to investigate the Urban Archipelago Effect (UAE) at a regional level over a group of relatively large cities along

Morocco’s Atlantic coast and assess the effect of the surface UHI on rainfall patterns. A key novelty of this research will be to explore the aggregate effects of an urban chain’ generated by a series of large cities on regional climate. Finally, we will parameterize the urban-induced land cover and land use changes and their environmental effects to investigate building energy demand as calculated in the Global Change Analysis Model (GCAM).

Eleanor Stokes/Universities Space Research Association, Columbia
A Multi-Faceted, Pan-Mediterranean Assessment of Urban Land Change for the Evaluation of Interconnected Climate Risks
21-LCLUC21_2-0002

More responsive to climate change than most other parts of the planet, future warming on the Mediterranean coast is expected to increase 25% faster than the global average—40% faster in summer. Climate change poses a series of inter-connected risks to the region and is poised to substantially increase biodiversity loss, food insecurity, and flooding in human settlements over the next decades. However, each of these risks is amplified by another major transition occurring in the region—urbanization. The Mediterranean and North Africa have quadrupled in population and doubled in urbanization rate since 1960, and also host nearly 1/3 of all international tourists. Forty percent of the coastline is already covered in manmade structures with the pressures of urban land change predicted to escalate, particularly in secondary cities that still have unmet infrastructure deficits.

As a hotspot of climate risk, where coastal urbanization increases the vulnerability of land systems to climate change impacts, there is an urgent need to better understand the where, how, and when of urban LCLUC surrounding the Mediterranean Sea as a step toward anticipating future impacts. Assessments of urban development across the entire coastal zone are still lacking, and in particular, some of the more vulnerable and resource-limited countries in the region have been insufficiently studied. A multi-faceted, pan-Mediterranean assessment of urban change is needed to understand how urban growth interacts with the interconnected risks in the region.

The proposed research aims to fill this knowledge gap by focusing on interactions between urbanization hotspots and climate change risks. Our main objectives are to: (1) to characterize, map, and quantify urban LCLUC changes (land + built environment) on the coast of the Mediterranean, (2) to assess how these land changes have impacted multiple risks in the region (risks to biodiversity, food security, and flooding), and (3) to document how or if these risks have in turn shaped urban development, leading to different patterns of urban growth and change. This project uses multi-scale, multi-sensor remote sensing data and state-of-the-science methods to answer four fundamental science questions:

(1) How are urban coastal settlements along the Mediterranean Sea changing? What land covers and land uses have been subsumed by urban coastal development?

(2) Urban land change is multi-dimensional. To what extent have urban changes consisted of urban expansion, urban intensification, vertical growth, or infrastructure development?

(3) How have urban changes (from (1) and (2)), interacted with or amplified the risks of biodiversity loss, flooding, and risks to food security in the region through habitat conversion, agricultural land encroachment, or expansion/intensification in flood zones? Where are the hotspots of multiple risk from urban LCLUC?

(4) What are the drivers of the different patterns of urban LCLUC across the region? To what extent have the risks in (3) influenced development patterns on the Mediterranean coast?

This proposal is novel in its characterization of multiple types of urban LCLUC. In addition to urban expansion, we propose to apply multi-sensor land imaging (using

NASA's Black Marble, Landsat-8, and Sentinel-1 C band) to map urban intensification, vertical growth, and infrastructural investment, improving linkages between the diversity of development patterns occurring on the Mediterranean coast and the risks they shape. We will also utilize new remote sensing techniques (continuous settlement monitoring, sub-seasonal nightlights time series classification, and vertical change assessment) that have not yet been applied routinely across the Mediterranean region. This project will identify hotspots of urbanization-climate compound risk and contribute to ongoing GOFC-GOLD-MedRIN efforts, exploring the mitigation of risk through spatial planning and active management.

Sean Woznicki/Grand Valley State University
Water Scarcity in the Serbian Danube: Agricultural Land Use Change and Irrigation
21-LCLUC21_2-0005

Climate change is driving water scarcity in the Middle and Lower Danube River Basins. As growing season precipitation decreases and becomes more unpredictable, farmers have difficult decisions to make. They can invest in irrigation to sustain yields or transition to less water-intensive crops. Water exploitation will exacerbate scarcity, and could result in a race to the bottom for irrigation access. In Serbia, this process plays out across 630,000 farms that employ 21% of the working population. Meanwhile, thirty years removed from the breakup of Yugoslavia and subsequent regional conflict, Serbia is negotiating accession into the European Union (EU). Their integration into the EU single market is increasing agricultural exports and altering domestic agricultural policy. The interactions of market integration, climate change, and increasing water scarcity are uncertain, but they are drivers of agricultural land use change in the region, and understanding the feedback between them is critical.

The goal of this proposed research is to quantify how climate, water scarcity, and changing markets drive farmer decision-making and resulting land use change. The specific objectives are to: (1) map annual cropland and crop water use (2) estimate water availability and exploitation as a function of agricultural use (irrigation) and green and blue water, (3) identify mechanisms driving agricultural change with conditional crop choice and irrigation investment models, and (4) identify potential alternative futures of agricultural land use and water scarcity in response to climate and market shifts. We will link remote sensing of cropland, irrigated extent, and evapotranspiration from 1990-2019 to socioeconomic and hydrological models. The core remote sensing assets we will use are Landsat Collection 1 supplemented with Sentinel-1, 2, and MODIS. Annual cropland and crop water use maps will be created using deep learning (Objective 1). Remotely-sensed products will be coupled with climatic data to feed a hydrological/crop model to quantify water exploitation, availability, and provisioning of green and blue water (Objective 2). Crop maps, water availability, and commodity prices will inform the conditional crop choice and irrigation adoption socioeconomic models to identify the drivers of agricultural land use change (Objective 3). Finally, the models developed in Objective 3 and Objective 4 will be forced with climate change and commodity price scenarios (Objective 4).

This research fulfills the NASA LCLUC program goals by linking socioeconomic factors (farmer choices, market access, and prices) and climate change/water scarcity to land use change. In addition, it supports multiple LCLUC Program Science Themes: Food Security, Water and Energy Cycle Impacts, and Climate Variability and Change. By focusing on Serbia, we will integrate into the NASA GOFC-GOLD South, Central and East European Regional Information Network (SCERIN).

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2021
NNH21ZDA001N-TE21
A.4 Terrestrial Ecology

The National Aeronautics and Space Administration (NASA) solicited proposals for Phase 3 of the Arctic – Boreal Vulnerability Experiment (ABoVE Phase 3) within the NASA Earth Science Division Research and Analysis Program. The due date for proposals was November 17, 2021. The previous ABoVE Phase 1 and Phase 2 solicitations were released in 2014 and 2018, respectively.

Climate change in the high northern latitudes of the Arctic-Boreal Zone is occurring faster than anywhere else on Earth, resulting in widespread transformation to landscape structure and ecosystem function. In addition to producing significant feedbacks to climate through changes in ecosystem processes, environmental change in this region is increasingly affecting ecosystem services and these changes in services can impact society. Recognizing the vulnerability and global importance of this region, ABoVE is focused on developing better abilities to observe, understand, and model the complex, multiscale, and nonlinear processes that drive the region's natural and social systems. The ABoVE Study Domain encompasses most of the boreal and tundra regions of Alaska and northwestern Canada. For Phase 3, NASA also solicited studies that could make use of insights gained from previous ABoVE efforts to extrapolate to the continental and circumpolar boreal and/or Arctic zones.

The overall focus of the ABoVE Phase 3 solicitation is on:

(a) Conducting synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of Arctic and boreal ecosystems in the ABoVE domain, across North America, and across the circumpolar region.
(b) Integrating research results and remote sensing data from ABoVE into a coherent modeling framework to diagnose and predict the impacts of environmental change on ecosystem dynamics and the consequent impacts on ecosystem services and society.
(c) Filling critical research gaps in our understanding of how environmental change impacts the dynamics of boreal and Arctic ecosystems within the ABoVE domain.

Studies proposed to fill critical research gaps in our understanding of northern ecosystem dynamics in the ABoVE domain were required to clearly explain the compelling reasons why filling a particular research gap is critical to understanding the vulnerability and resilience of northern ecosystems to environmental change.

A total of 46 proposals were received, and 20 have been selected for funding. The total funding to be provided for these investigations is approximately $15.5 million over three years. For the first year, approximately $4.8 million is allocated to the selected investigations. The investigations selected are listed below. The Principal Investigator, institution, investigation title, and abstract are provided.

Alexis Bloom/Jet Propulsion Laboratory
Using CO_2, CH_4 and Land-Surface Constraints to Resolve Sign and Magnitude of Northern High Latitude Carbon-Climate Feedbacks
21-TE21-0045

Summary: We propose to merge tower and aircraft carbon dioxide (CO_2) and methane (CH_4) observations with a mechanistic C cycle model to resolve the sign and magnitude of carbon-climate feedback potential of ABoVE domain ecosystems. There are currently large uncertainties on the potential responses of northern high-latitude ecosystem CO_2 and CH_4 fluxes to a changing climate. While increased temperatures and elevated CO_2 provide favorable changes for photosynthetic uptake, uncertainties on soil CO_2 and CH_4 respiration responses to a changing climate remain prominent. As a consequence, the sign and magnitude of carbon-climate feedback potential of northern high-latitude ecosystems namely CO_2 and CH_4 flux changes in response to hypothesized, observed or projected changes in climate remains effectively unresolved.

The ABoVE domain CO_2, CH_4 and ancillary ecosystem measurements including ABoVE and pre-ABoVE aircraft campaigns, tall tower and eddy covariance datasets within the ABoVE domain, and ancillary C and H_2O observations from space provide a key synergistic constraints on the processes controlling C cycle responses to climate. To synthesize ABoVE domain observations and mechanistic C cycle knowledge, we will use the Bayesian data-model integration framework (CARDAMOM) to produce observation-constrained model estimates of environmental controls of carbon exchange and its sensitivity to climate change in the ABoVE domain. Based on our analyses, we propose to address two science questions:

Question 1: How do ABoVE domain ecosystem CO_2 and CH_4 fluxes respond to climatic variability?

Question 2: Will the ABoVE domain CH_4 and CO_2 flux responses to projected climate changes induce positive or negative carbon-climate feedbacks?

To address these questions, we will (a) use collocated CO_2 and CH_4 flux measurements across 21 eddy covariance tower sites to observationally constrain CARDAMOM C cycle model process variables and states, (b) extend the CARDAMOM analysis across the ABoVE domain, and (c) calibrate regional CARDAMOM fluxes using WRF-Chem simulated CH_4 concentrations and atmospheric CH_4 and CO_2 measurements from ABoVE and pre-ABoVE aircraft and tall tower. To address question 1, we will use observation-constrained site-level and regional CARDAMOM analyses to explicitly quantify the integrated sensitivities of CH_4 and CO_2 fluxes to temperature, precipitation and atmospheric CO_2 fertilization. To address question 2, we will combine the CH_4 and CO_2 sensitivities by accounting for the Global Warming Potential (GWP) of CH_4 (28-34 times larger than CO_2 on centennial timescales) to explicitly quantify the net GWP impact of climate trends on ecosystem C fluxes. We will specifically determine whether the net GWP response (namely the combined GWP-weighed CH_4 and CO_2 responses) to observed or hypothesized climate trends amount to a negative or positive carbon-climate

feedback potential. Answering the proposed questions will in turn provide unprecedented observation-based insight on whether northern high latitude ecosystems have the potential to dampen or amplify global climate trends in the coming decades.

Natalie Boelman/Columbia University
The Future of the Forest-Tundra Ecotone: A Synthesis that Adds Interactions Among Snow, Vegetation, and Wildlife to the Equation
21-TE21-0020

The boundary between the circumpolar Boreal forest and Arctic tundra is one of the world's most extensive ecotones, with a distance spanning 13,400 km across the Northern Hemisphere. As such, the Forest-Tundra Ecotone (FTE) plays a critical role in global biogeochemical cycling and energy balance, biodiversity, and ecosystem services and socioeconomics of Arctic-Boreal regions (ABR). Ongoing warming has led to the common assumption of progressive northward advance of the entire FTE. Importantly, however, findings of observational studies do not show a spatially consistent FTE response to climate warming. In their circum-Arctic survey, Rees et al. (2020) found that during the 20th century only 52% of study sites have advanced northward, while 46% remained stationary and 2% retreated. They also found that overall, sites that advanced northward did so two orders of magnitude more slowly than expected if vegetation distribution remained in equilibrium with climate, and that rates of advancement varied substantially by region. There are several reasons for these discrepancies, including the possibility that changes in FTE biophysical structure may be too subtle to detect using traditional approaches, and time-lags between quantifiable FTE responses and the recent warming trend in ABRs. Further, herbivory is often overlooked despite the fact that trees and woody shrubs are an important food source for many FTE dwelling herbivores, suggesting that herbivory likely inhibits northward advance of portions of the FTE. Moreover, despite the fact that herbivore pressure varies strongly as a function of snow depth, snow-herbivore interactions have yet to be explicitly included in ecosystem models that predict changes in the position of the FTE. When combined with our own field based observations at the Alaskan FTE during phase 1 of ABoVE, these lines of evidence strongly suggest that critical interactions among local abiotic and biotic factors must be explicitly considered in any assessment of how climate change will alter not only the position and extent of the FTE - hereafter referred to as 'FTE behavior' - but also the implications for its ability to store carbon (C) and provide wildlife habitat.

This project's overarching science goal is to include the largely unconsidered role of interactions among snow, key herbivores, and vegetation in determining spatial and temporal dynamics observed in FTE behavior, and in turn how these dynamics impact both the amount of C stored and availability of wildlife habitat within the circum-Arctic FTE. Our general approach is to synthesize observations, knowledge, and models from multiple studies made during ABoVE Phases 1 and 2 to build and validate a new, quantitative ecosystem modeling tool, FTE - Snow+Vegetation+Herbivory (FTE-SVH), that represents what we currently understand are key interactions controlling FTE behavior, C storage, and wildlife habitat (Obj. 1). We will use published studies and biotic and abiotic data collected from 1980-present to guide FTE-SVH development and validation. These will include a combination of NASA, ABoVE specific, and other sources of accumulated knowledge and understanding, as well as previously developed remotely sensed products, ground-based observations, and numerical models. This modeling system will be capable of reproducing observed dynamics in FTE behavior over the last four decades. We will then determine FTE-SVH model sensitivities via five experiments: increased air temperature (Expt. 1) and atmospheric CO_2 (Expt. 2); changes in snowscape properties (Expt. 3) and herbivore pressure dynamics (Expt. 4); and circum-Arctic FTE simulations driven with future scenario data for climate and herbivore pressure (Expt. 5) (Obj. 2).

Laura Bourgeau-Chavez/Michigan Tech Research Institute
Integrating Remote Sensing and Modeling to Better Understand the Vulnerability of Boreal-Taiga Ecosystems to Wildfire
21-TE21-0013

Climate change has led to wildfire intensification in the boreal and Arctic biomes, with changes in vulnerability and resiliency of ecotypes and species, as well as changes in permafrost thaw and carbon cycling. In some areas, reburns are becoming more frequent and post-fire regeneration failure is occurring. The overall goal of the proposed work is to better understand, diagnose and predict ecosystem dynamics, especially the interaction of hydrology and associated variables (e.g. moss state, fuel loading, soil drainage, etc.) with wildfire on recovery, state changes and regeneration failure through the integration of field data, remote sensing and process-based ecological and hydrological modeling of the ABZ. In Phase 1 and 2 ABoVE grants, the Co-I s of the proposed work studied wildfires affecting peatland and upland systems of NWT and Alberta CA using field data, remote sensing and modeling. Focus was on analysis of field data and developing algorithms from coincident remote sensing and in-situ data for mapping a variety of variables to lay the empirical foundations for modeling C consumption and ecosystem processes in the peat-rich study area. The team developed Landsat-8 based map products of organic layer burn severity, SAR-optical derived maps of peatland and upland ecotypes, algorithms for biomass retrieval from UAVSAR, as well as soil moisture retrieval and drainage maps from C-band SAR. The proposed work focuses on an expanded study area to include the Taiga Shield and Taiga/Boreal Plains ecoregions with rich organic soils in western Canada. Our objectives are to: 1) Use AVIRIS-NG to map plant functional types (PFT), Sphagnum and feather mosses (indicators of moisture and nutrient cycling) in our study region in preparation for the NASA Earth System Observatory's (ESO) Surface Biology and Geology Mission (SBG); 2) Develop SAR-derived algorithms and products of biomass, soil moisture and soil drainage from L-band systems, in particular the NASA ESO's NASA-ISRO SAR (NISAR) mission; and 3) Refine fire behavior and effects modeling to include smoldering combustion, dynamic moss, and active crown fire behavior. This modeling will capture important hillslope heterogeneity and depth of burn with an integrated hillslope hydrology component. We will use comprehensive L-band SAR biomass and soil moisture products and drainage maps, hyperspectral mapping of moss PFTs, and ABoVE field data as validation of the ecosystem, hydrology and fire effects models for peatlands and uplands to improve our understanding of the interactions of wildfire and hydrology on post-fire vegetation dynamics. This work will allow for a mechanistic understanding of the vulnerability of ecosystems to wildfire, the hydrological effects (including permafrost changes) and the trajectories of succession. This is essential for landscapes that historically do not burn, such as wetlands, but also for determining thresholds and tipping points that may alter succession. This work addresses multiple ABoVE Phase 3 focus areas, including #1 integrating previous ABoVE research results and remote sensing data into a coherent modeling framework to diagnose and predict ecosystem dynamics improving model parameterizations and process level understanding; #3 analyzing ABoVE Airborne Campaign remote sensing data (AVIRIS-NG and UAVSAR L-band SAR) to prepare for future missions (SBG and NISAR); and #4c addressing impacts of ecological disturbance (fire) and environmental change (e.g. temperature, precipitation) on vegetation dynamics. This work will fill critical knowledge gaps including mapping biomass and spatial patterns of boreal woody vegetation, providing a more explicit understanding of fire impacts on subsurface hydrology and the influence on post-fire recovery, vegetation shifts and ecosystem change, as well as understanding the role of moss and site-level drainage patterns as an influence on combustion and post-fire successional trajectories.

David Butman/University of Washington
Do Changing Terrestrial-Aquatic Interfaces in Arctic-Boreal Landscapes Control the Form, Processing, and Fluxes of Carbon?
21-TE21-0003

Despite their relatively small coverage, surface water extent across boreal and arctic lowlands significantly impacts landscape-scale estimates of carbon emissions. In ABoVE Phase 1, field efforts showed that open water aquatic ecosystems change from sources of atmospheric carbon to sinks throughout the ice-free season in the Yukon Flats National Wildlife Refuge and that these lake environments are unlike most other lake ecosystems studied to date across northern latitudes. The form and function of organic carbon in these lakes represent autotrophic processes, counter to prevailing paradigms that link terrestrial and aquatic ecosystem metabolism through carbon.
In ABoVE Phase 2, we show that seasonal hydrology influences vegetation structure and inundation extent for lakes in the Yukon Flats National Wildlife Refuge, the Peace Athabasca Delta, and lakes in the Northwest Territories. Changing inundation extent influences the form and function of carbon across a littoral to open water gradient. Rapid shifts in hydrologic conditions alter the fluxes of CO_2 and CH_4. UAVSAR, AVIRIS-NG, and satellite-based Sentinel-1 data, identified locations of water area change, as well as littoral vegetation change. Finally, we identified and traced short-term and long-term trends in the molecular composition of dissolved organic carbon as it relates to the landscape.

We propose to expand our findings to the Arctic-boreal domain of North America. We will show changing environmental conditions enhance or reduce the importance of carbon transfers across the terrestrial-aquatic interface. We hypothesize that rapid and broad changes in precipitation patterns, temperature, littoral vegetation communities, and inundation extent create conditions that impact the relative influence of river flow, lithology, as well as soil and vegetation carbon on the source and processing of carbon in inland waters. We will use results from previous ABoVE efforts that estimate the probability of landscape change, including fire, permafrost loss, and vegetation conversion across the Landsat record. We will expand on our past fine-scale efforts using UAVSAR, AVIRIS-NG, and satellite-derived products using advanced machine learning methods for water detection from satellite remote sensing. We will establish a database of over seven years of field data collection supported by ABoVE, extensive ground truth from our past field campaigns, and historical time series data available from current and past collaborators from Canada and the USGS on the fluxes and concentrations of carbon across arctic inland waters. We will link the long-term shift in carbon concentrations and compositions with newly compiled data on satellite-derived optical properties of lake ecosystems, the lake area, and phenological signals using optical satellite remote sensing derived from Planet Labs and synthetic-aperture radar satellites NISAR and ALOS-PALSAR. Our goal is to provide informed estimates of inland water carbon processing and emissions form boreal-arctic inland waters.

Relevance to NASA: Our work directly addresses questions the Tier 2 Science Questions. In particular, we will identify the impacts of disturbance regimes on the connection between terrestrial and aquatic ecosystems. We will identify the consequences of changing hydrologic conditions on the processing, flux, and future potential change across aquatic gradients in the arctic and boreal zone. In response to the solicitation, our proposed work will directly address 4-a, as we will derive expanded products that identify seasonal shifts in inundation at a large scale, coupled with evidence of vegetation change linked to long-term changes in climate conditions. Our work addresses 4-c by utilizing previously collected field data on carbon flux and vegetation structure to identify the past influence of disturbance to carbon processing in aquatic environments.

Jinyang Du/University of Montana
High Resolution Mapping of Surface Soil Freeze Thaw Status and Active Layer Thickness for Improving the Understanding of Permafrost Dynamics and Vulnerability
21-TE21-0007

We propose to perform high-resolution (10-100 m) probabilistic mapping of soil freeze thaw (FT) dynamics and clarify environmental linkages driving local scale trends in permafrost active layer thickness (ALT) over the ABoVE domain. The proposed FT and ALT processing will capture finer scale features and processes represented from detailed field studies, but lacking in coarser satellite and landscape model assessments. We will resolve the complex ALT heterogeneity and clarify its relations with local environmental gradients in soil, terrain, vegetation, and disturbance. We will accomplish these objectives using a physics-based modeling and machine learning framework integrating multi-source and multi-sensor remote sensing, in situ biophysical measurements, and other ABoVE geospatial data.

We will exploit L-band Synthetic Aperture Radar (SAR) remote sensing to develop a probabilistic FT data record guided by modeled scattering physics and accounting for the impacts of vegetation, snow, and multi-layer soils with varying levels of organic matter and unfrozen water. FT data derived from satellite L-band SARs (PALSAR, NISAR) will quantify the seasonal timing and duration of active layer freezing and thawing. These results will be used to train a Convolutional Neural Network (CNN) for generating more continuous probabilistic FT daily time-series at fine resolution. The FT data will provide critical inputs to a more complex deep learning (DL) network combining CNN and Long Short-Term Memory (LSTM) algorithms for utilizing both spatial and temporal feature patterns, and estimating fine-scale ALT distributions, which will be informed by the extensive ABoVE data libraries.

The above analysis will be further informed by deploying a novel ground penetrating radar (GPR) sensor from a small aerial drone for mapping ALT distributions at very fine scales (2-10 m) over selected permafrost change hotspots. The ability of the drone for simultaneous low frequency (L- and P-band) SAR retrievals will resolve the spatial and vertical heterogeneity of soil profiles and deeper (>60cm) active layers closer to the level of local field observations and driving processes. The drone deployments will also fill a critical gap left by the lack of temporally consistent UAVSAR L-band and AirMOSS P-band SAR acquisitions from the ABoVE airborne campaigns.

This project will resolve finer scale active layer complexity and environmental relationships that are lacking in coarser landscape and global scale remote sensing and model assessments. Our results will clarify the natural complexity in FT and active layer patterns, and their underlying physical and environmental controls, and influence on other ecosystem attributes. This information is needed to inform coarser earth system model projections of active layer trends and associated water and carbon cycle feedbacks to projected climate change.

This project addresses solicited ABoVE Phase 3 research to perform synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of ecosystems in the ABoVE domain. Project outcomes will include next generation remote sensing algorithms utilizing L-band SAR measurements and deep learning techniques; new high-resolution FT and ALT data records; and improved understanding of the impacts of changing climate and disturbances in heterogeneous Arctic-boreal biomes. This project will demonstrate a multi-source data fusion framework for permafrost studies that leverages future NASA SAR missions, including NISAR. The project also addresses an active layer synthesis priority of the ABoVE Permafrost and Hydrology Working Group.

Laura Duncanson/University of Maryland
Mapping Boreal Forest Biomass Recovery Rates Across Gradients of Vegetation Structure and Environmental Change
21-TE21-0037

Significance:

Boreal forests account for nearly a third of this global forest area, contribute to ~20% of the global forest carbon sink and are warming faster than any other forests on the planet. Increasing fires, pests, warming temperatures, and shifting hydrologic regimes all influence the carbon balance of the boreal system. While boreal disturbances have been monitored through the optical satellite record, the associated biomass losses have large degrees of uncertainty due in part to a dearth of accurate biomass products. How these ecosystems will recover and sequester carbon after disturbances is even more uncertain. Understanding how boreal forest carbon dynamics are shifting in a rapidly changing environment is a key knowledge gap outlined by Goetz et al., 2021 (in review).

Objectives:
This research focuses on expanding on past ICESat-2 2020 maps with a new boreal-wide forest age product, a suite of forest disturbance products, and time series data from Landsat and SAR to analyze where and why biomass fluxes are changing across the boreal system. The objectives of this research are to:
1) Incorporate Sentinel-1 data for improved ICESat-2 biomass stock mapping and increased sensitivity to biomass fluxes across disturbance gradients;
2) Link 2020 ICESat-2 biomass with Landsat time series data and forest age data to map biomass recovery rates;
3) Monitor biomass losses related to new (post 2020) disturbances across the boreal using ICESat-2, Landsat and SAR (Sentinel-1); and
4) Analyze disturbance and recovery rates as a function of warming (temperature anomalies), topography, forest type, forest age and latitude.

Methods:
Our research team has recently produced a 30 m boreal-wide aboveground biomass map (all latitudes north of 50 degrees) using ICESat-2 forest structure and a combination of Landsat and other ancillary data products. This product will be updated and the methods extended for multiple years to map biomass recovery from 1985-2020 and loss from 2020-2024. Input datasets (Table 1, Table 2) include field, airborne, and satellite data. Field and airborne data will be used to create reference biomass change validation maps, while satellite data will be used to create and analyze biomass change products. Biomass growth will be mapped using two methods, 1) a stock-change method and 2) a chronosequence method. Growth rates will be analyzed as a function of disturbance, forest age, topography, latitude, and temperature anomalies from GISS data. Biomass losses associated with new disturbances will also be mapped during the period of the proposed research, and loss rates will be analyzed based on the same set of environmental layers. All data processing will be on the NASA-ESA Multi-mission algorithm Platform (MAAP), and all code will be published with products, supporting the transition in the biomass community toward Open Science.

Nancy French/Michigan Tech University
Informing Wetland Policy and Management for Waterfowl Habitat and Other Ecosystem Services Using Multi-Frequency Synthetic Aperture Radar

21-TE21-0023

Wetlands provide many ecosystem services, including waterfowl habitat, carbon sequestration, and water quality. Northern wetlands are threatened from both land use expansion and climate change disruptions, prompting the need for informed management strategies. We aim to assist communities in managing wetlands and set land stewardship policies by providing access to remote sensing-based information on short-term and long-term wetland dynamics. The research proposed will utilize methods for mapping wetland type and seasonal inundation developed by our research team in Phases 1 and 2 of ABoVE. In the next phase, these techniques will be further developed and expanded to make them accessible and useful for land management and policy decisions. Investments in data collection, algorithm development, and product creation by ABoVE will be used for capacity building for decision-making in the ABoVE region, as envisioned in the ABoVE Concise Experiment Plan.

For ABoVE Phase 2 our research team is focused on improving methods to map wetland status, sub-seasonal dynamics, and multi-year change for waterfowl habitat assessment within the ABoVE domain. In the next phase, we will focus on using these methods to assess specific wetland ecosystem services in regions where land stewardship activities lack sufficient information for informed management. In partnership with Ducks Unlimited Canada (DUC), we will identify key species, areas of concern, and ecosystem services vital to stakeholder needs by initiating discussions with regional indigenous communities, provincial and national governments, and waterfowl modeling experts. We will refine maps of wetland dynamics developed in the first part of this project to create information products valuable to stakeholders. We will do this by: (1) further testing the added value of L-Band SAR data from NISAR and the ABoVE airborne campaigns and C-Band SAR data from Sentinel-1 for wetland type and inundation mapping to target wetland types of interest and inundation patterns critical to ecosystem services, such as waterfowl breeding; (2) combining type maps with inundation status for characterizing site dynamics and informing best management practices; and (3) integrate products created from the newly launched Surface Water Ocean Topography (SWOT) mission on surface water elevation into our SAR-derived assessments of wetland hydroperiod and change. Integration of multi-frequency SAR-derived wetland type and inundation products to inform wetland mapping provides a novel source of information that will be demonstrated in pilot studies at several sites across the region, including the Peace-Athabasca Delta, a UNESCO World Heritage Site critical to waterbird population sustainability. We propose to hold initial outreach discussions facilitated by DUC and Environment Canada to identify regions and ecosystem services that are of most concern, in light of land use and climate pressures. We will conclude our project by conducting a second workshop focused on capacity building so stakeholders have access to the data and products developed under this project. Products and workflows will be disseminated in line with NASA's Open Source Science Initiative for Earth System Observatory.

The research addresses Topic 2 by advancing ability to monitor wetlands to inform policy and management objectives. Topic 3 and 4 are also addressed. The research will provide regional partners with a methodology to use SAR remote sensing data and products developed for wetland monitoring to inform policies for designating and managing Indigenous Protected Conserved Area (IPCA) lands and waters where Indigenous governments have the primary role in protecting and conserving ecosystems through Indigenous laws, governance, and knowledge systems. Development of approaches for wetland mapping and monitoring will have an impact on managing these regionally important protected areas, wetlands, and waterfowl populations.

Gerald Frost/ABR, Inc.
Towards a Warmer, Less Frozen Future Arctic: Synthesis of Drivers, Ecosystem Responses, and Elder Observations Along Bioclimatic Gradients in Western Alaska
21-TE21-0047

Within western Alaska there exists a strong convergence of environmental change processes, natural hazards, wildlife habitats, and a large subsistence-based human population. In response to rapid climate change, western Alaska's tundra ecosystems are experiencing widespread changes to vegetation (e.g., shrub expansion) and an array of ecological disturbances (e.g., a large proportion of global tundra fire activity) that are expected to intensify as the Arctic continues to warm. Tundra ecosystems of western Alaska's Bering and Chukchi Sea regions are distinctive in the circumpolar Low Arctic because they encompass exceptionally broad gradients of climate, latitude, continentality, sea-ice regime, and permafrost occurrence. Declines in the spatial extent of cryospheric features at sea (seasonal sea-ice) and on land (permafrost) raise the question of whether and for how long portions of western Alaska will fit historical concepts of "what is Arctic," given the influence the cryosphere has on the function and dynamics of tundra ecosystems elsewhere in the circumpolar region. Ongoing Arctic warming and diminishing sea ice suggest that the high climatic variability currently being observed in the Bering and Chukchi Sea regions could become common in other parts of the Arctic in the future.

Long-term spaceborne observations of tundra ecosystems, in the form of the Normalized Difference Vegetation Index (NDVI), provide foundational information concerning ecosystem conditions and responses to climatic trends, variability, ecological disturbance, and successional processes. In western Alaska, NDVI trends display very high spatio-temporal variability, with areas of both strong increase and decline in greenness found along the gradient in multiple satellite datasets, reflecting interactions of climate change, climate variability, landscape processes, and long-term shifts in vegetation structure. Yet, the attribution of greenness trends to specific environmental drivers remains a grand challenge that must be overcome in order to better understand environmental controls on tundra greenness in heterogeneous landscapes, and to predict the ecological trajectories of the future Arctic. We seek to meet this challenge through synthesis of a broad, multi-disciplinary information base that includes long-term spaceborne records of NDVI, observational climate and reanalysis data, model-based climate projections, high-resolution remote sensing data, field observations, and the knowledge base of western Alaska elders that predates the period-of-record of Earth-observing satellites. All phases of the project will leverage established partnerships with resource managers and local people in western Alaska.

Study objectives are to:

1. Evaluate observed and prognostic climate, cryosphere, and landscape-scale biophysical variables to identify predictors and project future scenarios of tundra vegetation greenness (NDVI) along climate gradients in a warmer, increasingly maritime and ice-free Arctic using conventional statistical modeling and machine learning.

2. Apply historical and modern satellite datasets, airborne remote sensing, and field data to model western Alaska tall shrubland distribution, change, and canopy heights at high spatial resolution to improve assessments of greenness drivers and address resource management priorities identified by land managers in western Alaska.

3. Throughout the project, document the observations, concerns, and expectations of village elders regarding Arctic change in their areas within a knowledge exchange framework and relate them to the scientific questions, findings, and synthesis efforts.

Scott Goetz/Northern Arizona University
Mapping and Modeling Attributes of an Arctic Boreal Biome Shift: Phase-3 Applications within the ABoVE Domain
21-TE21-0011

We propose to continue our investigation of the role of vegetation dynamics across the ABoVE study domain, building upon our extensive prior work documenting changes in arctic and boreal vegetation change over the past ~4 decades using satellite and airborne remote sensing and related field measurements. We will expand upon past activities with updated satellite data as well as data from the ABoVE airborne campaigns. These analyses will be coupled with extensive field measurements and species-specific process-based modeling to capture areas of documented boreal tree productivity, structure and mortality changes, and range expansion of trees into the tundra biome across climate, environmental and dispersal gradients. Our investigations will be in the context of exploring multiple lines of evidence for the progression of a boreal biome shift, where tree productivity decreases and mortality increases in the southern boreal while suitability for range expansion and densification of woody vegetation (e.g. trees and shrubs) increases in the northern boreal and arctic tundra.

The investigative team has worked extensively on these topics in Phases 1 and 2 so will be able to leverage existing data sets, results and resources to focus on aspects of boreal forest dynamics that make them vulnerable to productivity declines and tree mortality, while also incorporating multi-scale remote sensing data to inform modeling these processes using both machine learning and forest demography models with a history of well-developed capabilities. We will also advance our more detailed regional analyses focused on faunal habitat changes associated with vegetation composition and structure changes in both biomes, with a focus on areas of interior Alaska and western Canada (boreal biome), and the Seward Peninsula and North Slope of Alaska and northwestern Canada (tundra biome). These regions include the winter range of the declining western Arctic and eastern arctic Porcupine caribou herds, and the increasing Fortymile caribou herd of the eastern interior. Thus the proposed activity focuses on some of the largest issues of concern to management agencies in the region. A substantial contingent of the team has unique insights into these land and wildlife management issues, as well as the fine scale heterogeneity of vegetation pattern and process derived from our phase 1 and 2 projects. Other members of our interdisciplinary team have considerable complementary expertise in remote sensing and vegetation characterization for mapping and monitoring vegetation dynamics, forest demography process modeling, and other relevant experience in the study domain. PI Goetz is also applying to continue as the ABoVE Science Team Lead.

Our proposed activity will address several of the ABoVE Tier 2 science questions, particularly 3.1 How are environmental changes affecting critical ecosystem services..?" and 3.5 How are flora and fauna responding to changes in biotic and abiotic conditions, and what are the impacts on ecosystem structure and function?" We will also specifically address ABoVE science objectives focused on ecosystem dynamics, including Determine the causes of greening and browning trends and their impacts on ecosystem form and function" and Determine how the spatial and temporal dynamics in both faunal abundance and characteristics of fish and wildlife habitat co-vary across gradients of climate and disturbance." The proposed activity will also address objectives focused on ecosystem services, specifically Analyze how changes to natural and cultural resources will impact local communities as well as influence land management policies and practices" and Determine the degree to which changing environment and altered human activities result in synergistic or antagonistic changes in ecosystem services."

Mark Lara/University of Ilinois
ABoVE-Ground Characterization of Plant Species Succession in Retrogressive Thaw Slumps Using Imaging Spectroscopy
21-TE21-0040

Short title: Spectral characterization of Thaw Slumps
Full title: ABoVE-Ground Characterization of Plant Species Succession in Retrogressive Thaw Slumps Using Imaging Spectroscopy

Recent high-latitude climate and environmental change has elevated the prevalence of permafrost disturbances associated with the thawing of relict buried glacial ice in the form of thaw slumps across many Arctic tundra ecosystems. Retrogressive thaw slumps (RTS) are a common type of mass wasting (i.e., movement of rock and soil downslope) in permafrost regions, which dot the landscape of many northern ecosystems. These large-scale permafrost disturbances release significant volumes of soil carbon and nutrients, influencing regional carbon and nutrient cycling for years to decades following disturbance. The rate and magnitude of RTS activity is accelerating with warmer and

wetter climate conditions, -exacerbated by tundra fires. Despite remote sensing observations indicating thaw slumps are becoming larger and more prevalent on the Arctic landscape, little attention has focused on understanding the potential counteracting, carbon climate feedback mechanisms associated with the diverse patterns of succession (plant species recolonization) following RTS disturbance. Therefore, the primary objective of the proposed research is to characterize the primary and secondary successional responses of functionally important plant species following disturbance and model the implications of carbon storage and sequestration spanning the tundra of the ABoVE core study area.
To accomplish this objective we will leverage ground, air-, and spaceborne remote sensing products and field observations archived or planned by funded projects (via NASA, DOE, NSF, and ESA). We will use vegetation surveys and unmanned aerial systems (UAS)-derived hyperspectral and LiDAR observations collected across 35+ RTS sites across northern Alaska, with overlapping Airborne Visible InfraRed Imaging Spectrometer-Next Generation (AVIRIS-NG, 15+ sites) to characterize species composition in dwarf to tall-shrubs (Salix alaxensis, Salix pulchra, Salix glauca, Salix reticulata, Betula nana, Betula glandulosa, and Alnus viridis) and dominant herbaceous plant functional types (e.g., sedge, forb, moss) within slump scars in northern Alaska. Field observations will be integrated with Copernicus Sentinel-2 Multispectral Instrument (MSI) and AVIRIS-NG data to simulate AVIRIS-NG hyperspectral data for characterizing regional patterns of plant species composition within all identified RTS scars (identified with a deep learning thaw slump detection model) across the ABoVE tundra core study domain. We will link species composition with RTS age using a subset of dated scars using aerial and satellite image archives (1950-present), while published, archived, and planned 14C dating of RTS scars will be leveraged to approximate the age of RTS features that initiated prior to 1950. These datasets will be coupled with new and existing allometric biomass relationships to model the impact of RTS disturbance on carbon storage. Insights from this project will improve knowledge of (1) the temporal patterns of vegetation succession following disturbance, and (2) the spatial and temporal hot-spots of change in geomorphic, vegetation, and carbon dynamics as climate warming and disturbance regimes intensify.

Yanlan Liu/The Ohio State University
Characterizing Arctic-Boreal Vegetation Resilience Under Climate Change and Disturbances
21-TE21-0028

The Arctic-Boreal region has experienced widespread vegetation shifts over the recent decades. Rapidly changing climate and more frequent disturbances are expected to cause substantial uncertainties in predicted vegetation distribution and function. A major challenge on accurate prediction of Arctic-Boreal vegetation dynamics is to characterize vegetation resilience, i.e., when and where vegetation is vulnerable to disturbances and how fast it recovers after disturbances. However, besides studies focusing primarily on post-fire recovery at limited field sites, vegetation resilience before and after disturbances has not been systematically quantified at a remote sensing scale. The mechanistic controls on resilience also remain largely unknown. Even with accurate projections of disturbance occurrence, without characterizing vegetation resilience at a large scale, it is challenging if not impossible to determine future vegetation distribution and carbon sink strength of the Arctic-Boreal region

We propose to map spatial-temporal variation of vegetation resilience and identify the critical controls by leveraging the datasets collected in previous ABoVE projects. The proposed work consists of three main objectives. First, we will quantify the resilience of greenness and productivity, defined as the time to full recovery and the temporal autocorrelation, a measure of recovery rate from perturbations. Building upon our previous work, we will set up a Bayesian dynamic model to identify time-varying resilience signals from satellite imagery. Second, focusing on areas that experienced vegetation shifts, i.e., large biomass loss/gain or land cover change, we will investigate resilience variation throughout successional trajectories and across different disturbance types. Low resilience before shifts represents high vulnerability to disturbances, which will be used to assess the risk of vegetation loss. Remotely sensed resilience representing recovery rate after loss will be compared to available field measurements for validation and uncertainty evaluation. For areas that experienced vegetation gain, we will examine whether resilience is enhanced or impaired due to structural overshoot. Finally, we will identify critical controls on detected resilience variation by integrating previous ABoVE products and the physical and ecological properties acquired during the ABoVE airborne campaigns, including AVIRIS-ng, LVIS, SAR, and the fine-scale diversity reflected by these high-resolution airborne measurements. Machine learning and deep learning approaches will be used to identify critical controls among the satellite and airborne observables and to test whether fine-scale diversity enhances vegetation resilience.

The project will produce the first set of wall-to-wall annual maps of vegetation resilience covering the ABoVE core domain, which will provide a benchmark facilitating further observational and modeling research on the vulnerability and resiliency of ecotypes in the Arctic-Boreal region. The planned analyses on dynamic resilience throughout successional trajectories will identify hotspots of high vulnerability as an early warning of loss, slow recovery after loss, and possibly reduced resilience despite biomass gain. These resilience patterns and the to-be-identified critical controls will advance mechanistic understanding and representation of resilience using predictive models. Furthermore, the roles of SAR, Lidar, and hyperspectral data in explaining resilience will assess the potential of leveraging NASA's upcoming satellite missions for better characterization of vegetation resilience across the entire Arctic-Boreal region. The proposed work will provide impactful data products, analytical tools, and scientific findings on vegetation resilience, which will fill the critical gaps on addressing the impacts of disturbance and environmental changes on the Arctic-Boreal vegetation dynamics.

Anna Michalak/Carnegie Institution for Science
Quantifying Climate Sensitivities of Photosynthesis and Respiration in Arctic and Boreal Ecosystems from Top-Down Observational Constraints

21-TE21-0033

The large uncertainty in the sensitivities of photosynthesis and respiration to a changing climate leads to divergent future projections of Arctic and boreal carbon balance. The ability to empirically disentangle responses of photosynthesis and respiration to climate variability on regional scales has been complicated by the fact that atmospheric CO_2 observations alone can only inform responses of net ecosystem exchange (NEE) and not its component fluxes. Meanwhile, inferred climate sensitivities of NEE are not a reliable basis for projecting the future carbon balance, because different component flux sensitivities can lead to the same apparent net flux sensitivities for historical periods but divergent outcomes in future scenarios. In this project we will combine airborne and tower-based observations of CO_2 and carbonyl sulfide (COS) concentrations, satellite retrievals of solar induced chlorophyll fluorescence (SIF) and near-infrared reflectance of vegetation (NIRv), regional to global respiration data products, and the TRENDY v9 ensemble of terrestrial biosphere models (TBMs) to quantify the sensitivities of photosynthesis and respiration to temperature and soil moisture in Arctic and boreal biomes. We will then assess the impact of these corrected sensitivities on projections of the future carbon balance and the associated carbon climate feedbacks in the CMIP6 ensemble of earth system models (ESMs).

Objectives

1. Assess model-represented temperature and soil moisture sensitivities of gross primary productivity (GPP) and ecosystem respiration for Arctic and boreal biomes, delivering an understanding of the functional responses of simulated GPP and ecosystem respiration to temperature and soil moisture.

2. Constrain the temperature and soil moisture sensitivities of GPP and ecosystem respiration from regional-scale observational constraints. We will optimize the sensitivities of GPP against independent constraints from SIF, NIRv, and photosynthetic components in COS drawdown, and the sensitivities of ecosystem respiration against the respiratory components in CO_2 observations (after optimized GPP influences are subtracted). For the dormant season, we will also use upscaled soil chamber fluxes and global respiration data products to constrain the climate sensitivities of ecosystem respiration. This will yield an observationally-constrained understanding of climate sensitivities of carbon fluxes in the ABoVE domain.

3. Adjust TBM estimates of GPP and ecosystem respiration to reflect the optimized temperature and soil moisture sensitivities and evaluate the adjusted fluxes against top-down constraints, which will produce a robust understanding of the current carbon budget that can serve as a basis for model evaluation and improvement.

4. Use the optimized present-day temperature and soil moisture sensitivities to calibrate future projections of GPP and ecosystem respiration in the Arctic and boreal region, both through a direct application of the corrected present-day sensitivities to CMIP6 future projections, and the rerun of a representative ESM with adjusted physiological

parameters. This will identify the contribution of sensitivity biases to century-scale carbon flux projections, and inform model development priorities to deliver robust future projections.

Significance

The proposed research addresses critical knowledge gaps in understanding how rapidly-changing climate drivers shape the present and future carbon dynamics in Arctic and boreal ecosystems. The work will help attribute model bias in regional-scale carbon balance to climate sensitivities of photosynthesis and respiration, inform model improvements to better represent key underlying processes, and bring about a more robust understanding of Arctic and boreal climate futures.

Scot Miller/Johns Hopkins University
A Synthesis and Reconciliation of Greenhouse Gas Flux Estimates Across the ABoVE Domain
21-TE21-0008

We propose to evaluate CO_2 and CH_4 fluxes from the ABoVE domain and northern North America through a synthesis project that combines atmospheric observations, remote sensing, and bottom-up models of the carbon cycle. We will specifically focus on two aspects of the carbon cycle that are likely key indicators of the vulnerability of greenhouse gas fluxes to future change: (1) fluxes during the fall and spring cold seasons and (2) inter-annual variability. As part of the project, we will further diagnose discrepancies in current bottom-up estimates of CO_2 and CH_4 fluxes, and reconcile these discrepancies using atmospheric greenhouse gas (GHG) observations.

Our proposed approach is unique in two key ways. First, the proposing team includes experts in both bottom-up and top-down inverse flux modeling. Second, the proposed geostatistical approach to inverse modeling will allow us to directly probe the relationships between GHG fluxes and key environmental drivers of these fluxes, and compare these relationships against bottom-up models.

As part of the proposed research, we will make extensive use of NASA airborne greenhouse gas data, remote sensing products, and recent ABoVE research projects. The proposal is also directly relevant to several aspects of the solicitation, which calls for Studies that integrate previous ABoVE research results and remote sensing data into a coherent modeling framework to diagnose and predict ecosystem dynamics [...]", studies that explore Processes controlling the spatial and temporal dynamics of methane and carbon dioxide emissions as related to fire, inundation, shrub encroachment and/or permafrost dynamics in boreal and Arctic ecosystems", and studies that analyze the Effect of cold season processes on terrestrial ecosystem dynamics across annual or longer time scales," including carbon fluxes and budgets."

Charles Miller/Jet Propulsion Laboratory
Enhanced Methane Emissions in Transitional Permafrost Environments: An ABoVE Phase 3 Synthesis Investigation
21-TE21-0024

The inability to accurately quantify methane (CH_4) emissions across spatial scales has led to large uncertainties in the Arctic CH_4 budget and its future contributions to the permafrost carbon feedback. Our analysis of AVIRIS data from the ABoVE Airborne Campaigns revealed microtopographic CH_4 hotspots in diverse ecosystems across the ABoVE domain. We quantified relationships of these CH_4 hotspots with extraordinary fluxes and sub-surface permafrost thaw at local scales and with geomorphological controls at regional scales. We developed a novel L-band SAR algorithm to measure bubbles trapped in winter ice to quantify CH_4 ebullition in lakes, giving us unprecedented insights into terrestrial and aquatic CH_4 hotspots. Driven by these findings, we ask: What combinations of permafrost dynamics and geomorphology give rise CH_4 hotspots? Are landscape scale disturbances or sub-surface permafrost degradation accurate predictors of CH_4 hotspots?

We will exploit the unique AVIRIS CH_4 hotspot data to study CH_4 emissions across seven orders of magnitude in spatial resolution. Building on our Phase 1 (Miller TE-16) and Phase 2 (Miller TE-18) investigations, we will correlate CH_4 hotspots with landscape-scale permafrost disturbances and sub-surface degradation in transitional permafrost environments. We will validate these correlations with ground truth data from NW Alaska, the Minto Flats, and the Mackenzie Delta. We will synthesize our existing SAR and AVIRIS data products from the North Slope, NW Alaska, and interior Alaska with other remote sensing-derived products to understand geospatial relationships and provide landscape-scale flux estimates for model development. We will extend our synthesis to three high priority transitional permafrost areas   Kotzebue/Selawik, the Minto Flats, and the Mackenzie Delta   using NISAR data as available. Finally, we will use data from the ABoVE-CoMet 2.0 Arctic campaign to place our AVIRIS and SAR CH_4 data in context with other remotely-sensed CH_4 products prior to the launch of the NISAR, SBG, CHIME, MERLIN, and CO_2-M satellite missions.

Our goals to analyze and interpret Arctic-boreal CH_4 hotspots directly address ABoVE Tier 2 science question (6) How are the magnitudes, fates, and land-atmosphere exchanges of carbon pools responding to environmental change, and what are the biogeochemical mechanisms driving these changes? and ABoVE Phase 3 research goals 3 and 4a. Our Phase 1 and Phase 2 analyses of AVIRIS and SAR CH_4 data coupled meter-scale spatial resolution with the extensive spatial coverage of remote sensing, overcoming barriers that limited previous attempts to solve Arctic CH_4 spatial scaling challenges. In Phase 3 we will synthesize AVIRIS and SAR data with recently available pan-Arctic maps of MAGT and permafrost disturbance, and more spatially limited permafrost geophysics data sets. The results will correlate CH_4 emissions with permafrost occurrence, extent, and disturbance on scales from 10m to 10,000km, enabling us to study carbon-permafrost-hydrology processes, identify emergent properties, and quantify statistical characteristics. The scaling analyses that we pioneer in ABoVE anticipate pan-Arctic application of our methods with the NISAR, Surface Biology and Geology, and CHIME missions. Our comparisons of AVIRIS, CHARM-F, and MAMAP2D CH_4 products during the ABoVE-CoMet 2.0 Arctic campaign will accelerate science return from the MERLIN and CO_2-M missions. Our analyses will provide critical insights into the CH_4 component of the permafrost carbon feedback and enable the use of satellites to monitor its trajectory on interannual to decadal time scales.

Charles Miller proposes to as ABoVE Science Lead in Phase 3. He will focus on exploiting remote sensing data from the ABoVE Airborne Campaigns, planning and executing the SnowEx-ABoVE cold season campaign, and science syntheses that elucidate the role of Arctic ecosystems in Grand Challenge Earth Science questions.

Kenneth Tape/University of Alaska, Fairbanks
Characterizing a Widespread Disturbance Regime in the ABoVE Domain: Beaver Engineering
21-TE21-0041

North American beavers (Castor canadensis) are ecosystem engineers and a keystone species with wide-ranging effects on ecosystem structure, dynamics, and services. People in remote subsistence-based communities of Alaska and Canada have witnessed the influx of beavers and associated hydrologic engineering with concern, due to effects on fish, clean water, and boat access. Recently we showed that beavers have constructed over 13,000 ponds in the arctic tundra of Alaska as they have colonized new regions and transformed lowland permafrost ecosystems. These findings reveal that beaver engineering, where prevalent, is the dominant control on changes in surface water extent, which are closely linked to permafrost dynamics and ecosystem processes. Beaver engineering may trigger the inception of a more dynamic lowland arctic ecosystem, including permafrost thaw, thermokarst, excess methane emissions from anaerobic decomposition of previously frozen organic carbon, increased turbidity, and shifts in vegetation composition.

This project will investigate the idea that beaver engineering creates an evolving network of ponds that act as physical and biological oases in the arctic tundra and boreal forest. We hypothesize that there are 500 to 5000 beaver disturbances (ponds and affected areas) within the ABoVE AVIRIS-NG airborne data footprint. We hypothesize that these beaver engineering disturbances create biophysical oases with increased plant functional diversity, permafrost thaw, water turbidity, and methane emissions compared to unengineered lowland ecosystems nearby. To test these hypotheses,

We propose to:
1. Use high-resolution airborne and satellite imagery to map the visible extent of beaver disturbances across all ABoVE flight lines, including year of initiation.

2. Use AVIRIS-NG to classify terrestrial and wetland vegetation plant functional trait composition and diversity, spectral diversity, and biomass at beaver disturbances compared to control locations.
3. Use UAVSAR and AVIRIS-NG airborne data to examine permafrost thaw surrounding beaver ponds by comparing multi-year subsidence adjacent to beaver ponds and control locations, and to assess the turbidity of downstream aquatic ecosystems.
4. Use AVIRIS-NG methane hotspot data to examine spatial correlations between beaver engineering and methane hotspots. Collect methane flux measurements at A-BON beaver ponds that lie within AVIRIS-NG flightlines.
5. Compare findings across Obj 2-4, contextualize beaver engineering within the realm of other ABoVE disturbances, and disseminate results on local to global scales.

This multidisciplinary project aims to advance the goals of the NASA Terrestrial Ecology Program by using airborne, space-borne, and ground data to understand how terrestrial ecosystems and carbon cycling are changing in response to widespread and expanding beaver engineering in permafrost environments. This work addresses several tenets of the ABoVE solicitation. Beaver engineering is an understudied ecological disturbance in the Arctic (research topic 4c, Tier 2 Science Question (T2SQ) 2) that impacts all aspects of lowland ecosystems. We adopt a systems perspective to study critical ecosystem services like water quality and fish (T2SQ 1), to permafrost stability (T2SQ 3), hydrology (T2SQ 4), vegetation and aquatic ecology (T2SQ 5), and carbon cycling (T2SQ 6). These results will be integrated into ABoVE synthesis efforts that aim to understand the breadth of disturbance regimes active in permafrost regions. Interactions with rural Alaskan residents (research topic 2) seeks to share with them the impact of beavers discernible using ABoVE data. International collaborations ensure the reach of these results. The proposed research is complemented by fieldwork, large-scale pond mapping, Indigenous Knowledge, and synthesis underway as part of the Arctic Beaver Observation Network (NSF, 2021-2026).

Philip Townsend/University of Wisconsin-Madison
Functional Diversity as a Driver of GPP Variation Across the ABoVE Domain
21-TE21-0030

Ecosystems are changing rapidly across the Arctic tundra and boreal regions, but to predict future changes, an urgent need remains to understand what factors drive current variation in CO_2 uptake. Flux towers have long been the gold-standard for quantifying GPP and related fluxes, but they are sparse in geographic distribution and their measurements integrate variation in drivers at multiple scales. Specifically, spatial and within-season temporal trends in GPP at a given location are a consequence of both synoptic factors (weather, PAR) and local drivers related to moisture, soils, and vegetation. Emerging methods in air- and space-borne remote sensing offer new opportunities to disentangle the landscape-scale factors that drive within-season variability in tower-measured CO_2 uptake. We propose to couple flux tower measurements from the towers with ABoVE airborne remote sensing products to quantify the impacts of landscape heterogeneity on flux tower variation. We will use remotely sensed measurements of foliar functional traits from AVIRIS-NG (and NEON) such as leaf mass per area (LMA) and nitrogen -- the nominal plant-level determinants of potential photosynthesis -- in conjunction with flux tower GPP and derived weather-driven flux footprints to assess the contribution of vegetation patterns to intra- and inter-tower flux variation.

Using data from aligned flux tower and imaging spectroscopy data (124 pairs encompassing 34 towers are currently available for 2017-present), we will use trait maps generated for the ABoVE domain for Phase-2 ABoVE project to test hypotheses:
1) Temporal trait variation within flux tower footprints and spatially across flux towers -- especially for traits commonly used to estimate primary metabolism (N and LMA) -- explains temporal and spatial variation in CO_2 fluxes as flux tower footprints move across the landscape with prevailing winds. Our primary focus is on GPP, but we will also consider net ecosystem exchange (NEE), light use efficiency (LUE, GPP controlling for PAR) and water-use efficiency (WUE, GPP controlling for evapotranspiration).
2) Consistent with ecological theories of diversity and resilience, greater functional diversity of traits within footprints leads to greater temporal stability in CO_2 uptake.

We propose to use variance partitioning, mixed models and structural equation models to link CO_2 flux variables to traits, functional and spectral diversity, land cover variation (LAI, canopy height, bare ground, water), meteorological drivers, and broad-scale geographic factors (such as soils and topography). In addition to AVIRIS-NG, we will use LVIS airborne lidar data for canopy height and structural complexity metrics and UAVSAR active layer thickness data within flux tower footprints. Using existing data from ABoVE airborne campaigns as well as a rich network of flux towers in the region, the research will provide a comprehensive assessment of the vegetation drivers underlying GPP variation in time and space, and will provide the basis for using future satellite data to better extrapolate spatially-explicit variation in CO_2 fluxes. This research will also provide the quantitative foundation to incorporate biodiversity-ecosystem function relationships explicitly into the next generation of ecosystem models.

This work addresses multiple ABoVE science questions and research topics relating to the biogeochemical mechanisms of CO_2 fluxes at landscape scales, as well as using airborne AVIRIS-NG data for the development of methods to quantify biodiversity-ecosystem function relationships for deployment at global scales once SBG is launched in the late 2020s. We will release all code generated in this project through GitHub under an open-source license and make all data available through long-term public repositories.

Xanthe Walker/Northern Arizona University
Drivers and Impacts of Reburning in Boreal Forest Ecosystems (DIRE)
21-TE21-0001

Intensification of wildfire disturbance is one of the most rapid pathways through which climate warming could alter the structure and function of northern high-latitude ecosystems. Historically, northern ecosystems have acted as a net carbon (C) sink, accumulating C from the atmosphere over numerous fire cycles and centuries. Our field and remote sensing work in the Northwest Territories, Canada, during ABoVE Phase 1 (ABoVE-1) showed that shorter fire return intervals, or reburning, can shift these ecosystems to be a net C source. Our proposed research will fill the critical research gap of understanding where and when reburning occurs and the consequences of reburning for post-fire vegetation successional trajectories throughout the ABoVE Domain. Remote sensing is essential for assessing these reburning dynamics across large spatial and temporal scales and ultimately forecasting the resilience or vulnerability of boreal forest ecosystems under a warming climate.

Our proposed research fits within the scope of ABoVE Phase 3 by developing remote sensing data products that link satellite-based remote sensing, AVIRIS-ng hyperspectral image, and LVIS lidar data collected during the 2017, 2018, and 2019 ABoVE Airborne Campaigns (AAC) with field observations we compiled during ABoVE-1. We will develop mapping products of forest stand age, burned area, fire weather data, fire severity, tree aboveground biomass by functional group, forest stress, and post-fire successional trajectories in four ecoregions of the ABoVE Domain: Taiga Plains and Taiga Shield of the Northwest Territories, Interior Boreal Alaska, the Boreal Cordillera of Interior Alaska and the Yukon Territories. We will use our newly generated mapping products to test hypotheses about reburning and post-fire successional trajectories. We will then generate maps on the vulnerability of current forests to reburning and to long-term compositional state changes due to future wildfire across our focal ecoregions. These data are requested by land and fire management communities and we will draw on our collaborating institutions to facilitate engagement and knowledge transfer with local and regional stakeholders.

Our proposed research fits within the overarching focus of the ABoVE campaign as we seek to understand the impacts of an environmental change intensifying fire regime on boreal forest structure and function. Specifically, we will identify processes contributing to changes in disturbance regimes (Tier 2 Science Question 3.2) and associated shifts in vegetation composition (Question 3.5). We will also tackle societal needs at both global and local scales (Question 3.1) by improving our ability to project the impacts of increasing fire frequency on important ecosystem properties, including the goods and services used by humans and fauna that live in boreal forests and C cycling feedbacks to the global climate system.

Jonathan Wang/University of California, Irvine

Quantifying Disturbance and Blobal Change Impacts on Multi-Decadal Trends in Aboveground Biomass and Land Cover Across Arctic-Boreal North America

21-TE21-0022

The Arctic-boreal carbon cycle is inextricably linked to vegetation composition and demography, both of which are being altered by climate change, rising levels of atmospheric carbon dioxide, and climate-induced changes in disturbance regimes. In an ABoVE Phase 1 project, we used time series of Landsat imagery in combination with lidar data from ICESat GLAS to identify large-scale changes in forest composition, tundra shrub cover, and aboveground carbon stocks over the ABoVE core study region for the period 1984   2014. Results from this project indicate that increasing levels of wildfire disturbance are slowing rates of carbon accumulation in forests and that broadleaf deciduous forests are replacing evergreen conifer forests in many regions. However, the geographic extent and time span of this previous work restricted the conclusions that could be drawn regarding longer-term changes and trends in the composition, structure, and carbon balance of Arctic-boreal ecosystems at a continental scale.

To address this limitation, here we propose to improve and extend the aboveground biomass and land cover data sets developed through this previous effort to (1) include all of Arctic-boreal North America for the period 1984-2022, and (2) use these new data sets to improve understanding of how climate change is driving large-scale changes in the structure, composition, and aboveground carbon budget of Arctic-boreal ecosystems of North America. The land cover and biomass data sets will be compiled using Landsat Collection 2 imagery at 30 m spatial resolution at annual time step. The aboveground biomass maps will be calibrated with lidar data from LVIS and G-LiHT collected in the ABoVE Airborne Campaign, the ATLAS sensor flown on the ICESat-2 satellite, and the GEDI sensor flown on the International Space Station. We anticipate that the order-of-magnitude increase in high resolution lidar observations will considerably reduce uncertainties in our estimates. The datasets we create will be publicly available and contribute substantively to other science teams' work. We will then use these new data sets to address three core questions: (1) How are aboveground biomass and land cover changing across Arctic and boreal North America? (2) What are the drivers of long-term changes in aboveground biomass and land cover across Arctic-boreal North America? and (3) Can differences in aboveground carbon inventories and fluxes derived from models, national inventories, and remote sensing be reconciled?

The proposed research addresses two of the three ABoVE Phase 3 foci: (1) Synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of Arctic and boreal ecosystems in the ABoVE domain, across North America, and across circumpolar regions; and (2) Filling critical research gaps in our understanding of how environmental change impacts the dynamics of boreal and Arctic ecosystems within the ABoVE domain. Analyses from this work will test five hypotheses regarding the long-term drivers of Arctic-boreal ecosystem change. Specifically, our results will (1) improve understanding of how disturbance controls interannual and decadal trends in aboveground biomass, (2) test whether changes in post-fire succession are driving systematic changes in land cover and biomass across ecoregions, (3) quantify the nature and magnitude of growth enhancement in boreal ecosystems arising from environmental changes, (4) map the expansion of woody vegetation cover in taiga and tundra ecosystems, and (5) reconcile differences in carbon stock estimates based on models, remote sensing and field inventories. These analyses will provide a suite of important new insights regarding the impacts of climate change and disturbance on terrestrial ecosystem composition and function in the Arctic-boreal domain.

Jennifer Watts/Woodwell Climate Research Center
Contributions of Tundra and Boreal Systems to Radiative Forcing in North America and Russia Under Contemporary and Future Conditions
21-TE21-0004

The Arctic-boreal region, characterized by vast expanses of tundra, boreal forests and wetlands, continues to warm more rapidly than elsewhere on earth. Regional warming, associated shifts in the annual non-frozen season and simultaneous changes in hydrology, can greatly increase ecosystem vulnerability to change. Abrupt disturbances from fire and the rapid thaw of permafrost also threaten ecosystem structure and function, including contributions to carbon budgets and climate forcing. How changing Arctic-boreal systems are impacting climate under contemporary conditions is not well understood, and how these ecosystems might respond under future climate remains highly uncertain. Understanding how changes in environmental conditions and community structure ultimately affect atmospheric radiative forcing is key to identifying the role of these systems in amplifying or mitigating climate change.

A pressing challenge is improving process-model estimates of carbon dioxide (CO_2) and methane (CH_4) gas exchange for high latitude terrestrial and aquatic environments. Modeling studies continue to disagree regarding the: 1) net CO_2 sink or source status for the Arctic-boreal region; 2) magnitudes and spatiotemporal distributions of CH_4 fluxes and components (i.e., contributions from terrestrial vs. aquatic systems; emission vs. uptake); 3) regional trajectories of gas exchange given future climate conditions and ecosystem disturbances. Reducing uncertainties in ecosystem carbon budgets is necessary to improve our understanding of how the Arctic-boreal zone is responding to/impacting climate.

This study first focuses on improving estimates of CO_2 and CH_4 exchange for the Arctic-boreal region through the integration of terrestrial and aquatic field observations, a suite of remote sensing data and products, and modeling (biogeochemical and atmospheric). Here we focus on an improved version of the Dynamic Vegetation Dynamic Organic Soil Terrestrial Ecosystem Model (DVM-DOS-TEM), with updated ecosystem parameterizations for tundra, boreal forests and wetlands made possible through new ABoVE synthesis datasets of carbon flux, ecosystem properties, and disturbance. Site-level validations for DVM-DOS-TEM will employ a wealth of data from monitoring and validation sites within Alaska, Canada, and Siberia; we will also incorporate additional global and regional (i.e., ABoVE) model benchmarking. To assess model skill/uncertainty at the regional level, we will use a WRF-STILT (Stochastic Time-Inverted Lagrangian Transport model driven by a polar variant of Weather Research and Forecasting model winds) approach and atmospheric observations from tall towers and aircraft campaigns. Further, our study includes a carbon model intercomparison effort to better identify similarities and differences in carbon budget estimates and associated uncertainties across the ABoVE domain and eastern Siberia.

We will use our new 0.25 degree and 1-km monthly CO_2 and CH_4 flux records (2001-2021) for the Arctic-boreal region, satellite-informed records of fire emissions and albedo to identify how ecosystems are contributing to net radiative forcing and regional warming or cooling. Our final component explores possible future trajectories of Net Ecosystem Carbon Budgets (NECB; terrestrial & aquatic carbon flux plus fire emissions) and radiative forcing under alternative climate and disturbance scenarios through 2100.

This research directly benefits NASA by providing improved understanding of climate-carbon cycle-disturbance feedbacks in Arctic-boreal systems through enhanced regional process-model estimates of NECB, new radiative forcing assessments that consider NECB and albedo, and new evaluations of high latitude ecosystem response, including NECB and radiative forcing, under future climate scenarios.

Qianlai Zhuang/Purdue University
Role of Linked Hydrological, Permafrost, Ground Ice, and Land Cover Changes in Regional Carbon Balance Across Boreal and Arctic Landscapes
21-TE21-0032

High-latitude regions are warming at least twice as rapidly as the rest of the globe. These regions are also subject to degrading permafrost and melting ground ice and increasing recurrence and intensity of wildfires. These major perturbations and disturbances redistribute water and accelerate cycling of carbon (C) and nutrients, exerting large, but uncertain feedbacks to the climate system. This project targets the immediate and cascading effects of warming on terrestrial and aquatic ecosystems in Alaska. The proposed study will reduce uncertainty in estimated C emissions from high-latitude regions by integrating terrestrial and aquatic fluxes, and by characterizing long-term trajectories of permafrost and land cover change over heterogeneous landscapes. The proposed research is enabled by rich in situ, airborne, and satellite data on climate, permafrost, ground ice, hydrology, vegetation distribution, and C and nitrogen (N) dynamics produced in part by previous phases of the ABoVE program. We propose to quantify relationships among these components and to parameterize a suite of land surface models that estimate terrestrial, lateral, and aquatic fluxes of C. The modeling efforts will reduce uncertainty in regional C balance by enhancing representation of: 1) land-water fluxes of C and N, and 2) spatial heterogeneity in long-term relationships among ecological dynamics and permafrost. Specific project objectives are to: i) assess interactions among remotely sensed thermokarst extent, ground ice melting, and land cover change with climate across contrasting soil landscape units; ii) describe long-term patterns in soil temperature and thermokarst formation; iii) characterize lateral fluxes of water, C, and N from watersheds; and iv) detect and model biogeochemical responses to disturbances and land cover change at watershed and regional scales. Leveraging existing data, the study will advance understanding of climate-induced change in high-latitude ecosystems with three key innovations. First, the proposed study will compile a first-of-its-kind dataset of thermokarst and ground ice melting features and land cover changes to drive ecosystem models at site, watershed, and regional scales for the last few decades. Second, this study will use empirical relationships between water, lateral C and N fluxes, and permafrost degradation conditions revealed by long-term monitoring of watersheds to revise regional-scale dynamics of water, C and N across boreal and arctic landscapes.

Finally, we propose to examine mechanisms by which changing ground ice conditions influence lateral flux of water and solutes using a 3-dimensional model validated by existing high-frequency watershed monitoring data. The proposed efforts are therefore among the first to integrate empirical observations with process-based models to estimate the role of land-water interactions in regional-scale models of C balance. Overall, the proposed research will demonstrate empirical and modeling approaches that reduce uncertainty in estimated C emissions by explicitly accounting for the influences of permafrost and land cover change on hydrology and terrestrial-aquatic coupling, and are applicable across the ABoVE domain and pan-Arctic regions. This proposed research specifically targets the ABoVE Phase 3 research topics of (1) that is to integrate previous ABoVE research results and remote sensing data into a coherent modeling framework to diagnose and predict ecosystem dynamics and (4) that is to use satellite and airborne remote sensing within the ABoVE domain to fill critical gaps in our understanding of northern ecosystem dynamics.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2021
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A.7 Biodiversity: Marine, Freshwater, and Terrestrial Biodiversity Survey of the Cape (BioSCape) Airborne Campaign Science Team

Abstracts of Selected Proposals

The National Aeronautics and Space Administration (NASA) Science Mission Directorate solicited proposals for the Biological Diversity program within the Earth Science Division. The solicitation sought proposals to form a science team for the Biodiversity Survey of the Cape (BioSCape) airborne campaign.

NASA received a total of 16 proposals and has selected 10 proposals, 9 for funding at this time. The total funding to be provided for these investigations is approximately $5.28 million over three years. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided. Co-investigators are not listed here.

Peter Adler/Utah State University
Impacts of Invasive Alien Species on Biodiversity and Ecosystem Functioning
21-BIODIV21-0014

The Greater Cape Floristic Region (GCFR) is an ideal location to study the impacts of global change on biodiversity and ecosystem functioning. As a global biodiversity hotspot, the GCFR is under severe pressure from biological invasions and other global changes, and a large human population relies on the ecosystem services it provides. Within this unique context, the BioSCape project offers an opportunity to demonstrate how advances in remote sensing make it possible to not only map critical ecological variables, including biodiversity, ecosystem function, and biological invasions, but also to resolve long standing debates about the relationships among them. Our proposed research will work towards these goals by addressing two objectives.

First, we will utilize finer spatial and spectral resolution hyperspectral imagery and data fusion to generate improved maps of a) alien tree invasions (based on AVIRIS-NG, LVIS and ALOS), b) structural and spectral diversity (based on LVIS and AVIRIS-NG) at both local (alpha) and landscape (beta) scales, and c) four important ecosystem functions: primary production and the temporal stability of primary production (based on MODIS and FluxSat), water-use efficiency (based on the ECOSTRESS algorithm and using AVIRIS-NG and HyTES), and fuel loading (based on LVIS).

Second, using the maps produced under the first objective, we will test the following ecological hypotheses:
Ï Hypothesis 1: Higher structural and spectral alpha-diversity decrease invasibility, after accounting for confounding effects of landscape-scale covariates.

Ï Hypothesis 2: As alien tree invasions progress, they increase structural and spectral alpha-diversity, but decrease beta-diversity.
Ï Hypothesis 3: Ecosystem functioning (net primary productivity and its temporal stability, water use efficiency, and fuel load) depends on both invasion status (H3A) and biodiversity (H3B).
These hypotheses have traditionally been tested using statistics developed to analyze carefully controlled, small-scale field experiments where the effects of one or a few independent variables are isolated. These techniques are not appropriate for disentangling complex interactions among variables measured across large spatial extents. Fortunately, we can address this challenge by adapting statistical approaches for causal inference from econometrics and public health. The novelty of our proposed research, and contribution to the BioSCape Science Team, is the combination of remotely-sensed data with sophisticated statistical approaches to causal inference and hypothesis testing.

Our team includes biodiversity scientists from Utah State University and the University of Colorado, and remote sensing experts from the University of Colorado and the NASA Goddard Space Flight Center. The team also includes South African remote sensing specialists, botanists and ecologists with extensive experience working in the GCFR. Our proposed work will advance a general understanding of the interactions among invasions, biodiversity, and ecosystem function and address critical, regional conservation and management challenges.

Jeannine Cavender-Bares/University of Minnesota
Plant Community Assembly and Trait Evolution in the South African Greater Cape Floristic Region
21-BIODIV21-0015

The Greater Cape Floristic Region (GCFR) is a hotspot of plant biodiversity with high endemism. It includes southern Hemisphere lineages known to exhibit phylogenetically distinct traits with unique evolutionary histories. The spectral properties of these species remain understudied and the evolutionary processes that explain them are largely unknown. Plant communities are hypothesized to assemble along topographic and other environmental gradients and as a consequence of dispersal limitation. Deciphering the processes of community assembly can be advanced by examining long-term evolutionary processes and environmental filtering from trait, spectral and phylogenetic information coupled with topographic and environmental data. We plan a field campaign to collect plant traits and spectral data (400 nm to 2500 nm) at the leaf level from species within plots to enhance previously published collections. These data will provide plant functional trait and spectral information that can be compared to AVIRIS NG data and used to help validate modeled functional variation from airborne data. The campaign also serves as a reconnaissance mission to understand the processes of community assembly, evolutionary ecology and biogeographic history of the GCFR to help inform the NASA BioSCAPE mission. It will also serve to connect NASA BioSCAPE and the South African research community with the NSF-funded Biology Integration Institute

ASCEND (Advancing Spectral biology in Changing ENvironments to Understand Diversity).

Kerry Cawse-Nicholson/Jet Propulsion Laboratory
Intrinsic Dimensionality and Data Fusion to Monitor Cape Biodiversity
21-BIODIV21-0001

An international team of biodiversity and remote sensing experts, with extensive experience in the Cape Floristic Region (CFR), will tackle two of the BioSCape main objectives: 1) to understand the distribution and abundance of biodiversity, and 2) understand the role of biodiversity in ecosystem function. This work will address both of those goals by producing maps of taxonomic alpha, beta, and gamma diversity over the CFR using intrinsic dimensionality (derived from AVIRIS-NG reflectance and HyTES emissivity) and the generalized dissimilarity model, and relating the spatial patterns of diversity to an aspect of ecosystem function using evapotranspiration (from HyTES land surface temperature and ECOSTRESS) as a metric. This work will evaluate spatial diversity patterns by focusing on regions recovering from drought and/or fire.

This work is highly relevant to the goals outlined in the BioSCape solicitation, and is also important for the NASA Biological Diversity Program, which focuses on understanding the composition of life on Earth by documenting and identifying factors that determine the distribution, abundance, physiology of organisms on Earth. The approach proposed here does not require training data, and is able to detect sub-pixel vegetation, which will also be important in the design of upcoming missions such as SBG, which aims to understand the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space. In the 2017 Decadal Survey, biodiversity was identified as a Most Important" science question, but current techniques are not mature enough for global applicability.

Our international team combines interdisciplinary science with local expertise on the Fynbos: PI Cawse-Nicholson pioneered the Random Matrix Theory technique for calculating the intrinsic spectral dimensionality or number of sub-pixel components in a hyperspectral image, and the developer of the Generalized Dissimilarity Model as an unfunded collaborator to provide guidance and oversight in algorithm implementation and interpretation. The PI is also the deputy Science Lead for ECOSTRESS, and routinely produces evapotranspiration products that are publicly available. This team also contains a large South African contingent   almost all former colleagues of the PI, with a good working relationship. The South African scientists have proposed a complimentary effort to the South African NEOFrontiers solicitation, which contains a significant fieldwork component in the CFR. If successful, they will be active participants in the computation and evaluation of biodiversity of the CFR. They will provide invaluable in-country assistance for logistics and provide insight into interpretation given their extensive expertise in the area.

Matthew Clark/Sonoma State University
BioSoundSCape: Connecting Acoustics and Remote Sensing to Study Habitat-Animal Diversity Across Environmental Gradients
21-BIODIV21-0005

The planet is experiencing a rapid decline in biodiversity from increasing anthropogenic pressure and the onset of climate change. Measuring biodiversity loss at relevant spatial and temporal scales needed for effective conservation policies is challenging. New cost-efficient and scalable approaches are needed to better track and understand changes in biodiversity. In the biodiversity hotspot Greater Cape Floristic Region (GCFR) of South Africa, we propose to measure ground-based animal diversity using low-cost autonomous recording units (ARUs) and scale these measurements using remotely-sensed indicators of habitat variation. Our approach combines acoustic diversity with plant spectral (i.e., chemical) and structural diversity to address the central questions: 1) What is the relationship among measures of acoustic, spectral and structural diversity and how do those relationships change across spatial scales and vegetation types?; and, 2) How does anthropogenic and natural disturbance affect acoustic diversity and habitat quality?

ARUs collect large amounts of sound data at specific locations for days or weeks, are easy to use, and can be rapidly deployed to survey many locations with relatively low costs. The growing field of bioacoustics has made great progress in estimating animal diversity from acoustic indices and species detection with machine learning, yet techniques can be time consuming and often lack transferability across ecosystems. In contrast to previous techniques, we propose a generalizable and species agnostic approach to estimate animal diversity directly from acoustic diversity, giving it the advantage of being readily transferable to other ecosystems. During two field campaigns, we will deploy ARUs in 1,200 locations throughout the GCFR to record sounds (the soundscape"). At these locations, we will also quantify bird and frog species richness using traditional in situ observation techniques. Selected components of the soundscapes are processed to measure acoustic diversity, and we test the hypothesis that bird and frog species richness is positively related to acoustic diversity. Next, coincident imaging spectroscopy and LiDAR data from the NASA BioSCape airborne campaign is used to characterize plant spectral and structural habitat diversity, respectively. Our approach then integrates measures of acoustic, spectral, and structural diversity to investigate the strength and shape of the animal-habitat diversity relationship across vegetation types and gradients of natural and anthropogenic disturbance. We will study the change of the relationship across gradients of anthropogenic (distance to main roads) and fire (time since last fire, number of times burned) disturbance. Fire is an integral part of maintaining GCFR biodiversity at a regional scale, and thus we plan to analyze how soundscapes vary with fire history.

Our proposed research intends to address two of the general objectives of the BioScape solicitation. First, we will research the distribution and abundance of biodiversity in the GCFR at multiple spatial scales. Second, we will evaluate the response of biodiversity to global change by studying how natural processes (changing fire regime) and human pressure affect the animal-habitat relationship at a regional scale. This research is critical to understand how and why the diversity of life on Earth is changing, and will help us to scale biodiversity surveys from local to global scales using airborne and spaceborne sensors.

Matthew Fitzpatrick/University of Maryland
Integrating Remote Sensing and Biodiversity Observations to Map and Monitor Plant Taxonomic, Phylogenetic, and Functional Beta-Diversity in the Greater Cape Floristic Region
21-BIODIV21-0010

Scientists have long anticipated the potential for remote sensing to transform our ability to map and monitor global biodiversity. We are now entering an exciting period where technology and data have matured to the point that remote sensing of biodiversity at fine spatial and temporal resolution for most of the Earth's surface appears within reach. Given ongoing biodiversity losses and threats from global change, the alignment of these advances could not have come at a more crucial time. Yet substantial challenges remain - from questions regarding relationships between remote sensing observations and different components of biodiversity, to technical hurdles in the statistical integration of biodiversity observations with high-dimensional remote sensing data to extrapolate patterns across unsurveyed regions.

The goal of this project is to develop, evaluate, and demonstrate the applicability of a flexible biodiversity mapping pipeline that produces standard outputs to populate community composition essential biodiversity variables (EBVs). For this purpose, we will harness two community-level modeling algorithms - Gradient Forest and Generalized Dissimilarity Modeling - both of which have shown great promise for estimating turnover in community composition directly from analysis and modeling of high-dimensional remote sensing data and in-situ biodiversity observations. We will systematically evaluate these methods in our spatial modeling pipeline to quantify and map plant biodiversity in the Greater Cape Floristic Region (GCFR) of southern Africa. Our mapping pipeline combines several innovations to: (1) accommodate high dimensional optical and thermal imaging spectroscopy, multispectral, and LiDAR remote sensing observations, (2) perform nonlinear rescaling of these data such that they best represent community-level biodiversity and (3) predict taxonomic, phylogenetic, and functional beta-diversity EBVs. We also will test hypotheses regarding the relationships between remote sensing information and different dimensions of biodiversity. To demonstrate the applicability of our basic science objectives, we will work with partners in South Africa to map woody plant invasions and groundwater-dependent vegetation and assess outcomes of different management actions, including fire versus clearing for restoration.

We will collect new in-situ biodiversity data in the form of plot-level plant survey data and DNA for plant phylogenetics, which we will associate with plant functional trait data from existing sources.We will use data from AVIRIS, HyTES, and LVIS to quantify vegetation attributes and Landsat/Sentinel timeseries to measure phenological signals indicative of groundwater-dependent vegetation. We will use GF and GDM in tandem to integrate these data and predict continuous spatial patterns of community composition. We will comprehensively evaluate our mapping pipeline using multiple approaches and will quantify, document, and report errors and uncertainties in our analyses.

A critical research need is improving understanding of our ability to quantify biodiversity using different remote sensing platforms and how this varies when considering taxonomic, phylogenetic, or functional dimensions. Beta-diversity represents an especially critical component of the GCFR's biodiversity, which has some of the highest levels of species turnover globally. In addition, despite calls for the development of frameworks to produce EBVs, no such systems have been fully implemented. By filling these needs, our project will address several of BioSCapes primary research objectives as well as several priorities from the Decadal Survey and NASA's Earth Science Strategy. In addition, this project will fill key data and research needs that we have identified with our team of South African collaborators.

Liane Guild/Ames Research Center
Cyanobacteria and Surface Aquatic Vegetation of the Cape Freshwater Systems (CyanoSCape): A Hyperspectral Data Campaign and Analysis
21-BIODIV21-0017

In Southern Africa, the impacts of anthropogenic activities on biodiversity and ecosystem services are exacerbated by the climate crisis. Rapid land use change and the lack of emphasis on environmentally sustainable agricultural practices has hindered hydrological processes and compromised riverine and aquatic ecosystems. This poses obvious risks to natural/indigenous aquatic biodiversity and long-term ecosystem sustainability.

Phytoplankton serve as the foundation of the freshwater food web with zooplankton as consumers, which feed fish, invertebrates, and so on up the food chain that comprises the biodiversity of the freshwater system that serves as habitat for biodiversity as well. The diversity of phytoplankton includes photosynthesizing bacteria (cyanobacteria), plant-like diatoms, dinoflagellates, green algae, and coccolithophores. Eutrophication and toxic cyanobacteria blooms (cyanoHABs) in the inland waters of the Greater Cape Floristic Region (GCFR) incur significant effects on the biodiversity of the overall phytoplankton assemblage and provide a favorable environment for the overgrowth of floating aquatic vegetation (FAV), which is often invasive and associated with reduced aquatic biodiversity.

The algal biodiversity of the GCFR's freshwater systems is not well characterized. Hyperspectral optical observations are expected to facilitate the improvement of current phytoplankton functional type retrievals significantly, as the sensitivity is sufficient that the distinctive, fine spectral features of different phytoplankton groups can be detected. This will enable testing emerging algorithms and inform the development of new algorithms for use with upcoming hyperspectral satellite missions in this decade.

Innovations in optical sensor sensitivity and next generation machine learning capabilities considerably enhance the potential for accurate and rapid detection of phytoplankton, namely the presence, extent, and diversity of cyanobacteria present in cyanoHABs and additionally, invasive FAV. Upcoming hyperspectral satellite missions such as NASA's Surface Biology and Geology (SBG), Plankton, Aerosol, Cloud, ocean Ecosystem (PACE), and the European Space Agency's Copernicus Hyperspectral Imaging Mission (CHIME) will provide imagery with unprecedented spectral and spatial resolution which will further enable the discovery of linkages between the seasonality and dynamics of HABs and FAV.

The overarching goal of this project is to utilize hyperspectral data, with recently developed and next-generation algorithms, to determine the biodiversity of freshwater systems phytoplankton assemblage with emphasis on genus level distinction, as well as monitor the prevalence and diversity of FAV.
The proposed objectives are: 1. Characterize phytoplankton community composition of example freshwater systems of the GCFR through aligned field spectroscopy, water sample collection, and subsequent microscopy and HPLC analysis; 2. Collect field spectroradiometer hyperspectral data and surface bio-optical data coincident with airborne hyperspectral imagery for vicarious calibration and assessment of radiometric integrity of derived atmospherically corrected surface reflectance over productive waters; 3. Apply and test the capability of published and next-generation algorithms for hyperspectral delineation of the phytoplankton assemblage (biodiversity) using field and airborne measured surface reflectance and assess product uncertainty introduced through the processing of airborne data.; and 4. Discriminate FAV biodiversity to the highest taxonomic level possible using combined airborne hyperspectral and field spectroscopy (FAV spectral library) data. Expected results include the ability to distinguish phytoplankton assemblage and improved detection of the biodiversity of cyanobacteria genera and FAV as well as this variability in freshwater sites.

Erica Stavros/University of Colorado Boulder
Biodiversity Across Scales: Mapping Taxonomic, Phylogenetic, and Functional Diversity with eDNA, Field Surveys, and Remote Sensing Data
21-BIODIV21-0016

Biodiversity sustains life on Earth and is rapidly changing under the sixth mass extinction. While conservation focuses on species-specific management, there is a need for bioindicators to study, monitor, and assess our success at curbing biodiversity loss globally. Remote sensing can make consistent measurements globally, but work is needed to relate it to the scales of biodiversity that are managed (taxon and phylogenies). Imaging spectroscopy and thermal imaging can map key ecosystem functions that relate to species habitat. As such, the 2017-2027 Earth Science Decadal Survey recognized mapping biodiversity as a very important" observational need using imaging spectroscopy and thermal imaging. Thus, we critically need an objective method for calibrating and validating our algorithms from one location to another.

Current research has correlated remote sensing to field survey observations of keystone species as indicators representing broader diversity across kingdoms. These observations, however, are limited in the taxonomic breadth they can efficiently capture, are labor intensive, and have certain observer biases. In contrast, environmental DNA (eDNA) can be collected by citizen scientists and provides a unified bioinventory across organismal scales (bacteria, fungi, plants, invertebrates and vertebrates) that can explain point-to-watershed scale biodiversity patterns. The challenge with eDNA is that it is still a relatively new methodology and little is known about how transient the signal is and how it correlates with observations from above (i.e., remote sensing and traditional field metrics).

Because NASA will be launching a global imaging spectrometer and thermal imager as part of the Surface Biology and Geology (SBG) mission (expected launch in the late 2020s), there is a pressing need to understand how relatively affordable, and consistent observations of biodiversity like that of eDNA, relate to such remote sensing measurements. Specifically, there is a need to understand how taxonomic, phylogenetic, and functional diversity relate (BioSCape Objective 1b). Our cross-disciplinary, international team will collect eDNA, invertebrate, and vegetation surveys in the dry season in conjunction with NASA AVIRIS-ng and HyTES (precursors to SBG) and after rain (no flights). We ask: how do eDNA, traditional field, and remote sensing observations of biodiversity relate across spatial scales within the Berg and Eerste River watersheds? We test three hypotheses on: 1) the relationships between phylogenetic, taxonomic, and functional biodiversity, 2) how biodiversity organizes in a watershed, and 3) how signals relate to hydrometeorological processes. We will explore relationships between phylogenetic (eDNA), taxonomic (eDNA, vegetation), and functional (AVIRIS-ng and HyTES) biodiversity and create maps. We will apply unsupervised classification and correspondence analysis with hydrologic units (e.g. drainages) to assess scales of organization. Finally, we will conduct hysteresis analysis using stream gauge data to understand the temporal lags based on water surface processes (e.g., runoff vs. leaching). We will support future investigations and broader participation by delivering an open-source software package creating functional diversity metrics from trait data, building on previously published algorithms (Hytools and EcoSML), that feature our analyses as examples in user tutorials. Our women-led, citizen science approach fosters an inclusive international team by creating a pathway for mentorship to the NASA SERVIR Women's Global Develop Partnership, which can increase the success of female students who see themselves in leadership roles. Outcomes will have significant implications for global biodiversity mapping by testing applicability of joint eDNA-remote sensing while also advancing our understanding of the organizational units of biodiversity across scales.

Philip Townsend/University of Wisconsin-Madison
CapeTraits: Patterns of Functional Trait Variation and Diversity Across the Greater Cape Floristic Region and Comparison with Other Mediterranean Ecosystems
21-BIODIV21-0008

Mediterranean ecosystems globally exhibit characteristic flora, vegetation structure and function resulting from their mild, wet winters and warm, dry summers. Among Mediterranean ecosystems, the Greater Cape Floristic Region (GCFR) of South Africa contains an unusually high level of endemism and some of the most diverse vegetation assemblages in the world due to the region's long-term geologic and climatic stability, nutrient-poor soils and complex geography. Here, we ask whether the phylogenetically diverse and distinct flora of the GCFR exhibits a commensurate level of functional diversity-or functional distinctiveness-across scales within the region or in comparison to other Mediterranean areas. Theory predicts that vegetation functional traits (and trait variation) would be comparable to other Mediterranean regions due to convergent trait evolution and habitat selection by lineages that have evolved in and adapted to similar climates. Yet the Cape flora may exhibit distinct trait variation as a consequence of its unique biogeographic and evolutionary history.
We propose to:
1. Quantify functional trait composition and diversity and model their environmental drivers and the macroevolutionary processes that underlie them in the GSFC using NASA airborne AVIRIS-NG imagery, leaf-level spectra and phylogenetic information; and
2. Test the extent to which functional trait composition and diversity in the Cape mirrors that in other Mediterranean ecosystems with similar airborne imagery.

We will implement remote sensing approaches to characterize the floristic functional trait composition and diversity in the GCFR at multiple spatial scales, from which we will model drivers of functional trait variation resulting from evolutionary and environmental filtering processes in relation to climate and environment. Our analyses will be conducted first within and across ecosystems in the GCFR, and subsequently in comparison to other Mediterranean regions. The proposed work makes use of published and new plot, species and trait data from our South African Co-I. It also leverages extensive existing workflows for trait mapping from airborne imaging spectroscopy in California, NEON and elsewhere. These complementary efforts will allow us to readily apply image corrections, implement trait models and distribute to the community all resulting data, including trait maps for >20 foliar traits related to photosynthetic metabolism (e.g., nitrogen, pigments, LMA), defense and stress (phenolics), decomposition (lignin) and resource allocation (nonstructural carbohydrates). Existing trait maps from California and NEON provide a foundation for the proposed comparative analyses. To address our objectives, we will test the extent to which remote sensing data-and imaging spectroscopy data in particular-capture both the differences in phylogenetic composition within the GCFR and between Mediterranean floras. Likewise, we will evaluate whether similarities in trait composition over large spatial extents can be explained by similar bioclimatic drivers of macroevolution and community assembly, as has long been hypothesized but never before tested at this scale. Maps of functional diversity (richness, divergence, evenness) will be derived from probability density functions in the trait maps to assess variations in multivariate trait syndromes at different scales within the GCFR and between the GCFR and other Mediterranean systems, as well as to test whether the drivers of trait variation differ across these scales. This work will fill a significant gap in our knowledge of global functional trait variation by providing spatially explicit data of trait variation and functional diversity in the distinct Greater Cape Floristic Region. It will also inform forthcoming satellite missions such as Surface Biology and Geology (SBG) by testing the extent to which data-driven trait mapping approaches are transferable across physiognomically similar biomes.

Jan van Aardt/Rochester Institute of Technology
RadSCape: Radiative Transfer Simulation and Validation of the Dynamic Structural and Spectral Properties of the Vegetation of the Cape
21-BIODIV21-0007

The hyper-diverse Greater Cape Floristic Region (GCFR) encompasses two Global Biodiversity Hotspots, while also being a Global Extinction Hotspot, threatened by habitat loss and fragmentation, altered fire regimes, invasive species, and climate change, among others. Managing and mitigating these threats requires regularly-updated, spatially-explicit information for the entire region, which is currently only feasible using satellite remote sensing at relatively coarse scales. However, detecting the signal of change over and above the natural variability of ecosystems in the region, in both spectral and structural terms, remains a distinct challenge, especially given that the GCFR is dominated by open shrublands. This results in a high relative contribution of soils, stems, and other surfaces to observed reflectance, which is further exacerbated by the high variability of vegetation in space and time due to seasonality, natural disturbances such as fire or drought, and long-term post-disturbance recovery trajectories. Finally, and critical to this proposal, these interactions further increase in complexity due to the exceptionally high ecosystem diversity. This already-inherent diversity increases in complexity when one considers that the chemistry and physiology of foliage, and its interaction with structure, are key drivers of ecosystem functions. This has led to an interest in remote sensing of leaf traits as a means of leaf-to-ecosystem scaling. Although numerous studies - mostly forest focused - have demonstrated that leaf traits such as foliar nitrogen concentration (%N), leaf mass per unit area (LMA), and associated patterns of vegetation growth can be estimated from remotely sensed data, the mechanisms responsible remain unclear because, in whole plant canopies, leaf-level reflectance properties are confounded by the influence of structural variables at the leaf, stem, and whole-crown scales. This produces tremendous complexity in the number, size, orientation, and spatial arrangement of reflecting leaf surfaces and canopy gaps, and also affects the properties of light as it penetrates the canopy. All of these influences pose a parsimonious solution to the challenge of simulating land surface reflectance spectra in a region with >13 000 plant species and a similarly diverse abiotic environment. We thus propose to resolve this challenge by using a combination of in situ fynbos trait measurements and first-principles, physics-based radiative transfer modeling in a biophysically-robust simulation environment, validated with imaging spectroscopy and LiDAR remote sensing data from

NASA's BioSCape airborne campaigns. We will collect in situ spectroradiometer and terrestrial LiDAR data, to first develop and then annually refine, accurate virtual GCFR plot-level scenes, which will be used to i) assess the linkages between 3D (structural) and spectral diversity, ii) develop a mechanistic link between structure/spectra-to-traits, and iii) track biodiversity as a function of post-fire recovery, all of which will be iv) validated against the planned NASA airborne campaigns. An additional benefit of this work relates to a definitive assessment of what spatial and structural scales future air-/spaceborne missions should target in order to resolve the structural, species, and trait diversity in such complex ecosystems. The team boasts established imaging scientists and South African ecology collaborators, with both spectroscopy and LiDAR experience, as well as a vetted simulation tool (DIRSIG). We ultimately contend that achieving these project goals could significantly improve our understanding of interactions of photons with fynbos biophysical traits and inform innovative uses of remote sensing data for similar ecosystems at all scales, from airborne-to-satellite levels.

Jinghui Wu/Columbia University
BIOSCape - Mapping of Phytoplankton Functional Types from Space in Support of Coastal Resource Management and Decision Support Activities
21-BIODIV21-0002

Background:
Sheltered bays along South Africa's (SAs) long coastline are few and far in between, and therefore, of high socio-economic importance. Most are highly productive, but ecologically distinct because of the differences in water masses that influence them. Bays along the west coast are influenced by the cold Benguela Current, whereas those along the east coast are exposed to the warm Agulhas Current. Southern bays are exposed to a blend of the aforementioned currents, and environmental conditions within them vary depending on local winds and large scale atmospheric and oceanographic phenomenon. On account of their high productivity and extraordinary taxonomic biodiversity, these bays can sustain thriving fisheries, commercial shellfish farming, tourism and recreational activities that are vital to the socio-economic well-being of SA's coastal communities. There is growing recognition that the health of these bay ecosystems, and the goods and services they provide, are coming under increased anthropogenic and climate-mediated threats, witnessed in the form of extreme temperature events, intensification of upwelling and rise in the frequency and intensity of Harmful Algal Blooms (HABs). Although it is known that these changes are detrimental to phytoplankton species richness and diversity, conventional means of monitoring these changes for use by stakeholders, including resource managers has been challenging.
Specific Objectives and Methods:
Our overarching goal is to develop a hyperspectral radiometric method to map the spatial distribution of phytoplankton functional types (PFT) across environmental gradients within three ecologically distinct but socio-economically vital bays, i.e. St Helena [Namaqua Bioregion], Walker [Agulhas Bioregion] and Algoa [Agulhas Bioregion]. The proposed method will detect specific PFTs, taking advantage of the unique hyperspectral remote sensing reflectance (Rrs) signals arising from phytoplankton pigment variability.

Our method of identifying PFTs will combine in-situ optical data with bio-optical, microscopic, phytoplankton pigment and e-DNA data collections, to develop algorithms that detect PFTs in particular HABs using the narrow-band hyperspectral datasets from AVIRIS-NG and PRISM that will be flown during the BIOSCape field campaign. Field datasets will be used to first disentangle the optical complexity of bay waters by separating Rrs signatures of phytoplankton communities from other seawater constituents such as mineral particles, colored dissolved and particulate organic matter. Residual hyperspectral Rrs signals attributable to phytoplankton will be used to detect different pigments essential for discriminating specific PFTs. Our team will work closely with the BIOSCape team to plan flight lines to ensure that the data over our study sites are minimally impacted by cloud cover, aerosols, sun-glint, etc. In addition, we will extend our algorithms to multi-spectral data from MODIS-Aqua, Suomi-VIIRS, VIIRS-20 and PACE to generate satellite maps of PFTs (with associated uncertainties), to address 4 hypotheses pertaining to two theme areas: (a) Distribution and abundance of biodiversity in the Greater Cape Floristic Region of South Africa (GCFR) and (c) Feedbacks between global environmental change, and ecosystem services in the GCFR. Engagement with stakeholders will take advantage of existing partnerships between our SA team and coastal industries.
Relevance to NASA activities:
Development of the capability to monitor PFTs from space opens its application to hyperspectral data from NASAs planned PACE and GLIMR missions. All QC'd field optical and bio-optical datasets, will be disseminated for public use via NASA SEABASS and NASA-BIOSCAPE and NASA-LDEO web portals. New satellite data products resulting from this study along with associated uncertainties, will be made publicly accessible via NASA-OBPG.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – NNH21ZDA001N-OSST
A.9 Ocean Salinity Science Team

This program element selected members for the Ocean Salinity Science Team (OSST) to support the salinity science within NASA's Physical Oceanography Program. The goals of the OSST are to produce the best possible satellite-derived ocean salinity datasets and to demonstrate the Earth science applications arising from analyses of the ocean surface salinity data. The objectives of this program element are to renew existing membership the OSST members and to select new members that will expand the breadth of applications of salinity remote sensing to meet new scientific and environmental demands. NASA received 29 proposals and selected 13 with funding of ~$8M over four years.

Lucas Cardoso Laurindo/University of Miami Rosenstiel School of Marine and Atmospheric Science Scale-Dependent Analysis of the Drivers of the Upper-Ocean Salinity Variability (Univ. of Miami)
21-OSST21-0030

Previous regional assessments of the upper-ocean salinity balance show contrasting conclusions on the role of advection by transient ocean motions on the upper-ocean salinity variability. Such discrepancies can potentially stem from the sensitivity of the budget estimates to the choices of observational products, the size and location of the adopted control volumes, and the temporal averaging periods chosen for the assessments. To reconcile and expand upon previous results, we propose analyzing the upper-ocean salinity budget in spectral space to objectively define the temporal and spatial scales where different terms of the budget prevail. The proposed research is global in nature and takes advantage of the excellent spatial coverage of satellite observations (including the now decadelong time series of sea surface salinity satellite measurements) and the current public availability of the outputs of climate model simulations run at eddy-resolving ocean resolutions. Our main goal is to determine the physical mechanisms governing the evolution of upper-ocean salinity anomalies (SSSA) at different spatial and temporal scales across the global ocean.

Our overarching hypothesis is that the physical mechanisms governing the SSSA evolution are scale-dependent. In the horizontal domain, the surface freshwater fluxes and the horizontal freshwater advection by Ekman currents should predominantly mirror the scale of synoptic atmospheric motions and thus dominate the upper-ocean salinity variability at large spatial scales and away from western boundary current extensions. In contrast, freshwater advection by ocean eddies dominates at the ocean mesoscales, generating large salinity anomalies. Lastly, in the temporal domain, linear stochastic theory indicates that white noise forcing by either oceanic or atmospheric processes can generate low-frequency salinity variability. To test these hypotheses, we propose examining the salinity variance budget in frequency and zonal wavenumber domains, and the cross-spectral statistics between several key quantities, including the surface

freshwater flux, horizontal freshwater advection by the Ekman and geostrophic ocean currents, and sea surface salinity anomaly and its temporal derivative. We will interpret the observed features in light of the linear stochastic theory where possible, and lastly, link the physical mechanisms responsible for maintaining the SSSA to the halosteric sea-level variability across different spatial and temporal scales and locations.
We will first analyze NASA satellite-based observations derived from orbital altimeters, radiometers, and scatterometers, combined with ECCO ocean state estimates. Then, to assess potential limitations of satellite and ECCO datasets to represent the SSSA variance, we will contrast this quantity against pseudo-Eulerian estimates of the near-surface salinity variance computed using data from the Argo global array of vertical profiling floats. Finally, to further explore the importance of mesoscale ocean phenomena in maintaining the upper-ocean salinity variability, we will apply the proposal spectral analysis to existing, freely available HighResMIP simulations
run at contrasting horizontal ocean grid resolutions: 0.1° (eddy-resolving) and 1° (eddy-parameterized). This will complement the analysis of ECCO that is also based on an eddy-parameterized model. We will also use these simulations to investigate the salinity variability over decadal scales and longer, which is currently beyond the reach of existing satellite datasets, and to identify potential limitations of climate models.
The proposed combination of satellite, in-situ, and ocean state estimation data, novel analysis methods, and high-resolution atmosphere-ocean numerical simulations represent a unique strength of this study. We expect that the obtained results will help to shed light on the role of ocean dynamics and air-sea interactions in the global freshwater cycle.

Scott Durski/Oregon State University
Ocean Salinity Variability Influenced by Shelf-Interior Ocean Interactions
21-OSST21-0025

We would like to use a combination of high-resolution (on the order of 2-km) regional ocean models of the Bering Sea and the US West Coast regions, satellite and in-situ salinity observations to understand variability in the surface salinity in the ocean offshore waters influenced by the coastal and shelf processes. The focus will be on the annual cycle and anomalies of the interannual temporal scales that can be observed in the existing satellite sea surface salinity (SSS) products. The modeling efforts will be based on our previous documented success in these areas. Model and observational analyses will be done for a period of 2009-2021, and the models will be based on the Regional Ocean Modeling System (ROMS).

The Bering Sea model will include the 500-km wide shelf and the entire deep basin. Two-way coupled ice-ocean circulation simulations will be done for the period of 2009-present to focus on the recent warming trend and the diminished ice extent over shelf, not reaching the shelf break anymore. We hypothesize that this effect will result in the measurable positive anomaly in the SSS over the deep basin, where the anomaly is fluxed with the eddies. The model will help to identify the effect on the near-surface stratification and circulation patterns on the shelf and in the deep basin.

The US West Coast model will be extended to the Gulf of Alaska coast and augmented to include the terrestrial discharge in regions with the significant rainfall rate. Analyses comparing the model to the satellite SSS data will allow us to see the contribution of this discharge and shelf-interior ocean eddy transport to maintaining the seasonal cycle in the offshore waters, in particular to the west of Washington, British Columbia and southeast Alaska coasts.

We would like to contribute to the work of the Ocean Surface Salinity Team (OSST) providing information on the required accuracy of the SSS products to be useful for shelf-interior ocean interaction studies.

Our study will address the following research areas, from the solicitation:

- characterization of mesoscale haline features and the role of eddy transport in the ocean freshwater budget

- air-sea coupling and major modes of climate variability from intra-seasonal to inter-annual and longer time scales

- demonstrating the utility of salinity remote sensing in improving our understanding of ice dynamics in polar ocean regions and ice-ocean coupling using existing satellite, in situ, and modeling capabilities

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Severine Fournier/Jet Propulsion Laboratory
Coastal Salinity, A Proxy for Human and Natural Hydrological Cycle Changes
21-OSST21-0002

The coastal ocean represents the interface between the land, ocean and atmosphere. Large rivers are key components of the land-ocean branch of the global water and biogeochemical cycles and can influence physical, biological, optical and chemical processes in coastal oceans. Riverine freshwater inputs into the ocean affect ocean circulation and air-sea interactions (e.g., hurricane intensification) through their effects on stratification. They also affect biogeochemistry and biological and ecological activities (e.g., carbon fluxes, primary productivity, ecosystems) through the supply of nutrients, sediments, organic and inorganic matter into the ocean. These riverine freshwaters can be traced in the coastal ocean using sea surface salinity (SSS) observations. Several 'hotspot' regions have been identified as locations where these processes are especially important: the Maritime Continent, the Amazon plume region, the Bay of Bengal, the Gulf of Guinea and the Gulf of Mexico.
Runoff itself is influenced by precipitation over land, which is then partitioned between different components of the hydrological cycle: a portion is stored above and below the ground in lakes, soils, snow and ice, another portion is used by plants and transpired, evaporates from surfaces, with the remainder becoming runoff. On interannual to decadal timescales, terrestrial hydrology variability is dominated by natural climate modes

including the El Nino Southern Oscillation (ENSO), Atlantic Multidecadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO). Human activity can also impact regional water balances through agriculture, forest fires, land cover change. Increasing temperatures associated with anthropogenic climate change can also alter the availability of water by altering the components of the water cycle.
Characterizing the linkage between terrestrial hydrology and coastal SSS in each of these regions is necessary given their importance in major earth system processes. Further, attributing the response of coastal SSS to natural climate variability, human activity and climate change is needed to understand the land-ocean linkages in these regions. Extending this work to examine the coastal ocean SSS also will provide new information on whether coastal SSS can be used as an indicator of global terrestrial water cycle changes.
This proposal will extend existing work from the proposing team, using state-of-the-art SSS measurements from satellites, to characterize how terrestrial water cycle processes impact coastal SSS. The aims of this proposal are therefore as follows: for the five key regions listed above, use satellite observations to 1) understand the nature of linkages between coastal SSS and terrestrial hydrology, 2) disentangle the natural and human drivers on terrestrial hydrology, and subsequently the detectability on coastal SSS, and 3) extend the analyses of hotspot regions to examine the relationship of the global terrestrial hydrological cycle with global coastal SSS.
This proposal responds to the OSST call, in particular in responding to: 1) enabling advances in the study of the linkages between SSS and terrestrial hydrology" Through the use of NASA satellite SSS measurements and ancillary data, our study proposes to improve the knowledge and understanding of the terrestrial water cycle linkages with coastal SSS. (2) Exploring the impact of climate variability on SSS: part of our proposed work is to study the monthly, seasonal to interannual variability in coastal SSS and its relationship with land water budgets and particularly runoff. By examining the linkage between river discharge and coastal SSS, the proposed work will also produce a framework for integrating future measurements from the Surface Water and Ocean Topography (SWOT) mission.

Renske Gelderloos/Johns Hopkins University
Using Satellite Surface Salinity Measurements to Derive and Predict Changes in Dense Water Properties in the Labrador Sea
21-OSST21-0020

This project will demonstrate the value of satellite salinity measurements by using them to derive and predict changes in dense water mass properties in the Labrador Sea, which is one of the key variables in the Earth's climate system and global ocean circulation; the project will thus contribute to priority area 2.1:Role of salinity in ocean circulation and climate variability". The occurrence and intensity of deep convection in the Labrador Sea is determined by the strength of the ocean stratification and wintertime atmospheric conditions. The upper Labrador Sea is stratified by salinity in winter and the buoyancy erosion happens almost exclusively through surface heat fluxes. Thus, local surface salinity is a prime indicator for the likelihood of convection. Furthermore, salinity properties in the two upper buoyant layers of the Labrador Sea is advected in from the surface Arctic Ocean and surface subtropical North Atlantic Basin, respectively. Thus, it is largely predictable ahead of time. The objectives of the project are to demonstrate to what extent (1) satellite surface salinity measurements in the Labrador Sea can be used to derive changes in dense water mass properties, and (2) satellite surface salinity measurements over the Arctic and Subtropical North Atlantic can be used to predict changes in dense water mass properties in the Labrador Sea. We will use ASTE/ECCO for a proof of concept and to quantify the relationships between surface salinity, air/sea forcing, and dense water mass properties. We will then apply this knowledge to Aquarius/SMAP time series to demonstrate how much can be learned from satellite surface salinity measurements. We will verify the results using Argo float observations of dense water mass properties.

Semyon Grodsky/University of Maryland, College Park
Satellite View of Bering Strait Exchanges
21-OSST21-0011

Bering Strait is the only oceanic gateway from the Pacific to the Arctic. Although relatively weak in transport values (~0.8 Sv), Bering Strait exchanges shape the thermohaline properties of the Chukchi Sea and have primary impacts on the Arctic and beyond. On average, they provide approximately a third of freshwater transport to the Arctic and are the principal source of its interannual variability. The entering Pacific water affects near-surface (top ~100-200m) stratification in roughly half of the Arctic Ocean. It sets up stable haline stratification, which near-surface cold layer separates (thus protects) Arctic sea ice from potential melting by the warm and salty Atlantic water. As a major source of oceanic nutrients, the Bering Strait throughflow affects ecosystems in the Chukchi Sea. Ultimately, it also impacts the way the Pacific Waters leave the Arctic through the Canadian Archipelago and/or Fram Strait.

Regardless of its importance, traditional studying the region via in-situ measurements is challenging at these high latitudes. While satellite SST has proven applications in the region, the better way to track the pathways of water exchanges is through the application of a more conservative ocean state salinity variable, which distributions are stronger affected by oceanic advection and lesser impacted by air-sea exchanges. All parameters, including SST, sea surface height (SSH), sea surface salinity (SSS), and scatterometer winds are remotely detectable only in ice-free conditions that occur in the local summer. Are regional oceanic fields in boreal summer to fall representative of the exchanges? Being a shallow meridionally oriented channel, the Bering Strait dynamics is driven by local meridional winds and the pressure difference between neighboring parts of the Chukchi and Bering Seas. Such equator-like balance is explained by a virtual cessation of the cross-strait velocity component and explains the seasonality of Bering Strait exchanges which amplify in the summer due to seasonal strengthening of southerly winds. Hence, remote sensing parameters observed in local summer reflect the seasonal peak of the exchanges and can be used to study their characteristics and variability.

The proposed research focuses on SSS as a tracer of Pacific-Arctic exchanges. In that, we intend to demonstrate its role as an essential climate variable. In combination with a wide variety of in situ observations from Argo, ships, unmanned vehicles, and moorings we will demonstrate the role of salinity in regional ocean circulation and its synergy with other NASA remote sensing data, including winds, sea level, and SST, with the primary focus on the role of salinity in polar environments. All the above fit into the OSST-21 announcement.

This project focuses on the investigation of interannual salinity variation in the Bering Strait and adjacent Bering and Chukchi Seas using the new large-scale perspective afforded by satellite SSS sensors. The proposed study focus areas will include coastal and cold-water seas where it is understood that the L-band satellite salinity measurements may be compromised. This is a recognized project risk. However, preliminary results show that the salinity anomalies and gradients under study are large and well-resolved using Aquarius, SMAP, and SMOS data. Our team includes expertise in working directly with the radiometric and derived SSS data and their limits over similarly complex Gulf of Maine winter conditions. The objectives and work plan are designed to exploit such mutual benefits between these in situ observations, satellite data (SSS, wind, SSH, and SST), and models to demonstrate value added by a new large-scale salinity measurement capability.

Shineng Hu/Duke University

Ocean Salinity's Role in the Interplay of Intraseasonal WindBursts and the El Niño-Southern Oscillation: Insights from Satellite Observations and Coupled Model Simulations

21-OSST21-0008

MOTIVATION: Westerly and easterly wind bursts in the equatorial Pacific, lasting a few days to weeks, play a critical role in the El Niño-Southern Oscillation (ENSO) cycle. For example, the 2015/16 extreme El Niño is believed to be shaped by the interplay of a series of intraseasonal wind bursts since 2014. What role ocean salinity plays in the wind bursts-ENSO interaction is not fully understood. Recent findings about the impact of the ocean barrier layer on the intensification of tropical cyclones, a major source of westerly wind bursts, suggest that ocean salinity can potentially interact with the development of intraseasonal wind bursts and therefore influence the development of ENSO events. The increasing availability of high-resolution, satellite-based salinity observations presents an emerging opportunity to understand those multi-scale interactions.

OBJECTIVE: The primary objective of this research is to use satellite salinity data to understand the influences of ocean salinity on the interactions between intraseasonal wind bursts and the underlying ocean and on the development of ENSO events. The overarching goal of this project is to improve the seasonal forecast skill of ENSO events, particularly extreme El Niño (e.g., the recent one in 2015/16).

APPROACH: To achieve the project objectives, we will perform comprehensive satellite-based observational analyses, develop data-informed theories, and design novel coupled model experiments to further test the hypotheses. Satellite observations of sea surface salinity (SSS), temperature, and height will be combined to reconstruct the vertical thermal and salinity structures and will be evaluated against the in-situ measurements by moored buoys and profiling floats. Satellite salinity observations will be one of the most critical elements to our analysis and the datasets to be used include the Aquarius (2011-2015), Soil Moisture Active Passive (SMAP; since 2015) SSS datasets, and the Level 4 Optimum Interpolation SSS product (since 2011). We will conduct observation-informed coupled model experiments with various combinations of imposed wind burst forcing (i.e., through momentum, heat, and freshwater fluxes) and ocean background state. Those sensitivity experiments will inform how the intraseasonal wind bursts interact with the underlying ocean and affect the seasonal development of ENSO events and what role ocean salinity plays in those interactions.

IMPACT: This project will refine our mechanistic understanding and enhance the predictability of weather and climate extremes. ENSO dominates the Earth's climate variability on interannual timescales, and the occurrence of an ENSO event, especially extreme El Niño, is often associated with devastating natural disasters on a global scale. Westerly wind bursts are closely related to the Madden Julian Oscillation and tropical cyclones, both originating in the tropics and influencing extreme weather events worldwide. Better understanding and prediction of those extreme events will have prominent environmental and socio-economic impacts worldwide.

RELEVANCE: This project emphasizes the role of ocean salinity in air-sea coupling and climate variability on a broad range of timescales from intraseasonal to interannual, closely relevant to the current solicitation. The outcome of this project has direct implications for both ENSO seasonal forecast and future projection, which directly supports long-term NASA goals.

Laifang Li/Pennsylvania State University

Utilizing Satellite Remote Sensing of Sea Surface Salinity towards Improved Subseasonal-to-Seasonal Forecasts of Hydroclimate Extremes in the Conterminous US
21-OSST21-0006

Accurate subseasonal-to-seasonal (S2S) prediction of precipitation becomes increasingly critical for societal preparedness for high-impact climate events. However, current S2S prediction models, based primarily on sea surface temperature anomaly (SSTA), still cannot generate the level of skill that meets societal needs. Our series of studies has presented evidence that sea surface salinity anomaly (SSSA), an indicator of the variation of the oceanic water cycle, demonstrates promising potentials to bridge this gap. Specifically, in regions like the Southwest and Midwest US, SSS-based rainfall prediction offers significantly superior predictive skill one-season ahead compared to SSTA-based predictors. As satellite remote sensing measures SSS with unprecedented temporal resolution and spatial coverage, new windows of opportunity for S2S prediction of US hydroclimatic extremes open up. This opportunity motivates this study to explore and realize the S2S prediction skills from SSS at lead time of 2-8 weeks.

We propose to study the sources of S2S prediction skills of US heavy precipitation from SSS. Of particular interest here will be predictability skill with lead time of 2-8 weeks, which is now accessible with the higher temporal resolution of satellite SSS products compared to ARGO. We will utilize a combination of satellite remote sensing of SSS (SMAP, Aquarius, and SMOS), precipitation (GPM), and soil moisture content (SMAP and SMOS), as well as MERRA atmospheric reanalysis to evaluate the S2S rainfall prediction skills and explore the physical processes from the perspective of moisture balance. Based on the physical mechanisms, we will implement SSS into AI-aided statistical S2S prediction models for US heavy precipitation. The results obtained from the study are expected to improve the existing S2S prediction of heavy precipitation. The results will also serve as a benchmark for dynamical models to improve the representation of the processes key to S2S prediction.

Oleg Melnichenko/Earth and Space Research
Variability of the Northern North Atlantic Sea Surface Salinity and the Role of Arctic Freshwater Transport
21-OSST21-0019

The northern North Atlantic is an important region of deep water formation, a key component of the Atlantic Meridional Overturning Circulation (AMOC). Because salinity in the northern North Atlantic controls stratification and, therefore, deep water formation, characterizing, quantifying, and understanding the distribution of sea surface salinity (SSS) and its variability is crucial for understanding changes in the regional and global climate and for climate monitoring and prediction.

Freshwater fluxes from the Arctic Ocean are the main source of freshwater for the northern North Atlantic. The Arctic water entering the North Atlantic influences the intensity and timing of deep convection in the Nordic and Labrador Seas with significant implications for the AMOC. Although the gateways that connect the Arctic with the North Atlantic are well established, the advective pathways associated with these gateways and their temporal variability are much less known. Moreover, much attention has been paid to the low salinity anomalies (e.g., the Great Salinity Anomaly" of 1970s; Dickson et al., 1988) but very little to the high salinity anomalies (Sundby and Drinkwater, 2007), although the two types of anomalies seem to be linked together and are part of a large-scale decadal oscillation with important implications for the AMOC and climate variability.

Satellite observations during the last decade provide an unprecedented resource to study the spatial distribution and temporal evolution of SSS in the northern North Atlantic, including monitoring pathways of the Arctic water. Importantly, satellite SSS can 'see' shelf areas (e.g., Labrador shelf) and remote areas (e.g., Greenland Sea, Baffin Bay), typically not available by in-situ components of the ocean observing system such as Argo. Indeed, significant low and high salinity anomalies have been observed with satellite SSS in these areas. The SSS anomalies seem to propagate along the major currents, causing substantial freshening (and salinification) in the sub-polar seas. Using 10+ years of satellite observations, we will characterize and quantify spatial and temporal variability of SSS in the northern North Atlantic with a particular attention to anomalies arising from the Arctic freshwater transport. By combining satellite observations with ocean state estimates and in-situ measurements we will address the following questions. (1) How and where do salinity anomalies originate? (2) How and where do they propagate and dissipate? (3) What are the driving mechanisms? (4) What are possible implications for the deep convection and AMOC?

The overarching objectives of the proposed research are to: (1) provide a systematic description and characterization of SSS variability in the northern North Atlantic, (2) identify and characterize the physical processes responsible for the observed variability, (3) assess and characterize SSS anomalies associated with the Arctic water entering the North Atlantic; and (4) assess and characterize their downstream evolution and impacts.

The proposed work addresses the objectives of the Ocean Salinity Science Team. By investigating SSS variability in the northern North Atlantic using satellite SSS and in-situ data, the project will contribute to the research theme 1, Role of salinity in ocean circulation and climate variability".

Tangdong Qu/University of California, Los Angeles
Unique Characteristics and Variability of Sea Surface Salinity in the Subtropical South Indian Ocean

21-OSST21-0018

Sea surface salinity exceeds 35.7 psu in the subtropical South Indian Ocean (SIO). Compared with its South Pacific and South Atlantic counterparts, this high salinity water in the SIO is fresher and extends further southward by at least 10 degrees of latitude. Some of this high-salinity water subducts and fills the subtropical gyre at depths of the upper thermocline. The subducted high salinity water in the SIO directly contributes to the ocean's overturning circulation via a unique salt cycle associated with the Cross-Equatorial Cell and Southern Hemisphere Super Gyre. As a consequence, variability in the subtropical SIO can be conveyed into the North Indian Ocean and possibly the South Atlantic, playing a potentially important role in the world's climate system and hydrological cycle.

The unique characteristics and variability of sea surface salinity in the subtropical SIO reflect strong influence of ocean dynamics, especially, the Indonesian throughflow and its derived circulation and eddies through a leaky eastern boundary. However, due to the historic paucity of research-quality hydrographic observations, these unique characteristics and variability have not been carefully examined. Taking advantage of the recent advance in satellite observations and ocean state estimates, here we propose a study that will first examine the time-varying nature of sea surface salinity and then the governing processes of this variability in the subtropical SIO. The overall objectives of the proposed investigation are: (1) To assess and characterize the nature of variability in sea surface salinity and its downstream impacts, and (2) To identify the causal mechanism of the unique characteristics and variability of sea surface salinity in the subtropical SIO. Particular attention will be paid to the role of eddy processes in shaping salinity distribution.

To achieve these objectives, we will analyze the newly available salinity observations from the Aquarius and SMAP missions and the latest ocean state estimate of the Consortium for Estimating the Circulation and Climate of the Ocean (ECCO) in combination with ancillary in-situ (mainly Argo) observations.

Aneesh Subramanian/University of Colorado, Boulder
An Improved Understanding of the Role of the Ocean Surface Salinity and Salinity Stratification in Modulating Tropical Atmospheric Intraseasonal Oscillations
21-OSST21-0026

Improving the prediction of tropical intraseasonal variability (ISV) is important because of the global impacts of the MJO, monsoons, and their associated socioeconomic implications. A decadal time series of satellite sea surface salinity (SSS) has only recently become available for improving our characterization of the global hydrological cycle. SSS observations from the SMAP, Aquarius, and SMOS missions are key to understanding the role of SSS and salinity stratification in air-sea interactions in the Tropical Oceans.

SSS, combined with temperature, helps to improve the estimates of near surface density changes and associated ocean mixing. In recent SSS assimilation experiments with the NASA GMAO S2S forecast system, it has been shown that satellite SSS assimilation improves coupled forecasts by adjusting the large scale equatorial waves that are integral to ENSO development. We intend to use SSS datasets from SMAP, Aquarius and/or SMOS surface salinity for analyzing seasonal and ISV anomalies and their role in atmospheric ISV propagation. We will identify fresh/salty water pools, salinity fronts and their variability using satellite-observed (skin) SSS datasets and compare with available in situ (bulk) surface salinity observations (e.g., Argo, RAMA, DYNAMO). We will further assess the effects of salinity on upper-ocean stratification by calculating and comparing the mixed layer depth (MLD) with/without salinity using available observations and NASA GEOS-S2S reanalysis products and examine the relationship between the fresh/salty pools, salinity fronts, MLD, and barrier layer thickness (BLT).

We will then focus on three main regions: the mini warm/salty pool in the eastern Arabian Sea where observational and empirical analyses show that variability of MLD modulate Indian summer monsoon intraseasonal oscillations (MISOs) before they deluge the Indian subcontinent (e.g., Li et al. 2016), the Bay of Bengal (BoB) where MLD and BLT are highly correlated with Indian monsoon strength (e.g., Li et al. 2017), and the Seychelles-Chagos Thermocline Ridge (SCTR) region and eastern equatorial Indian Ocean warm pool where ocean dynamics play an important role in MJO initiation and propagation. Here we document the relationships between SSS, MLD and BLT and MISO (MJO) in summer (winter).

In addition to freshwater pools, we will also focus on understanding salty water pools and salinity fronts, which play crucial roles in causing MLD and SST horizontal gradients, and therefore affect ISO/MJO. We will quantify the sensitivity of monsoon ISO to salinity stratification over the Arabian Sea mini warm pool region and the BoB region during summer months. We will study the sensitivity of MJO initiation, development, and propagation to salinity stratification over the equatorial region and thermocline ridge region in the winter months. We will use NASA GEOS5 global subseasonal forecast experiments (with and without salinity assimilation) to analyze the change in forecast skill due to changes in surface salinity initializations, and compare the MLD, BLT with/without salinity assimilation.

Since atmospheric MJO and MISO have global scale impacts on weather and climate, their improved understanding and forecasts have large societal benefits. Given that application of the spatially and temporally continuous satellite SSS is essential for achieving the project goal, this proposal directly contributes to the objectives of NASA OSST by investigating the role of salinity variability in ocean circulation, air-sea coupling, and major modes of climate variability on intra-seasonal timescale (i.e., MJO and MISO).

Caroline Ummenhofer/Woods Hole Oceanographic Institution

The Influence of Salinity on Stratification Over the Northeast U.S. Shelf and Slope and Its Implications for Weather Systems and Marine Heat Waves
21-OSST21-0003

The Northeast U.S. continental shelf is a highly productive and economically important region that has experienced robust changes in upper-ocean properties in recent decades. Warming rates exceed the global and North Atlantic average and several episodes of anomalously warm temperatures, so called marine heatwaves, have had devastating impacts on regional fisheries over the past decade. Highly dynamical due to the Gulf Stream and its interactions with the adjacent slope seas, the region is characterized by strong horizontal gradients in temperature and salinity, and hence density gradients. Cross-shelf density gradients are a controlling factor for shelf-break exchange. Gulf Stream warm core rings can interact with the shelf break causing intrusions of warm and salty waters on the otherwise cooler and fresher continental shelf. Ocean salinity is a critical factor that strongly impacts the vertical stratification and mixed layer depth across the continental shelf. The mixed layer depth and upper-ocean thermohaline structure has important implications for the development of marine heatwaves and interaction with extreme weather events, such as hurricanes.

Here we propose to complement the traditional focus on upper-ocean temperature structure and its impact for and interaction with extreme events, such as marine heatwaves and synoptic weather systems, with a view towards the contributing role of ocean salinity. Considerable salinity changes have been observed across the region recently, likely contributed by a changing hydrological cycle and/or ocean advective processes associated with a meandering Gulf Stream and variations in ring shedding. Using NASA remote sensing data from Aquarius and SMAP, as well as ESA's SMOS, complemented with in situ observations in the region and reanalysis products, upper-ocean characteristics across the Northeast U.S. continental shelf and slope. Implications of ocean salinity for the development and depth structure of marine heatwaves and air-sea interactions with frontal weather systems will be quantified, contributing towards an improved understanding of the ocean freshwater budget in the Northwest Atlantic and towards benefiting ocean predictive capabilities across the region.

The interdisciplinary team from the Physical Oceanography Department at Woods Hole Oceanographic Institution (WHOI) and the Department of Earth, Ocean and Atmospheric Science at Florida State University (FSU) has extensive expertise in observational and coastal oceanography, ocean and climate models, air-sea interactions and synoptic meteorology, variability and change in the hydrological cycle including for extreme events, as well as process-understanding of drivers for marine heatwaves. Funds are sought for a three-year project and will provide support for a graduate student in the MIT-WHOI Joint Program, a postdoctoral researcher, and two PIs at WHOI, as well as travel, publications, and computing resources; with a subaward to FSU supporting an early career faculty member.

Gabriel Vecchi/Princeton University

Investigating Global Cloud Feedback Dependence on Southern Ocean Salinity
21-OSST21-0016

Cloud feedback is the greatest source of uncertainty in estimating climate sensitivity. Idealized modeling studies suggest that Southern Ocean heat uptake can play a primary role in regulating cloud feedbacks (Rose & Rayborn, 2016), and preliminary analysis of CMIP6 models by our team indicates that there is a strong connection between background Southern Ocean salinity and global cloud feedbacks. If true, this relationship provides a promising approach to use satellite-observed SSS as an emergent constraint on cloud feedback. However, the detailed mechanisms behind this connection remain to be fully understood; understanding these mechanisms is a pre-requisite for utilizing these statistical relationships as an emergent constraint, and capitalizing on this promise. In this proposal, we seek to understand the impact of Southern Ocean salinity, through its controls on ocean heat uptake, global energy transport and global patterns of SST, on cloud feedbacks. We propose to produce and analyze climate model experiments, which will help develop this needed understanding in combination with analysis of satellite-derived and in situ salinity estimates. Our ultimate goal is to generate a satellite-SSS informed Bayesian estimate of global cloud feedbacks, to help narrow the uncertainty in climate sensitivity estimates.

The main questions for this proposal are: i) How does Southern Ocean salinity modulation of ocean heat uptake influence global cloud feedbacks? ii) What processes are responsible for the non-local effects of Southern Ocean heat uptake on cloud controlling factors? iii) Why are salinity-driven ocean heat uptake changes in the Southern Ocean much more effective in altering clouds than those in other basins? iv) Given the exquisite sensitivity of cloud feedback to background salinity, do natural fluctuations in Southern Ocean salinity on decadal to centennial timescales result in state-dependent climate sensitivity? v) Using SSS as an emergent constraint", can we narrow the estimate of global climate sensitivity?

A key resource will be satellite observations of salinity, rainfall and surface wind speed from NASA's Aquarius satellite and NASA's Soil Moisture Active-Passive (SMAP), complimented by observations from the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite. Additional information on the vertical structure of salinity and temperature in the ocean will come from the Argo array of profiling floats and from ocean analyses obtained from the NOAA GFDL and NASA GEOS iODAS ocean data assimilation systems. We now have a decade of high-quality global sea surface salinity measurements that could enable a constraint of global cloud feedback using data that is novel and independent of heretofore used methodologies. We propose to explore the detailed mechanisms connecting Southern Ocean salinity with global cloud feedbacks across the CMIP6 ensemble, and design, run and analyze coupled climate model experiments to isolate oceanic and atmospheric pathways to connect the Southern Ocean with global cloud feedbacks. In particular, it is notable that Southern Ocean salinity in climate models is connected to both extratropical and tropical/subtropical cloud feedback differences. We will constrain a climate model's Southern Ocean salinity to that of other climate models and to that informed from observations. By completing these tasks, this proposal will directly support the program goals of exploiting satellite salinity measurements and their synergistic use with other observations to investigate salinity variability, particularly near-surface salinity stratification, and its linkage the global climate response to increasing greenhouse gases. In doing so, this proposal will directly address the first goal of the Ocean Salinity Science Team: Exploitation of NASA satellite SSS measurements to investigate SSS variability, its influence on ocean circulation, and the linkage with climate and water cycle."

Lisan Yu/Woods Hole Oceanographic Institution
Inferring the Water Cycle Change from Interbasin Differences in Salinity, Surface Freshwater, Flux, and Ocean Bottom Pressure
21-OSST21-0004

Growing evidence indicates that climate-warming induced intensification of the global water cycle is already underway. In the ocean, one distinct manifestation is the increased contrast in sea surface salinity (SSS) between the relatively salty Atlantic and the relatively fresh Pacific. This interbasin asymmetry is regarded as one of the most fundamental mechanisms for the global overturning circulation (MOC). However, how and at what rate has the water cycle been changing to give rise to this unabated amplification remain to be determined, owing primarily to the lack of reliable estimation of the water cycle fluxes (evaporation (E), precipitation (P), runoff (R), and ice melting (Ri)). Given the ability of the ocean to integrate the complex multifactorial variations in the water cycle, satellite SSS and in situ salinity observations will continue to be one important water-cycle proxy indicator.
This proposed study aims to improve the utility of salinity in the water cycle research by addressing the following three objectives: improving the understanding of the mechanisms governing the interbasin salinity change and variability, improving the characterization of the surface freshwater signals in SSS and subsurface salinity, and expanding the capability of the salinity proxy through integrating satellite gravimetry observations of ocean bottom pressure (OBP). A summary of the motivation and prime focus for each of the three objectives is as follows.
(1) It is evidenced that SSS seesaw exists between the North Pacific and North Atlantic on interannual and decadal timescales and the stability of this anti-phase oscillation may affect the rate of change of the interbasin SSS difference. Two mechanisms will be investigated: the out-of-phase coupling between the low-pressure centers in the North Atlantic and North Pacific during the late winter, and the trans-basin and intra-basin moisture transports.
(2) There is a considerable spread in the water cycle amplification rate inferred from using SSS or full-depth salinity. This disparity raises questions as to how deep the water cycle signals can get into the ocean interior and by what ocean processes. The latest ECCO ocean estimates and a series of sensitive experiments will be used to help interpret the effects of ocean processes in distributing and sustaining the changes induced by surface freshwater fluxes.

(3) Surface freshwater flux is a mass flux. The freshwater added at the surface by P, R, and Ri reduces salinity while adding mass to the ocean. Conversely, the freshwater removed by E increases salinity while removing mass from the ocean. A change in mass would lead to a change in oceanic bottom pressure (OBP), which should be detected by satellite gravimetry. Indeed, the connection between the changes in SSS, P-E and OBP during the GRACE data period is evidenced in the Pacific. This gives an incentive for this proposed study to develop an improved monitoring of ocean water cycle by taking advantage of the existing remote sensing capacity in observing the two effects of surface freshwater fluxes: salinity and mass.

The proposed objectives will be accomplished through using observations, ECCO ocean estimates, and sensitivity experiments. This proposed work will improve the understanding of the mechanism governing the amplification of the Atlantic-Pacific salinity difference that is potentially important for improving climate model prediction of future changes in the global MOC. It will develop new and innovative utilization of the built-in redundancy in the observational system to improve the monitoring capability of the water cycle. It has the potential to gain unprecedented views into the relationship among ocean salinity, water cycle, and mass. The proposal contributes to the following two themes in this OSST program call: role of salinity in ocean climate and climate variability, and salinity remote sensing in support of inter-disciplinary research.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-CRYO
A.15 Cryospheric Science

This synopsis describes the proposals selected in response to the NASA Research Announcement “Cryospheric Sciences”, that is sub-element A.15 of NASA ROSES 2021. NASA’s Cryospheric Sciences Program supports investigations of polar ice, including the Antarctic and Greenland ice sheets, polar glaciers, and sea ice in the Arctic and Southern Oceans, that are based on satellite and airborne remote sensing. Polar ice is a key component of the global climate system, interacting with the biosphere, atmosphere, oceans, and solid Earth. Melting ice from the Antarctic and Greenland ice sheets contributes to sea level rise, while changes in sea ice impact ocean biology, air-sea exchanges, and ocean circulation. Polar ice is highly reflective, and changes in its surface area impact radiation balance on a local scale with global implications. Several feedback mechanisms amplify the impact of the polar regions on the global climate. Thus, monitoring the cryosphere and understanding the underlying physical processes that govern its behavior are crucial to understanding recent and future global change. The program seeks to improve our understanding of cryospheric processes, link the cryosphere to the global climate system, and advance predictive capabilities.

This opportunity requests proposals that use remote sensing data to provide new insights into the stability of ice shelves of Greenland and Antarctica in a changing climate, their governing processes and inter-relationships, specifically:

- Surface processes at the ice shelves (incl. surface mass balance, surface hydrology, melt water routing);
- Ice shelf thermodynamic and mechanical behavior (incl. hydrofracturing, marine ice cliff instability); and
- Ice shelf - ocean interactions (incl. assumption on hydrostatic equilibrium, bottom melt, roughness and bottom crevassing, impact of and interactions with the adjacent sea ice).

Proposals submitted to this program were evaluated using a dual-anonymous peer review process in which, not only are proposers unaware of the identity of the members on the review panel, but the reviewers do not have explicit knowledge of the proposal teams during the scientific evaluation of the proposal. The overarching objective of dual-anonymous peer review is to reduce unconscious bias in the evaluation of the merit of a proposal.

Out of 33 received proposals, 11 were selected for awards. The total funding for the program is approximately $1.5 million per year for three years. Te Principal Investigator, institution, project title, and abstract are listed below.

Jeremy Bassis/University of Michigan, Ann Arbor
The Role of Fracture and Melt in Ice Shelf Stability
21-CRYO21-0002

Ice sheets are currently losing mass and irreversible retreat through a spectrum of instabilities has been speculated to already be underway in portions of the West Antarctic Ice Sheet (WAIS). Marine based portions of the West Antarctic Ice Sheet, like Thwaites and Pine Island glaciers, that have been subject to increased ocean forcing are especially vulnerable to collapse through marine ice sheet and marine ice cliff instabilities. However, both of these instabilities are modulated by the presence of freely floating platforms of ice, called ice shelves, that buttress the discharge of inland ice flow. The fate of the ice sheets is thus tightly controlled by the continued stability and health of these ice shelves. Recent observations, collected in part through NASA's own Operation IceBridge (OIB), show that the bottom of ice shelves is not smooth, as simulated by most ice sheet models, but instead shows extensive bottom topography. Current literature speculates that these features are the direct result of basal crevasse formation and melt channels, excavated by the ocean. These features create stress concentrations, providing templates for crevassing, rifting and, potentially, enhanced calving that could eventually lead to ice shelf disintegration. Here we propose a study characterizing the mechanisms and processes that links ocean forcing to ice shelf stability. This will be carried out by investigating the following questions:

(1) How does increased roughness influence the stress and the failure regime of ice shelves?
(2) How does ocean forcing contribute to enhancing the bottom roughness and failure of ice shelves?
(3) What are the conditions where pinning points and suture zones (de)stabilize ice shelves? And
(4) How likely are ice shelves to disintegrate under continued oceanic and atmospheric warming?

Links between basal melt, crevassing, rifting and roughness have previously been elusive to characterize, but the launch of ICESAT 2 combined with the existing Operation IceBridge and gridded data products, like REMA, provide extensive coverage of the surface and, at least for OIB, the bottom topography of ice shelves providing the means to quantify the roughness of ice shelves. We propose to address our overarching questions by combining ICESat 2 and REMA with OIB ground penetrating radar and surface altimetry data products to quantify the roughness of ice shelves. Using these datasets, we can compare roughness between ice shelves in different climate regimes (warm ocean cavities vs cold ocean cavities, high basal melt vs refreezing) and in different glaciological regimes (large stresses vs small stresses) to relate the generation of roughness to climate forcing and glaciological processes. These observations of roughness will be combined with (i) numerical ocean plume models that simulate the development of subglacial melt troughs and channels beneath ice shelves and; (ii) ice dynamics models capable of simulating the flow and fracture of ice to understand the physical processes responsible for the generation and decay of features, including crevasses, rifts and melt channels that lead to roughness. By fusing our estimate of ice shelf roughness with a set of innovative models, we can constrain the processes responsible for both quasi steady-state calving and potential ice shelf disintegration to improve our understanding of the future stability of ice shelves.

Our study is directly relevant to the solicitation, seeking to understand the stability of a broad swath of ice shelves. Our proposal is also specifically designed to comply with best practices in Open Science, contributing to and making use of publicly available software and, not only archiving datasets, but documenting workflows necessary to reproduce the datasets.

Alexandra Boghosian/Columbia University
Ice-Shelf Hydrological Evolution and Impacts on Ice-Shelf Stability
21-CRYO21-0021

Understanding the influence of surface hydrology on ice-shelf stability is critical for forecasting sea-level rise, as ice shelves restrain ("buttress") the seaward flow of glaciers and ice streams. Ice-shelf supraglacial stream/river networks (hereafter called "ice-shelf rivers") are important because they can mitigate the potential for surface-pond-driven ice-shelf collapse. However, ice-shelf rivers may also damage ice shelves through enhanced incision that can promote fractures transverse to ice flow, or by forming "estuaries". Ice-shelf estuaries occur when ice-shelf rivers fully incise to sea level, resulting in temporary flow reversals that allow channel waters and saline ocean water to mix, widening the channel. The first observations of the estuary at the Petermann Ice Shelf in northwest Greenland indicate that estuaries may promote fracture propagation parallel to ice flow, leading to rectilinear calving. This is a new ice-ocean interaction that could develop in Antarctica within the next 50 years and potentially foster new longitudinal fracture development and calving. As surface melting is predicted to increase in Antarctica, and ice-shelf river networks are expected to become more abundant, a process-level understanding of ice-shelf rivers and estuaries is fundamental to inform future ice-shelf buttressing and sea-level. Yet only a few studies of ice-shelf rivers have been conducted, and no in situ measurements have been collected. This proposal focuses on making the first in situ measurements of ice-shelf river and estuary processes necessary for future studies of ice-shelf surface hydrology. By combining these measurements with remote sensing, we will develop an ice-shelf river and estuary incision model that can be extended to other ice shelves, as well as address the potential impacts of ice-shelf river and estuary formation on ice-shelf stability.

The Petermann Ice Shelf offers a unique opportunity to glimpse into the potential future of Antarctica's surface hydrology. Ice-shelf rivers have been active for decades at the Petermann Ice Shelf, and an estuary has recently formed. This proposal will focus on three main objectives:

1. Make the first measurements of fundamental hydrographic characteristics of ice-shelf rivers and estuaries, including velocity, discharge, incision, temperature and salinity.

2. Determine how ice-shelf estuaries form and morphologically evolve, by testing, evaluating and developing sound channel incision models constrained by field observations and satellite-observed variables.

3. Use satellite remote sensing to assess the potential relationships between ice-shelf rivers, estuaries, fractures and calving.

Consistent with this call's focus on ice-shelf surface processes/surface hydrology and new ice-ocean interactions, this proposal will enhance our understanding of how ice-shelf rivers influence ice-shelf stability. The first-ever measurements of ice-shelf river discharge and incision will enable us to evaluate whether ice-shelf rivers are capable of removing sufficient surface melt to mitigate ice-shelf collapse, or whether these rivers may weaken ice shelves through enhanced incision and estuary formation. The development of an incision model for ice-shelf rivers and estuaries will support future remote-sensing studies of ice-shelf river-to-estuary evolution, predictions of estuary formation, and impacts of river/estuary incision on fracture propagation. Finally, an analysis of the hydrological development and calving history at the Petermann Ice Shelf will enhance our understanding of how estuary development may be linked to fracture propagation and calving. By linking critical measurements of ice-shelf rivers and estuaries with remote sensing, this work will address NASA's broad goal to understand important cryospheric processes, and will support future ice-sheet wide studies of ice-shelf surface hydrology.

Jamin Greenbaum/University of California, San Diego

External Drivers of Ice Shelf Basal Melting and Their Impact on the Present-Day and Future Stability of the Aurora, Byrd, and Wilkes Subglacial Basins, Antarctica

21-CRYO21-0031

We seek to investigate the processes driving glacier thinning along the major outlets of the Aurora, Byrd, and Wilkes Subglacial Basins (ASB, BSB, WSB) in East and West Antarctica, and to estimate how these processes may drive future glacier retreat. These basins contain at least 12.3 m of eustatic sea level potential in ice mostly grounded below sea level and are thus naturally vulnerable to climate-paced ocean forcing. The Totten and Denman Glaciers are the primary outlets of the ASB, Thwaites and the unnamed glacier feeding the Cook Ice Shelf are the primary outlets of the BSB and WSB, respectively. Thwaites, Totten, and Denman have been thinning rapidly since the beginning of the satellite altimetry record. Thwaites and Totten are famously vulnerable to intrusions of warm ocean water; however, surprisingly, the average ice shelf basal melt rate between 2010 and 2018 near Denman Glacier's grounding line was the highest in all of Antarctica despite experiencing lower known ocean forcing than Thwaites and Totten. Thinning near Cook Ice Shelf has been more variable, without a strong negative trend; however, geological proxies indicate that the WSB collapsed during the Pliocene Epoch. Taken together, we are motivated to understand the relative behavior of ASB and BSB outlet glaciers, explain why the WSB is not changing as rapidly, and predict how each system will evolve under possible climate forcing scenarios.

Recent work has highlighted the role of subglacial hydrological systems in enhancing ice shelf basal melt rates in areas where grounding line retreat has been observed. However, without coupled ice sheet and ocean modelling studies using realistic subglacial hydrological boundary conditions, the importance of subglacial freshwater discharge across grounding lines relative to atmosphere (e.g. wind stress) and ocean forcing is unknown. We will apply new airborne remote sensing data acquired by NASA's Operation IceBridge and other surveys to improve subglacial and sub-ice shelf boundary conditions of the Thwaites, Totten, Denman, and Cook systems. We will use these data to update simulations of the subglacial hydrology system underlying each glacier catchment using the Glacier Drainage System (GlaDS) model with constraints supplied by NASA's Ice-sheet and Sea-level System Model. This output will provide boundary conditions necessary to derive a novel parameterization of ice shelf basal melting that resolves both large-scale sub-shelf ocean overturning and localized convection driven by subglacial discharge. We will validate this parameterization using new satellite altimetry inferred basal melt rates and by performing forward simulations of Thwaites Glacier to test the accuracy of the ice dynamical response of the system under present day forcing. Once validated, we will use this parameterization to translate the modeled ocean state adjacent to the ice shelf simulated by the MITgcm and the modeled subglacial discharge flux simulated by GlaDS into a basal melt rate field used in transient ice sheet models of the targeted systems in East Antarctica. We will then force our coupled future simulations with anomalies in oceanic and atmospheric variables used by the ice sheet and ocean model following low and high greenhouse gas emission scenarios.

The coupled simulations proposed here will be the first-of-their-kind and will provide updated sea level estimates from dynamic areas of Antarctica. In doing so, the proposed research will produce an efficient parameterization of ice shelf basal melting that can be used by the ice sheet modeling community in the next generation of coupled simulations while also improving our understanding of the relative roles of climate forcing and subglacial discharge on ice shelf basal melting. This proposal addresses the solicitation's charge to utilize remote sensing datasets and the predictive capability of numerical models to improve our understanding of ice shelf-ocean interactions.

David Porter/Columbia University
COMBINED: Channelized Ocean Melting Beneath Ice Shelves: Non-Hydrostatic Ice and Estimating Shelf Densities
21-CRYO21-0018

Ice shelves in Antarctica buttress the ice discharge from the continent into the oceans, mediating ice–ocean interactions and regulating Antarctic contributions to sea level rise. Ice shelf thinning reduces the buttressing of the adjacent grounded ice sheet, leading to accelerated ice flow. One of the main drivers of ice thinning and mass loss from the Antarctic Ice Sheet is the ice shelf basal melt, which occurs across scales, from narrow channels to distributed melting. Basal channels have a large potential impact on the stability of ice shelves by focused thinning, altering stress distributions, and making the ice shelf more susceptible to basal and surface fractures and atmospheric warming.

The only viable approach to continent-scale quantification of basal melt rates uses satellite data to estimate ice thickness, flow, and thickness change. Because these satellite data observe only the ice surface, quantification of basal melting requires simplifying assumptions about ice-shelf density and stresses. These assumptions yield accurate melt rates in areas where spatial gradients in ice-shelf properties are small but introduce uncertainty in areas where gradients are large. Where melt rates vary over small scales, like a basal channel, non-hydrostatic englacial stresses cannot be ignored, affecting satellite-derived estimates of ice thickness and basal melt. Here we aim to understand how each of these assumptions influences satellite ice thickness estimates and derived basal melt rates, and develop methods to improve calculations and predictions of channelized basal melting.

We will leverage high resolution aerogeophysical data collected over Antarctic ice shelves over the last two decades, using the differences between the altimeter-derived ice thicknesses and those interpreted from ice penetrating radar to indicate where a failure of one or more of the assumptions exists. We will assess different time series of overflown surveys as independent evidence for basal channel formation, advection, and evolution. Capitalizing on coincident observations of airborne lidar and ice penetrating radar, we will test the assumptions of constant density and hydrostatic equilibrium as they relate freeboard to calculated and observed ice thickness. We will use physics-based models to identify regions where the ice shelf is not in hydrostatic balance to constrain and fine-tune this new ice shelf density model. On well-constrained ice shelves, additional density variations arising from the surface processes of snow accumulation and firn densification will be incorporated using a suite of atmospheric reanalysis and 1-D firn models.

The resulting new ice shelf density model, maps of basal channels and hydrostatic-disequilibrium, and improved quantification of uncertainties across a wide range of scales, will provide spatial and temporal corrections to altimetry-based estimates of localized basal melting in key areas of ice shelves. Our findings will partition the processes that control the origin, development, and fate of surface and basal topography across ice shelves, revealing relationships and controls on channelization that can be applied to ice shelves around both Antarctica and Greenland to improve projections of ice shelf strength and stability.

Ted Scambos/University of Colorado, Boulder
Ice Cliff Formation and Glacier Response After Ice Shelf Collapse in the Antarctic Peninsula
21-CRYO21-0029

The formation of large ice cliffs on tidewater glaciers has a significant impact on ice front retreat, ice flux, and net mass balance of glacier and ice sheet systems. Several large glaciers in the northern Antarctic Peninsula have in the past few decades exhibited periods of rapid retreat and increased calving, in some cases with ice front cliff heights that approach or exceed modeled thresholds required for rapid cliff ice failure. These

changes occurred in the aftermath of ice shelf disintegration events (Larsen A and Prince Gustav in 1995; Larsen B in 2002) that resulted from decades of strong climate warming. However, in the past decade, slightly cooler conditions have re-stabilized some of the glaciers, as persistent m´elange and fast ice at their ice fronts has permitted their readvancement. The Antarctic Peninsula thus provides examples of the effects of rapidly warming and cooling climatic conditions on a large ice-shelf and its fjord glacier system over a period of several decades. We will analyze the history of the region and provide new insights into a range of ice shelf and glacier processes by assembling and examining a multi-temporal multi-sensor data set spanning these warming and cooling periods.
A primary focus of the study will be the rapid, post-ice-shelf-loss transformations of the ice fronts and lower trunk areas of Crane, Hektoria-Green-Evans (hereafter, Hektoria), DinsmoorBombardier-Edgeworth (hereafter, D-B-E) and R¨ohss Glaciers. We intend to examine the ice cliff failure process from a primarily observational basis, as a complement to current model literature on ice cliffs; however, model analysis and field work on the processes we infer from the remote sensing observational data will be included. We will use several data sets that have not been previously exploited in this region before. US Navy Trimetrogon images from the 1960s (Figure 4) will be used to generate early surface elevation and flow speed data for the study region.
The proposed work will be the focus of a new Ph.D. student dissertation, comprising several publications on the region and its wider implications for ice shelf and marine terminating glacier evolution.

Michael Schodlok/Jet Propulsion Laboratory
Investigating the Role of Ocean/Ice Sheet Dynamics on Ice Shelf Rift Evolution
21-CRYO21-0016

Antarctic ice shelves are the interface between ice and ocean and substantially contribute to buttressing the grounded ice. Increased basal melt rates and changes in surface mass balance are thought to be causes of their subsequent disintegration. The loss of ice shelves can trigger acceleration of upstream glaciers, grounding line retreat and sea level rise. The ice shelf structure itself is often interrupted by rifts parallel to the ice shelf edge that episodically calve icebergs, which, in turn, pose a risk to ice sheet stability. Digital elevation models have long shown the existence of ice shelf melt channels at the bottom of the ice shelves; however, their relevance on ice sheet destabilization is unknown.

In this proposal we investigate the interplay of ice shelf rifts and ice shelf melt channels with ocean and ice sheet dynamics. Our aim is to identify key oceanic and glaciological triggers that determine the interactions between sea ice, ice mélange, ice shelves, grounding line, melt channels, and rifts controlling the stability of ice shelves, and their role in possible scenarios of evolution in a changing climate.
The study will focus on three main scientific objectives: (1) Quantify the impact of cavity geometry alterations (ice shelf rifts and basal melt channels) on the ocean dynamics underneath Larsen C Ice Shelf; (2) Determine whether sea ice/mélange encased in rifts on Larsen C Ice Shelf evolved in response to incursion of modified Warm Deep Water; (3)

Quantify the impact of cavity geometry alterations (ice shelf rifts and basal melt channels) on grounding line and ice shelf retreat.

To address these objectives, we will use a high resolution (250m grid spacing) ocean/ice sheet model system set up (both stand-alone and in a weakly coupled mode) to simulate the temporal evolution of rifts and its ocean dynamics in Larsen C ice shelf. The ocean model (Massachusetts Institute of Technology general circulation model - MITgcm) includes an explicit ice shelf, ice front and sea ice module, that will be modified to simulate mélange accumulation in the rift. The ocean model output will be used as boundary conditions for simulations with the ice sheet component of the Ice Sheet and Sea Level System Model (ISSM). Modifications to the cavity/rift geometry derived from ISSM will be returned to the ocean model.

The expected significance of this effort is to improve modeling of ice-ocean interactions below fractured ice shelves and to gain a better understanding of how alteration of the cavity geometries (rifts and melt channels) are impacting ice-ocean dynamics and grounding line retreat. This in turn may allow us to reconstruct key triggers in ice shelf collapse.

The proposed work is responsive to the objectives of the solicitation and to NASA interests. In particular, this proposal addresses two of the specific topics solicited for this opportunity: “Ice shelf thermodynamic and mechanical behavior” and "Ice shelf - ocean interactions". This proposal implements Open Science (OS) approaches consistent with the recommendations of the report Open Science by Design: Realizing a Vision for 21st Century Research from the National Academies of Science, Engineering and Medicine. The team will conduct research using tools compatible with open sharing, and will prepare data and tools for reproducibility. Sharing will occur openly and frequently via team meetings, contributions to open repositories, and other communications with colleagues.

Helene Seroussi/Dartmouth College
Designing Antarctic Ocean Forcing for ISMIP7 by Combining Remote Sensing Data and Numerical Modeling
21-CRYO21-0022

Uncertainties in future Antarctic Ice Sheet mass loss continue to dominate projections of sea level rise over the coming century, despite a decade of rapid progress in numerical ice sheet modeling. While there is today a clear consensus that the current mass loss of Antarctica is driven by ice-ocean interactions, it is still unclear how these interactions should be represented in ice sheet numerical models. Observations of oceanic conditions in ice shelf cavities are very limited, and estimates of spatio-temporal variability of sub-ice shelf melt rates are only emerging now. Coupled ice-ocean models that capture the ice-ocean interface could address this problem but they are not expected to be available for continental scale simulations at the required spatial resolution over the next decade. To overcome this problem, a number of sub-ice shelf melt parameterizations have been proposed as an alternative way to capture ice-ocean interactions (e.g., box models, plume models, etc), but the choice of parameterization has a substantial impact on the modeled ice mass change, as highlighted by the recent Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6).

This project aims at improving spatio-temporal estimates of sub-ice shelf melt rates, and use them to evaluate sub-ice shelf melt parameterizations currently used in ice flow models. We will identify and calibrate the best parameterizations for future large scale projections efforts, such as ISMIP7. We will use ICESat-2 data combined with other ice sheet observations to extend sub-ice shelf melt rates time series over the entire ice sheet. We will then perform simulations of the Amundsen Sea Sector in West Antarctica with: (i) the Ice-sheet and Sea-level System Model (ISSM) using a number of melt parameterizations, (ii) ocean simulations using the MIT General Circulation Model (MITgcm), and (iii) coupled ice-ocean simulation using ISSM and the MITgcm. The ocean and ice-ocean simulations will be used to refine temporal changes of melt rates and provide a target for how well parameterizations could perform given the existing limitations in observations. We will calibrate the melt parameterizations with time average estimates of melt rate, assess the ability of parameterizations to reproduce temporal evolution of melt rates, compare parameterizations with ocean and coupled ice-ocean simulations and select parameterizations that best capture these melt rates and their variability. Finally, we will use the selected parameterizations, weighted according to their ability to reproduce melt rates estimates at continental scale, and force them with Global Climate model outputs to revise Antarctic mass loss projections. We will create maps of future ice shelf melt rates and their associated uncertainty until 2100 and identify the ice shelves most vulnerable to ocean changes.

Matthew Siegfried/Colorado School of Mines
Seeds of Change: Investigating the Impact of Antarctic Basal Channel and Persistent Polynya Co-Evolution on Ice Shelf Stability
21-CRYO21-0026

Motivation: Ice shelves and their tributary glaciers that drain Antarctica account for almost the entirety of net mass loss from the Antarctic Ice Sheet, the source of the greatest uncertainty in 21st-century sea-level rise projections. Nearly half of the glacier ice that reaches the ocean to form floating ice shelves is lost to basal melting by the ocean. This melting varies substantially in time and space as a result of complex climate, ocean, and ice interactions, making projections of future ice loss difficult. In particular, enhanced localized basal melt rates can incise ice-shelf basal channels that may structurally weaken ice shelves. Many of these channels convey water sourced from the upstream locations where the channels form to the edge of the ice shelf. This outflow often includes residually warm ocean water with enough heat to maintain local sea ice-free ocean conditions seasonally or year-round for small areas near the ice front, known as persistent polynyas. The water in these polynyas represents a mixture between the ocean water mass that initiated basal melt and the melt content entrained as the water exits the ice shelf cavity. Variability in these features over time, as a result of climate and oceanographic changes, provides insight into ice-shelf evolution (e.g., strain and melt rates) and the processes that can weaken ice shelves. However, mapping of basal channels and their impact on ice-shelf evolution are limited. Further, direct in situ outflow measurements are sparse and little work has explored the use of remote sensing for this task.

Objectives: The proposed work will use optical and thermal infrared imagery from the Landsat 7 through 9, Aqua and Terra, Sentinel-2, and Sentinel-3A/B instrumentation in a multi-sensor and multi-modal data fusion investigation that will assess the characteristics and variability of the persistent polynya ice-ocean features in Antarctica. Data from field observations and ICESat-2 laser altimetry will be examined using modern machine learning approaches and cloud-based, open-sourced workflows. The proposed work is organized around three specific goals:

1) Automate persistent polynya detection and characterization for community use;
2) Optimize Landsat, MODIS, and Sentinel-3 SST retrievals to build year-round upper ocean temperature records for multiple Antarctic basal channel outflows; and
3) Assess ice shelf and water outflow co-evolution using a data fusion framework for deriving ice shelf and ocean parameters.

Relevance: Our proposed ice-sheet-wide study of Antarctic ice-ocean governing processes and inter-relationships using remotely sensed imagery and existing field data directly responds to the solicited topics (a) 'surface processes of the ice shelves', (b) 'ice shelf thermodynamic and mechanical behavior', and (c) 'ice shelf-ocean interactions' of document 'A.15 Cryospheric Sciences' of the Research Opportunities in Space and Earth Sciences 2021 solicitation.

Tyler Sutterley/University of Washington, Seattle
Investigating Antarctic Grounding Zones Using ICESat-2
21-CRYO21-0003

The Antarctic grounding zone is an important element of the ice sheet, as it is the boundary between ice that is grounded to bedrock and ice that is freely floating on the ocean. This feature is critical to ice-sheet modelers, as it defines the line between ice that is accounted for in the global sea level assessment (i.e., the freely floating ice shelves), and ice that is not (i.e., the grounded ice sheet). It is important for tide modelers, as it defines the inward limit of tidal fluctuation on the height of the ice shelf and locations of ice shelf flexure due to tidal bending. For this project, we propose to develop a new suite of tools to use NASA Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) data to determine the precise location of this critically important ice-sheet feature. We then propose to compare this new result to a similarly determined result from ICESat (2003-2009) to assess where this feature has demonstrated the greatest amount of change.

To accomplish this goal, we propose to compare the ICESat-2 data with a high-resolution digital surface model (Reference Elevation Model of Antarctica: REMA) to delineate various features of the grounding zone using a new and efficient method. We will directly compare 1) a version of the REMA digital surface model that has been corrected for vertical forcing due to the ocean tide to 2) uncorrected ICESat-2 data, specific to ice sheets (ATL06). The comparison will give us information about both the upstream and downstream limits of the grounding zone location for each reference ground track of ICESat-2 data.

We acknowledge that the data volumes of ICESat-2 and REMA are large. The investigators will make use of the NASA Goddard Space Flight Center cloud-computing platform (the NASA Center for Climate Simulation Advanced Data Analytics PlaTform: NCCS ADAPT), enabling the relatively rapid analysis of large datasets. Our proposal meets the Open Data, Services and Software Policies of NASA, as we plan to: 1) develop code in an open-source platform; 2) make this code available, documented, accessible to other researchers; 3) make results available through the appropriate NASA Distributed Active Archive Centers (specifically, the National Snow and Ice Data Center) and reproducible from the available code; and 4) publish our derivations and results in leading peer-reviewed Open Access journals.

This proposal would ultimately create resources for the glaciological community, including code that provides an optimized resource for high-resolution comparisons between altimetry data and a digital surface model. It will also provide a series of new ICESat-2 assessments of the Antarctic grounding zone, which modelers can use for more accurate assessments of the contributions of ice sheets to mean sea-level rise. Publicly available code will allow for future assessments of the Antarctic grounding zone, beyond the proposed duration of a successful award.

One of the most interesting scientific outcomes of this proposal would be the comparisons between the resultant ICESat-2 grounding zone and the previous ICESat assessment. Knowledge of local grounding zone variability is important for evaluations of long-term glacier and ice shelf stability. These long-term comparisons will allow us to quantify grounding-zone retreat in regions that we know are changing rapidly. Further, they will also illuminate previously unknown regions of change, or changes in regions associated with smaller spatial scales that remained unidentified for data resolution reasons.

Catherine Walker/Woods Hole Oceanographic Institution
On the Precipice: Investigating the Strength, Stability and Persistence of Ice Cliffs
21-CRYO21-0013

What is the maximum height to which an ice cliff can persist on Earth? Theory and related models suggest a subaerial stability limit at ~100 m, beyond which a cliff could undergo collapse and trigger runaway retreat [1,2]. The Marine Ice Cliff Instability (MICI), as this scenario is known, has been employed in several model scenarios that predict a potentially catastrophic future for the Antarctic Ice Sheet in terms of collapse [3]. Anecdotally and in small sample sets this height limit appears to hold true [2,4,5], but

has yet to be empirically tested against a larger, diverse set of cliffs in different physical and environmental settings.
This study seeks to determine properties of existing ice cliffs, and also better understand regions where ice shelf collapse or glacier retreat could expose tall cliffs with the potential to collapse in the future. Using satellite and airborne laser altimetry over a variety of ice shelves and marine-terminating glaciers, we will determine calving front surface topography and overall ice cliff height. With existing bathymetry measurements, we will determine associated seafloor depth. We will determine crevasse characteristics, extent of proglacial mélange, and glacier geometry (e.g., calving front changes). These observables will be used to understand how ice cliff height, and relatedly stability, relates to grounded depth, water height, crevasse population, proglacial mélange extent and climate forcing (from reanalysis data) over time among different glacier settings. At locations with floating ice shelves, we will use these datasets to determine where future collapse of an ice shelf might create an unstable ice cliff.
This project would be focused on placing observational bounds on structural ice stability through a large-scale survey of ice topography, crevassing and cliff height at glacier termini using remote sensing and modeling efforts. A variety of marine-terminating glaciers will be surveyed, both with and without floating ice shelves/ice tongues, through the following two research prongs:
(1) Observations. We will collect a variety of remote sensing measurements over target locations to catalogue ice cliff heights and structural and environmental characteristics. We will use best-known bed depth values from digital elevation models. We will use contemporaneous measurements of water height in front of the glacier to determine ice cliff height above the water surface. Variability in cliff heights will also be contrasted against variability in mélange thickness to understand the correlation between wasting rates/magnitudes/styles (proxies for stability) and cliff height.
(2) Modeling. To complement the observational component, a modeling effort will be employed to predict, calving front position, velocity, calving front uplift, and slumping based upon observational inputs. Experimenting with a range of ice strengths and cliff-face melt profiles, we can test the model and calibrate the failure strength of ice for a range of glaciological and climate regimes to determine the broader-scale implications for our observational results.
Put simply, the main objective of this study will be to use observations to empirically test the hypothesis that ice cliffs above a certain height are unstable, and determine how glacier geometry, atmospheric and oceanic forcing, and glaciological characteristics contribute to states of (in)stability, relating to the potential of MICI.

Shujie Wang/Pennsylvania State University
Characterization of Fracture Morphology for Assessing Antarctic Ice Shelf Vulnerability
21-CRYO21-0023

The Antarctic ice shelves provide important buttressing force regulating upstream glacier flow dynamics. Destabilization of ice shelves can trigger marine ice-sheet instability and marine ice-cliff instability, which represent large uncertainties in projecting future sea-level rise. Processes driving ice shelf retreat and thinning are intricately linked to atmospheric warming, oceanic forcing, ice mechanics, flow dynamics, and fracturing processes, including hydrofracturing and rifting. Knowledge of fracture distribution and temporal evolution is key to assessing the vulnerability of ice shelves, since meltwater-driven hydrofracturing and rift propagation are preconditioned by structural weakness due to surface and basal fractures. However, observational data of fracture morphology are lacking, limiting our ability to accurately predict the retreat of ice shelves using model simulations. Recent progress in satellite remote sensing enables us to acquire detailed information about fracture distribution and fracture morphology. In particular, the recent launch of the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2), provides high-resolution surface elevation measurements, allowing us to derive the vertical information (e.g. depth, shape) of fracture features, complementary to the horizontal information (e.g. length, distribution) from satellite optical and radar imagery.

We propose a novel framework to leverage multisource remote sensing data, advanced computer vision and machine learning algorithms, and ice mechanical models to characterize fracture distribution and morphology over Antarctic ice shelves, and examine how fracture patterns modulate ice shelf damage, rift propagation, and vulnerability to hydrofracturing. We will produce several fracture datasets, including fracture lines derived from satellite images, cross-sections and vertical profiles of fractures extracted from the ICESat-2/ICESat data, and fracture indices characterizing fracture density/volume/complexity at different grid resolutions. We will combine the fracture datasets with continuum damage mechanics and linear elastic fracture mechanics for an improved understanding of the role of fractures in causing ice shelf damage and rift propagation. To our knowledge, this will be the first effort to combine 3D morphological measurements of fractures with ice mechanics modeling using machine learning. We anticipate the produced algorithms and datasets will provide important tools to gain new insights and/or a deeper understanding of the features contributing to ice shelf vulnerability, thus laying the foundation for a realistic parameterization of ice shelf retreat in models predicting the future evolution of the Antarctic ice sheet.

The proposed work directly addresses the solicitation goal “This opportunity requests proposals that use remote sensing data to provide new insights into the stability of ice shelves of Greenland and Antarctica in a changing climate, their governing processes and inter-relationships”. The proposed investigation is highly relevant to “b) ice shelf thermodynamic and mechanical behavior (incl. hydrofracturing, marine ice cliff instability)”, and the spatial distribution of fractures and fracture morphology are also important for surface water ponding and routing, which is relevant to “a) surface processes at the ice shelves (incl. surface mass balance, surface hydrology, melt water routing)”.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-ARCSIX
A.17 Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment

The Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) will address key questions regarding the interactions between clouds, aerosols, meteorology and sea ice, as driven by solar radiation and radiation emitted from the Earth's surface. The field campaign will be based in Thule and make measurements over the Arctic Ocean. Primary observations will include cloud properties, aerosol particle properties, meteorological parameters, presence/absence and properties of sea ice, as well as solar radiation and radiation emitted from the Earth's surface.

The ARCSIX campaign will take place during two periods; one in late May to early June and the other from mid-July to early August 2024 during the start and most intense period of sea ice melt.

NASA received 33 proposals and selected 18. Funding from the Radiation Sciences and Cryosphere Programs is $628K in the first year and a total of $15.5M over six years.

Anthony Bucholtz/Naval Postgraduate School
Aircraft Measurements of the Solar and Infrared Radiative Budget in the Summertime Arctic Atmosphere to Characterize the Coupling Between Radiation, Clouds, Aerosols and Sea Ice Surface Properties During ARCSIX
21-ARCSIX21-0033

We propose aircraft measurements of the broadband solar and infrared (IR) irradiance, sea and ice surface temperatures (SST/IST), cloud top and base brightness temperatures, and the all-sky cloud conditions to characterize the radiative environment of the summertime Arctic atmosphere during the Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX). Our objective is to provide a set of fundamental radiative measurements that can be used to gain a process-level understanding of how surface properties, and cloud and aerosol conditions in the region modify the atmospheric heat budget and radiative forcing, and how those changes in the radiative field feedback on the surface radiation budget, and the evolution of the clouds and sea ice.
We will mount identical pairs of customized solar pyranometers and IR pyrgeometers on the top and bottom of both the lower-flying in situ aircraft and the higher flying remote sensing aircraft to measure the down- and up-welling total solar and IR irradiance at multiple altitudes throughout the atmospheric column. These instruments are commercially available solar and IR radiometers that we have modified in-house for aircraft use. They have flown successfully on a variety of research aircraft during previous field studies from the Arctic to the tropics – including the NASA P-3 for CAMP2Ex (2019), the NASA C-130 for ARISE (2014), the NASA DC-8 and ER 2 for SEAC4RS (2013), and the NASA P-3B for ARCTAS (2008). We also propose mounting

an SPN-1 pyranometer on top of both aircraft to measure the down-welling direct and diffuse broadband solar irradiance in order to characterize the partitioning of the solar radiation between direct and diffuse components, and for use in correcting the down-welling total solar irradiance for the attitude of the aircraft. We successfully flew the SPN-1 on the NASA P-3 for CAMP2Ex (2019), and on the NASA C-130 for ARISE (2014). We also propose mounting down- and up-looking Heitronics KT19.85 IR pyrometers on both of the aircraft to measure SST/IST, and cloud top or base temperatures. The KT19s have flown successfully on numerous aircraft and are considered 'standard' instruments for measuring SST from an aircraft. They are routinely flown on NOAA's P-3 'Hurricane Hunter' aircraft, and we recently flew them on the NASA C-130 for ARISE. Finally, we propose mounting an all-sky camera on top of both aircraft to monitor the sky/cloud conditions above the aircraft. We flew the all-sky camera for the first time on the NASA P-3 for CAMP2Ex. All of the proposed instruments will be fully characterized and calibrated pre- and post-mission in our comprehensive in-house radiometer calibration laboratory.

The proposed fundamental aircraft measurements of total, direct, and diffuse solar irradiance, total IR irradiance, SST/IST, cloud brightness temperatures, and all-sky cloud conditions will be used to characterize the radiative budget in the atmospheric column for the different distinct regimes of cloud, sea ice, and meteorological conditions planned for targeted sampling during ARCSIX. This will directly address science question 1 (Radiation) listed in the ARCSIX ROSES call. Our broadband solar and IR measurements will also provide a useful dataset for testing of CERES satellite retrievals of solar and IR radiative fluxes over the Arctic, addressing the ARCSIX 'Remote Sensing Objective' that calls for "validating and improving remote sensing algorithms".

The PI, Dr. Bucholtz, also proposes to serve as flight scientist on the aircraft and to assist in flight planning.

Brian Cairns/NASA Goddard Space Flight Center
Research Scanning Polarimeter (RSP) Team Support for ARCSIX
21-ARCSIX21-0011

The Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX) is an airborne investigation that is focused on providing detailed observations of surface radiative and physical properties together with the microphysical properties of aerosols and clouds and the atmospheric state during the early melt season in the Arctic. Here, we propose to include the Research Scanning Polarimeter (RSP) in the campaign's instrument suite and deliver campaign-wide RSP-based retrievals of surface, aerosol and cloud properties. The RSP's unique combination of dense angular measurements of total and polarized reflectance at VISible Near InfraRed (VNIR) and ShortWave InfraRed (SWIR) wavelengths provide retrievals of surface, aerosol and cloud properties that are essential to address the ARCSIX science questions, while the match of its spectral bands to those of operational satellite sensors enhances its value in achieving the ARCSIX remote sensing objectives.

Since the first RSP was completed in 1999, RSP instruments have successfully participated in many airborne campaigns and as a result several algorithms are readily

available to obtain aerosol and cloud properties from RSP observations that are highly relevant for the ARCSIX objectives. In addition to the published, operational RSP products, we propose to develop several other products that are highly relevant to the ARCSIX objectives. An improved threshold-free, neural-network cloud screening and surface classification algorithm will be implemented. We will extend the previously developed RSP surface/aerosol retrieval scheme to be applicable to sea ice/snow covered surfaces and provide surface total and polarized bidirectional reflectance distribution functions (BRDFs) for all clear sky scenes. Physically-based fully polarized radiative models of snow, sea ice and melt ponds will be developed to facilitate the classification of observed BRDFs into different surface types and improve constraints on remote sensing over sea ice/snow. Previous work using RSP to identify mixed phase clouds will be extended and will also include a technique that is applicable to operational satellite remote sensing. Both operational and proposed products will be evaluated against detailed model simulations of Arctic mixed phase clouds.
As outlined in the ARCSIX white paper, the complex interactions between the surface, clouds, aerosols, and atmospheric conditions necessitates collecting a statistically significant set of observations that allow these relationships to be disentangled in post deployment analyses. The first analysis of the RSP retrievals that we propose is therefore to evaluate how Arctic cloud condensation nuclei (CCN) concentrations impact cloud micro- and macro-physical properties, cloud phase and act to enhance or suppress precipitation formation, an essential component in addressing one of the key science questions of ARCSIX. This observational analysis will inform, and be informed by, Large Eddy Simulations (LES) of clouds that will be used with the unique suite of RSP cloud property retrievals through the mixed-phase temperature range to study the coupling of aerosol, cloud, and radiative processes under well-observed ARCSIX conditions. Finally, an assessment of the NASA GISS General Circulation Model (GCM) treatment of sea ice, clouds and the consequent simulation of the surface radiation budget is proposed. This assessment will make use of RSP-retrieved surface and cloud properties to evaluate the joint simulation of sea ice and clouds in the GCM, which is a critical coupling that regulates sea ice melt.

Paul DeMott/Colorado State University
Aerosol Influences on Ice Formation in Arctic Clouds During the Summer Melt Season in ARCSIX
21-ARCSIX21-0005

Climate and weather models exhibit significant Arctic cloud biases, including unrealistic cloud cover, too little supercooled liquid and too much cloud ice, and unrealistic seasonal variations that lead to biases in the surface radiation budget. A major source of bias is the lack of knowledge of Arctic aerosols, their properties, sources, vertical distribution, and interactions with clouds. This gap limits process-level understanding of factors governing the evolution of sea ice surface properties during the melt season, and of the life cycle of low-level Arctic clouds. These needs frame ARCSIX, and our focus herein on measurements to characterize the spatial distribution and budget of aerosols that impact ice phase transitions of clouds, or ice nucleating particles (INPs), and to use these data to establish realistic representation of INPs in climate and process models for the Arctic in summer.

This proposal targets defining the abundance of INPs and testing whether immersion freezing is their primary mode of activity. The relative importance of diverse aerosol sources in the central Arctic will be assessed, including emissions from melt regions, sea spray emissions transported from open ocean regions, and long range transported sources that include land-based bioparticles, terrestrial dust and biomass burning aerosols. We will institute a comprehensive INP measurement plan during ARCSIX. Real-time INP measurements at specific temperatures and relative humidity using a continuous flow diffusion chamber, enhanced using an aerosol concentrator, will test for the presence of deposition INPs active below water saturation in contrast to those INPs triggered following immersion in activated water droplets. Offline immersion freezing measurements will be done on total-particle filter samples, including treatment processes to define heat labile, organic, and inorganic INP contributions across mixed-phase cloud temperatures. Collaborative size-resolved filter sampling will align immersion freezing measurements with composition measurements in the same size classes. By sampling cloud particle residuals via a counterflow virtual impactor inlet, we will characterize INPs present within clouds, in addition to sampling below- and above-cloud reservoirs. Other aerosol measurements in ARCSIX will provide context and support for development of parameterizations.

Using the INP data and parametric relations to aerosols, we will explore how to represent the INP budget sufficiently in models in order to accurately represent cloud and precipitation processes and radiative fluxes. We will explore INP budget dynamics relevant to commonly encountered Arctic cloud types and life cycle stages through case studies employing a cloud-layer-following Lagrangian modeling framework that can be applied identically to large-eddy simulations (LES) and climate models run in single-column mode. We will additionally employ a simple Lagrangian 1D PBL model approach to examine first-order impacts of differing INP treatments in the absence of the feedbacks that act in the LES. We thereby seek both best understanding and practical solutions for climate models.

The proposed work is highly responsive to mission-relevant hypotheses regarding the controlling nature of the sparsity of INPs on low cloud life cycles; whether Arctic INPs are active only after incorporation into water clouds; and how INP concentrations in the boundary layer over open water differ from those over ice surfaces or in the free troposphere. This effort aims at a level of attribution and understanding of INP sources, compositions and budgets/life cycles relevant to the central Arctic that will resolve current aerosol influences on INPs and cloud properties within this region, and drive improved strategies for next generation spaceborne observations, and that will lead to improved prediction of changing aerosol impacts in climate models such as Model E3.

Mary Kleb/NASA Langley Research Center
In-Situ Fast Response Three-Dimensional Winds and Dropsondes: Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX)
21-ARCSIX21-0013

In support of the Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) we propose to deliver instrumentation for profiling the atmosphere (with dropsondes) and making fast response three-dimensional (3-d) wind and atmospheric state parameter measurements. The dropsonde measurements will be made with the NCAR's (National Center for Atmospheric Research) Airborne Vertical Atmospheric Profiling System (AVAPS) for both the high flying and low flying aircraft. If the NASA P-3 is selected as the in-situ platform, we are proposing the fast-response, high precision Turbulent Air Motion Measurement System (TAMMS) for the wind and state parameter measurements. Post-mission analyses will address the characterization of the Arctic troposphere via thermodynamic profile data from AVAPS and look at sensible, latent, and momentum fluxes in the areas around Arctic clouds and polynyas with the data provided from TAMMS. During flight, we will provide real-time and near real-time data from both the AVAPS and TAMMS to the on-board experimenters and downlinked to the personnel on the ground that can be used for flight planning and atmospheric layer observations.

AVAPS is a dropsonde system designed by NCAR in 1996. The current iteration provides fast response (>1 Hz), high resolution (2.5m vertical) vertical profiles of temperature, humidity, pressure, wind speed and direction from a dropsonde with a GPS antenna for positioning and winds, and sensors for pressure, temperature, and humidity. Our system was acquired in 2019 and first used by Colorado State University in support of NASA's Cloud, Aerosol, and Monsoon Processes Philippines Experiment (CAMP2EX). Post CAMP2EX, we took over the operation of AVAPS and have successfully operated it on three NASA sponsored missions (Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) on the NASA Wallops P-3, Aerosol Cloud Meteorology Interactions over the Western Atlantic (ACTIVATE) on the NASA Langley King Air UC-12, and Convective Processes Experiment – Aerosol and Winds (CPEX-AW) on the NASA AFRC DC-8).

TAMMS has been operated on the P-3 since the 1990's, with recent missions including IMPACTS, CAMP2EX, and ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS). We provide fast response (? 20 Hz) and high-precision measurements of the 3-d wind field (u, v, w, and wind speed/direction), ambient state parameters (temperature, pressure, and dew point (via NSRC)), and aircraft position/attitude data (latitude, longitude, altitude, pitch, roll, and heading). In the absence of high liquid content clouds or icing conditions, the system can run autonomously. Calibration and validation maneuvers are done periodically to account for errors in pressure due to flow around the aircraft, heading offset, and determine the calibration coefficients, which improves the accuracy and precision of the vertical and horizontal winds.

Each of the systems proposed above has heritage aboard NASA aircraft. AVAPS has been used on NASA aircraft since its inception, and since 2019 by our group. TAMMS has been on the NASA P-3 aircraft since the mid 1990's. Archived data sets for AVAPS will be individual files for each dropsonde launch that include multiple variables to characterize the Arctic troposphere (time, pressure, altitude, dew point, location, wind speed and wind direction). The TAMMS archive files will include 20 Hz measurements of the 3-d wind field (u, v, w, wind speed and direction), ambient temperature and pressure as well as aircraft positioning and attitude variables.

High priority measurements and scientific analyses proposed here help with post-mission data analysis efforts to characterize the troposphere in the Arctic and provide an understanding of the vertical transport of fluxes of heat, moisture and momentum from the surface throughout the troposphere and in the region of polynyas and Arctic clouds.

Paul Lawson/Stratton Park Engineering Co., Inc.
In Situ Microphysics Measurements and Analysis in Support of ARCSIX
21-ARCSIX21-0004

The 2021 International Panel on Climate Change (IPCC) report on the physical basis of climate change confirms that the Arctic is warming at nearly twice the rate of the global average. The scientific objectives of the ARCSIX project include collection of in situ microphysical measurements of low-level clouds in the Arctic, which contribute strongly to melting of sea ice and the Greenland Ice Sheet. SPEC Incorporated proposes to equip the NASA P-3B research aircraft with state-of-the-art cloud particle probes that were successfully flown on the NASA P-3B during the CAMP2Ex project in 2019, plus two and possibly three new-technology instruments that have or will be developed. A fast 2D-Gray probe with 10-micron resolution has been successfully tested on the SPEC Learjet, as has an advanced High Volume Precipitation Spectrometer (HVPS-4). The HVPS-4 simultaneously images particles from two orthogonal views with 50- and 150-micron pixel resolution, which provides high-resolution combined with high-volume measurements of the shapes of falling raindrops. The HVPS-4 will be a valuable instrument for correlating in situ rain rate through melting layers with remote polarimetric radar retrievals from the high-altitude aircraft. The third new instrument is under development and is specifically designed to improve measurements of particle phase in mixed-phase clouds, which are ubiquitous in summer Arctic clouds. The Particle Phase Spectrometer (PPS) is a combination of a 2D-Gray probe with 5-micron pixel resolution and a cloud particle imager (CPI) with 1-micron pixel resolution. The 1-micron CPI is aimed at distinguishing small (< ~100 micron) water drops from small ice particles, while the 2D-Gray probe with 5-micron pixels is designed to identify the phase of particles > 100 microns. SPEC scientists will focus on analysis of mixed-phase clouds with an emphasis of separating the ice/water budget and producing bulk parameters (e.g., total ice and water particle concentrations, mean mass water and ice values, extinction coefficient, effective radius and radar reflectivity factor) that can be compared with remote measurements. Our instrument proposal includes a Leadership proposal led by Prof. Greg McFarquhar from the University of Oklahoma (OU). Dr. McFarquhar has extensive experience leading research programs in Arctic regions and in the processing and analysis of cloud particle measurements. While SPEC's instrument proposal can standalone, if Dr. McFarquhar's proposal is awarded, SPEC and OU scientists will collaborate on the analysis of collected data and publications.

Linette McPartland/NASA Goddard Space Flight Center
Sea Ice Surface Evolution Flight Planning for ARCSIX
21-ARCSIX21-0029

Sea ice is a critical component in the Earth climate system and since it has declined in extent, thickness, and age in recent decades, it has drawn attention in the scientific community and beyond. These changes in the Arctic sea ice cover have a three-fold impact on climate: 1) sea ice cover is a less effective buffer in the exchange of energy, moisture, and momentum between the ocean and atmosphere; 2) sea ice cover is considerably more sensitive to atmospheric forcings than its thicker, multi-year counterpart; and 3) amplification of the albedo feedback causing warming temperatures. Changes in the atmosphere-ice-ocean coupling will have complex consequences that are still largely unknown. Critical surface-atmosphere processes are not well understood or characterized by observations or models, especially during the melt season where conditions are rapidly evolving. Additionally, little is known regarding the seasonal sea ice pack response to the changes in this new atmospheric state and episodic weather events, specifically related to sea ice melt and the survivability of the ice pack. Uncertainties and a lack of understanding of these important processes hinder our ability to produce accurate future projections.
The complexities of observing and understanding small-scale atmosphere-ice-ocean interactions is causing a severe knowledge gap in understanding the complex interactions during the melt season on an Arctic-wide scale and beyond. By surveying multiple sea ice types and their evolution throughout the melt season, prior to and after atmospheric events, we can more completely understand the coupling between them. An airborne campaign, like ARCSIX, provides a way to better understand the evolution of the sea ice surface and atmosphere through the melt transition. It has an advantage over 'boots on the ground' measurements because of the wider coverage and increased distances that the aircraft can travel, enabling measurements from a wide variety and distribution of sea ice and atmospheric properties. However, without the proper preparations and flight planning, valuable data collection could be missed.

We are submitting a flight planning proposal for the ARCSIX campaign with a focus on monitoring the sea ice surface properties and evolution through the summer melt season, thus fulfilling the requirements of Science Question 3 in the ARCSIX White Paper. What sets us apart from other teams is our extensive expertise with 1) our prior experience planning, conducting and leading successful airborne science missions in the Arctic (PI Boisvert and Co-I's Kurtz and Sonntag have worked closely together on OIB), and 2) our expertise with satellite and airborne sea ice data and analysis (Co-I Kurtz, Deputy Project Scientist, and Co-I Tilling, science team member, for IS-2). We propose a series of tasks which will ensure that the appropriate flights will be completed so that data collection during the ARCSIX campaign and the campaign itself is a success.

This will be accomplished by:
-Producing recent climatologies of sea ice properties and atmospheric states.
-Creating a series of flight lines that will measure various sea ice properties. These will be easily adaptable and allow for ‘drop-in’ segments for ease in piecing together ‘Frankenstein Flight Plans’ which satisfy more than one science question.
-Developing, assessing and refining a sea ice drift algorithm to track and forecast sea ice locations so that sea ice can be revisited and its evolution can be monitored during the campaign.
-Completing a dry-run practice campaign, which involves using and refining a decision tree to ease in collaboration and flight planning decision making during the ARCSIX campaign.
-Collaborating with other team members during science team meetings.
-Assisting in flight planning and operating decisions while deployed in the field.
-Providing a post-campaign assessment and analysis of the sea ice properties that were surveyed.

Alek Petty/University of Maryland, College Park
Summer Arctic Sea Ice Characterization and Cal/Val Flight Planning for Maximizing ARCSIX Sea Ice Data Collection
21-ARCSIX21-0024

The Arctic near-surface atmosphere has warmed at a rate more than double the global average over recent decades. Arctic sea ice has undergone rapid decline over this same time-period, including a halving of its summer ice extent thickness. The resultant decrease in albedo and increased heat absorption has contributed significantly to global warming and has significantly altered the physical and biogeochemical balance of the upper Arctic Ocean. Various feedback mechanisms are working in tandem to drive and amplify these changes, many of which are till poorly constrained.

To provide new insights into these complex feedback processes and better understand key atmosphere-surface coupling processes over the Arctic, NASA is launching the Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX) – a multi-sensor airborne investigation over summer Arctic sea ice, planned to take place during the summer of 2024. This proposed project seeks to provide support to ARCSIX mission through efforts to contextualize and maximize sea ice data collection activities. The key project objectives are:

Objective 1: Characterize expected ARCSIX sea ice conditions through the sea ice melt season
Objective 2: Provide sea ice-focused flight planning support during ARCSIX
 - Assess near-real time sea ice state information during ARCSIX
 - Deliver satellite underflight information and recommendations

- Provide sea ice drift correction flight planning support

The proposed project offers a low-cost and efficient effort (funding for a single PI researcher) to help ensure ARCSIX sea ice profiling efforts are fully maximized, benefiting both the ARCSIX research team and wider sea ice community. The PI will leverage recent Arctic climate focused projects (e.g. PolarMERRA) and sea ice mission support activities (e.g. Operation IceBridge and ICESat-2). The proposal also includes a significant Open Science element to ensure the analysis and data collated and characterized during this project will be rapidly disseminated and easily utilized in expected post-mission analysis efforts following ARCSIX.

Steven Platnick/NASA Goddard Space Flight Center
PICARD Hyperspectral VNIR/SWIR Imagery and Cloud and Aerosol Products for ARCSIX
21-ARCSIX21-0017

Imager observations and geophysical cloud retrievals have been identified as core measurement objectives for the ARCSIX high-flyer remote sensing aircraft, notionally the Johnson Space Center Gulfstream V (G-V) aircraft. Specifically, the ARCSIX concept white paper high-flyer aircraft Priority 1 campaign needs included spectral reflectance observations (minimum 400-1600 nm) along with retrievals of cloud fraction (where imager observations are indicated as being essential) and nadir cloud thermodynamic phase and optical thickness.

We proposed to provide airborne calibrated VNIR/SWIR spectra from the Push-broom Imager for Cloud and Aerosol Research and Development (PICARD) hyperspectral imager along with cloud and aerosol optical and microphysical retrievals. PICARD is a NASA Earth Science Division (ESD) facility instrument managed and maintained by the Ames Airborne Sensor Facility (ASF); ASF participation (other than MPCs) is provided through directed ESD support. PICARD observations will be synergistic with other expected ARCSIX sensors, provide scene context in support of general ARCSIX flight evaluation and analyses, and enable high spatial resolution assessments of Arctic satellite retrievals from the imager Program of Record (MODIS, VIIRS).

PICARD’s 380–2400 nm spectral coverage includes visible/near-infrared (VNIR) and shortwave infrared (SWIR) bands that have demonstrated information content for clouds and aerosols. Retrieved cloud datasets will include cloud extent (fraction), thermodynamic phase, radiative height, optical thickness, effective particle radius (using different spectral pairs), derived water path and pixel-level cloudy-sky flux calculations (TOA and surface); retrieved aerosol datasets will include optical depth. Initially, these separate cloud and aerosol products will be based on Program of Record (PoR) algorithms that leverage team member experience with other airborne multispectral imagery retrievals (eMAS, MASTER, et al.) as well as in-flight airborne and satellite imager calibration assessments. With an approximate instantaneous pixel spatial resolution of 30m from a notional G-V 12 km altitude, PICARD spectral imagery is well suited to observing small scale cloud structures and cloud-aerosol boundaries.

Kerri Pratt/University of Michigan, Ann Arbor
Online Single-Particle Measurements During ARCSIX for Improved Understanding of Arctic Aerosol Radiation and Cloud Impacts
21-ARCSIX21-0002

The Arctic is warming at a faster rate than anywhere else on Earth, with rapidly shrinking sea ice that has transformed the region into "the New Arctic". With these rapid changes, there is an urgent need to improve knowledge of interactions between the dramatically changing Arctic surface and the overlying atmosphere, including aerosols and clouds that contribute significantly to the highly uncertain Arctic surface radiation budget. Depending on size and chemical composition, atmospheric aerosols directly scatter and/or absorb radiation, serve as cloud condensation nuclei and/or ice nucleating particles, and/or reduce the reflectiveness of the snow surface, thereby altering the atmospheric energy budget. The objective of this proposed research is to conduct in-situ measurements of the size and chemical composition of individual aerosol particles through the deployment of a real-time single-particle mass spectrometer on the in-situ measurement aircraft during the Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) flights. By measuring aerosols and investigating their interactions with clouds, this project will directly contribute to the overarching goal of ARCSIX to quantify the contributions of surface properties, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season. In particular, this project has three specific goals: 1) Measure the size and chemical composition of individual aerosol particles in real-time using single-particle mass spectrometry, 2) Identify and quantify the contributions of locally-produced and long-range transported (remote) aerosol sources to the Arctic troposphere, 3) Identify and quantify the sizes, chemical composition, and sources of individual aerosol particles serving as Arctic cloud droplet and ice crystal nuclei. The ability of the single-particle mass spectrometry method to directly identify aerosol and cloud residual particle sources will be key to differentiating and quantifying the contributions of local and remote (long-range transported) aerosol sources to clouds in the summertime Arctic (ARCSIX Science Question 2). By measuring both primary and secondary marine aerosol, we will directly examine how the changing Arctic sea ice surface, specifically the loss of sea ice and formation of leads and polynyas, are increasing marine aerosol emissions that may alter cloud formation and properties (ARCSIX Science Question 3). Our in-situ measurements will also assist in validating remote sensing optical approaches to aerosol source typing (ARCSIX Remote Sensing Objective). We will work with other ARCSIX researchers to collaboratively investigate the proposed ARCSIX science questions and objective, as well their associated hypotheses. At the same time, this project's proposed goals will allow us to investigate the following specific project hypotheses: 1) Sea spray aerosol particles are locally produced from Arctic sea ice leads and polynyas, and episodically serve as Arctic cloud droplet nuclei. 2) Locally produced marine biological particles and long-ranged transported dust particles serve as Arctic cloud ice nucleating particles.

Overall, the proposed in-situ measurements of the size and chemical composition of individual aerosol particles and cloud residual particles (i.e. likely cloud condensation nuclei and ice nucleating particles) will yield significant insights into Arctic aerosol and cloud processes and interactions during summer in the New Arctic, and thereby enable improved understanding of the contributions of clouds and aerosols to the Arctic surface radiation budget when the Arctic surface is changing dramatically.

Jens Redemann/University of Oklahoma
AirMSPI2 Imaging and Retrievals of Cloud, Surface, and Aerosol Properties in ARCSIX - University of Oklahoma
21-ARCSIX21-0009

Arctic sea ice is transitioning from a state of thick, multi-year ice to thinner, seasonally varying ice, with climate models struggling to represent the underlying physical processes and feedbacks. There is a lack of reliable observations of the cloud and surface properties that drive the regional radiation budget and sea ice melt. Such data would enable the parameterization of physical processes and test models for future projections of Arctic sea-ice evolution.

This is the University of Oklahoma's (OU) component of a collaborative proposal entitled "AirMSPI2 Imaging and Retrievals of Cloud, Surface, and Aerosol Properties in ARCSIX" in partnership with NASA's Jet Propulsion Laboratory (JPL). JPL will be responsible for deployment of the JPL Airborne Multiangle SpectroPolarimetric Imager (AirMSPI2) on the ARCSIX high-flying platform, and OU will be responsible for retrieval and data analysis work. The two collaborative proposals are identical in structure (e.g., section headings), but sections that describe the proposed work only contain text if the work will be carried out by the submitting organization.

We propose to address the following science questions:

1. What is the range of cloud droplet size distributions and cloud optical depths observed by AirMSPI2 in the ARCSIX region for each of the main Arctic cloud regimes (low-level liquid, high-level Ci, multi-layer mixed-phase)?

2. What is the impact of the observed cloud properties and simultaneously derived surface albedo on the Arctic surface and top-of-atmosphere radiation budget?

To address these questions, we intend to deploy the AirMSPI2 instrument (enhanced version of AirMSPI1; airborne simulator of the Multi-Angle Imager for Aerosols - MAIA instrument) on the high-flying platform in ARCSIX to acquire multi-angle, spectral imaging between 367 and 2185 nm, with polarization-sensitive measurements at 445, 645, 865, 1615 and 2185 nm. In combination with auxiliary observations, most notably lidar, these measurements will enable retrievals of surface, aerosol, and cloud properties, which will help address the overarching ARCSIX science questions 1.1 – 1.3 (surface radiation budget), 2.1 (low-cloud evolution), and 3.1 (effects of sea ice evolution).

Specifically, we will explore conventional and machine learning algorithms to detect and identify different observed Arctic cloud types leveraging AirMSPI2 and colocated lidar observations where available. We will retrieve cloud properties, as well as aerosol, and surface information. ARCSIX in-situ data will be included to study the accuracy and representativeness of the derived cloud properties of observed cloud regimes.

The proposing team is a partnership between the School of Meteorology at OU and the AirMSPI2 team at NASA JPL. The JPL team consists of scientists and engineers with vast experience in instrument deployment and data analysis. The OU team includes experts in remote sensing retrieval development, including joint polarimeter-lidar retrievals, radiative transfer, aerosol-cloud interactions, and campaign leadership. In its partnership, this team is uniquely qualified to carry out the proposed work. Dr. Redemann is a co-author of the ARCSIX white paper and hence intimately familiar with ARCSIX science questions and objectives. In addition to the instrument deployment and retrievals, this proposal contains a leadership proposal for Dr. Redemann to serve as platform scientist for the ARCSIX high-flying aircraft.

Konrad Schmidt/University of Colorado, Boulder
Measurements, Analysis, and Interpretive Modeling of Shortwave Radiation and Imagery for ARCSIX
21-ARCSIX21-0028

We propose three activities for the ARCSIX investigation:
(1) The preparation and calibration of our radiation and imaging payload for the low flier, including (a) priority-1 measurements of spectral shortwave upwelling and downwelling irradiance measurements with our heritage Solar Spectral Flux Radiometer (SSFR) in conjunction with the Active Leveling Platform (ALP); (b) spectral diffuse and global downwelling irradiance by a custom-built novel radiometer, the SPN-S, first flown during ORACLES and CAMP2Ex; (c) a geometrically and radiometrically calibrated nadir-viewing wide (horizon-to-horizon) field of view (WFOV) camera, also previously flown during ORACLES and CAMP2Ex; (d) upwelling (nadir) and downwelling (zenith) spectral radiance, which we have previously measured on the ground, but not yet on aircraft. These four instruments complement one another for many applications, including cloud and aerosol remote sensing; surface albedo and reflectance measurements through the combination of (hemispherical) irradiance and (directional) radiance measurements; determining the spectral shortwave cloud radiative effect as a function of the underlying surface properties; and the systematic validation of satellite products such as imagery-derived net irradiance or the cloud radiative effect near the surface. Our proposed standard configuration is to fly this instrument suite on the low flier, but we also offer (as an option), to fly a second payload on the high flier, which includes a second SSFR and camera. In addition to deploying our instruments and archiving the data, we also offer to provide tools for in-field data visualization and for near real time calculation of irradiances along the flight track from satellite products.

(2) For interpretative modeling, we propose to first develop important products, most importantly for the detection of clouds over bright surfaces. This will not only rely on our traditional irradiance measurements, but also on multi-angle radiance measurements, where clouds and surface pixels 'travel' across the camera field of view at different apparent speeds and can thus be separated, potentially using machine learning, which we are increasingly using in our research. Another important product will combine the radiance measurements by the WFOV camera from the lower hemisphere with similar measurements from other ARCSIX instruments and SSFR spectral surface albedo and spectral nadir reflectance measurements, to produce a consolidated and regionally dependent surface property product. Finally, we will generate a high-accuracy estimate of irradiances, as well as cloud, aerosol, water vapor radiative effects with their uncertainties near the surface, and extrapolate from aircraft observations to a regionally valid cumulative estimate of the surface shortwave radiative budget via satellite remote sensing observations.
(3) In the leadership appendix, I propose to lead the science team in translating the science objectives and priorities into a specific mission plan, leveraging my experience from seeing the concept paper through from the beginning, as well as leadership experiences in multiple suborbital campaigns. Further, I propose to coordinate the science team during the campaign and the analysis phase itself, guided by the philosophies of previous suborbital investigations, and in the context of ongoing and future orbital missions.

Armin Sorooshian/University of Arizona
Airborne Aerosol Hygroscopicity and Refractive Index Measurements During ARCSIX
21-ARCSIX21-0001

The objective of the proposed 6-year project is to deploy the Differential Aerosol Sizing and Hygroscopicity Spectrometer Probe (DASH-SP) on a NASA aircraft during the Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX), followed by processing, dissemination, and analysis of collected data. The DASH-SP was developed specifically for aircraft experiments to provide rapid measurements of size-resolved aerosol hygroscopic growth factor (GF = ratio of humidified diameter to dry diameter) and the real component of the dry particle refractive index (RI). Owing to instrument upgrades, the DASH-SP will be able to select dry diameters up to 2000 nm and characterize humidified diameters between 160-3000 nm. Rapid and size-resolved measurements of this nature have yet to be collected on an airborne platform in the study region, which can help advance knowledge of aerosol-water interactions and aerosol radiative forcing. High time resolution data (as fast as ~1 Hz) from the DASH-SP can be meaningfully compared with other simultaneous rapid measurements, including those for gas- and aerosol-phase composition, f(RH), and cloud condensation nuclei (CCN) concentrations, all of which can be used collectively to conduct closure studies to validate and improve model parameterizations of water uptake and light scattering by particles. Additionally, the proposed measurements of aerosol hygroscopicity and RI will be helpful for using and interpreting remote sensing data.

Specific project tasks will include the following in order of occurrence: (i) Preparation and planning for the flight campaign, (ii) Preparation and integration of the DASH-SP on an aircraft; (iii) Operation of the DASH-SP during test and research flights; (iv) Submission of preliminary data after each flight; (v) De-integration of DASH-SP after the campaign; (vi) Submission of final data; and (vii) Data analysis and collaboration focused on peer-reviewed publication(s) as well as presentations at major scientific conferences and science team meetings.

The proposed research is directly relevant to NASA strategic goals as the data collected will help address how natural and human-induced changes alter air quality, as well as the planet's radiation balance and hydrologic cycle. DASH-SP measurements have direct relevance to the Radiation Sciences Program which "supports studies to improve the theoretical understanding of radiative transfer as well as field measurements of aerosol and cloud particle concentration, composition, microphysics, and optical properties." The proposed project is highly relevant to Science Questions 2 (Cloud Life Cycle) and 4 (Remote Sensing and Modeling Objective) owing to the influence of aerosol water-uptake properties and RI on aerosol processes including their impacts on clouds and remote sensing and modeling. RI data are relevant to Science Question 1 (Radiation), especially Science Question 1.3 that is reliant on knowledge of aerosol optical properties. The case can be made that this project also is relevant to Science Question 3 (sea ice) as atmospheric forcings affecting sea ice evolution are influenced by aerosol hygroscopicity and RI.

Patrick Taylor/NASA Langley Research Center
Maximizing ARCSIX Science with Near Real Time Data, Regime Development, and a Progress Tracking Dashboard
21-ARCSIX21-0025

The Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX) is an airborne investigation planned for late spring and early summer 2024 based from Northern Greenland. The overarching objective is to quantify the contributions of surface properties, clouds, aerosols, and precipitation to the Arctic surface radiation budget and sea ice melt during the early melt season. In support of ARCSIX, NASA is soliciting instrumentation and flight planning proposals that can include a campaign leadership application. This proposal is responsive to the requests for flight planning support and campaign leadership.
We propose three activities in support of ARCSIX Mission Science and flight planning:
1. Provide near-real time cloud, atmospheric, and surface state satellite data and assimilation products in support of pre-campaign planning, flight planning, and post-campaign analysis.
2. Develop science question-specific regimes to support pre- and in-campaign flight planning.

3. Create an ARCSIX Mission Science Dashboard (AMSD) to support in-campaign flight planning and near-real time science progress tracking.
The proposed activities aim to maximize ARCSIX science. Each activity contributes to this goal by assisting campaign leadership with making informed decisions to get the ARCSIX aircraft into proper position and obtain the measurements needed to address the science objectives. The proposed activities align with the AO requirements and ARCSIX white paper recommendations.
The delivery of near-real time cloud and atmospheric state satellite data products and analysis leverages >25 years of SatCORPS experience and builds upon the existing capabilities. Near-real time data products will be sourced from relevant NASA and non-NASA Satellites including Terra, Aqua, Suomi NPP, JPSS, METOP, etc.
The development and application of science question-specific regimes to guide flight planning, track mission progress, and aide post-campaign analysis is a key deliverable of this project. The ARCSIX white paper recommends that the campaign be organized around a statistical, regime-based approach. However, regimes were not developed as part of the white paper and remain outstanding. Our project explores candidate regimes and identifies those that most closely align with ARCSIX science objectives and hypotheses. Deeper analysis is performed on the selected regimes to provide information on the expected conditions, including regime characteristics (including mean properties, variability, and frequency of occurrence), spatially-resolved climatology, relationships between regimes, and estimates of flight hour requirements needed to characterize regime properties. This information is critical for candidate flight plan development and in-campaign flight planning decisions to maximize ARCSIX science.
Lastly, we develop an ARCSIX Mission Science Dashboard AMSD to track the progress towards science goals in near-real time and serve it via an easily navigable page on the SatCORPS website. The AMSD is built upon the robust back-end infrastructure already in place that ingests and processes the data. The AMSD contains flight hour targets for each regime, a progress bar showing accumulated flight hours (updated in-flight), regime analysis results (e.g., regime climatology and statistics), and candidate flight plans with rationale. The AMSD represents an integration of the near-real time data serving activity and the science question-specific regime activity providing ARCSIX leadership key information for making decisions to maximize ARCSIX science. In summary, our intent is to provide key deliverables to support flight planning with the aim to maximize ARCSIX Science and for the Project PI to serve on the ARCSIX campaign leadership team as campaign science lead.

David Thompson/Jet Propulsion Laboratory
Next Generation Airborne Visible Infrared Imaging Spectrometer (AVIRIS-NG) Participation in the ARCSIX Campaign
21-ARCSIX21-0003

We propose to operate the Next Generation Airborne Visible Infrared Imaging Spectrometer (AVIRIS-NG) on the high-altitude aircraft of the ARCSIX campaign. AVIRIS-NG will provide spectroscopic imaging across the entire solar-reflected range from 380-2500 nm. Its 5 nm spectral resolution enables simultaneous measurements of radiative properties (such as cloud top reflectance, surface reflectance, and albedo), and compositional properties (such as sea ice condition and cloud microphysics). By mapping both composition and radiation from a single instrument, AVIRIS-NG data can be used to upscale ARCSIX in situ measurements, linking them to observed statistics of the regional solar-reflected radiation field.

AVIRIS-NG represents the state of the art for remote VSWIR imaging spectroscopy, with a six-year history of successful campaigns across three continents, Greenland, and the Arctic Ocean, and a mature science data system validated at dozens of in-situ measurement sites. The team has already demonstrated challenging aspects of the ARCSIX campaign, such collocating remote cloud microphysics retrievals with in situ airborne sampling. This makes AVIRIS-NG a low-risk option for ARCSIX measurements including column water vapor; aerosol loadings; spectral surface reflectance, from which spectral albedo can be derived; and cloud top reflectance, which we will use to calculate cloud thermodynamic phase, optical thickness, and effective radius.

This spectroscopic dataset will provide several advantages beyond traditional multiband imagery. First, compared with multiband data, spectrally-resolved measurements can more accurately estimate certain cloud optical properties, with particular sensitivity to mixed phase clouds. Mixed-phase clouds are common in the Arctic, and form an important but poorly understood part of the radiation budget. Second, AVIRIS-NG's participation in the campaign will validating these spectroscopic measurements for a new generation of spectroscopic imagers, the Surface Biology and Geology mission and Atmospheric Observing System mission, which can then continue ARCSIX observations into the next decade. A formal uncertainty quantification exercise, conducted with the help of in situ airborne and ground-based sensors, will attempt to demonstrate a closed uncertainty budget, validating spectroscopic cloud property retrievals for use by these future missions.

In addition to validating and delivering the core products, we will conduct a targeted investigation of cloud radiative properties. Cloud properties are a dominant source of uncertainty in models of surface radiative flux. Moreover, Climate GCM experiments forced with increases in CO2 have demonstrated that a rapid loss (gain) in ice (liquid) cloud occurs when compared to the more gradual poleward shift in cloud fraction regardless of phase. The rate of change of the phase partitioning is strongly correlated to the spread in equilibrium climate sensitivity (ECS) among the CMIP5 model simulations. A robust benchmark of cloud thermodynamic phase observations between the GCM grid scale (10s of kilometers) to the sub-kilometer scales is sorely lacking, and especially in arctic areas. These small-scale observational benchmarks are critical for advancing subgrid parameterization development in GCMs. Here, we will use AVIRIS-NG cloud property maps to document the phase, radiative properties, extent and evolution of clouds over the ARCSIX measurement domain, and relate these to their thermodynamic and surface environments. This will fill an important gap in the observational record and clarify the role of different cloud types in the early melt season.

Rei Ueyama/NASA Ames Research Center
Meteorological Measurement System and Forecasting and Flight Planning Support for ARCSIX
21-ARCSIX21-0010

Accurate, high-resolution in-situ state measurements such as temperatures and winds are essential for any science investigation that utilizes airborne measurements. Thus, meteorological measurements such as temperature, pressure, relative humidity, and three-dimensional winds are identified as Priority 1 measurements of the low-altitude aircraft for the ARCSIX campaign. These measurements are critical for investigating the processes controlling the predominant Arctic cloud regimes and their properties (Science Question 2 on the cloud life cycle). Recent studies have shown that small-scale fluctuations in the atmosphere such as gravity waves and turbulence significantly impact Arctic cloud formation and evolution. Despite the importance of these processes on Arctic cloud life cycle, the distribution and properties of these small-scale fluctuations in the Arctic cloud environment are largely unknown.

Organized meteorological and flight planning support is as essential for the success of the ARCSIX campaign as the instruments that make the measurements. The ability to quickly and comprehensively develop flight plans would allow the required measurements to be made within the constraints of aircraft operations.

In response to these needs, we propose the following:
(1) To provide high-resolution, high-precision state measurements of pressure, temperature, and three-dimensional wind with the Meteorological Measurement Systems (MMS) instrument on one of the aircraft for ARCSIX science investigation;
(2) To characterize small-scale fluctuations (gravity waves and turbulence) using MMS measurements and assist in the investigation of their impact on the Arctic cloud life cycle;
(3) To provide forecasting and flight planning support for ARCSIX.

Our team is highly qualified to carry out all aspects of the proposed work. As evidence of the success and usefulness of MMS data for science investigations, the MMS has a proven performance heritage on multiple platforms, including the DC-8, as part of over 30 airborne missions since the 1980s. We also have a proven record of successful contribution to forecasting and flight planning as well as mission leadership activities in NASA airborne missions, and are well positioned to support all chosen ARCSIX platforms (G-V and P-3 or DC-8 platforms).

The impact of the proposed work will be evident in all stages of the ARCSIX campaign, from preparation to post-flight data analysis. The outcomes will include an efficient forecasting and flight planning process as well as necessary inputs for large-eddy simulation and single-column models to quantify the impact of gravity waves and turbulence on Arctic cloud characteristics.

Jian Wang/Washington University
High Time Resolution Measurements of Aerosol Size Distribution and Analysis of Aerosol Properties and Processes for ARCSIX
21-ARCSIX21-0027

We propose to provide high time-resolution measurements of aerosol size distribution on board the low-flying aircraft (i.e., NASA P-3B or DC-8) during Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX), and to conduct post-mission data analyses to investigate the aerosol properties, sources, and processes in the summertime Arctic. The overarching goal of ARCSIX is to quantify the contributions of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season (May through mid-July).
A unique instrument called Fast Integrated Mobility Spectrometer (FIMS) will be deployed to provide 1 Hz measurements of aerosol size distributions from 10 to 500 nm. The FIMS was successfully deployed in many aircraft-based field campaigns, including a recent foreign deployment on board the NASA P-3B in Southeast Asia. Given its fast response and good sampling rate, FIMS is ideally suited for airborne characterization of aerosol size distribution in the Arctic during summer, when aerosol concentration is often low. The high time-resolution measurements by the FIMS will help address high priority science questions of ARCSIX relating to the spatial variation of the aerosol field, and its impact on cloud and radiation. We will also develop value-added data products, including high time-resolution CCN spectra and particle hygroscopicity by combining the aerosol size distribution and CCN measurements expected as part of the low-flying aircraft payload.
Our post-mission data analyses will focus on the properties, sources, and processes of aerosols in the summertime Arctic. As described in the mission white paper, Lagrangian type flights are planned with two coordinated aircraft to track the coupled evolution of air mass thermodynamic structure, aerosol and cloud properties, and radiation during the advection and transport events from lower latitudes. We will analyze the measurements from the Lagrangian flights to quantify the impact of such transport on Arctic CCN population and cloud microphysics (e.g., droplet number concentration), and to investigate key aerosol processes, including condensational growth, vertical mixing, and wet removal of aerosol particles. the contribution of local and external aerosol sources to the CCN population in the summertime Artic will be examined for a range of contrasting aerosol environments (e.g., pristine vs. advection-influenced by dust or pollution) and across air mass boundaries. We will also investigate the impact of both locally and externally sourced aerosols on cloud microphysics for representative atmospheric thermodynamic structures and surface types.

Lauren Zamora/University of Maryland, College Park
Aerosol Forecasting Constrained with Satellite Data to Support Flight Planning as Well as ARCSIX Remote Sensing, Modeling, and Cloud Life Cycle Research Objectives
21-ARCSIX21-0026

The Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) field campaign is a unique opportunity to collect comprehensive airborne data in the under-sampled and yet highly climate-sensitive Arctic environment. However, this environment is complex, and the campaign will have limited flight hours. Thus, significant preparation will be required to maximize the likelihood that the numerous ARCSIX goals are met. This preparation will include creating a merged product that takes advantage of the strengths of satellite observations and model simulations in representing aerosol distributions and cloud regimes in the Arctic. For example, passive remote-sensing satellite aerosol retrievals are more reliable in sub-Arctic aerosol source regions than over snow and ice surfaces, and models are more reliable when constrained by such aerosol observations. The merged product will provide a climatology of environmental-regime occurrence to help prioritize measurement objectives pre-deployment, will help target ARCSIX field observations to specific aerosol and cloud conditions during deployment, and will help relate specific aircraft observations to larger-scale regimes and processes subsequently.

In this 4-year project, we propose to support ARCSIX flight planning and experiment execution with a focus on meeting the Remote Sensing and Modeling objective and the Science Question 2 (Cloud Life Cycle) goal. Specifically, we propose to leverage our prior experience with aircraft, model, and satellite data analysis to provide a merged cloud-aerosol-meteorology regime product based on a combination of GEOS, MERRA-2, and ICAP ensemble model output and AIRS, CALIPSO, CloudSat, EarthCARE, EPIC, MISR, MODIS, OMI, TropOMI, VIIRS satellite data. This merged product will have (a) a retrospective component that can assess the likelihood and representativeness of different cloud-aerosol-meteorological conditions and (b) a near-real time component that can provide a key flight-planning tool during deployment, including aerosol forecasts. By identifying atmospheric regimes from models and satellite data, we will help provide a statistical framework for integrating the detailed but highly localized aircraft data with satellite observations and model simulations that operate on larger spatial and temporal scales. This product, in combination with the forecasting efforts of our team and other teams, will help identify in advance which locations within the sampling area are the most promising targets to meet the objectives of all selected PIs. It will also increase the diversity of questions that can be addressed by investigators responding to a future ROSES ARCSIX science solicitation, enhancing the campaign’s scientific payoff.

In our post-campaign analysis, we will focus on the following science objectives: 1) improving Arctic aerosol composition and microphysical assumptions in global models, 2) identifying likely aerosol effects on clouds over the ARCSIX sampling area during the early melt season using combined satellite, aircraft, and model information, and 3) improving our understanding the aerosol-cloud interaction mechanisms behind those effects with the help of well-targeted aircraft observations. This research would help directly address the campaign Science Question 2 and the Remote Sensing and Modeling objective. Post-campaign, we will also document and make publicly available the merged product to facilitate analysis and interpretation of the aircraft data in a wide variety of remote sensing, modeling, cloud, and aerosol studies. This proposal includes an application by R. Kahn and L. Zamora to join the campaign's leadership team.

Paquita Zuidema/University of Miami, Key Biscayne
Observing Arctic Cloud, Moisture and Aerosol Structures During ARCSIX
21-ARCSIX21-0018

Executive Summary

We propose to deploy two moisture sensors in support of the science and remote sensing objectives of the Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX): the downward-viewing Multi-function Airborne Raman Lidar (MARLi) and the upward-viewing 183 GHz G-band Vapor Radiometer (GVR). Both are intended for the low-flying aircraft platform and are explicitly identified within Table 4 of the ARCSIX White Paper as priority instruments. The GVR is responsive to the liquid water path dominating the optical depth of all-liquid and mixed-phase clouds, with a retrieved liquid water path uncertainty of less than 10 g m-2. The high sensitivity of the GVR to small amounts of liquid water is particularly valuable for ARCSIX, as many of the Arctic clouds important to the surface radiation budget are optically-thin and overlooked by heritage passive imagery cloud characterizations. The MARLi provides unprecedented simultaneous detail on the vertical moisture, aerosol and cloud structure with temperature and water vapor uncertainties of less than 0.5K and 5% in water vapor mixing ratio. Its vertical resolution of 0.6 m supports characterization of the near-surface air and humidity structure, and of mixing processes occurring at the boundary layer top. In tandem the two instruments provide the main inputs needed for a full radiative flux closure. They aid cloud process understanding through their assessment of the full cloud lifecycle - formation, maintenance and dissipation - for ice, mixed-phase and liquid clouds within air mass transformations into and out of the Arctic, and as a function of the underlying sea ice properties (melt pond fraction, surface reflectance). We note most, perhaps all, of the loweraltitude clouds in the Arctic begin in the liquid phase. The measurements contribute to answering all of the sub-questions motivating ARCSIX and are highly synergistic with the other measurements planned for ARCSIX.

This is a five-year proposal primarily intended to support the deployment of the two instruments in a cost-competitive manner, with post-campaign analysis focusing on data quality control and integration with other ARCSIX datasets including the satellite and model forecast products used for the campaign. The proposal will support two graduate students, one at each institution.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences -2021
NNH21ZDA001N-RSWQ
A.21 Remote Sensing of Water Quality

The National Aeronautics and Space Administration (NASA) solicited investigations related to the Remote Sensing of Water Quality under the NASA Research Announcement (NRA) ROSES-21 NNH21ZDA001N-RSWQ. This element is supported by the Terrestrial Hydrology and Ocean Biology and Biogeochemistry Programs. Investigations were sought to improve and exploit the capability of Earth Observing Satellites to remotely sense water quality from space. Proposals were asked to respond to one of two topics: (1) atmospheric corrections to improve retrieval of water quality properties when the direct satellite radiance measurements are confounded by complex atmospheric conditions, and (2) improving the understanding of the link between optical and biogeochemical properties of a water body. Projects were strongly encouraged to consider conditions that may (or may not) exist prior to harmful algal bloom events, and how these may be better resolved through satellite remote sensing. Also stated in the solicitation was the importance that projects leverage on-orbit NASA satellites and/or build a connection to future NASA missions, currently under development, such as the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission.

Originally, NASA advertised that $1.2 M would be available annually to fund approximately six projects for up to three years of research activity. NASA received a total of 38 proposals in response to this NRA and selected 10 for funding. The total funding to be provided for these investigations is approximately $6.1 M over 36 months.

The Principal Investigator, institution, and investigation title are provided for the selected projects. Other co-investigators are not listed here.

Kevin Arrigo/Stanford University
Detecting Harmful Algal Blooms in the Pacific Sector of the Arctic Ocean
21-RSWQ21-0013

The Arctic is in a period of rapid transformation, experiencing the most severe effects of anthropogenic climate change anywhere on Earth. These changes are drastically altering the ecology and biogeochemistry of the Arctic Ocean, and in particular, its patterns of primary production. Nonetheless, how different groups of primary producers are responding to the changing AO is still poorly understood. For this proposal, we will focus on the toxic harmful algal blooms (HABs) that form each summer in the Chukchi Sea. These HABs threaten many local ecosystems, some of which humans rely on for food. The objective of this proposal is to use a combination of satellite remote sensing observations and data from cruises to the Chukchi Sea to identify the environmental conditions that lead to the development of HABs in this critical inflow region of the AO. Our primary research question is: Are observed distributions of HABs in the Chukchi Sea associated with a specific set of physical or biological features that can be detected

remotely from space-based platforms? By increasing our understanding of the factors that lead to the development of HABs, we will be better positioned to forecast their development in the future and possibly mitigate some of their more deleterious consequences to human health (i.e., early warning), particularly of indigenous peoples.
The foundation of our study will be the use of satellite data to understand the physical, chemical, and biological conditions that led to the development of two different HABs that were sampled in the Chukchi Sea in 2018 and 2019. We will produce daily and weekly maps of SST, SSH, wind speed, AOT, sea ice concentration, and products derived from ocean color for the Chukchi Sea in both 2018 and 2019 leading up to and during the observed HABs. Retrieval of variables based on ocean color, such as ag, ad, bbp, and Chl a, will be accomplished using our new empirical and semi-analytical algorithms developed specifically for the AO. Spatial statistical analyses will be performed to determine if surface waters where HABs developed in 2018 and 2019 were associated with conditions that were significantly different from waters where HABs did not develop. We will also look at satellite imagery and other spatial data extending back to 1998 to see if the conditions promoting HAB development in 2018 and 2019 were also present in earlier years. These analyses will provide valuable insight into the factors leading to HAB development and provide a framework from which to develop a HAB prediction system for the region and more broadly.
We have been invited to participate in an upcoming NSF-sponsored cruise to the Chukchi Sea in 2023 to better understand HAB distributions and bloom evolution in Arctic waters. If funded here, we will measure key bio-optical properties and radiometric quantities such as downwelling irradiance, upwelling radiance, and remote sensing reflectance both inside and outside of waters dominated by HABs. These bio-optical data will be combined with data collected during the cruise to characterize the relationships between measured radiometric quantities and variables such as turbidity and CDOM absorption. After the cruise, we will perform the same satellite-based analyses for 2023 as we will for the 2018 and 2018 to further strengthen statistical relationships between HAB distributions and physical and biological properties of surface water.
This proposal is responsive to NASA's interest in proposals that improve and exploit the capability of Earth Observing Satellites to remotely sense water quality from space (A.21) and assess the impacts of water quality on ecosystem health and to consider conditions that may exist prior to harmful algal bloom events, and how these may be better resolved through satellite remote sensing. Our proposal falls into the category described in Section 2.3: Improving understanding of the link between optical and water-body properties.

Brian Barnes/University of South Florida, Tampa
Linking Biogeochemical and Optical Water Quality in Coastal and Inland Waters: Data Synthesis, Algorithm Development, and Effective Product Delivery
21-RSWQ21-0006

The increasing demands from various stakeholders for estuarine and lake water quality (WQ) data have encountered challenges of lacking resources to implement and sustain WQ monitoring networks. Based on previous NASA support, customized algorithms and

WQ data products from MODIS measurements have been developed for several estuaries, and these products have been made available online since 2013 with daily updates through a Virtual Buoy System (VBS), which has been used by many stakeholders for a variety of purposes. However, several shortcomings have been identified, many of which are indicative of larger issues in the field of satellite ocean color, including:

1) Satellite data in nearshore environments are limited in both data quantity (overly restrictive quality control flags) and data quality (errors due to atmospheric correction artifacts);
2) The existing algorithms are restricted to only a few optical WQ parameters (OWQ), while other biogeochemical WQ (BWQ) parameters are often demanded by resource managers;
3) Spatially, the existing OWQ algorithms are restricted to only a handful of estuaries because universal algorithms applicable for other estuaries and lakes do not exist;
4) As the VBS currently relies on an aging MODIS instrument, incorporation of data from newer sensors (VIIRS and OLCI) is needed to ensure continued dissemination of these valuable data.

Therefore, based on recent progress in algorithm development and to meet the demands of various stakeholders for WQ monitoring, the goal of this project is to understand the linkage between OWQ and BWQ, and to improve and expand the VBS to operationally monitor OWQ and BWQ in estuaries and lakes in US Gulf of Mexico coast. Specifically, the project has the following objectives:

1) Improve data processing methods to increase quantity while ensuring quality of reflectance data;
2) Develop broadly applicable OWQ algorithms and products for selected estuaries and lakes;
3) Understand the two-way linkage between OWQ and BWQ in the selected estuaries through both statistical and mechanistic analyses, from which BWQ algorithms and products will be developed;
4) Expand the VBS to cover all selected estuaries and lakes in the Gulf Coast towards establishing a satellite-based WQ monitoring network which more broadly serves management agencies and other stakeholders.

The project will work on multi-sensor data including MODIS, VIIRS, MERIS, and OLCI, with specific focus on ensuring a consistent merged-sensor dataset while preparing for the NASA PACE and SBG missions. The OWQ data products emphasized in this research will include CDOM and chlorophyll absorption coefficients, turbidity, Secchi Disk Depth, and particulate backscattering. The specific BWQ data products studied will depend on publicly available in situ data, but are likely to include chlorophyll concentration, salinity, net primary production, total suspended solids, and others.

Technical challenges to overcome in this project include: 1) data quantity is often too low due to globally optimized quality control flags; 2) inconsistencies between extant in situ BWQ datasets, and; 3) non-linear and spatiotemporally varying relationships between OWQ and BWQ. These challenges will be addressed through algorithm development, product validation using both empirical orthogonal function and machine learning methods, and quantification of remaining uncertainties related to these challenges. Project outcomes will include algorithms specifically tailored for estuaries and lakes for both OWQ and BWQ. Deliverables will include algorithms, software, and OWQ and BWQ data products through the VBS.

The project benefits from previous and ongoing efforts funded mainly by NASA to improve algorithms/products and to enhance satellite data service to the community. In this regard, the project is significant not only for this particular RFP but also for the overarching goals of NASA's water quality program.

Keith Cherkauer/Purdue University
Advancing Remote Sensing of the Biogeochemical State of Midwestern Inland Waters
21-RSWQ21-0024

As water quality experiences pressures from both environmental and anthropogenic events, it is critical that we can effectively identify current potential threats in multiple waterways to reduce impact on both human and ecosystem health. To do so, remote sensing technologies must be able to work across a range of waterways from small ponds and rivers to reservoirs. In the North-Central U.S., thousands of inland lakes and reservoirs provide critical ecosystem services including supplying water for residential, industrial and agricultural users, providing recreational spaces and, in some cases, generating electricity. The health of these systems is under stress not only from increased agricultural, industrial and residential usage, but also due to increasingly dramatic shifts in precipitation and water availability. In the Midwestern U.S. more precipitation occurs in the winter and spring while summer and fall receive the same or less precipitation. For both agriculture and human use, greater heat in the summer increases water demand, which means that quality water storage in reservoirs is becoming more critical to both monitor and maintain. One of the most prominent water quality issues in the slow-moving and more stagnant bodies of water in the region is Harmful Algae Blooms (HABs), which are closely related to the eutrophication of water bodies, especially due to phosphorus and nitrogen loads from surrounding agricultural lands. In this remote sensing of water quality project, the Purdue team draws on significant expertise, resources, and experience to develop methods for improved quantification of the linkage between the optical and thermal properties of lake and river water and their biogeochemical states. We will then integrate remote sensing, in-situ water quality sampling and supplemental information on land use, soils and climate using machine learning based approaches to improve the prediction of water quality indicators including the potential for HAB formation in waters heavily impacted by agriculture.

While remote sensing has been used to identify lakes experiencing algal blooms, the goal of this project is to improve the rapid quantification of the biogeochemical state of both river and lake water by remote analysis of optical and thermal properties so that preconditions leading to HABs can be identified and timely prediction of HAB occurrences in Midwestern U.S. lakes and rivers can be improved. Specific objectives include: (1) in order to improve our understanding of the link between optical, thermal and water-body properties, we will conduct intensive monitoring of the biogeochemical state, optical and thermal properties of a small number of lakes and reservoirs within the Wabash River watershed. The team will use multispectral, hyperspectral and thermal imagery from unmanned aircraft systems (UASs) and satellite remote sensing platforms, balanced by analysis of supplemental water samples and spectral reflectance ground reference information; (2) to identify inflow contributions to the formation of HABs and the mixing of river water into water bodies, the team will develop simulations of river plumes entering lakes and reservoirs based on flow rates and thermal conditions. This field work and analysis will enable us to extend the relationship between optical properties, supplemental information and the biogeochemical state of rivers and lakes to lakes throughout both the Wabash River and Illinois River watersheds. The team's evaluation of those relationships will then serve as a component of the project's outputs: an improved prediction model for regional HABs based on remote sensing imagery. Significantly, this approach will enable time and resource efficient analysis and predictive capacities that will allow for the implementation of active strategies for HABs management in real time as well as across field seasons.

Evan Dethier/Dartmouth College
Satellite Monitoring of Rivers: A Distributed-Sampling Approach to Improve Satellite Estimates of River Water Quality on a Global Scale
21-RSWQ21-0003

Changes to river water quality provide powerful, often near real-time, insight into anthropogenic watershed impacts, including changes to the water cycle, land use, and the proliferation of dams. Suspended sediment concentration (SSC) and flux, in particular, affect water quality and pollutant transport, maintain riverbanks and floodplains, and mitigate flooding on heavily populated deltas and coastal regions. However, our understanding of patterns and trends in SSC and flux, which are critical to water management decisions, remains limited by the sparse availability of their measurements. While these water quality parameters are perhaps the most commonly measured river variables besides water discharge, existing measurements only provide an inconsistent global patchwork, with limited available data for many regions and few or no measurements for many others.

For decades, in situ measurements of river water quality have been supplemented by Earth Observing Satellites (EOSs). However, complicating the usefulness of these satellite observations is the variability in optical properties of i) rivers in different climates and landcover settings around the world and, to a lesser extent, ii) across different seasons or events for an individual river. This variability limits the successful application of continental and global algorithms for estimating SSC and confounds estimates of other important river and estuarine properties such as DOM.

We propose to address the challenge posed by global river variability in optical properties, aiming to improve satellite estimates of river water quality using global, massively-scalable algorithms. To that end, we propose to compile and analyze a global inventory of river suspended sediment samples, expanding our calibration datasets to more diverse sites and capitalizing on the improved capabilities and coverage of the current EOS constellation. This unprecedented, global dataset will build on our existing state-of-the-art training dataset of in situ river water quality measurements matched with Landsat satellite images. We will leverage this dataset to i) improve global calibrations and develop local and/or regional calibrations for all the sampled rivers; and ii) demystify the relationship(s) between river water optical signature and sediment provenance, grain size, color, and organic fraction.

This proposal directly addresses the Water Quality Program's solicitation and key elements of the NASA Terrestrial Hydrology mission. We will attempt to "improve and exploit the capability of Earth Observing Satellites to remotely sense water quality from space". Specifically, we will answer Section 2.3 of the solicitation, seeking to improve our understanding of "how the biogeochemical properties of a water body may influence its optical properties" by relating the properties of in situ river water samples from around the world to contemporaneous satellite measurements of the same river. Since the major rivers of the world are integrators of changing land use and climate signals, this work will fulfill the NASA Terrestrial Hydrology Program's mission to "further the scientific basis of water resources management" by i) improving our spatial and temporal understanding of these systems, and ii) boosting the ability of scientists, water-resources stakeholders, and government and transnational actors to understand and contextualize water system changes, both past (up to 37 years) and in near real-time in the future. Our overarching aim is to dramatically improve satellite efforts to detect water quality and suspended sediment transport in global rivers, such that satellite monitoring of water quality can be a reliable tool for riparian stakeholders, water managers, and private and government decision makers.

Robert Frouin/University of California, San Diego
Improving the Satellite Retrieval of Water Quality Properties Under Complex Atmospheric and Aquatic Conditions
21-RSWQ21-0015

Accurate satellite data products are needed to monitor spatial and temporal changes in water quality of coastal and inland aquatic environments in support of management practices. Optimum utilization of satellite optical remote sensing in such waters is hindered by atmospheric correction issues which include the influences of optically complex water properties, bottom reflectance, absorbing aerosols, Sun glint, clouds, and adjacency effects. Substantial challenges to accurate satellite retrievals of water quality parameters are also caused by intricate linkages between the water optical properties and many environmental processes that control the sources, variability, and fates of various optically-significant constituents of water. The overarching goal of this project is to advance the capabilities of ocean color remote sensing of water quality by developing improved atmospheric correction and in-water algorithms for applications in optically complex coastal and inland aquatic environments and demonstrate these improvements for a specific inland water body of the Salton Sea.

The atmospheric correction algorithm will be based on principal component analysis of the TOA and water signals. After correction for gaseous absorption, the TOA signal will be decomposed into principal components (PCs), and the PCs sensitive to water reflectance will be combined to retrieve the PCs of this reflectance signal. The development of in-water algorithms for retrieval of water quality parameters will be based on field data of optical and water constituent properties collected in the Salton Sea. The spectral remote-sensing reflectance, Rrs, will serve as the sole input to a suite of empirical algorithms to estimate POC/SPM followed by estimation of particle concentration metrics of POC and Chla from composition-specific algorithms based on classification of water bodies into organic-dominated, mineral-dominated, and mixed particulate assemblages. The Rrs-based algorithms will be also formulated for estimation of SPM, CDOM, and light attenuation coefficient in water. The algorithms and processing lines will be developed for VIIRS/S-NPP&JPSS-1, MSI/Sentinel-2, PRISMA/PRISMA, and the planned OCI/PACE. The algorithms will be evaluated with quantified uncertainties using independent field data and satellite-in situ matchup datasets.

The study will result in an effective atmospheric correction algorithm for satellite imagery over coastal and inland waters. The algorithm is expected to provide accurate water reflectance retrievals with associated uncertainties under challenging conditions caused by absorbing aerosols, adjacency effects and optically complex waters, the applicability to imagery affected by sun glint and thin clouds which will enhance the operational utility of satellite data, and improved consistency across sensors and continuity in the quality of water reflectance retrievals due to weak sensitivity to radiometric calibration biases. The improved Rrs-based in-water algorithms for estimating water quality parameters across a wide range of conditions in the Salton Sea are expected to demonstrate the key advancements associated with the proposed capability to estimate the particle composition parameter, POC/SPM, which quantifies the proportions of organic and mineral particles, with subsequent improved estimations of POC and Chla from composition-specific formulations.

The proposal responds to the solicitation under both elements “Atmospheric corrections” and “Improving understanding of the link between optical and water-body properties”, and to the NASA science goals of understanding and predicting aquatic ecosystems. The algorithm improvements will result in more accurate and frequent monitoring of water quality of coastal and inland ecosystems which are vulnerable to human activities and climate change, so that future conditions can be better predicted and mitigation strategies devised for better water resource management.

Brice Grunert/Cleveland State University

SPM and CDOM Spatiotemporal Dynamics as Predictors of Internal Phosphorus Cycling and HAB Variability in Western Lake Erie
21-RSWQ21-0038

Earth's biogeochemical processes are inextricably linked across aquatic, terrestrial, atmospheric, and anthropogenic systems. This coupling is readily visible in western Lake Erie, where intensive agriculture, climate and invasive species lead to annual harmful algal blooms (HABs). HAB forecasts for Lake Erie rely on measured concentrations of bioavailable phosphorus and river discharge in the Maumee River. Forecasts of HAB severity are an important early indicator for water resource managers, and forecasts have been improved by considering legacy phosphorus loading from the Maumee River. However, significant variability in observed HAB extent and severity remains unexplained using tributary phosphorus loading alone, indicating a focus on tributary loading isn't considering all factors driving western Lake Erie HAB variability. To date, internal phosphorus loading has been identified as the largest unknown parameter likely driving year-to-year variability. Constraining the role of the internal phosphorus cycle on spatiotemporal variability of western Lake Erie HABs within and across years is critical to improve our predictive capabilities.

Satellite observations have been crucial for expanding our understanding of western Lake Erie HABs; however, improving our understanding of internal phosphorus cycles via satellite observations requires strong relationships with optically active constituents. Sediment resuspension occurs frequently in Lake Erie, is readily visible from space and is related to phosphorus cycling in eutrophic Great Lakes systems. During these events, benthic phosphorus and sediment-derived colored dissolved organic matter (CDOM) is introduced into the water column, altering water column biogeochemistry and exacerbating eutrophication in Great Lakes systems. Sediment resuspension has long been hypothesized as a driver of western Lake Erie HAB severity. However, estimates of sediment resuspension frequency, intensity and relationships with internal phosphorus cycling and HAB variability have not been directly characterized.

Here, we seek to relate satellite observations of suspended particulate matter (SPM) and CDOM to internal phosphorus cycling and HAB variability. We will: 1) Characterize sediment resuspension, associated internal phosphorus cycling and shifts in western Lake Erie biogeochemistry in situ; and 2) Characterize inherent optical property variability and western Lake Erie biogeochemistry preceding HABs through an existing optical water type framework and a suite of regionally-tuned algorithms applied to the full MODIS Aqua data record. We expect these observations will allow us to generate a spatiotemporally-resolved, internal phosphorus loading dataset coincident with optical measurements that will enable improved HAB predictions from satellite observations.

The research proposed here directly responds to sub-element 2.3 of the program solicitation. We seek to utilize SPM and CDOM variability to characterize internal phosphorus dynamics, a poorly characterized driver of western Lake Erie HAB variability unexplained by tributary nutrient loading. This information is critical to continue improving HAB modeling efforts and further science-based water management. By constraining interactions between internal phosphorus dynamics and biogeochemistry, we will expand our knowledge of Lake Erie ecosystem services and contribute to improved HAB forecasts for this system.

Rebecca North/University of Missouri, Columbia
Retrospective Analysis of Anthropogenic Change in Midwest Reservoirs: Integrating Earth Observing Data with Statewide Reservoir Monitoring Programs
21-RSWQ21-0005

Water quality (WQ) monitoring of US waterbodies rely almost exclusively on in-situ sampling. Satellite remote sensing (RS) is a valuable tool to extend records in space and time. Due to the small size and optical complexity of many waterbodies, machine learning algorithms are increasingly applied to estimate WQ from LandSat and Sentinel 2 data. This approach is well suited for routinely monitored systems as the sheer quantity of data permits robust algorithm development and training. PI North runs 2 long-term monitoring programs. The Statewide Lake Assessment Program (SLAP) has been ongoing since 1976 and accounts for 9,000 water samples at 250 reservoirs. The Lakes of Missouri Volunteer Program (LMVP; 1992-present) is a citizen science program that has collected 14,000 water samples at 200 reservoirs. WQ data includes nitrogen, phosphorus, chlorophyll a, Secchi, particulate organic and inorganic matter, and cyanotoxins. In Missouri (MO), numeric nutrient criteria was established in 2018 and by 2020 there were 60 reservoirs listed as impaired. Only reservoirs with monitoring data can be identified as impaired and 85% of MO reservoirs are not monitored. Well calibrated RS data provide the only means to assess WQ in these reservoirs and can improve our understanding of anthropogenic drivers impact on WQ and cyanobacterial Harmful Algal Blooms (cyanoHABs).
Objectives: Assess the efficacy of RS data to emulate the goals of MO WQ monitoring by applying an extant (Co-I Silsbe) Google Earth Engine pipeline to LandSat 7/8 and Sentinel 2 data. The pipeline can toggle between different atmospheric correction (AC) methods; the default AC methods and an AC approach developed for inland waters. RS, SLAP and LMVP data will be paired in space and time for machine learning algorithm development and include uncertainty analyses as they pertain to numeric MO WQ criteria. We will map the color of MO reservoirs through space and time by applying an unsupervised classification technique to RS data to identify dominant optical water types (OWTs). We hypothesize that performing this analysis at a regional level will better constrain WQ parameters within OWTs relative to analyses conducted at national and global scales. We will assess if known Best Management Practices (BMPs) and stressors have resulted in shifts in OWTs and/or WQ. We have documented the presence and impact of invasive species (grass carp and zebra mussels), herbicide additions, and BMPs. We will expand our monitoring programs to include in-situ hyperspectral RS measurements and phycocyanin concentrations (a proxy for cyanobacterial biomass). Collected over the 2-field seasons, in-situ RS and WQ data will be an independent test of AC performance and machine learning algorithms.
Methods: SLAP and LMVP data are available online. All RS analysis will use existing Google Earth Engine and Python pipelines either developed by Co-I Silsbe or retrieved from public repositories. We will augment the extant MO monitoring capabilities by adding direct measurements of RS via deployment of a hyperspectral radiometer float following NASA protocols.

Significance and relevance of proposed work: This research directly addresses how satellite RS data can inform critical links between biogeochemical and optical properties of inland waters. The optical diversity of MO reservoirs, including identified long-term regime shifts in particulate matter and chlorophyll a, make them well suited to this application. RS data will allow us to characterize conditions associated with cyanoHABs. Direct RS measurements will help inform the efficacy of AC performance. The information will be disseminated to the research community, the volunteers conducting the sampling, regulatory agencies, and the general public. Sharing of information in this manner can promote innovation, inform management decisions and guide policy development.

Nima Pahlevan/Science Systems And Applications, Inc.
Algorithm Developments for Synergistic Use of Water Quality Products from Multispectral and Hyperspectral Satellite Observations
21-RSWQ21-0011

The changing climate manifests itself in various forms of extreme weather patterns (e.g., wildfires, droughts, floods) that increase the pressure on inland and coastal waters, thereby threatening global food and water security. Human overexploitation of land resources for food production and urban development further stresses the already vulnerable aquatic ecosystems. Examples of such adverse impacts are the increased frequency of harmful algal blooms, the warming and browning of inland and coastal waters, and excessive sedimentation in global waterways.

Satellite remote sensing of water quality (WQ) at regional and global scales has been possible for more than two decades, owing to research and developments enabled by radiative transfer modeling and in situ bio-optical/-geochemical measurements. The satellite remote sensing capability has evolved over the years and will continue to advance due to the advancements in (satellite and field) sensor technology, enhanced awareness of water quality issues, more temporally and spatially extensive field monitoring exercises, and the availability of open-source analytics tools. In preparation for more capable hyperspectral satellite sensors currently being planned by NASA, adept algorithms that enable a seamless integration of WQ products from past (MERIS and HICO) and existing (OLI, MSI, OLCI, and Italian Space Agency's PRISMA) satellite sensors are needed.

We aspire to formulate and implement a universal algorithm to generate high-quality WQ products accompanied by their pixel-level uncertainties to enable the construction of a reliable long-term record of WQ across global inland and coastal waters. Specifically, we will build upon our recently developed machine-learning method to simultaneously estimate multiple WQ parameters, namely concentrations of chlorophyll-a (Chla), Total Suspended Solids (TSS), and phycocyanin (PC), as well as absorbing components of inherent optical properties (e.g., phytoplankton absorption; aph). This universal algorithm, Mixture Density Networks (MDNs), will be developed and tested using a compiled in situ database obtained from the existing public databases (e.g., SeaBASS) and from global field measurements assembled through a community-wide data-sharing arrangement.

The developed algorithms will be implemented, validated, and demonstrated for near-coincident images of MERIS and HICO (past), as well as those of OLI, MSI, OLCI (present), and PRISMA (as a proxy for future hyperspectral sensors) over multiple geographic regions. These regions will include well-monitored U.S. coastal estuaries (e.g., San Francisco Bay, Chesapeake Bay) and select lakes and estuaries across Canada (e.g., Lake Winnipeg) and Europe (e.g., Lake Trasimeno and Venice lagoon in Italy). We will further devise novel methods to label each WQ and IOP estimate with uncertainty metrics for facilitating integrations of multi-source products. Our products will be demonstrated and shared with the community through our public webpage.

This research directly addresses the objectives outlined in the Remote Sensing of Water Quality program element, which requests proposals for algorithm developments to improve NASA's research and applied science activities related to WQ studies and monitoring. This project will enable the production of high-quality harmonized WQ products from a well-trained algorithm for quantifying and characterizing changes in water resources, as well as for advancing the use of satellite-based WQ products to address the United Nations Agenda 2030's Sustainable Development Goal 6, focusing on clean water and sanitation for all. Our algorithm can also be adapted for, and transferred to, future NASA missions or studies, such as the Surface Biology and Geology (SBG) Designated Observable (DO) and Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR), for generating consistent products at varying revisit frequencies.

Matthew Ross/Colorado State University
Understanding and Predicting Algae Blooms in Networks of Rivers and Reservoirs
21-RSWQ21-0007

Algal blooms are a major threat to human, ecological, and economic health. It is critical to quantify, understand, and predict algal blooms specifically in rivers and reservoirs given 68% of the US population relies on surface waters for drinking as well as other essential services such as power generation and wastewater disposal. However, algal blooms in river systems and their frequency, severity, and causes remain vastly understudied compared to other water bodies.

Understanding and predicting algal blooms in river systems requires a "network" perspective that takes into account hydrologic connectivity as well as variability in dominant controls over blooms such as river discharge, temperature, sunlight, and nutrients. No one approach-satellite observations, in-situ sensors, or modeling-can be used to both measure algal blooms and quantify the antecedent bloom conditions over both time and space. Therefore, we propose to close major methodological and conceptual gaps in remote sensing, machine learning modeling, and understanding algal blooms in rivers and reservoir using a cutting-edge monitoring platform that will provide chlorophyll-a (chl-a) observations (a proxy for algal blooms) at the spatial and temporal density required to understand why, where, when, and how riverine and river/reservoir algal blooms occur.

To accomplish this goal we will produce daily estimates of chl-a by fusing continuous sensor, grab sample, and environmental driver data (e.g. discharge, temperature, climate etc.) with Landsat OLI and Sentinel-2 observations of chl-a within a hydrologic-network-aware Process Guided Deep Learning model (PGDL, Jia et al., 2021). Our objectives include, 1) Build chl-a database across all rivers/reservoirs using satellite imagery. 2) Develop PGDL model fusing in-situ and satellite data to generate chl-a database with a daily temporal resolution and spatial resolution equal to the National Hydrography Database to identify algal bloom. 3) Interpret PGDL model to identify the antecedent conditions over time and space that lead to algal blooms. We focus on two bloom-prone systems: the Ohio River Basin and the Illinois River Basin. These are ideal locations to develop and test our approach since the Illinois Basin is a focal area for USGS Next Generation Observing System focused on blooms, and the Ohio River is relatively data sparse to test transferability of our approach. Our overarching science question is: what are the antecedent conditions over time and space that are linked to algal bloom occurrence and severity in rivers and reservoirs?

Our proposal is directly responsive to NASA Remote Sensing of Water Quality, specifically section 2.3 “Improving understanding of the link between optical and water-body properties”. The solicitation “highly encouraged” the use of remote sensing to understand the antecedent conditions causing algal blooms in inland waters, the focus of our work. Our long-term vision is to set the stage for a suite of operationalized products that use remote sensing to observe water quality across inland waters. Specifically, we will build the foundation for operationalizing a national, joint USGS-NASA, remote sensing/in-situ fused product of daily chl-a and algal blooms over inland waters that currently remain un-observed, with the ultimate goal of using this data for forecasting algal dynamics. Network-aware PGDL has the potential to identify very early warning signs based on upstream conditions. Further, our approach will be able to ingest future satellite imagery (e.g. Landsat 9/10, Surface Biology and Geology) and river discharge products from the NASA Surface Water and Ocean Topography (SWOT) mission, providing the inputs to potentially generate chl-a observations and short-term bloom forecasts for large rivers and reservoirs globally.

Daniel Sousa/San Diego State University
Mapping and Monitoring Coastal Wastewater Pollution Using Empirical Line Method-Based Atmospheric Correction and Manifold Learning-Based Data Fusion
21-RSWQ21-0012

According to the United Nations, over 1.8 billion people worldwide – largely in low-resource countries – are impacted by untreated wastewater. In the San Diego/Tijuana metropolitan area alone, this problem subjects over 5 million inhabitants and 35 million annual visitors to frequent beach closures and health impacts. Multispectral satellite imaging has been capable of detecting post-discharge eutrophication for decades, but this is of limited utility for municipal governments since it is an indirect indicator of past sewage contamination events. Hyperspectral remote sensing offers hope for near-realtime detection of environmental releases of wastewater, which would allow health officials to gain critical lead time in implementing beach closures – but applications cannot be developed without a feasible retrieval.

Two major hurdles to enabling this needed wastewater retrieval include: 1) accurate, operational atmospheric correction routines valid over the municipal region of interest, and 2) reliable optical signatures of direct or indirect indicators of untreated wastewater. We contend that recent advances in low-cost sensors and machine learning now allow both these hurdles to be overcome, enabling a key advance in the science and applications of coastal remote sensing.

We propose to overcome the first of these hurdles (atmospheric correction) by leveraging a fundamental property of impacted coastal waters: a fixed, synoptic-scale region of interest (ROI) defined by the location of point sources and plumes. This fixed ROI, along with recent advances in mini-spectrometer manufacturing, allows for an Internet-of-Things (IOT) in-situ radiance sensor network that can be used in deploying a highly accurate local atmospheric correction routine based on the empirical line method (ELM).

We propose to overcome the second hurdle (optical wastewater signatures) by developing a surrogate retrieval method that fuses data from an in-situ hyperspectral radiance sensor network with both satellite imagery and additional water quality monitoring measurements. The in-situ hyperspectral radiance network continuously collects spectra of surface and sky radiances, which are then fused with both satellite fly-over imagery and direct measurements of biophysical water properties (e.g. turbidity, fluorescent compounds, pigments, …), thereby extending the effective spectral observations of satellite imagery alone across the local region of interest.

Specifically, the proposed work will accomplish the following goals:

- Goal G1: Install and demonstrate proof-of-concept for empirical line method-based atmospheric correction using a network of low-cost, commercially available radiometric sensors at Imperial Beach and Boca Rio Estuary, San Diego, CA.

- Goal G2: Execute field spectroscopy experiments to quantify atmospheric and aqueous decorrelation length scales in estuarine and nearshore coastal waters of Imperial Beach and Boca Rio Estuary, San Diego, CA.

- Goal G3: Develop manifold learning-based surrogate methods and quantify retrieval accuracy of bacterial indicators from hyperspectral and multispectral satellite imaging.

- Goal G4: Coordinate with stakeholders in San Diego local government to disseminate results and integrate into their operational sampling strategy for beach hazard monitoring.

In summary, we will demonstrate how using a low cost IOT in-situ radiance sensor network can both improve the fidelity of product retrievals and extend the useful product range for both existing assets (Landsat-8, Sentinel-2) and future NASA Earth System Observatory missions like PACE and SBG. Further, by working with county and state partners in the San Diego region, we will demonstrate how these new operational remote sensing water quality products can improve the day-to-day activities of the local water managers and the safety of recreational users.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH21ZDA001N-ESI
A.23 Earth Surface and Interior

The National Aeronautics and Space Administration (NASA), Science Mission Directorate, Earth Science Division has selected new projects from the 2021 Earth Surface and Interior (ESI) focus area solicitation. The overarching goal of ESI is to use NASA's unique capabilities and observational resources to better understand core, mantle, and lithospheric structure and dynamics, and interactions between these processes and Earth's fluid envelopes. The 2021 solicitation called for proposals to address Innovative Solid-Earth Science and Strengthening ESI Community Knowledge and Skills. These studies will provide basic understanding and data products that inform the assessment, mitigation, and forecasting of natural hazards, advance our understanding of the solid Earth by exploiting the time-variable signals associated with other natural and anthropogenic perturbations to the Earth system, and refine our knowledge of Earth's shape, rotation, orientation, and gravity.

NASA received a total of 49 proposals and has selected 16 for funding. The total funding from NASA anticipated for these investigations is approximately $8.6 million over three years. The selected investigations are listed below, including Principal Investigator, institution, title, and abstract. Co-Investigators are not listed here.

Surendra Adhikari/Jet Propulsion Laboratory
Bedrock GNSS for Constraining Glacier Discharge and GIA in Greenland
21-ESI21-0011

Theoretical studies have shown that kinematic glacial waves travel downglacier following extreme climatological events such as excessive snow accumulation and intense surface melting (Nye, 1962, DOI: 10.1098/rspa.1960.0127). The Greenland Ice Sheet has already seen extreme summers, for example, in 2012 and 2019. While the conventional glaciological datasets lack the required spatiotemporal coherence, Adhikari et al. (2017, DOI: 10.1002/2017GL073478) developed a novel adjoint-based approach utilizing the continuous bedrock GNSS data to discover kinematic waves in Rink Glacier in 2012. As the intensity and frequency of extreme climatological events are expected to increase, glacial mass transport waves are likely to become a common phenomenon at the major outlet glaciers. It is unclear how such pulses of glacial mass transport affect the long-term dynamics and, eventually, the ice sheet's fate.

We propose further developing the adjoint-based technique that relies on the solid Earth as a natural filter for determining glacier mass changes year-round. In particular, we set to test a hypothesis that an optimally designed network of bedrock GNSS can provide continuous and near-real-time monitoring of ice and water discharge through Greenland outlet glaciers. The granularity of these observations may unmask competing processes that control ice-water dynamics over seasonal and interannual time scales. We also hypothesize that the same GNSS configuration can provide unprecedented constraints on glacial isostatic adjustment (GIA) at the glacier-basin-scale resolution, facilitating the advancement of more granular load models as well as the 3-D structure and rheology of underlying solid Earth.

We will begin our analysis with a systematic assessment of the current Greenland bedrock GNSS network (GNET) regarding its suitability and lack thereof to test these hypotheses. We will then formulate an optimization problem, constrained by available remote sensing datasets and ancillary model outputs, to determine optimal numbers and configurations of GNSS stations for major glaciers and glaciated regions in Greenland.

Greenland will likely be the dominant contributor to future sea-level rise over the next century. We anticipate that NASA, NSF, ESA, and Danish Space Institute will have an enduring commitment to mass transport observations and ferreting out the underlying physics involved during intensely warm summers with large melt expulsions. Therefore, the proposed research to develop a novel multi-station GNSS-based observing technique will have a lasting impact.

Geoffrey Blewitt/University of Nevada, Reno
Improving and Expanding GPS Data Products to Address Key Challenges of Solid Earth Science
21-ESI21-0042

We propose (1) to improve and expand solid Earth data products generated by the Nevada Geodetic Laboratory (NGL) using GPS data from over 19,000 stations; (2) to use those improved and expanded products to address 5 of the 7 key scientific challenges identified by the solicitation from the 2016 CORE Report ""Challenges and Opportunities for Research in ESI." NGL has for over a decade generated products from all the geodetic GPS data in the world that is publicly available. Currently this includes products for >19,000 GPS stations (with epoch intervals of 5 minutes and 24 hours) since January 1994. "Final" products are updated every week, "Rapid" products are updated daily, and "Ultra Rapid" products are updated every hour. Products include station coordinates and velocities in ITRF2014 and various plate-fixed reference frames, tropospheric parameters including conversion to integrated water vapor (IWV), quality control statistics, a step discontinuity database, and metadata.   We make NGL products freely available, and we advise scientific investigators on their usage. This often leads to interdisciplinary collaboration, pushing the intersecting boundaries of various disciplines, such as geodesy, tectonophysics, mantle structure and processes, magmatism, seismicity, climate variability, hydrology, and sea level.
(1) To improve and expand our GPS products, we have the following objectives:
• Improve all products by a complete reanalysis of all GPS data in the new framework of ITRF2020 (scheduled for late 2021), together with JPL's GPS orbits to be reprocessed in ITRF2020. Product improvement also results from improved models (e.g., antennas) in the ITRF2020 framework.
• Improve our IWV product using the latest ECMWF numerical models at higher resolution.

•	Improve interpretation of vertical coordinate time series by examining correlation with IWV on a spectrum of time scales. Improve treatment of extreme tropospheric conditions and events to mitigate systematic error on station positions, e.g., by using dynamic stochastic constraints.
•	Develop and generate new products including seasonal station motion parameters, inferred seasonal surface mass variation, time series corrected for surface mass loading, and time-series corrected for common-mode components. Use correlation between maps of seasonal GPS downward displacement and seasonal GRACE surface mass to identify which GPS stations can be used to infer mass variation accurately and which are most suitable for reference frames.
(2)	We will then apply these expanded and improved products to address key solid-Earth science challenges, specifically the first 5 of the 7 identified by the CORE Report. Examples include:
(2.1) Use time series corrected for loading to refine maps of tectonic strain rates in plate boundary zones; assess accuracy and opportunity for improvement by testing this in stable plate interiors.
(2.2) Use surface mass loading data to investigate seasonal seismicity at plate boundaries.
(2.3) Use time series corrected for loading to refine maps of vertical land motion, providing essential constraints on rates of relative sea level change, mountain uplift, crustal subsidence and flexure.
(2.4) Expand our published work on modulation of magmatism with variation in crustal strain at Long Valley and build on our discovery of plume-induced deformation at the Eifel volcanic field.
(2.5) Expand our published work on GIA by including horizontal as well as vertical time series, corrected for loading. Investigate modulation of GIA-induced horizontal velocity field caused by zones of lithospheric tensional weakness, such as the mid-Atlantic ridge.
Based on past experience, our project will have broader impacts arising from investigators in other disciplines who will apply our improved and expanded data products in novel ways. This project will also train a graduate student in the art and science of geodesy and interpretation of geodetic data.

Roland Burgmann/University of California, Berkeley
Incorporating Multi-Sensor Remote Sensing for Landslide Kinematics Characterization and Hydromechanical Modeling
21-ESI21-0034

Landsides are a natural geomorphic process yet a dangerous hazard, which causes thousands of casualties and billions of dollars in property losses on a global scale annually. Understanding landslide kinematics and mechanics, from early initiation to final deposition, is critical for monitoring, assessing, and forecasting landslide movement in order to mitigate their hazards. Slow landslides consistently damage infrastructures in their near vicinity, whereas sudden, catastrophic landslide failures pose escalated hazards to both infrastructures and human lives with extended spatial extents. Consequently, monitoring variable landslide motion dynamics, deciphering their underlying controlling factors, and generating insights for forecasting other similar hillslope failures serve as a critical approach for future hazard reduction.

Here, we propose to incorporate multi-platform and multi-sensor remote sensing to observe landslide motions and integrate hydromechanical modeling to characterize their kinematics. In particular, we will extensively utilize high-resolution satellite/airborne optical and radar images and airborne lidar Digital Elevation Models (DEM) through advanced quantitative techniques such as sub-pixel offset tracking and radar interferometry to capture landslide motion dynamics. Data from other satellite missions such as the GPM (Global Precipitation Mission) and the SMAP (Soil Moisture Active and Passive) and from airborne SAR (Synthetic Aperture radar) and ground meteorological instruments will be used for gauging landslide surface hydrology. Note that satellite missions usually offer global data coverage and hence enable investigating diverse landslides across variable clime zones and geological settings worldwide. Further, we will incorporate discrete element modeling to mechanically interpret the observed landslide kinematics and to further generate insights for evaluating and forecasting other similar landslides. Knowledge from hydrogeology, soil mechanics, and grain-flow mechanics will be integrated to decipher and model the impacts on landslide kinematics from precipitation-contributed pore pressure, soil shearing dilation and contraction, dynamic boundary friction, rupture propogation, and basal topography.

Existing studies from around the world have well documented the instigation of many natural hillslope failures by various triggers such as head loading, undercutting, and basal pore-pressure rise. However, movement evolutions after the early initiation are still relatively poorly understood for both long-term slow-moving landslides and catastrophic landslides. For example, the post-initiation dynamics of slow landslides may be strongly regulated by basal topography, dynamic rheological variations, soil shearing dilation and contraction, and evolving landslide boundary friction. The dynamic behavior of catastrophic landslides may present considerably variable precursory periods ahead of their final failure. Deciphering how landslide movement evolves under representative hydrogeological settings is critical for evaluating risks of slow landslides and establishing effective early warning systems for catastrophic landslides. We propose to approach these problems by combining satellite observations and discrete element modeling for about 50 slow-moving and catastrophic landslides in Americas and aim to generate new insights for enhanced landslide kinematics characterization and hazard mitigation.

Jingyi Chen/University of Texas, Austin
A Spaceborne Observatory Spanning Highly Active Subduction Zones in the Solomon Islands and Papua New Guinea
21-ESI21-0019

The Solomon Islands, New Britain, and the Mainland of New Guinea are located within the boundary zone between the Australian and Pacific plates. The overall high rates of oblique convergence (11 cm/yr) between the Australian and Pacific Plates through this region, combined with rapid rotation of both the Woodlark and South Bismarck Plates leads to a situation where the convergent margins in this region are among the fastest-converging and most seismically active subduction and collision zones in the Pacific (the San Cristobal Trench, ~9-10 cm/yr; the New Britain Trench, ~ 6-16 cm/yr; and the Ramu-Markham Fault, ~3-6 cm/yr). Because of the highly active tectonic settings, the Solomon Islands and Papua New Guinea region is an ideal natural laboratory to use satellite geodetic data for studying a wide range of slip behaviors on subduction megathrusts and their implications for natural hazards.

Since the mid-90s, researchers at University of Texas Institute for Geophysics (UTIG) have been using terrestrial-based GPS and coral paleogeodetic data to study surface deformation associated with tectonic processes at the Solomon Islands, New Britain, and elsewhere in Papua New Guinea. Because the study area is hard-to-access, the acquisition of field data has been somewhat limited (e.g., Tregoning et al., 1999; Wallace et al., 2004, 2014; Biemiller et al., 2020), and the existing GPS and coral data coverage is sparse. We propose to remedy this by using spaceborne Interferometric Synthetic Aperture Radar (InSAR) techniques to map surface deformation with improved spatial coverage spanning this highly active subduction system. In addition to the relatively high convergence rates on this system, there are frequent, large (Mw >7.5) earthquakes in this region, offering outstanding opportunities to investigate deformation processes throughout the earthquake cycle. Because of the tropical, highly vegetated setting, the proposed study site is considered challenging for InSAR analysis, and the existing InSAR observations across this three-plate boundary are scarce. Our preliminary analysis shows that the recent dramatic improvement in Sentinel-1's temporal sampling rate has made it possible to obtain coherent interferograms over the most densely vegetated tropical islands. The proposed work is a timely pilot study for the upcoming NISAR mission, which will further improve our ability to use space-based remote sensing to investigate tectonic deformation in highly vegetated regions.

We will build on UTIG's long-term efforts to acquire geodetic data in the Papua New Guinea-Solomon Islands region, with the intent of providing a new and improved way of leveraging existing knowledge to obtain a comprehensive InSAR surface deformation dataset. The availability of this dataset will allow us to develop a better understanding of the relationship between surface deformation and the processes that control interplate slip (seismic and aseismic) at subduction zones. A key component of the project will undertake numerical modeling to investigate rheologies and fault zone processes that may control the observed deformation and earthquake cycle processes. The proposed work will advance InSAR time series analysis techniques and generate critical observations for evaluating potential tsunamigenic potential, and benefit hazard assessment in a region of the southwest Pacific that is heavily exposed to geohazards, but where such hazards remain ill-characterized.

Yuri Fialko/University of California, San Diego
Tracking Deformation Transients on the Southern San Andreas Fault Using Precise InSAR Measurements

21-ESI21-0012

We propose to analyze a suite of space geodetic observations along the Southern San Andreas fault (SSAF) in California to investigate the spatio-temporal evolution of shallow creep that occurred since 2015, including a slow slip event triggered by the 2017 M8.2 Chiapas (Mexico) earthquake. We will combine large InSAR data sets from Sentinel-1 and ALOS-2 missions (on the order of 10^3 acquisitions from diverse look directions) with continuous and campaign GNSS data to generate high-resolution maps of surface displacements around the SSAF revealing the details of the ongoing deformation transient. The InSAR data analysis will include evaluation of errors introduced due to multi-looking and filtering of radar phase in the presence of phase decorrelation. We will apply an efficient algorithm for correcting the respective errors, thereby increasing the accuracy of measurements of subtle deformation signals. We will also perform a comparative analysis of the ""phase closure"" errors for Sentinel-1 (C-band) and ALOS-2 (L-band) data. Results of this analysis will be relevant to the observation strategy and data products of the upcoming NASA's L-band InSAR mission (NISAR). To validate the InSAR-derived displacement time series and provide independent measurements of surface creep, we will conduct a GNSS survey of a dense profile of geodetic monuments crossing the SSAF trace in Painted Canyon (Mecca Hills, CA).

We will invert the time series of surface displacements to constrain the spatio-temporal evolution of creep on the SSAF. The inferred slip history will be used to inform models of earthquake cycle with rate- and state-dependent friction to constrain the key rate and state friction parameters and their variation with depth; moment accumulation rate; and recurrence interval of large events. Both the data processing and inverse modeling are computationally demanding but fortunately avail themselves for parallel execution. We are requesting access to the High-End Computing (HEC) resources at NASA to take advantage of our recently developed computational framework for processing and analysis of rich catalogs of InSAR data. The proposed research is directly relevant to the Earth Surface and Interior (ESI) general focus area (assessing, mitigating, and forecasting the natural hazards that affect society, through understanding of the Earth's surface and interior structure and dynamics), as well as the specific focus of the ROSES-2021 solicitation (innovative hypothesis-driven scientific research addressing the seven scientific challenges from NASA's CORE Report and the NAS Decadal Survey). Results of the proposed data analysis will be used to address a number of outstanding problems, including the mechanisms and time scales of unsteady slip on seismically active faults, the associated stress and strain transfer in the seismogenic crust, and transient response of the Earth crust to stress perturbations. Physically-based models of shallow fault creep constrained by space geodetic data will help forecast the evolution of stress and strain within the seismogenic zone, and provide useful input for time-dependent seismic hazard estimates. Surface displacement data and modeling tools developed under the auspices of this project will be made available to a broader research community. The proposed work will result in an improved understanding of interseismic strain accumulation, earthquake recurrence, and time-dependent aspects of seismic hazard due to Southern San Andreas Fault, the most seismically hazardous fault in California.

William Frank/Massachusetts Institute of Technology
Teasing Out the Hidden Complexities of Slow Slip from the Geodetic Record in Cascadia
21-ESI21-0027

Continuous GPS monitoring of the Cascadia subduction zone led to the discovery of slow slip almost two decades ago. We now know that this type of slow rupture accommodates a significant portion of the convergent plate motion, upending our conceptual model of the tectonic slip budget at major plate boundaries. In Cascadia, slow slip happens every 14 months beneath Puget Sound, releasing as much built-up tectonic stress as a M6.7 earthquake. Given slow slip’s proximity to the site of a future megathrust earthquake in Cascadia, its impact on the earthquake cycle is essential in forecasting the regional seismic hazard in the Pacific Northwest.

Geodetic images of slow slip are our principal record of the evolution of slow slip along the Cascadia margin, but the underpinning inversion for slip on the plate interface is a constant battle between observational uncertainties and the spatiotemporal resolution of the slip model. Slow slip models driven by GPS observations are suggestive of non-trivial rupture patterns, but the recovered complexity is severely limited by the observational uncertainty of GPS-captured surface motion. Slow slip is systematically accompanied by colocated, repetitive low-frequency earthquakes. The precise timing and locations of this seismic proxy of slow slip perfectly complement the moment release that is well constrained by GPS.

In this context, our research will focus on when, where, and how does slow slip release tectonic stress downdip of the Cascadia megathrust? We will address these fundamental questions by developing a novel multidisciplinary approach, systematically integrating low-frequency earthquake seismicity with the continuous GPS record to impose crucial spatial, temporal, and moment rate constraints on geodetic slip models of slow slip. This approach will allow us to reduce and potentially avoid the impact of the non-physical constraints, such as imposed slip rate time functions and spatiotemporal smoothing, that are typically imposed on geodetic models of slow slip. This will allow us to unravel the evolution of slow tectonic release with unprecedented resolution over two decades across the Cascadia subduction zone, allowing us to pinpoint which portions of the subduction zone are building towards a major earthquake.

This research directly addresses Challenge 2.1 of NASA’s Challenges and Opportunities for Research in ESI (CORE) [2016]: ``What is the nature of deformation associated with plate boundaries and what are the implications for earthquakes, tsunamis, and other related natural hazards?''. We will leverage seismological information to exploit NASA's GNSS data products to a greater extent than has previously been possible with the goal of shedding light on the nature of slow deformation and its impact on the slip budget at tectonic plate boundaries. Such a multidisciplinary strategy will be applicable to other geological contexts where transient aseismic slip plays a significant role in the deformation of the Earth’s crust.

Pavel Inchin/Embry-Riddle Aeronautical University, Inc.
Inferring the Source Processes of Earthquakes from Their Acoustic-Gravity Wave Impacts on the Atmosphere
21-ESI21-0043

Due to the contact of material particles at solid/water-air interfaces, the mechanical energy generated within the earth and ocean interiors leaks into the atmosphere in the form of acoustic and gravity waves (AGWs, or more specifically coseismic acoustic waves, CAWs). Recent advances in the understanding of these coupled processes suggest pathways towards the incorporation of in-situ and remote observations of earthquake-induced CAWs into the analyses of their sources. These datasets have a potential to provide information on spatial and temporal evolutions of tsunamigenic or complex earthquakes, which in cases cannot be inferred from classical ground- and space-based seismic or geodetic datasets.
However, the robust interpretation of earthquake-induced CAW signals still remains challenging due to the complexity of the underlying dynamics that must be appropriately described. Modeling this coupled system is indeed a major difficulty, leading to a lack of reproducibility and validation of observational studies. The analysis of CAW dynamical characteristics under a wide range of conditions, suitable for the constraining of earthquake rupture processes, is necessary prior to the incorporation of new datasets into Earth Surface and Interior applications. The need also remains to explore the uncertainties and non-uniqueness of model parameters.
We propose, for the first time, a comprehensive parametric and case modeling and data-driven studies to address the following Scientific Questions:
1. Which characteristics of earthquake kinematics and dynamics (i.e., source properties, temporal and spatial evolution of rupture and its surface interaction) can be constrained with TEC observations of CAWs?
2. How do topography and the focal region affect CAW excitation and their ability to reach ionosphere and to drive detectable and quantifiable TEC signals?
We will use our recently improved (partially in NASA ESI 80NSSC20K0495 project) three-dimensional multi-species atmospheric and ionospheric numerical models MAGIC and GEMINI, coupled with fault rupture and seismic wave propagation model SPECFEM3D and SeisSol, specifying realistic dynamic and kinematic fault processes. Our state-of-the-art, full-physics-based, highly scalable modeling capabilities allow investigation of a broad spectrum of earthquake-induced CAWs (at sub-minute and sub-kilometer resolutions) and simulation of their nonlinear evolution at unprecedented levels of detail, as well as specification of realistic background atmospheric and ionospheric states. The studies will address a broad range of earthquake source characteristics, investigating the dynamics at near-epicentral and far-field regions.
The remote atmospheric datasets for the validation of modeling results include recently available high-rate (>=1Hz) Global Navigation Satellite System signal-based total electron content (TEC) observations. Ground/ocean-level observations include in-situ and remote seismic and geodetic and ocean datasets for the validation of earthquake source modeling results.

The proposed interdisciplinary project addresses relevant topics of the amended A.23 solicitation. We will study and suggest new and innovative ways of investigation of the solid Earth interaction with the broader Earth system. These studies will open up new opportunities for utilizing existing and future atmospheric and ionospheric observations to better understand earthquake source processes, and to supplement tsunami early-warning systems. As a result, the outcomes of the project will provide the fundamental understanding of interactions between Earth's fluid envelopes, as well as of forecasting of natural hazards, including earthquakes and tsunamis.

Rowena Lohman/Cornell University
Augmentation of InSAR Time Series Analysis with SAR Intensity and Optical Data; A Path to Improved Deformation Mapping
21-ESI21-0032

Interferometric Synthetic Aperture Radar (InSAR) has been widely used over the past few decades to examine ground displacements associated with earthquakes, volcanoes, landslides, and human activity in a range of environments. As data from new satellites has become available, the quality of these observations has improved dramatically, with precisions of a few mm/yr now achievable in areas with certain land cover/land use types. However, other regions continue to present significant challenges to the use of InSAR - areas with agriculture or heavy vegetation tend to not only have a larger noise level overall but can also have biases associated with soil moisture and vegetation variability. Many of these regions are also sites of ground deformation signals of interest to society, including those associated with groundwater withdrawal in intensively cultivated areas such as the Central Valley of California.

We propose to examine how the inclusion of SAR intensity information can augment InSAR deformation time series analysis. We will also explore how the use of vegetation indices derived from optical imagery can enhance our ability to separate the ground deformation signal from other contributions to the InSAR phase. Changes in surface moisture, i.e., soil moisture and water content of vegetation, impact SAR intensity as well as InSAR phase, to a degree that depends on the scattering properties of the surface. The surface moisture contribution to the InSAR phase is often correlated with SAR intensity changes, suggesting that SAR intensity could serve as a proxy for the components of phase that are not due to ground deformation. The effectiveness of this proxy depends on the scattering mechanism that dominates the backscattered signal for a given pixel. We observe strong correlations between intensity and phase changes in interferograms in our study area over both bare soil and moderately vegetated areas. In these locations, changes in dielectric contrast dominate the backscattering behavior and the intensity change can be used to mitigate or assess the contribution from moisture-induced phase changes. However, if changes in the size and position of scatterers dominate backscattering, the intensity and phase changes may show no significant correlation. We will examine the correlation between InSAR phase and SAR intensity in two agricultural regions in California and will use InSAR coherence and vegetation indices from optical data as a means of evaluating the dependence on land cover types.

The proposed research would improve InSAR-based deformation measurements by reducing soil/vegetation moisture induced phase artifacts through the inclusion of SAR intensity, InSAR coherence and optical observations. This work will advance NASA's pivotal role in space geodesy and respond directly to the focus areas of this NASA/ESI solicitation by developing new methods and associated science to improve the mapping of ground deformation associated with plate boundaries, landslides, volcanoes, land subsidence, and human activities. This research addresses NASA's core scientific challenges; "What is the nature of deformation associated with plate boundaries and what are the implications for earthquakes, tsunamis, and other related natural hazards? How do tectonic processes and climate variability interact to shape Earth's surface and create natural hazards? How do human activities impact and interact with Earth's surface and interior?" In addition, this study will contribute the scientific, economic, and social values of the future NISAR mission. The algorithms and developed codes will be freely available to the science community.

Jeremy Maurer/University of Missouri, Rolla
Testing for Active Subduction off Northern Hispaniola with Geodetic Data and Crustal Deformation Modeling
21-ESI21-0045

The island of Hispaniola, including the countries of Haiti and the Dominican Republic, has hosted large and disastrous earthquakes in the past, including the 2010 Haiti earthquake. There is a considerable earthquake hazard due to its location on the transpressive boundary between the North American (NA) and Caribbean (CA) plates. Deformation is partitioned between north-south convergence and slip on two major transform faults, namely, the Septentrional-Oriente Fault Zone (SOFZ) and the Enriquillo-Plantain Garden Fault Zone (EPGFZ). North-south convergence may be accommodated by the Trans-Haiti Thrust Belt (THB) and/or the Northern Hispaniola / Haiti Fault (NHF), a westward extension of the Puerto Rico subduction zone (Calais et al., 2016; Rodríguez-Zurrunero et al., 2020). The convergence between the NA and CA plates at ~18-20 mm/yr has resulteresulted in the development of a complex tectonics with strain partitioning in Hispaniola (e.g., Mann et al., 1995, 2002; Calais et al., 2002; Ten Brink and Lin, 2004; Jansma and Mattioli, 2005; Ten Brink and Lopez-Venegas, 2012). These fault systems pose a significant hazard to the population, and the sparsity of on-land geodetic observations makes investigation through remote sensing methods ideal. In addition, the area presents a unique opportunity in that there is a transition from oblique subduction, to oblique collision, to purely transform tectonics moving from east to west (e.g. Calais et al., 1992; Dolan et al., 1998; Calais et al., 2016), corresponding to a change in fault locking inferred from geodesy (Symithe et al., 2015) and a change in tectonic regime (Calais et al., 2016). The unusually close distance between land and trench compared to other subduction zones, combined with the modern availability of remotely-sensed geodetic data, provides an excellent opportunity to study the transition and the interactions between the subduction zone and other faults in Hispaniolaon the island.

We propose to investigate the transition from active subduction to collision on the NCM using remotely-sensed and ground-based geodetic observations (InSAR, GNSS, tide gauges) and modeling strain accumulation and stressing rate across the island. We will develop geodetic deformation models for the island, compare with geologic deformation data including published uplift rates and timing, and assess implications for future hazard from earthquakes, tsunamis, and coastal VLM. This project will result in an updated surface deformation map and an improved understanding of tectonics and seismic hazard in Haiti, which we will make publicly available in online archives and publications. We will be contributing to and updating an existing regional fault model, CCAF-DB: the Caribbean and Central American active fault database (Styron et al., 2019). Finally, we will develop and use open-source software tools for combining InSAR, GNSS, and tide gauge data sets, which we will contribute to the public domain, enabling future advances in data analysis from multiple remote sensing platforms for the solid earth, landslides, SLR, and hydrology communities.

Diego Melgar/University of Oregon
Forecasting Earthquake Shaking Intensity and Tsunami Amplitude from Crustal Deformation Patterns with Machine Learning
21-ESI21-0004

Large earthquakes produce significant hazards to people and infrastructure through strong shaking and inundation from tsunami waves. In the United States alone, annualized losses expected from strong shaking are ~5 billion dollars (Jaiswal et al., 2015). Meanwhile, large tsunamis continue to exact an onerous toll. The tsunami from the 2004 M9.2 Sumatra earthquake led to ~250,000 casualties (Doocy et al., 2007). The problem is not restricted to developing nations alone. The tsunami from the 2011 Tohoku-oki earthquake in Japan, arguably the best prepared nation for earthquake hazards, led to ~20,000 casualties.

To defend against this, societies rely on a combination of science, engineering, and public policy, all of which must function in synchrony to be effective against mitigating risk. From the scientific standpoint, early warning systems which leverage cutting-edge geophysical knowledge about earthquake rupture processes, and tsunami and elastic wave propagation are being widely adopted worldwide. As many as 15 independent national earthquake early warning (EEW) systems have been documented. Tsunami early warning (TEW) meanwhile, has a slightly more complex, but also vigorous ecosystem of both national and international systems.

In spite of this enthusiasm for funding and building warning systems, critical knowledge gaps of both fundamental and applied science remain. Perhaps the largest open basic science question is whether large (M8+) earthquakes are deterministic in nature. That is, do earthquakes know how large they'll grow prior to achieving their final size? If so, when within a minutes long rupture process is a very large earthquake distinguishable from an only large one? The existence of any determinism (or lack thereof) conditions the next challenge. If any determinism exists, how can it be measured and identified? And this leads to the final fundamental issue; if and when the earthquake has been characterized, can shaking and tsunami amplitudes be accurately forecast for critical locations (e.g. population centers or critical infrastructure sites) on short timescales that have utility for warning?

While debate is ongoing, recent work has coalesced around the concept of “weak determinism”; large ruptures can be characterized, at a minimum, ~25-50% of the way through the rupture process. Furthermore, it has been convincingly shown that near-field measurements of crustal deformation from high-rate global navigation satellite system (GNSS) data can be used to extract these signals. However, how to do so in real-time remains challenging because large ruptures can be very complex. To compound this difficulty, while real-time GNSS positions have improved in quality, they are still noisy enough that they can limit the earthquake magnitudes for which they are useful and lead to lower resolution models. Fortunately, machine learning approaches that use physics-driven simulations to build the training data sets, have shown promise in addressing these challenges.

Building on recent progress, this proposal addresses the final question. In a real-time setting, earthquake parameters (magnitude, depth, etc.) are less important than estimates of the hazards. Our hypothesis is that for large earthquakes time-varying crustal deformation patterns encode information that can be used to estimate shaking intensities and tsunami amplitudes. Further, that deep learning techniques can be used to extract this information from noisy data and use it to forecast the hazards, before they affect locations of interest. Here we detail an approach to forecasting both shaking intensities and tsunami amplitudes using advanced data science techniques. We discuss strategies for validation that rely on both real events and simulations. Importantly, we argue for the need of deep-learning based denoising of real-time GNSS and discuss how advances by seismology in this field can be used and modified for geodesy.

Vincent Realmuto/Jet Propulsion Laboratory
Inferring Eruption Processes from the Composition of Volcanic Plumes
21-ESI21-0009

Our investigation targets Section 2.1, Innovative Solid-Earth Science, of ROSES-2021 Appendix A.23, Earth Surface and Interior, and follows the Programmatic Guidelines in Section 3. Specifically, we will test the novel hypothesis that evolving eruption and plume dispersion pro-cesses, together with changes in magma composition, can be reconstructed through the detection and tracking of changes in the composition of gas emissions and eruption plumes. We will make substantial use of remote sensing data, mapping plume composition through the analyses of multispectral and hyperspectral observations collected with a suite of airborne and satellite instruments.
Volcanic plumes can contain sulfur dioxide gas (SO2), sulfate (SO4) aerosols, and fragments of crystalline rocks (volcanic ash) and glass (erupted juvenile material). The concentrations of SO2, together with the composition, size, shape, and mass

concentrations of particulates (SO4 aerosols, ash, or glass) in plumes are direct expressions of eruption processes, magma composition, and the dispersion/chemical evolution of plumes. Synoptic remote sensing, from aircraft or satellites, is the most practical means for mapping the airborne components of plumes and tracking changes in plume composition over time and space.
We will analyze records of airborne and satellite data for eruptions of Kilauea Summit (2017 and 2018), Chaitén (Chaitén-2008) and Eyjafjallajökull (Eyjaf-2010) volcanoes These eruptions are ideal case studies for our investigation, as the comprehensive monitoring and investigation of these events has resulted in numerous publications describing the eruption processes and related phenomena. This literature will facilitate our efforts to correlate our records of plume composition with eruption and plume dispersion processes.
Our investigation of the Kilauea Summit eruption will focus on the dispersal and rapid chemical evolution of SO2 plumes emitted from the summit vent. We will analyze data collected during airborne campaigns to Kilauea in 2017 and 2018. These campaigns featured multispectral imaging with the MODIS-ASTER Airborne Simulator (MASTER), and hyperspectral imaging with the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) and, in 2018, Hyperspectral Thermal Emission Spectrometer (HyTES).
Our investigation of Chaiten-2008 will focus on changes in plume composition due to the transition from explosive to effusive activity punctuated by episodes of dome collapse. For Eyjaf-2010, we will focus on changes in plume composition due to transitions between phreatic and phreatomagmatic eruption phases, together with changes in magma composition over the course of the eruption. We will analyze the records of satellite data collected by the Atmospheric Infrared Sounder (AIRS), Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), and Moderate-Resolution Imaging Spectrometer (MODIS). Our investigation of the Chaitén-2008 and Eyjaf-2010 ash plumes will be founded on spectroscopic, chemical, and crystallographic analyses of samples of volcanic ash prepared and curated at the University of Pittsburgh’s Image Visualization and Infrared Spectroscopy (IVIS) facility.

Bertrand Rouet-Leduc/Geolabe LLC
Autonomous Detection of Fault Deformation in InSAR Time Series Using Deep Learning (Geolabe)
21-ESI21-0051

An outstanding goal of the geoscience community is to exhaustively observe and study slip phenomena on faults, in order to better understand fault processes, shed light on the interplay between slow and fast earthquakes, and better characterize earthquake nucleation. Provided it can be systematically and automatically analyzed, Interferometric Synthetic Aperture Radar (InSAR) is poised to play a crucial role in this search for the full spectrum of slip modes on faults. InSAR is routinely used to measure ground deformation due to hydrologic, volcanic, and tectonic processes. Rapid, large-amplitude deformation signals such as co-seismic displacement fields often exceed the amplitude of other known sources of noise. Similarly, slow but steady accumulation of deformation over long periods of time may be quantified using InSAR either through stacking or time series analysis. However, detecting low-amplitude deformation related to transient sources such as slow earthquakes, episodes of volcanic activity or hydrology related motion remains challenging and requires significant human intervention and interpretation. The possible continuum of slip behaviors that may exist between steady creep on faults and large dynamic ruptures (and encompasses slow earthquakes) therefore remains largely out of reach due to tropospheric turbulences, that create spurious apparent deformation often much larger than transient deformation of interest.

The launch of the Sentinel 1 constellation provides systematic radar mapping of all actively deforming regions in the world with a 6 to 12-day return period. The rapidly upcoming launch of the NISAR mission will be a game changer, as it adds a 12-day return global coverage at even higher spatial resolution and two frequency bands. Such wealth of data represents an opportunity as well as a challenge that has yet to be met. In order to expand the detection and characterization of all slip events to a global scale, we propose to develop a tool based on machine learning algorithms automatizing detection capabilities of all data types, including Sentinel 1 data, to build time series of ground motion.

Over the past 2 years we have developed a deep auto-encoder architecture tailored to untangle ground deformation from noise in InSAR time series, that autonomously extracts deformation signals, without prior knowledge of the deforming systems (e.g., fault location). In preliminary results of the approach, applied to InSAR data over the North Anatolian Fault, our method reaches 2 mm detection, revealing a slow earthquake twice as extensive as previously recognized.

The proposed work has two objectives: (i) develop a framework for generating realistic synthetic InSAR time series, with the goal of dramatically improving our denoising prototype, (ii) detect ground deformation transients from noisy InSAR time series at large scale, with the aim of improving our understanding of slip phenomena in general, and transient events in particular.

Our new methodology aims at detecting ground deformation automatically at a global scale, with a much finer temporal resolution than existing approaches, and a detection threshold of a few millimeters. Equipped with autonomous detection of deformation on faults, we will have a tool that will help close the gap in existing detection capabilities and form the foundations for a systematic exploration of the properties of aseismic slip along active faults.

Gregory Tucker/University of Colorado, Boulder

Using NASADEM to Understand Feedbacks Among Landslides, Topographic Evolution, and Sediment Dynamics Across Tectonic and Climatic Regimes

21-ESI21-0047

Landslides are among Earth’s most destructive hazards. On short timescales, observational records and remotely sensed data enable us to indicate regions susceptible to landsliding. However, little is known about the longer-term interplay between landslides, sediment dynamics, and the topographic evolution of Earth’s surface. Yet such understanding is fundamental to quantifying how climate variability or large earthquakes in any given mountainous terrain will influence landslide activity and consequent downstream impacts.

This project will test the hypothesis that mountainous landscapes encode, in their topography and sediment dynamics, signatures of the landsliding processes that help shape them. This encoding provides a way to test mechanistic theory of landslide frequency, magnitude, and sedimentary impacts, and such theory in turn can help us understand how a given landscape may respond to a change in climate or the occurrence of large, rare earthquakes. An integrated, dynamic model of landsliding and sediment transport would enable prediction of downstream impacts such as valley sedimentation, river damming, and changes to flood risk. To test the above hypothesis, we propose to develop a numerical model of long-term landscape evolution, and test the model using NASADEM and other remotely sensed data.

We propose the following objectives: (1) Develop SLIDESCAPE, a long-term Landscape Evolution Model that accounts for the dynamic interplay among landslide activity, soil fluxes, river incision, and sediment dynamics. (2) Extract topographic metrics from NASADEM data for four case study sites that span a range of tectonic and climatic regimes (NW Pacific, Taiwan, New Zealand, Appalachians). (3) Evaluate necessary and sufficient conditions required to reproduce these metrics in the model. (4) Evaluate the degree to which SLIDESCAPE can reproduce observed patterns of sediment distributions (e.g., dated landslide deposits in the North Western Pacific). (5) Test SLIDESCAPE's capability to simulate the frequency and magnitude (area-volumes) of both earthquake-triggered and storm-triggered landslide events using remotely sensed NASA products and datasets (NASADEM, GLDAS, event imagery products from ARIA) documenting well-constrained events such as the Gorkha 2015 earthquake and the 2020 Hurricane Eta. (6) Evaluate the sensitivity of the study sites to future environmental change in terms of landslide frequency and magnitude, sediment dynamics, and potential flood risk due to river sedimentation.

The project will contribute to understanding the distinctive role of landsliding in shaping mountainous terrain by tectonic and geomorphic processes, which will in turn contribute to understanding how tectonically active landscapes respond to climate and tectonic (seismic) variability. These goals are directly relevant to the CORE report challenge of understanding "how do tectonic processes and climate variability interact to shape Earth's surface and create natural hazards". SLIDESCAPE supplements the empirical work on landslide dynamics in the natural hazard focus area and provides a fundamental underpinning of landslides dynamics on geologic timescales, thereby providing NASA with an additional tool to evaluate the impact of earthquakes and intense storm events on landslide occurrence and their implication for large-scale sediment dynamics.

Shimon Wdowinski/Florida International University
Coastal Vertical Land Motion and Its Implication to Coastal Flooding Hazard Assessments

21-ESI21-0038

Vertical land motion (VLM) is a term used by the oceanographic community to describe/quantify the contribution of solid Earth movements to tide gauge measurements of relative sea level change. The oceanographers, who are interested in quantifying the oceanic component of sea level change, view VLM as 'noise' that needs to be removed from the measurements. In the geodetic community, VLM is termed 'coastal subsidence or uplift' and is measured using the same techniques as inland vertical movements. Quantifying VLM is also very important in assessments of coastal flooding hazard, as the exposure of coastal communities to sea level rise is affected by both actual sea level rise and VLM, especially when the motion is of subsidence. The goals of this proposed research are: (1) quantify VLM along selected shorelines (US Atlantic, Gulf, and Pacific coasts), (2) model the deformation based on spatial and temporal characteristics of the observations, (3) project VLM into the future, to the time frame of most sea level rise projections (until the end of the century or 2120), in order to provide decision-makers a better assessment of the VLM contribution to coastal flooding hazard, and (4) measure VLM at tide gauges, in order to better determine the oceanic component from the measured relative sea level change.

The proposed project aims at monitoring, modeling, and projecting VLM along selected coastlines. The monitoring component will be designed to detect movements at multiple temporal and spatial scales, because VLM is the surface expression of various natural (tectonics, GIA, sediment compaction, surface loading) and anthropogenic-induced (fluid extraction, shoreline reclamation) processes; each process occurs at different characteristic spatial and temporal scales. We will use GNSS measurements, which are acquired at distances of several to tens of km apart, to detect regional-scale (10-500 km) VLM signals and InSAR observations to detect the local-scale (<10 km) signals. InSAR measurement will also be used to measure the stability of GNSS monuments and tide gauges, which can be locally anomalous. The modeling part of the project will be based on temporal characteristics of the observed VLM, as follows: (1) Time-independent movements induced by GIA, sediment compaction, and inter-seismic deformation, will be modeled using observed linear rates. (2) Local-scale time-dependent movements induced by soil consolidation in urban areas will be modeled using a hyperbolic consolidation model. (3) Time-dependent movements induced fluid extraction and surface loading will be estimated using the observed variability in GNSS time series. (4) Time-dependent co-seismic vertical movements will be estimated based on published modeling results. All models and estimates will be used to calculate and project VLM until 2120, in order to improve assessments of regional coastal flooding hazards along the selected coastlines.

Significance:
Two decades of rapid increase in relative sea level has resulted in increased frequency of coastal flooding, which affected millions of people living in coastal communities. The proposed research aims at quantifying regional- and local-scale geodetic observations of coastal VLM and evaluating their contribution to coastal flooding hazard along the selected coastlines. The project will produce VLM projections for the next 100 years,

which will be provided to coastal flooding hazard advisory committees (e.g., SE Florida, Maryland) in order to generate improved recommendations on coastal flooding hazard to state- and local-level governments.

Clark Wilson/University of Texas, Austin
The Quasi 6-Year Oscillation in Earth Rotation, Deformation and Gravity Field and Connections with Surface Mass Load and Core-Mantle Interactions
21-ESI21-0006

Accurately measured Earth rotational changes provide a measure of global scale mass redistribution and movement in the Earth system, and likely interactions between the core and the mantle. Surface deformation observations from the global positioning system (GPS) network offer a means to study load change from mass variations in the climate system and connections between global scale deformation and Earth rotational dynamics. A quasi 6-year oscillation (SYO) (at period of ~ 5.9 years) has long been observed in the axial component of Earth rotation, i.e., length-of-day (LOD) observations. Observed geomagnetic secular variations (SV) reveal similar periodic signatures. Recent studies have confirmed that the SYO also exists in polar motion (PM), the equatorial components of Earth rotation. A similar SYO has been discovered in GPS surface deformation observations by a few previous studies based on analyses of global GPS measurements. Interestingly, the SYO was recently discovered in the analysis of sectoral degree-2 spherical harmonics of the gravity field observed by satellite laser ranging (SLR) and the Gravity Recovery and Climate Experiment (GRACE) satellite gravimetry.
The exact driving forces of these quasi SYOs are unknown, although interactions between the core and the mantle have been speculated as the likely origin. However, previous studies suggest that surface mass load and motion terms of the climate system also exhibit notable SYO signals, although not showing enough power to explain the observed SYOs. The coexistence of the SYO in both the axial and equatorial components of Earth rotation, global GPS deformation, gravity field, geomagnetic field and climate system provides a unique chance for us to better understand the driving forces of this oscillation, such as the geophysical connections with mass load changes in the surface geophysical fluids system (including the atmosphere, ocean, and hydrosphere) and possible contributions from interactions between the core and mantle.
We propose to carry out a comprehensive investigation of the SYO in the Earth system using extended records of Earth rotational observations, global GPS data, SLR and GRACE and GRACE Follow-On (GFO) gravity solutions, mass load estimates from advanced climate models (for the atmosphere, ocean, and land hydrology), and core-mantle interactions derived from geomagnetic data assimilations. The main objectives include:

1) To improve the quantification of the SYOs in LOD and PM and climate (atmosphere, ocean and hydrosphere) excitations, and determine the SYOs in LOD and PM that are likely related to the core and mantle.
2) To improve the quantification of the SYO in GPS deformation and mass loading using extended record of global GPS series and outputs from advanced climate models,

and identify the SYO (spatial mode, amplitude and phase) in GPS deformation that is likely driven by core and mantle interactions.
3) To improve the quantification of the SYO in low-degree gravitational changes observed by SLR and GRACE/GFO and estimated from mass loading of the climate system using model outputs, and isolate the SYO in the gravity field that is connected to the core and mantle.
4) To improve the understanding of angular momentum exchanges, deformation and gravitational interactions between the core and mantle at sub-decadal scales through geomagnetic data assimilation using improved observational constraints from the above analyses.
The proposed investigation is in the Innovative Solid-Earth Science focus of this ESI solicitation, by understanding the solid Earth response to global scale mass load changes and core-mantle interactions. It directly addresses the science goals specified in NASA's Strategic plan and in ESI CORE report (e.g., No. 3 & 5. "How does the solid Earth respond to climate-driven exchange of water among Earth system …?", "What are the dynamics of Earth's deep interior and how does Earth's surface respond?")

Xiaoping Wu/Jet Propulsion Laboratory
Consistent Global Ocean Tide Loading Determination from GNSS
21-ESI21-0007

Ocean tides and their loading effects on solid Earth contain significant signals in space geodetic data. These can alias into various non-tidal signals of interest and present serious challenges to studies of other oceanic and solid Earth phenomena if not removed correctly. On the other hand, measurements of ocean tide loading offer unique opportunities to learn more about ocean tides and the Earth's rheological properties with a particular advantage of known forcing frequencies. Currently, ocean tide models and their loading effects are less well constrained in the polar oceans, shallow seas, and coastal waters. The loading effects have not been consistently determined with regard to satellite orbits, reference frame, and rotational pole due to various technical limitations. In particular, geocenter motions due to ocean tides remain not well determined.

Recently, rapid advances in Global Navigation Satellite Systems (GNSS) technology have occurred including the emergence of several new GNSS satellite systems with different orbit and repeat periods, more accurate background and spacecraft models, absolute ground- and space-based antenna calibrations, and long orbit arcs. With such impressive progress and much better computational resources, we seek to use more than 10 years of high frequency global GNSS data and JPL's GipsyX software to determine ocean tide loading precisely. Geocentric station displacements of a well-distributed global network, Earth orientation variations, and GNSS orbits and clocks will be estimated consistently and optimally during orbit determination at major tidal frequencies. The consistently determined orbits and clocks can subsequently be used to determine tidal displacements of a vast and dense network of GNSS sites efficiently by the Precise Point Positioning (PPP) method. A unified global inversion will be applied to the results to estimate for spherical harmonic coefficients of the ocean tide load including the degree-1 terms that drive geocenter motion. We will compare the estimated tidal displacements, geocenter motion, and Earth orientation variations with state-of-the-art solid Earth tide and ocean tide loading models. The inverted anomalous ocean tide loads will also be mapped geographically to study weaknesses in the ocean tide model and possible anomalies in solid Earth's rheological properties in a global and quantitative way.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences -2021
NNH21ZDA001N-PMMST
A.24 Precipitation Measurement Missions Science Team
Abstracts of Selected Proposals

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC has selected proposals for the Precipitation Measurement Missions Science Team in support of the NASA Earth Science Division (ESD)'s Precipitation Science Program within the Weather and Atmospheric Dynamics Focus Area.

The Precipitation Measurement Missions Science Team (PMMST) call seeks investigations related to satellite observations of precipitation using measurements from, but not limited to, the Global Precipitation Measurement (GPM) Core Observatory, GPM mission constellation partner spacecraft, and the Tropical Rainfall Measuring Mission (TRMM). This program supports scientific investigations for: (1) algorithm/data product enhancement and validation, (2) science and process studies, and (3) methodology development for improved application of GPM data products. While the major focus of the expected research should be on GPM and TRMM satellite data products, observations from other satellite, aircraft, and ground sensors may be used for the proposed research.

The selected proposals will achieve the research goals through the development of algorithms for mixed-phase and frozen precipitation, generation of data products and/or the utilization of data products in studies of precipitation to better understand storm structures, precipitation trends and extremes.

A total of 114 proposals were received, and 36 have been selected for funding. The total funding to be provided for these investigations is approximately $16.4 million over 3 years. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided.

Ian Adams/Goddard Space Flight Center
Quasi-Physical Representation of the Microphysics, Dynamics, and Single Scattering Properties of Falling Snow
21-PMMST21-0071

Building on the recent successful development of a high-resolution, quasi-physical code to simulate melting of complex hydrometeors using a gridless Lagrangian approach (Snow MEshless Lagrangian Technique or SnowMELT) and motivated by our analysis of synthetic and real radar and radiometer observations of falling snow and mixed-phase precipitation, we propose innovative advancements to SnowMELT to elucidate the behavior of frozen and melting hydrometeors in a dynamic environment and the expansion of the OpenSSP database with high-fidelity single-scattering properties (SSP) these particles, supporting Algorithm/Data Product Enhancement and Validation. We will validate particle and scattering models using remote sensing and in situ data collected during the recent Olympic Mountains Experiment (OLYMPEX) and the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Storms (IMPACTS) field campaigns, and we will work with other science team members to compare validation techniques and results. We will make SnowMELT publicly available, provide extensions to OpenSSP, and submit relevant publications.

Falling snow and ice cloud particles are particularly difficult to model due to the large variability in particle morphology and the scattering dependence on fine scale features at at Ka band and shorter wavelengths. Our team has shown significant success in producing a library of particles representing a range of falling snow conditions. The first iteration of OpenSSP only included particles that are completely randomly oriented; however, due to aerodynamical forcing, hydrometeors fall in preferential orientation such that the largest particle dimensions tend to align perpendicular to the fall direction. Efforts of our team and international partners have demonstrated that considering orientation allows us to reproduce the relationship between brightness temperature (Tb) intensity (v-pol or v/h average) and polarization difference (PD; v-pol minus h-pol) at 166 and 89 GHz, with better agreement at 166 GHz due to lack of sensitivity to melting particles. However, given the limited set of aligned particles considered thus far and the wide range of observed PD (0 K to > 20 K) that we need to capture, we must refine our assumptions of particle size, morphology, and degree of orientation. Thus, by considering particle alignment, we will reduce some of the large uncertainties in understanding the 166-GHz Tbs. At longer wavelengths the orientations of partially- and fully-melted hydrometeors become increasingly important, but the magnitudes of the PDs are much smaller. Particle orientation and morphology are also important for polarimetric radar observations, but radar backscatter also exhibits enhancement at nadir due to aligned particles. Particle orientation results in preferential melting of particles and particles may reorient during the melting process. Therefore, understanding the dynamics of frozen and mixed-phase hydrometeors is vital for reducing the uncertainties in our modeling and inversion approaches and for using polarization to constrain microphysical models.

To advance knowledge of microphysics and improve the fidelity of radiative transfer modeling, we propose to develop a size-dependent particle orientation scheme. Resulting orientation distributions can be applied to existing or new SSPs for frozen hydrometeors. Additionally, upgrades to the SnowMELT code will allow us to account for the effects of preferential melting resulting from drag, providing a new level of fidelity to partially melted particles and the derived SSPs. These synthetic particle populations and resulting scattering properties will then be validated with multi-frequency radar, radiometer, and probe data from airborne sensors collected during field campaigns targeting frozen and mixed-phase precipitation. We will make codes and particle database updates publicly available, while documenting results in peer-reviewed literature.

Rebecca Adams-Selin/Atmospheric & Environmental Research, Inc.
Use of GPM to Understand Production of Hail in Organized Multicellular Systems in Subtropical South America

21-PMMST21-0090

Subtropical South America (SSA) is home to some of the most intense convection in the world as determined by depth of convection, size of organized convective systems, lightning flash rates, and satellite-estimated hail production. Unsurprisingly, hail frequently causes over US$100 million a year in damage annually in Argentina alone. Yet, understanding of how hailfall is produced in SSA is highly limited: for example, while the Argentinian government has spent over 60 years investing in hail suppression techniques, a recent review paper suggests it has been entirely ineffective. Recent research using TRMM-based hail detection and convective mode classification has suggested these SSA hail-producing storms differ significantly from their counterparts in the U.S.: they remain close to the nearby elevated terrain, suggesting an orographic link, and they tend to be organized or linear multicellular convective modes as opposed to the discrete supercells that more commonly produce hail in the U.S.

The availability of GPM data over South American now offers the opportunity to revisit these hail and convective mode climatologies, using the finer spatial resolution of the GPM data along with recent advancements in satellite-based hail detection algorithms. The recent RELAMPAGO field campaign in the region also allows for comparison with convective mode determined by C-band radars installed in the region for the campaign. Finally, the addition of high-resolution GOES data offers an opportunity to directly interrogate convective updraft characteristics. This new observational information can be combined with high-resolution modeling and newly developed sophisticated hail trajectory modeling and clustering techniques to understand for the first time how hail is produced in these unique storm systems. Specific uncertainties that will be addressed include: What processes make SSA organized multicellular systems more likely to produce hail than their counterparts in the U.S.? How important is orography to the creation and longevity of these processes? This project will answer these science questions through the following objectives:

1. Update satellite-based hail and convective mode climatologies over subtropical South America using GPM and RELAMPAGO field campaign data.
2. Construct composite environments associated with hail and non-hail producing organized multicellular systems to understand how these environments differ from each other as well as those observed in the U.S.
3. Use high-resolution model simulations, coupled with sophisticated hail trajectory modeling, to understand the impact of orography, environment, and updraft structure on hail production in SSA convective systems.

Improved understanding and forecasting of severe weather is recognized as a “national priority” by the most recent NASA Decadal Survey and provides an answer to the Earth Science Division Strategic Science Question “How can Earth system science provide societal benefit?”. Yet, forecasting improvements of hail-producing storms cannot be made without understanding of how that hail is produced, a problem this proposal will address through use of GPM and RELAMPAGO information “for observational and modeling studies of…weather”. The coupling of satellite climatologies with high-resolution model simulations will allow for the identification of the environmental, microphysical, and dynamical processes necessary to produce hail within specific convective modes, aiding answer of Question W-9 in the Decadal Survey, “What processes determine cloud microphysical properties and their connections to…precipitation?”. Finally, understanding of what environmental characteristics and dynamical processes are important to produce hail in a specific convective mode offers the opportunity to “better characterize precipitation systems at microphysical, local, and regional…scales”.

Anantha Aiyyer/North Carolina State University
Maintenance of Long-Lived Easterly Waves and Their Transformation to Tropical Cyclones: The Role of Precipitating Moist Convection and Scale Interactions
21-PMMST21-0085

African easterly waves (AEWs) - the generic name given to the synoptic-scale disturbances that originate over West Africa during the summer monsoon - are the primary precursors to Atlantic tropical cyclones. While most AEWs weaken and dissipate after leaving west Africa, many are able to survive for over 2 weeks. These long-lived waves can lead to tropical cyclone formation as far west as the eastern North Pacific. In preparation for this proposal, we examined the individual storm reports prepared by the National Hurricane Center and found that during 1995--2019, nearly 65% of eastern Pacific tropical storms were attributed to long-lived AEWs. These waves can be tracked in satellite images which reveal cycles of convective organization and rapid weakening. The vacillations in the wave structure and intensity pose a major challenge to the operational forecasting of tropical cyclone formation. There are several open problems related to the maintenance of these long-lived waves and their transformation into tropical cyclones.

We examine the following science questions in this proposal:

1) How do cloud populations, precipitation, and vertical heating profiles vary during the life-cycle of long-lived AEWs?

2) How do AEWs respond to the vacillation in convection once they have left their source region (i.e., the region of dynamic instability)? What theoretical constructs can we apply to this issue?

3) Can the merger of decaying AEWs and vorticity generated by antecedent convection lead to its amplification, leading to tropical cyclogenesis?

Method

A series of testable hypotheses and extensive analysis using GPM/TRMM data is proposed. Our work will combine observations and theory to address the questions posed above.

The maintenance of these long-lived easterly waves can be viewed as a competition between factors that damp (e.g., Rossby wave dispersion and damping) and those that amplify (e.g., balanced response to diabatic heating). By focusing on periods where the convection decays and periods where it reestablishes - as is seen dramatically in satellite images - we will unravel some of the underlying scale interactions.

Cloud and precipitation processes will be analyzed using products from GPM and TRMM retrievals of the vertical structure of heating, precipitation, and distribution of surface rain rates. Additionally, a variety of other TRMM/GPM-based data sets for convective features and cold-pool tracks will be employed. These data, along with global reanalysis (MERRA-2, ERA5) will be used to characterize convective storm structures and their interaction with synoptic-scale AEWs. We will calculate potential vorticity generation and the associated balanced response as a result of the heating derived from TRMM/GPM retrievals. We will examine the sensitivity of the response to the background flow and AEW structure, and account for why some AEWs can survive while others decay. We will also conduct idealized and cloud-resolving real-case numerical simulations to develop a conceptual model for the maintenance of long-lived AEWs.

Relevance to Program:

This project directly relates to opportunity 2.2 (Science and Process studies) of the request for proposals (RFP) and to NASA SMD science goals. It covers more than one broad topic identified in the RFP, including analysis of TRMM, GPM, and other satellite-based precipitation information for observational and modeling tropical convection and science studies to improve the indicators of tropical cyclone evolution.

Sarah Bang/Marshall Space Flight Center
A Multi-Perspective Analysis of Hail Processes, Melting, and Their Environments
21-PMMST21-0067

Severe hailstorms pose threats to myriad aspects of human life and society, infrastructure, and agriculture. The significant, widespread impacts of hail motivate the construction of global hail climatologies. For a globally uniform approach, satellite platforms offer consistent observations, even in remote, data-sparse, and oceanic regions, that ground-based networks exclude. There are, however, potential disconnects between the processes identified aloft by the satellite and the resultant weather at the ground. This study will address the subcloud hail processes which we hypothesize are a major source of uncertainty in retrievals that may propagate into satellite-based climatologies. Using Global Precipitation Measurement (GPM) passive and active sensor data, T-28 aircraft in-situ observations, GPM Validation Network (VN) data, and HAILCAST simulations, we will investigate the relationship between the signatures of hail aloft and the dynamic processes and environments with which it interacts throughout its trajectory.

Hail exhibits distinct signatures in satellite imagery that have been leveraged to construct hail detection algorithms and global hail climatologies. For example, hail often registers high radar reflectivities above the melting level and pronounced brightness temperature depressions in passive-microwave imagery. However, these spaceborne datasets leverage the signal of hail aloft and not necessarily at the ground, where the threats to life and society exist. This issue is pronounced in the tropics, where there are abundant strong, but not necessarily hailing, storms that are strongly represented in the current satellite climatologies. The satellite-based retrievals do not account for processes that occur during hails' trajectories toward the surface and the environments with which they interact. The hail particle size distribution is dependent upon the melting that occurs along its trajectory. The extent of the melting is dependent on the environmental temperature, humidity, and other kinematic details, such as location relative to up- and downdrafts.

We propose to investigate hailstorms around the globe to determine the relationship between the size distributions of hailstones aloft and the dynamic processes and environments with which they interact throughout their trajectories. The proposed work comprises three main objectives: (1) Examine relationship between the particle size distributions of hail identified aloft, hail at the surface, and the environment through which it is falling. (2) Investigate the sensitivity of hail trajectory and melt to environmental conditions, in-storm rainfall, and storm kinematics (e.g. up- and downdrafts). (3) Determine how the relationships between environmental conditions, melting, and satellite hail signatures vary geographically.

We hypothesize that the disconnect between a hail signature aloft and a lack of hail at the surface is due to the lack of representation of melting processes in our observations and simulations. The proposed work seeks to address this gap by synthesizing GPM satellite, airborne in-situ, ground-based remote sensing, and simulated data for a multi-perspective targeted analysis of the hail melting processes between the cloud top and surface.

Ali Behrangi/University of Arizona
Snowfall Analysis in High Latitudes to Advance NASA IMERG
21-PMMST21-0017

The proposed work will bring together various ground validation (GV) and non-GV datasets to assess input precipitation products to the NASA Integrated Multi-satellitE Retrievals for GPM (IMERG) in high latitudes and guide the bias correction of the final estimates. The focus will be on snow and ice surfaces poleward of 60oN/S, a broad region where IMERG currently has no data due to the poor performance (and sometimes lack) of PMW estimates over these surfaces. We will utilize GV (e.g., SNOTEL, ground radar, and quality gauges), non-GV (e.g., snowfall mass change enabled by GRACE, snowfall accumulation on sea ice enabled by OIB, and SWE estimate from various observational products), and CloudSat observations to produce complementary datasets for assessing the total amount and spatial distribution of snowfall from input sources (e.g., from PMW and IR sensors) to IMERG, determine the most effective inputs, and provide quantitative guidance for bias adjustment of the final product. This will be performed by synthesizing the datasets into a single standardized format, providing uncertainty estimates, and making them available to the community and precipitation product developers. We will:

- Integrate and process various high-quality snowfall-related GV and non-GV data sets, use them to quantify snowfall amount and distribution, and determine associated uncertainties for assessment of satellite snowfall products.
- Assess satellite snowfall products (i.e., from PMW and IR) that are considered as input or potential input to IMERG, and calculate representative statistical skill scores for snowfall amount and distribution together with considering regional variations, environmental conditions, and surface type (e.g., over snow and ice surfaces) to improve analysis and facilitate the implementation of the outcomes into IMERG.
- Determine ranking for snowfall products for integration into IMERG and provide quantitative guidance and uncertainty for bias adjustment of the IMERG.
- Establish a database and share GV and non-GV data that are utilized in the project with the community, so they can be used for assessment or development of the current and future versions of the snowfall products.

We propose under Topic 2.1: Algorithm/Data Product Enhancement and Validation that “emphasizes specific topics that need to be addressed to improve GPM algorithms and data products, including Level 1-3 products” through the “Development of methodologies for evaluating satellite precipitation products from non-GV sources”. The proposed study addresses the NRA scope of research by establishing a framework and methodology in which GV and various non-GV products are used to assess precipitation products with direct application to “improve the fusion of precipitation estimates from multi-instrument and/or multi-satellite platforms”, which is the case for IMERG (i.e., the most popular GPM product in terms of the number of users).
We have a long-standing working relationship with the IMERG team that helps improve the efficiency of the proposed effort to guide the development of IMERG. Furthermore, the basis of most of the non-GV sources used in the proposed work is already developed using previous projects supported by NASA, enhancing the quality and reducing the risk of the proposed work.

Edward Beighley/Northeastern University
A Precipitation-Based Risk Index for Well Water Contamination
21-PMMST21-0056

In the U.S., nearly 50 million residents are reliant on unregulated private wells, which do not have the same level of protection from drinking water hazards as regulated municipal water. This is a significant problem because up to 60% of wells exceed at least one health-based drinking water standard. Building on our recent efforts, we hypothesize that well water contamination is impacted by precipitation-induce processes and pathways with initial hydrologic conditions, land cover, household (income, race), and well system (well depth, well type) characteristics amplifying contamination rates. Here, we propose to develop a precipitation-based risk index that utilizes NASA satellite observations, specifically GPM's IMERG precipitation product(s), U.S. Census data, and the North Carolina Department of Health and Human Services (NC-DHHS) well sampling database to better identify and characterize private wells susceptibility to rainfall-induced contamination. Along with GPM precipitation, remotely sensed observations will be used to integrate additional contributions to well water contamination rates and variabilities such as hydrologic conditions derived from NASA's SMAP, GRACE-FO, and future SWOT missions, proximity to flood prone areas derived from LANDSAT, and land cover characteristics derived from LANDSAT and MODIS.

The GOAL of the proposed project is to develop a GPM precipitation-based risk index to provide NC-DHHS the capability to rapidly detect and respond to well water problems resulting from rainfall driven contamination. The index will provide time-history and near real-time insights on precipitation induced impacts on drinking water supplied by wells. To develop and assess the index, our OBJECTIVES are: (1) Generate geospatial data repository with remotely sensed data (e.g., IMERG) and integrate with exiting well testing data; (2) Determine relationships between precipitation, household- to regional-scale hydrologic conditions, well/user characteristics, and well water contamination rates; (3) Develop precipitation-based risk index for well water susceptibility; and (4) Validate the index with historical and newly collected well data. Key QUESTIONS are: (Q1) What are the relationships between GPM precipitation and well water contamination rates and how do these relationship vary based on: Initial hydrologic conditions, Household- to regional-scale hydrologic characteristics, Well and household characteristics, and Household- to neighborhood-scale race and socioeconomic characteristics; (Q2) what precipitation threshold(s) and associated hydrologic/well/user information can be used to define a risk index for well water susceptibility; and (Q3) How well does the index perform? How does performance vary with event magnitudes, initial conditions, landscape, well and household characteristics; compare to methods based on surface water inundation; and enhance NC-DHHS surveillance?

The risk index will be validated using historical post-disaster data and a new well sampling campaign that leverages our past/current collaboration with NC-DHHS (see current & pending). This proposed project builds on our current 12-month NASA Rapid Response and Novel Research in Earth Science grant (ending Jun 2022) supported by the Disasters Program to use remotely sensed data to identify the number of inundated wells from major flooding events and quantify the racial and socioeconomic disparities in well water flooding, testing, and contamination rates after three major hurricanes in NC. This proposed project builds on our NASA Rapid Response efforts by moving beyond surface water flooding (i.e., result of may processes) to explore a broader range key hydrology fluxes and storages over a range of spatial and temporal scales (i.e., event precip., past precip., initial hydrologic conditions) that influence contamination pathways/processes and associated well water contamination rates and integrating that understanding into a risk index.

Alexis Bloom/Jet Propulsion Laboratory

Using GPM to Resolve Plant Water Supply in Wet Tropical Soils
21-PMMST21-0109

Proposal summary: We propose to use 2001-2020 satellite-based precipitation data to investigate and improve estimates of plant-available water supply—and its associated seasonal, inter-annual and decadal variability—across wet tropical ecosystems. Productivity (photosynthetic CO_2 uptake) in wet tropical ecosystems is fundamentally characterized by abundant precipitation; in turn, these productive and densely vegetated ecosystems are a critical store of carbon, and mediators of freshwater fluxes between atmosphere land and ocean. Parametrizations of key processes regulating tropical ecosystem water availability—namely surface infiltration, rooting depth, moisture retention and evapotranspiration processes—remain uncertain in land models. As a consequence, the plant-available water states and their sensitivity to changes in precipitation supply and evaporative demand remain poorly understood. The NASA Integrated Multi-satellitE Retrievals for GPM (IMERG) dataset—which combines information from TRMM (2000 - 2015) and GPM (2014 – present) core instruments as well as a constellation of sensors going back to 2000—provides a unique opportunity to improve constraints on the timing and magnitude of soil water storage dynamics into wet tropical soils.

Here we propose to integrate 2001-2020 IMERG precipitation data into the CARDAMOM Bayesian model-data fusion system to explicitly estimate (i) plant-available water supply, and (ii) associated states and process variables related to the dynamics and climate sensitivity of plant-available water. Based on this approach, we will address two questions on the role of precipitation on plant-available water supply:

(1) Technical question: Do IMERG-informed model-data fusion estimates of soil water storage accurately predict streamflow dynamics in wet tropical ecosystems?

(2) Science question: Are seasonal and inter-annual plant-available water deficits in wet tropical ecosystems more sensitive to variations in precipitation H_2O supply or atmospheric H_2O demand?

To address the technical question, we will constrain the CARDAMOM soil hydrology module—and associated process parameters regulating infiltration, runoff and evapotranspiration—using IMERG precipitation data and ancillary satellite-based terrestrial water storage and vegetation observations; we will quantify IMERG-informed model skill by comparing 2001-2020 CARDAMOM watershed discharge estimates against river gauge datasets across the Amazon and Congo basins. To address the science question, we will use the IMERG-informed CARDAMOM analysis to investigate (i) seasonal-to-decadal PAW dynamics, (ii) their spatial and climatic variability, and (iii) the sensitivity of PAW seasonal-to-decadal variability to vapor pressure deficit (demand) and precipitation (supply). In addition to addressing the science questions, outcomes of the proposed effort will include monthly 0.5 degree resolution 2001-present IMERG-inferred soil H_2O budgets for the Amazon and Congo river basins.

Rafael Bras/Georgia Tech Research Corporation
Using Satellite-Based Precipitation Estimates to Obtain the Conditional Probability Distribution of Soil Moisture
21-PMMST21-0005

Natural and managed vegetation ecosystems depend on soil moisture for their metabolism and survival. Soil moisture at any time is fundamentally a function of precipitation (or irrigation), redistribution and evapotranspiration demand. Precipitation and resulting soil moisture are particularly critical for understanding and predicting floods and droughts, managing water resources, ecosystem health, and developing efficient irrigation practices.

This proposal seeks to use satellite-based precipitation estimates to elucidate soil moisture conditional probabilistic distributions over a period of time and quantify the relative importance of the precipitation input. The conditioning is on precipitation observations, forecasts, and initial moisture state. Ultimately, this knowledge will be essential to applications like irrigation control and management.

There have been only a few attempts to obtain the probabilistic distribution of soil moisture. Cordova & Bras (1981) is unique in that it formulates an approach to derive the theoretical CONDITIONAL distribution of soil moisture sometime in the future, GIVEN that the soil moisture at the moment is known. The initial soil moisture plays a role because it sets the initial value from which drying occurs AND fixes the parameters of the infiltration, which are dependent on soil moisture. The key to the approach is that, relative to the inter-storm period, the impact of rainfall and resulting infiltration is effectively instantaneous. Soil moisture depletion occurs and then increases rapidly when the next storm, and resulting infiltration, occurs. The uncertainty in the distribution of soil moisture comes only from the rainfall and hence the infiltration. It is an explicit assumption that rainfall is the most important source of variability, an assumption that others have supported. The two other sources of variability, not accounted for in the initial effort, are the evapotranspiration (ET) demand and the soil type. Conceptually, including them is possible. Cordova and Bras' results were not fully tested with observations but were verified mainly with simulations. The results were shown to be potentially valuable in irrigation scheduling in areas where deficit irrigation is used. GPM precipitation estimates and SMAP observations can be used to verify the validity of the formulation and expand the results to uncertain ET, soil types and handle spatial heterogeneities at subgrid scales.

Two hypotheses are made:

1: There exists a CONDITIONAL distribution of near-surface soil moisture uniquely defined by the precipitation, soil, vegetation, and potential ET at every location over land.

2: The relative importance of precipitation as the source of variability in the distribution varies with local climate, i.e., precipitation is the most dominant element in arid and semi-arid climates

Expected outcomes include:

1-A robust conditional probability distribution of soil moisture driven by GPM precipitation.

2-An estimate of this distribution in different parts of the world.

3-Preliminary formulation of these ideas for use in agriculture as well as other problems.

Chandra V. Chandrasekar/Colorado State University
GPM Global Observations and Precipitation Microphysics: Algorithm Support, Enhancement, Cross Validation, and Adding the Third Dimension to the Classification Module
21-PMMST21-0065

The objective of the proposed research is to improve, enhance, and continue the support for GPM algorithms, conduct validation and also offer a major enhancement to the classification module from DPR, namely add a third dimension to the retrieved products.

We will continue to support analysis, to study precipitation microphysical parameters such as hydrometeor and precipitation types at global and regional scales to derive microphysical inferences of precipitation variations at these scales, with the main goal of algorithm support, validation and enhancement for the classification module for DPR. These studies will be conducted, using space-borne observations from the GPM platform as well as ground dual-polarization radars and in-situ observations. Some of the most important tasks of the current proposal are a) validate the performance of the new products introduced in V7 that will be released later this year, b) test and validate the existing and new dual-frequency products for inner and outer swath of the DPR profile, c) study internal consistency and contrast between products and d) Provide a significant leap by adding the third dimension to the classification module.

In order to make an impact on the use of GPM observations and retrievals, the microphysical information must be correlated to the space-borne observations. The specific activities in that direction include: a) simulation of GPM precipitation radar profiles for categories of microphysical significance, b) the development of techniques to generate maps of hydrometeor types such as snow, hail and graupel and compare them against ground dual-polarization radar based retrievals, and c) making use of the advances in steps (a), (b) to improve GPM microphysical retrieval algorithms, specially vertical profile hydrometeor classification at a global scale.

Currently our team plays a key role in the DPR algorithm development group, and is responsible for the classification module, and hydrometeor type development (that includes the snow index module, graupel and hail products), that has been released and operational. We will continue to test, validate and refine the classification module and introduce the vertical profile of hydrometeors. The PI and the team, propose to continue to play that role and be a part of the international DPR algorithm team, and in addition, play a significant role in the analysis of ground radar and other in-situ sampling infrastructure for the cross-validation of hydrometeor classification as well as mixed-phase precipitation studies with space-borne measurements focusing on the modules under discussion.

GPM precipitation radar observations, combined with the knowledge of precipitation microphysics observed on the ground worldwide, provide a sound basis for modeling the precipitation observations for space-borne systems. We propose the use of observations-based simulations as well as ground-based dual polarization and dual-frequency radar observations to develop data-based models to evaluate the space-borne dual-frequency radar observations. Continuous educational outreach associated with the research will be an integral feature of this proposal.

Jiun-Dar Chern/University of Maryland, College Park
Use of Satellite Observations and Global Cloud-Resolving Model Simulations to Study Precipitation Characteristics and Microphysical Processes
21-PMMST21-0107

In this proposed research, high-resolution GPM satellite observations are combined with the global cloud-resolving (or "cloud-permitting") model (GCRM) simulations to improve our understanding of the characteristics of precipitation systems and precipitation processes. Simulations from two NASA global models (i.e., the Goddard Earth Observing System version 5 (GEOS-5) and the Goddard Multi-scale Modeling Framework (GMMF)) with 1-4 km horizontal grid spacings will be used. The advantage of such fine?resolution modeling is that atmospheric convective processes and meso-scale circulations are explicitly depicted instead of using a cumulus convection scheme (a major source of uncertainty in conventional GCMs). Since the resolution of these simulations are comparable to the size of a GPM radar footprint, GPM-equivalent observables can be derived via the multi-instrument Goddard Satellite Data Simulator Units (G-SDSU). This proposed study will develop an innovative methodology to derive simulated precipitation feature (PF) databases from the GEOS5 and GMMF simulations. The simulated PFs will be evaluated against the GPM PFs. The aim is to improve our understanding of precipitation processes and their representation in high-resolution GCRMs.

The major objectives of this proposal are to:
(1) Develop a novel methodology, in close analogy to the GPM PF approach to derive simulated PFs from model output to facilitate the use of GPM PF data to evaluate GCRMs in a consistent way,
(2) Derive simulated PFs from the kilometer-scale GEOS5 simulations and the output of the embedded 2D CRMs within the GMMF to better characterize simulated precipitation systems from local to global scales,
(3) Analyze both GPM observed and model simulated PF data to better understand the occurrence frequency, storm structures and intensity of dominant precipitation systems under various climate regimes and quantify model biases,
(4) Evaluate and improve the precipitation processes in the microphysical schemes using a series of GCE and GMMF sensitivity experiments versus satellite observations.

Our proposed research facilitates the use of GPM PF data to evaluate and improve the GEOS5 and the GMMF in a consistent and statistically robust manner and improves our understanding of global precipitation characteristic, storm structures, and the role of precipitation in the Earth's system. It meets the requirements and addresses the Research Category 2.2 Science and Process Studies. This research category covers physical process studies utilizing satellite and GV data and the application of existing data sets to improve atmospheric and land-surface models ranging from cloud-resolving to climate scales. Our proposed study also addresses the PMM objectives of improving knowledge of precipitation systems and improving weather and climate modeling and prediction; essentially GPM's Scientific Objectives (b), (c) and (d). In addition, a comprehensive dataset of simulated PFs and an analysis algorithm will be provided to other PMM science team members and the GCRM and MMF modeling communities to promote the use of the GPM PF dataset for model evaluation.

Anthony Didlake/Pennsylvania State University
Understanding the Dynamics and Predictability of Tropical Cyclones Using PMM Microwave Observations
21-PMMST21-0094

The goal of this research is to improve understanding and prediction of tropical cyclone (TC) dynamics and precipitation through an integrated observational and modeling analysis of all-sky radiance observations from passive microwave (MW) sensors onboard the NASA GPM constellation satellites, along with other in situ and remotely sensed observations. Recent efforts have been successful in simultaneously assimilating all-sky GPM MW radiances, GOES infrared (IR) radiances, aircraft wind observations from the NOAA P3 Tail Doppler radar (TDR), and traditional surface and radiosonde observations into the convection-permitting Weather Research and Forecasting (WRF) model using the Pennsylvania State University Ensemble Kalman Filter data assimilation system (PSU WRF-EnKF). In these efforts, a combined assimilation of these data has shown improved representation of TC inner-core dynamic and thermodynamic structures and improved TC intensity and rainfall forecasts. This work utilizes these data assimilation advances to examine the inner core and environmental processes that shape the intensity and precipitation structure of TCs. Specific focus is placed on the TC intensity change and precipitation processes of rapid intensification (RI) and eyewall replacement cycles (ERCs), which are often incorrectly forecasted. An observations-only (GPM MW and P3 TDR) examination is first performed to identify and characterize the key inner core and environmental features that lead to RI and ERC in select Atlantic basin TCs. These observations (GPM MW, GOES IR, and P3 TDR) are then assimilated to generate high-resolution, convection-permitting re-analyses used for a detailed examination of the dynamic and thermodynamic processes involved in the RI and ERC events of focus. Finally, ensemble sensitivity experiments are performed to examine the dynamics and predictability of the Atlantic basin RI and ERC events, as well as other RI and ERC events globally that are observed by GPM satellites but not by regular aircraft reconnaissance.

Ardeshir Ebtehaj/University of Minnesota

Extending Forecast Skills of Global Precipitation: A Deep Learning Framework for IMERG Data Assimilation over the Wasserstein Space
21-PMMST21-0025

The IMERG product provides a global picture of precipitation with unprecedented accuracy. The direct use of this product is still limited for (1) extending forecast skills of mesoscale weather models and (2) global precipitation nowcasting through statistical post-processing. Operational data assimilation (DA) is remained limited to assimilation of brightness temperatures and nowcasting skills of statistical post-processing techniques decay quickly in time. We are not taking full advantage of decades of research and developments in active-passive retrievals of precipitation for its improved forecasts.

The main reasons are as follows: (1) Precipitation is an integral quantity and not a prognostic variable in weather models. (2) The error in precipitation forecasts are significantly non-Gaussian and biased, especially in convective regimes. (3) Current space-time extrapolation of satellite retrievals cannot condition their results to the underlying physics, controlling the moist processes and storm motions.

For direct precipitation DA, we need to propagate the information content of its retrievals into key prognostic state variables, which requires an inverse representation of all equations of moist processes through a “tangent linear model”. Accuracy of such model is limited as the forecast lead-time increases. Can deep learning provide a nonlinear approximation of moist processes beyond the accuracy of a tangent linear model?

Current DA techniques rely on least-squares penalization of unbiased Gaussian errors over the “Euclidean space” and are limited to a data structure that lives on a flat surface. However, precipitation data are highly non-Gaussian, biased and live on manifolds. How can we assimilate precipitation over a manifold?

Statistical extrapolation of satellite precipitation is shown to provide improved nowcasts than global forecasts. However, the nowcasting skills of current approaches decay fast after a few hours. How can we extrapolate IMERG in time conditioned on full equations of motion and optimally merge it with global precipitation forecasts?

The hypothesis is that new advances in deep learning and DA over Riemannian manifolds, equipped with the Wasserstein metric, can extent precipitation forecast skills using IMERG retrievals. The objectives are:

1- To investigate and test an optimal architecture for deep learning of cloud microphysics via convolutional neural networks (CNN) to link 3D fields of key atmospheric state variables to the cloud precipitation content and its surface flux. The training examples will be based on historical short-term forecasts from the NOAA's convective allowing High-Resolution Rapid Refresh (HRRR) over the United States as well as the Global Forecast System (GFS).

2- To develop and validate a fundamentally new hybrid DA paradigm and integrate it with the Gridpoint Statistical Interpolation (GSI) platform for assimilation of IMERG into the Weather Research Forecasting (WRF) model. Unlike classic DA techniques, this framework assimilates precipitation over the Wasserstein space and allows formal penalization of non-Gaussian forecasts with systematic errors in position of convective precipitation cells. To that end, this new DA relies on the CNN developed in Obj. 1.

3- Examine and validate the CNN in Objective 1 to produce a new 3-hourly precipitation nowcasting product with a lead-time of up to 18 hours, called IMERG-Nowcast. The goal is to establish a functional relationship between previous GFS forecasts and IMERG retrievals for evolving the retrievals in time and optimally merge them with short-term GFS forecasts.

Overall, the outcomes will extend the use of IMERG retrievals for improved precipitation forecast focusing on convective storms. The results will support weather-related tactical, transportation, public health and economic decisions from regional to global scales.

Gregory Elsaesser/Columbia University
Constraining Drivers of Tropical Precipitating Cloud Shield Areas Across Scales to Inform Climate Model Development
21-PMMST21-0079

Deep convective systems produce expansive stratiform raining regions that contribute substantially to the global rainfall climatology. These stratiform regions are several times larger than the convective regions that seed their initiation, yet smaller than the surrounding anvil high cloud regions whose characteristics include long lifetimes that result in significant cloudiness spanning the tropics-wide ITCZ envelope. Since stratiform regions initiate the early coverage of the anvil high clouds, understanding and modeling their evolution is important for constraining high cloud feedbacks. Recent work, informed by GPM observations, shows a strong relationship between the vertical profile of GPM-inferred latent heating in convective cores (which ties to convective vertical mass convergence), and stratiform region areal time tendencies. This relationship is different from how most climate models parameterize stratiform regions, where area fractions are typically related to relative humidity and ice water content and assumed equivalent to anvil cloud areas, with convective vertical mass flux itself governing only the condensate amount within the pre-determined stratiform fraction.

What is unknown is to what extent spatial organization of convective towers and stratiform rainfall itself (the latter as a sink) within systems further shapes raining stratiform areal coverage and overall contribution to tropics-wide ascent regions and the ITCZ. At the system scale, ongoing work shows a strong relationship between the current size of the stratiform region and its current decay rate, but this varies as a function of system duration. Using GPM DPR convective-stratiform rainfall flags, GPM GMI-DPR combined rainfall, GPM diabatic heating products, and a convective system tracking database, we propose to advance our understanding of the sources and sinks of stratiform raining regions, with a focus on how the vertical profile of latent heating in convective areas and spatial connectedness of convective cores serves as a source for stratiform region, and how stratiform rainfall itself serves as a decay for stratiform area. We also propose to further our understanding of how system anvil cloud areas evolving on short timescales aggregate to impact the overall rainfall and cloud characteristic of the ITCZ and tropical ascent regions.

Overall goals include development of simple models (informed by GPM and complementary NASA satellites) that represent the competition between growth and decay processes toward understanding system sizes, durations and links to variations in Earth's ITCZ. The proposed work builds on the PI's effort to improve representation of deep convective systems in the NASA-GISS GCM via implementation of simple models for deep convective system features, fully informed by GPM and a host of other NASA satellites, while ensuring that emergent mean state GCM ITCZ and rainfall patterns in tropical ascent regions, characterized by the Co-PI, improve for the right process-level reasons. The proposed research addresses solicited research category 2.2 Science and Process Studies. It is targeted at overall GPM science objectives (b) improving knowledge of precipitation systems, water cycle variability, and freshwater availability, and (c) improving climate modeling and prediction, as well as several solicited topics of importance.

Efi Foufoula-Georgiou/University of California, Irvine
Enhancing the Representation of Precipitation Space-Time Dynamics in Satellite Products: Validation, Error Modeling and Improvement of Retrieval Algorithms
21-PMMST21-0031

Precipitation exhibits variability over a wide range of spatial and temporal scales. Numerous studies have underlined the fact that, for basins of any size, the hydrologic response to precipitation depends not only on the precipitation average over the basin but is also strongly dependent on the spatio-temporal structure of the precipitation systems. In particular, several case studies of catastrophic flood events report that some extreme hydrologic responses can be linked to the particular spatio-temporal dynamics of a storm rather than to an unusual total precipitation amount. The spatio-temporal structure of precipitation is also an important aspect of the global weather and climate system, with the organization of convection playing a particularly significant role in the Earth's energy balance. In addition to causing complex hydrologic responses and complex atmospheric energy flux, the multi-scale variability of precipitation renders its measurement particularly challenging. Indeed, any observation system of precipitation has inherent limitations associated with the spatial and temporal sampling and instrument resolutions. Moreover, a given observation system may show varying performance in capturing different modes of precipitation variability, ultimately leading to a scale-dependent retrieval performance.

The proposed research has two main objectives: (1) develop and implement a framework for space-time satellite precipitation error diagnostics, uncertainty quantification and error modeling across space-time scales relevant to climate, weather and hydrologic applications; and (2) improve existing operational retrieval algorithms and develop new algorithms specifically geared toward enhanced representation of the space-time dynamics of precipitation.

Regarding Objective 1, we propose to develop a methodology for product assessment and validation focused on the multiscale space-time dynamics of precipitation, relying in particular on spectral representations. Within this multiscale spectral framework, we will develop a quantitative error model for computing sensor-dependent uncertainty estimates. The uncertainty quantification is not only important for the end user who often needs information on the accuracy of precipitation estimates but it is also a necessary step for optimal merging of multi-sensor observations. The developed methodologies will first be tested in the continental US using MRMS as the reference product, followed by analysis in other parts of the world for which ground observations are missing and other innovative indirect assessment methodologies have to be developed. Regarding Objective 2, we will work on modifying existing operational retrieval and merging algorithms and on developing new algorithms for enhanced representation of the space-time dynamics in multi-sensor precipitation estimates. For this purpose, we will explore the use of mixed-scale deep convolutional neural networks which offer the advantage of efficiently learning space-time features and keep in memory the whole pathway of learning for improved performance. We will also focus on defining appropriate objective functions that go beyond the pixel-wise penalty metrics to explicitly incorporate the space-time dynamics of the target variable in machine learning algorithms.

John Galantowicz/Atmospheric & Environmental Research, Inc.
Combining Satellite Observations of Rainfall, Numerical Weather Prediction, and Historical Satellite Flood Mapping to Forecast Flood Disasters for Humanitarian Mission Support
21-PMMST21-0099

Accurate, timely, frequent, and spatially complete rainfall inputs are essential for flood disaster forecasting. In data-poor regions, satellites are often the best source for comprehensive rainfall observations. NASA’s Global Precipitation Mission (GPM) Integrated Multi-satellitE Retrievals for GPM (IMERG) dataset is the leading source for frequent rainfall estimates with global coverage. With a 30-minute update cadence and latency as short as four hours, IMERG data can capture the types of widespread, enduring, heavy rainfall that trigger extreme flooding. The goal of this project is to build a model for translating the invaluable IMERG data stream into actionable flood forecasts for decision makers directly involved in humanitarian assistance for flood disasters and their support teams. Disaster relief workers need up-to-date geospatial flood forecast data for immediate resource allocation and logistics and long-term planning. Hydrological models driven by numerical weather prediction (NWP) rainfall data often provide long lead-time warnings of impending disasters but with large spatiotemporal error bars that are particularly acute in regions of the world where weather monitoring capacity is limited and model parameterizations are hard to accurately calibrate. We plan to overcome these problems using a data-driven model that leverages machine learning (ML) approaches now common in many data science applications.

This project will develop and test a novel ML-based flood extent forecast model driven by IMERG rainfall data combined with NWP rainfall forecasts, soil moisture observations from NASA's Soil Moisture Active Passive (SMAP) satellite, and flood extent data from FloodScan. The project is made possible by FloodScan's 1998-present daily, coast-to-coast flood maps updated every day in near real-real time. The FloodScan system uses passive microwave data from TMI, AMSR-E, GPM, and AMSR2 and downscaling methods to map flood extent at 90-m resolution through clouds—but notably not rain. We will train the ML model to predict FloodScan's flood maps in 1- to 5-day forecast windows. With over 7500 daily FloodScan maps available since the IMERG data record began in 2000 and with complete river basin coverage, there is ample data for rigorous ML model training and validation. We have selected the Limpopo River Basin, which drains a major portion of southern Africa, and the much smaller Ikopa River Basin at Antananarivo, Madagascar as study areas because of their contrasting flood histories. Using data from these basins, we will train four ML model varieties with different predictor and target dataset formulations with two key goals in mind: (1) meeting flood forecast requirements for disaster preparedness and relief operations and (2) demonstrating the flood forecast improvement attributable to GMP IMERG data.

The project will contribute to NASA's Precipitation Measurement Mission (PMM) goals by developing an innovative ML-based flood forecast model that uses IMERG near real-time and historical data as its primary rainfall input for training and forecast operations. The ML model will provide a framework for combining information from GPM with FloodScan and SMAP observations and NWP model forecasts to produce improved predictions of floods, one of the world's highest-impact natural hazards in terms of number of people affected yearly. The project's results will help NASA provide improved data for operational use by first responders to flood disasters.

Mircea Grecu/Morgan State University
Clustering-Based Quantification and Mitigation of Uncertainties in the GPM Combined Algorithm
21-PMMST21-0035

The GPM combined radar radiometer precipitation algorithm is based on a Bayesian estimation methodology and is inherently sensitive to assumptions regarding the "a priori" joint distribution of geophysical variables involved in the estimation process. In addition, the physical models embedded in the likelihood maximization process are not error-free, and inversion process is not perfect. Consequently, although considerable effort has been put over the years in mitigating these issues, the combined algorithm is still amenable to improvements. To improve the algorithm performance, we propose a systematic investigation of its precipitation retrievals as a function of the archetypal vertical distribution of observed reflectivity, a rigorous evaluation using ground-based precipitation estimates and/or gauge-adjusted satellite precipitation estimates, and an enhanced retrieval methodology of deep convective precipitation. Specifically, we propose to cluster the combined precipitation profiles into multiple classes based on the vertical distribution of observed reflectivities and analyze the retrieval accuracy as a function of cluster. As multiple pieces of evidence already suggest that deficiencies still exist in the retrieval of deep convective precipitation, we propose the development of an enhanced retrieval methodology that features a more effective way to incorporate and make use of “a priori” information. The methodology will be based on two advanced statistical models developed using a state of art deep learning library. The first model will be implemented using a Long-Short-Term-Memory (LSTM) architecture and will be used to predict DPR observations from particle size distribution (PSD) related variables and to inversely relate observations to these variables. The second model will be based on a Conditional Generative Adversarial Network (CGAN) and used to compensate for the fact that some PSD-related variables may be in the null-space, i.e. they have no impact on the observations. For example, surface precipitation is a variable in the null-space if the attenuation is so severe that no signal above the noise level is detected by the radar at the longest clutter-free range. The two models will be trained using realistic cloud resolving model (CRM) simulations and retrievals from aircraft radar observations and will be incorporated into the combined algorithm for operational use. The major benefit of the methodology is that deep learning can incorporate vast amounts of "a priori” information in a compact and easy to retrieve way through inverse optimization and generative modeling processes. An in-depth analysis of the impact of the enhanced retrieval methodology will be carried out using bias-free precipitation estimates from the Multi-Radar Multi-Sensor (MRMS) product and the Global Precipitation Climatology Product (GPCP).

In summary, to further enhance the performance of the GPM combined algorithm we propose:

1) The implementation and application of a profile clustering methodology that will enable a more rigorous performance evaluation of the current (Version 7) combined precipitation estimates and the development of an enhanced retrieval methodology for the classes found most deficient.

2) The development of an enhanced retrieval methodology based on deep learning models. The methodology will be incorporated in the combined algorithm and used to provide either ensembles of preliminary estimates that can be further processed by the standard combined algorithm or just stand-alone final estimates.

3) The validation of the improved precipitation estimates against bias-free products.

The successful completion of the proposed research will provide additional insight into the uncertainties of the GPM combined precipitation algorithm and lead to performance improvements.

The proposed research is aligned with Objective 2.1 of the research call, i.e. Algorithm/Data Product Enhancement and Validation.

Gerald Heymsfield/Goddard Space Flight Center

Addressing Global Blind Zone Precipitation Estimate Errors from Space Using Observations and Modeling

21-PMMST21-0033

Available global precipitation products (TRMM-3B42, CMORPH, PERSIANN, IMERG, etc.) show up to 90% uncertainty relative to the multi-product mean and consistently underrepresent total rainfall in mountainous, oceanic, and other data-sparse regions. Precipitation bias in these products stems from several factors, including ground clutter (i.e., the “blind zone” or “BZ” hereafter), rain gauge network density, terrain blockage, and the tendency to locate ground-based measurements in valleys and on land masses where people and cities are located, amongst others. Our previous work produced novel lookup tables (LUTs), which estimated missing precipitation information in the BZ in orographic regions. The LUTs were constructed from Weather Research and Forecasting model (WRF) model simulations, using five bulk microphysics schemes, for several flight missions during two unprecedented field campaigns in mountainous regions: IPHEX (May-June 2014), OLYMPEX (Nov. 2015- Feb 2016), for warm-season and cold-season orographic precipitation regimes, respectively. A theoretical performance analysis was conducted where LUT-based BZ corrections were compared to those using constant reflectivity profiles, which GPM presently uses. This analysis revealed that LUT-based reflectivity profiles reduced simulated rain rate RMSEs by up to 40%, most notably in regions of higher terrain and lower, mean low-level relative humidity. The model-derived LUTs were evaluated for self-consistency. Microphysical characteristics and physical properties of orographic precipitation from GPM algorithm retrievals, GPM GV, and WRF were cross-correlated. During our previous investigation, we also found evidence that large BZ-related precipitation biases occur not only in orographic regions, but in many other regions of the world (such as the Southern Ocean) and that they demonstrate seasonality, which motivates our proposed work effort.
Leveraging the tools, techniques, and team from our previous orographic-focused research, we will broaden the utility of our LUTs by expanding their scope globally with the aim to reduce global GPM DPR BZ-related biases, which would then be incorporated into a future release of the GPM combined algorithm (CMB) (Grecu et al., 2016). To achieve these aims, we propose an investigation comprised of three main tasks.

1) Use the Vertical Profile of Precipitation (VPP) technique developed by Co-I Grecu (planned for GPM combined algorithm Version 7 release), which compares nadir/near-nadir profiles, to identify global BZ problem regions and evaluate the accuracy of this technique using airborne radar data taken during several GPM-focused field campaigns.
2) Update existing cold-season (FZL ? 3km above ground level) LUTs using at least thirty targeted WRF simulations guided by the VPP-based BZ maps.
3) Update existing warm-season (FZL ? 4km above ground level) LUTs following a similar methodology as for the cold-season LUTs.

To ensure that the best quality LUTs are produced, both our WRF model simulations and VPP technique will be vetted against data from four GPM field campaigns (MC3E, IPHEX, OLYMPEX, and IMPACTS) and other campaigns, where possible. Additionally, the WRF model simulations used to build the LUT will operate at up 500 m horizontal grid spacing with 121 vertical levels (average vertical spacing of 187 m), which will permit explicit simulation of all but the smallest precipitating systems. This proposal focuses on applications of state-of-the-art radar retrievals, numerical models, and airborne field data to address the problematic BZ and a physically based correction for it. Therefore, the proposed study addresses Topic 2.1: “Algorithm/Data Product Enhancement and Validation.”

Svetla Hristova-Veleva/Jet Propulsion Laboratory
Understanding and Predicting Tropical Cyclone Rapid Intensity Changes Using Passive Microwave Observations from GPM and TRMM
21-PMMST21-0101

Recent advances in analyzing and predicting rapid intensity change (RIC) in tropical cyclones (TCs) suggest that the distribution and intensity of convective activity in the storm have an important role, particularly their occurrence with respect to the dynamically-significant vortex structure. We developed a framework to detect and analyze these features from satellite observations of precipitation. We focus on the importance of the condensed water structure, using it as a proxy for the distribution of the associated latent heating and, hence, the intensity of convective activity. We developed our approach using passive microwave (PMW) measurements of the condensed water from the GPM and TRMM conically-scanning radiometers (GMI, TMI, AMSR2, SSMISs) as these observations have two important characteristics: good spatial coverage; sensitivity to the vertical extent of the precipitating and non-precipitating clouds in the column, not just the surface rain. In the analyses of the condensed water, we employ a previously-developed measure – the Rain Index (RaIn) – a multi-channel non-linear combination of the PMW observations that depicts the 2-dimensional (2D) storm structure in a way similar to that provided by radars. We then employ a low-wave-number decomposition (LWND) of the 2D fields of columnar condensate (as depicted by the RaIn) to depict the radial distribution of the azimuthally-averaged fields (the magnitude of wave number 0 – WN0), as well as the radial distribution of the first order asymmetry that is captured by the magnitude and azimuthal orientation of the first harmonic in the Fourier decomposition (WN1). We have analyzed a number of hurricane cases to demonstrate the ability of the approach to detect the features of interest.
Our results illustrate the potential predictive abilities of this satellite-based analysis framework. In agreement with previous studies, we found that Rapid Intensification (RI) follows after observing significant precipitation in close proximity to the storm center (within 75km range). Based on this, we formulate the following:
Hypotheses: TC RIC is strongly affected by the radial distribution of precipitation intensity with respect to the TC core and by its first-order asymmetry. Specifically,
Hypothesis 1: TC RI will follow 12-24 hours after observing significant precipitation inside the 75 km range from the storm center.
Hypothesis 2: Rapid Weakening (RW) will follow the occurrence of significant precipitation at distances > ~200km from the storm center.
Hypothesis 3: At the RI onset, the inner-core precipitation is asymmetric, signifying the presence of intense precipitation over certain quadrants. Ongoing RI results in axi-symmetrization.
Hypothesis 4: The location of the intense precipitation with respect of the shear vector is important for the RI. At the onset of the RI the intense but localized precipitation is in the

Down-Shear-Right quadrant and propagates counterclockwise during the axi-symmetrization.
To address the needs for accurate prediction of TC RIC, we set three goals and five objectives:
Goal 1: To use a 20-year record of satellite PMW observations of precipitation to test these hypotheses.
Goal 2: To use the observations-based characterization of the precipitation structure as a tool to evaluate TC forecast models.
Goal 3. To develop observational predictors of TC RIC using Machine Learning (ML) approaches.
Objectives:
1. To develop a database of the 2D structure of observations as depicted by the PMW-based RaIn. To augment each observation with its low-wavenumber decomposition (LWND).
2. To build a climatology of the TC structures as depicted by the RaIn and the LWND.
3.To test our hypotheses by analyzing the LWND of the PMW observations for improved understanding of the TC processes.
4.To collaborate with TC forecast modeling groups (NRL/HRD) to use the new metrics for model evaluation.
5.To develop observational predictors of TC RIC.

Matthew Igel/University of California, Davis
Assessing the Tropical Two-Layer Moisture-Precipitation Paradigm
21-PMMST21-0011

Numerous observational and modeling studies have shown a consistent relationship between total column water vapor and mean precipitation. The rapid onset of mean precipitation in columns moister than a critical threshold in total moisture has proven to be a useful lever with which to pry out physical understanding of the coupling between the large-scale thermodynamics of the tropical atmosphere and convective precipitation. Unfortunately, it is impossible to relate column moisture to the canonical population of convective clouds in the tropics unambiguously. Yet, precipitation production and dissipation depend crucially on cloud type. Extending the existing framework, Igel (2017) suggested that contributions to total column moisture from above and below the melting layer be considered independently when attempting to relate moisture to precipitation production. This additional consideration helped link moisture to precipitation through clouds and cloud types. That study only used data from a high-resolution cloud model. Those results need to be confirmed and significantly expanded with observations (see below). Thus, we propose to use Global Precipitation Measurement (GPM) mission satellite data to improve our physical understanding of the sensitivity of clouds and precipitation to environmental moisture.

The proposed study will use global, remotely sensed precipitation data from both current generation (i.e. GPM) and legacy platforms (i.e. the Tropical Rainfall Measuring Mission [TRMM]). Both high spatial resolution, vertically-resolved radar precipitation measurements and spatially-extensive microwave precipitation estimates will be used. These precipitation data will be paired with data from NASA's A-Train satellites and reanalyses. The proposal will use cloud radar data from CloudSat and vertical profiles of temperature and moisture from the Atmospheric Infrared Sounder (AIRS). The proposed project will be responsive to research objective 2.2 in the solicitation. It will improve our understanding of the sensitivity of clouds and precipitation to environmental conditions and will provide a unified framework for investigating the water and energy budgets of the atmosphere.

The proposal will:
1) Use collocated measurements of precipitation and vertically-resolved temperature and moisture to examine the dependence of mean precipitation on moisture below and above the melting layer, as well as column moisture. This will provide a robust test of the results of Igel (2017) who argued that the layer-dependence they saw in their cloud model represented a physically meaningful relationship.
2) Examine the vertical structure of both clouds and rain as a function of layer moisture and column moisture. In the proposed work, we will systematically link the vertical structures of moisture, clouds, and rain by developing simple comparative metrics for each quantity. Previous observational studies examining column moisture and mean precipitation have largely neglected the role of clouds in mediating any physical relationship. The rain vertical structure has also largely been ignored in the past.
3) Construct composite time evolutions of precipitation, clouds, and environmental moisture. Igel (2017) suggested that atmospheric column moisture follows a simple limit cycle which allows the moisture state of the atmosphere to evolve in a predictable way. The evolution of clouds was suggested to follow this limit cycle. These suggestions will be tested rigorously by constructing composite temporal progressions following the general method of Masunaga (2012) which utilizes the different observing times of GPM/TRMM and A-Train satellites.

Christopher Kidd/University of Maryland, College Park
A Framework for Precipitation Retrievals from the Evolving GPM Constellation
21-PMMST21-0100

The spatial and temporal variability of precipitation requires sufficient sampling to ensure that the characteristics of precipitation are properly represented. No single passive microwave sensor (PMW) sensor can adequately observe precipitation at the timescales of precipitation events, consequently, observations from many different sensors are required to capture the evolution of precipitation systems. The Global Precipitation Measurement (GPM) mission aims to provide observations every 3 hours at least 90% of the time, although this is very much dependent upon the current configuration of the GPM constellation. Currently, several of the GPM constellation satellites are approaching their end-of-life (MetOp-A will be decommissioned in the Fall 2021), while others are in back-up orbits that are similar to other PMW sensors. Consequently, significant temporal gaps of up to four hours, necessitate the inclusion of additional observations.

The primary aim of this proposal is to develop the necessary retrieval scheme framework to maximise the exploitation of all PMW sensors, particularly those not currently included in the current GPM constellation, as well as incorporating observations from newly launched missions. The development of such a framework is particularly important when L2 data products are passed through to the L3 products which rely upon a steady, timely and reliable data stream to ensure the generation of high quality, high resolution (temporal and spatial) precipitation products.

In addition to the observations from the current GPM constellation, the framework will encompass observations from cubesats and smallsats, such as the upcoming TROPICS constellation, as well as those from new missions such as the Copernicus Imaging Microwave Radiometer (CIMR). In addition, the proposal work will reach out to new experimental systems, such as the H8 (CLIVAR and TEMPEST) on ISS to assess the utility of incorporating missions-of-opportunity within the retrieval schemes. Many of these new observations build upon the high-frequency observations of the MHS/ATMS sensors, thus leading to a greater reliance upon high-frequency observations within precipitation retrieval schemes.

The framework retrieval scheme will build upon the PRPS scheme (Kidd et al, 2016, 2021) which relies upon a combination of model and observations to generate hybrid retrieval databases. The retrieval scheme incorporates redundancy levels which allow retrievals to be made despite loss of channels within the input data, together with measures of errors and uncertainties of the retrieval precipitation products. Crucially, the proposed work will demonstrate the utility of a rapidly deployable and updatable retrieval scheme based upon model/observations, provide improved integration of precipitation products into merged scheme, such as IMERG – essentially generating a L2C-type product for which precipitation retrievals are cross-calibrated, exploit easily-obtainable data sets, such as Global-IR data, to better constrain retrievals and allow the flexibility to incorporate products from new missions as soon as possible, and possibly from less-than-optimal sources, or short-duration missions.

Dalia Kirschbaum/Goddard Space Flight Center
Characterizing Extreme Storms to Better Inform Hydrometeorological Hazard Assessment
21-PMMST21-0046

Hydrometeorological hazards are caused by extreme precipitation events, such as floods and landslides, and account for a dominant fraction of significant natural disasters worldwide, killing over 65,000 people and costing $280 billion (USD) between 2002-2011, according to the World Disasters Report. Identifying the characteristics of extreme precipitation events that may trigger hydrometeorological hazards is paramount to better modeling their impacts on populations and infrastructure around the world. The Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (GPM) (IMERG) has provided valuable information for direct use by the hydrometeorological hazards community. However, IMERG has been shown to severely underestimate the magnitude and extent of some extreme precipitation events. As a result, corresponding estimates from hydrometeorological hazard models that rely on IMERG products may miss the widespread impacts to populations and infrastructure. There is a compelling need to evaluate and improve how extreme precipitation estimates from IMERG are used in hazard applications. Using landslides as a focus, the proposed work explores where and when extreme events are mapped by the IMERG Early product, and examines how additional satellite-based information (e.g. lightning, total precipitable water, multiband infrared) may improve performance of a global landslide model developed by the proposal team. The results of this work will provide additional insight into the use and possible enhancement of IMERG for hydrometeorological hazard applications and modeling more broadly.

The goal of the proposed work is to demonstrate how IMERG can be better used to resolve hydrometeorological hazards by characterizing the distribution of extreme events on Earth and considering complementary data to address deficiencies in IMERG to improve estimations for these events. We will then test the effect upon model performance by integrating IMERG with these complementary data into a global landslide hazard modeling framework. We will work towards these goals by addressing the following questions:

1. Where does IMERG identify extreme events and how well are those events resolved?
2. Can we better characterize these events by augmenting IMERG with complementary data and machine learning?
3. Can these enhancements improve a real-time global landslide hazard model?

This work is responsive to Category 3 in the PMM Solicitation by developing a methodology for improved application of IMERG data. The global landslide hazard model developed by the proposal team—which will be enhanced as part of the proposed work—already uses IMERG data for near real-time hazard assessment. As such, it directly addresses the solicitation’s goal of developing precipitation-related applications that make use of GPM data for monitoring and decision support systems. Our targeted end users include emergency response managers, non-governmental disaster support centers, regional and local governments, global aid organizations, and disaster management groups, many of whom are already utilizing the global landslide model outputs provided by the proposal team. Improving model performance for these types of extreme events will be critical for more local applications. The proposed work will have practical implications more broadly for understanding the use of the GPM satellite data for hydrometeorological hazard assessment at local, regional, continental, and quasi-global scale.

Christian Kummerow/Colorado State University
GPROF and Regime Dependent Uncertainties

21-PMMST21-0050

Validation efforts have been integral components of satellite missions in order to provide users with not only the desired products, but also the necessary data quality information. This strategy implicitly assumes that validation statistics are generally reproducible form one region to another so that a few validation efforts are enough to fully characterize products. Unfortunately, with passive microwave rainfall estimates, the information content is limited, and validation results often retain distinct regional differences. Well correlated and nearly unbiased results in the Central United States, for instance, can become negatively biased with much poorer correlations when the same algorithm is applied over South Korea.

Here, we attack this problem specifically for the GPROF algorithm, although some of the methods are likely generalizable to other rainfall sensors and products. Because regional problems are caused neither by random or systematic errors, but rather by regime dependent variations in the cloud systems, biases and uncertainties must also be framed in the regime framework. On an hourly basis, for instance, the diurnal cycle of precipitation is critical, but its importance diminishes as weeks and months are averaged. On a daily or synoptic scale, the general circulation and the relevant thermodynamic regimes are likely the biggest contributors to regional differences, while at large domain, seasonal scales, small, but persistent differences in the atmospheric forcings are likely to blame for regional biases such as those that have been observed between equatorial South America and Africa.

To overcome these limitations, we hope with this work, to begin generalizing validation statistics that have been collected for individual regions, to apply to observational and meteorological “regimes” that are applicable globally. If we can properly define these “regimes” such that GPROF validation statistics are reproducible any time, and anywhere that the “regime” is observed, the validation paradigm can be extended to predict validation statistics globally as long as the defined “regimes” are well observed by some of GPMs current validation networks. We focus here on regime-dependent errors on 1°, instantaneous and 5° seasonal (indexed by the central month) scales for their immediate applications to IMERG in the case of 1°, daily precipitation, and for climate variability and trend studies in the case of 5°, seasonal grids. With this work, we hope to lay the foundation for predicting uncertainties at these two scales in regions without validation data – arguably the regions in which satellite uncertainties are most critically needed. By relying on “regimes” (rather than locations) we hope to significantly expand the applicability of validation data that has been collected to date, thereby expanding the usability of this product, and the products who use GPROF in the merged applications. While the approach of using “regimes” instead of geographic locations perhaps new to rainfall validation, it is a concept that has long been used to better understand storm dynamics and the bedrock of many of the TRMM and GPM Field Experiment planning. This provides some basic assurances that the method should prove useful for predicting uncertainties in remote locations, as long as their precipitation regimes overlap regimes that are well observed by our current networks of ground-based radars

Timothy Lang/Marshall Space Flight Center
Investigating Cloud-to-Precipitation Transitions with Airborne Passive Microwave Observations
21-PMMST21-0007

Spaceborne radiometers within the Global Precipitation Measurement (GPM) constellation (including the GPM Microwave Imager; GMI) have instantaneous fields of view (IFOVs) that are often multiple km in horizontal size, indeed even 10s km for lower frequencies like 10 GHz. These large IFOVs are subject to significant non-uniform beam filling (NUBF) and thus mask high-resolution spatial variability that occurs within precipitation systems. Ultimately, this limits spaceborne radiometers' ability to characterize high-resolution microphysical and precipitation processes such as the transition from clouds to precipitation.

Moreover, the cloud/precipitation transition has not been studied much using observations from airborne radiometers. The Advanced Microwave Precipitation Radiometer (AMPR) and the Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR) both feature very high spatial resolution, with IFOVs many times finer than those provided by spaceborne radiometers like GMI. Together, they cover almost every frequency measured by GMI (10-183 GHz), and they operated in tandem during the GPM Ground Validation (GV) campaigns called the Integrated Precipitation and Hydrology Experiment (IPHEx; 2014) and the Olympic Mountains Experiment/Radar Definition Experiment (OLYMPEX/RADEX; 2015).

While AMPR and CoSMIR have already delivered quality-controlled radiances from these GPM GV campaigns, these datasets have not been adequately merged, including accounting for occasional instrument/channel dropouts, and in the case of OLYMPEX/RADEX, handling the physical separation of the instruments on different aircraft. The proposed effort, which directly addresses subelement 2.2 of the NASA Precipitation Measurement Missions call (Science and Process Studies), will create merged AMPR/CoSMIR datasets for IPHEx and OLYMPEX/RADEX. Furthermore, the Community Radiative Transfer Model (CRTM) and the One-Dimensional Variational Inversion Algorithm (1DVAR) will be adapted to work with these unique airborne radiometers, and thereby provide an accurate set of retrieved geophysical parameters (e.g., cloud liquid water, atmospheric water vapor, etc.). This work will leverage the recent application of an unaltered 1DVAR to the AMPR dataset from OLYMPEX/RADEX, and use lessons learned from that study to broaden the scope and improve the accuracy of airborne retrievals. Where possible, the retrievals will be validated using other GV datasets.

In and near precipitation, airborne radiances (along with retrievals of cloud ice, cloud water, and water vapor) will be studied in detail, in concert with profiling observations provided by triple-frequency (W/Ka/Ku) airborne radars, in order to understand how high-resolution radiometers characterize transitions between clouds and precipitation. This information will be used to build an empirical model that statistically characterizes vertically distributed and vertically integrated active/passive microwave observations of the cloud/precipitation transition process. The results will bring better understanding of cloud/precipitation transitions, and will inform potential improvements to satellite-based identification of precipitating vs. non-precipitating clouds, as well as determine how suborbital campaigns can best contribute to our understanding of the precipitation onset process.

Chuntao Liu/Texas A&M University - Corpus Christi
Upgrade Precipitation Feature Databases and Assess Uncertainties in PMM Products
21-PMMST21-0002

In this collaborative project, we plan to improve and update the Precipitation feature databases derived from the TRMM, GPM, constellation satellites, IMERG, and upcoming CubeSats product. These databases will be utilized to diagnose the uncertainties in two important PMM products and address a broad range of science questions. We plan to focus on following objectives:

• Maintain, improve, and validate PMM PF databases with continues help of the PPS.

- The 22+ year TRMM, GPM PF databases have been and continues to be an invaluable asset to the precipitation science community. We will keep maintaining and updating it for reprocessing of Version 7 products with the continued help of the PPS.
- The NAAPS aerosol reanalysis parameters, including the aerosol optical depth and wet sink from four different aerosol species, will be incorporated into the TRMM and GPM PF databases. This addition will enable the PF database a tool to understand the role of aerosols in the precipitation processes in various precipitation systems around the globe.
- A new precipitation feature algorithm will be developed based on the precipitation retrievals and the brightness temperature at high frequency channels from CubeSats, starting with the TEMPEST-D, then adapting to the upcoming TROPICS mission.

• Diagnosing and quantify the biases and uncertainties in the current PMM precipitation product, including:

- underestimation of warm rain rates during monsoons in the Combined product,
- inconsistency in the heating depth between the SLH and the CSH latent heating products,

• Address specific scientific questions, including:

- How does raindrop microphysics vary in warm rain systems during monsoons? why is rainfall underestimated in this type of systems by the Combined algorithm?
- How would latent heating profiles vary at different life stages of precipitation systems, and under different weather regimes?
- What are the impacts of various types of aerosols on the precipitation process in different types of precipitation systems over different regions?

To accomplish these tasks, we plan to collaborate with Dr. Xian and Dr. Turk on incorporate NAAPS reanalysis data, Dr. Wei-kuo Tao on understanding the differences between the CSH and the SLH products, Dr. William Olson on microphysics retrievals in the Combined product, Dr. Edward Zipser at the University of Utah on the assessment of tracking the development of organized convection, and the PPS on processing the data. This project fits into the research category 2.1 - Algorithm/Data product enhancement and validation.

Daniel McCoy/University of Wyoming
Constraints on Extratropical Cloud Feedback Through Analysis of Cyclone Precipitation Structure
21-PMMST21-0037

In the last decade confidence has grown in a positive subtropical shortwave cloud feedback, with progress on quantifying the feedback magnitude and underlying mechanisms (Sherwood et al. 2020). However, despite a tendency in models to simulate a negative feedback, the extratropical cloud feedback has remained poorly constrained. Between CMIP5 and CMIP6, the extratropical (~ 45-75°) shortwave cloud feedback has shifted to more positive values by nearly a standard deviation relative the distribution of CMIP5 models, leading to emergence of high climate sensitivity GCMs (Zelinka et al. 2020).

Recent literature suggests that the response of extratropical liquid clouds to warming is determined by how efficiently converging extratropical moisture is converted into precipitation (McCoy et al. 2019, 2020). GCMs that convert moisture into precipitation efficiently have a weakly negative feedback, while models with inefficient precipitation processes exhibit strong negative feedbacks. We believe that insight given by GPM and IMERG into extratropical precipitation processes (Cannon et al. 2017), combined with observations of clouds and water vapor from other NASA data products, will allow us to better understand and constrain cloud feedback and ECS.

To evaluate the parameterization of clouds and precipitation in a GCM we will examine simulation output from a perturbed parameter ensemble (PPE) developed to determine the GISS-E3 model configuration. The structure and intensity of precipitation in extratropical cyclones in simulation output will be contrasted with precipitation structure observed by GPM and IMERG. Cyclone compositing, frontal identification, and tracking will be performed to evaluate the evolution and frontal structure of cyclones in GCMs. We hypothesize that we will see rapid removal of precipitation along fronts in GCMs with weakly negative feedback and more diffuse precipitation in GCMs with strong negative feedback. Secondarily, we might expect that GCMs that create more ice-phase precipitation may manifest efficient frontal precipitation. GPM overpasses of extratropical cyclone fronts will be contrasted with GCMs. IMERG precipitation rates will be used to examine lifecycle for cyclones intersecting with the GPM overpass. Moisture convergence will be examined using WVP and wind speed observed by the MEaSUREs MAC-LWP data set (Gregory S. Elsaesser et al. 2017). Liquid water path from MAC-LWP will be used to provide simulation-compatible diagnostics of cloud liquid. MERRA-2 reanalysis will be used to perform cyclone/frontal compositing and tracking.

Cannon, F. et al. 2017: GPM Satellite Radar Measurements of Precipitation and Freezing Level in Atmospheric Rivers: Comparison With Ground-Based Radars and Reanalyses.
Gregory S. Elsaesser, et al. 2017: The Multi-Sensor Advanced Climatology of Liquid Water Path (MAC-LWP).
McCoy, D. T., and Coauthors, 2019: Cloud feedbacks in extratropical cyclones: insight from long-term satellite data and high-resolution global simulations.
McCoy, D. T., et al. 2020: A regime-oriented approach to observationally constraining extratropical shortwave cloud feedbacks.
Sherwood, S. C., and Coauthors, 2020: An assessment of Earth's climate sensitivity using multiple lines of evidence.
Zelinka, M. D et al. 2020: Causes of higher climate sensitivity in CMIP6 models.

Lisa Milani/University of Maryland, College Park
Snowfall Type Classification for Improving Passive Microwave Falling Snow Estimation/Retrieval
21-PMMST21-0086

Falling snow is a key component for the global atmospheric, hydrological and energy cycles, and its retrieval from space-based observations represents the best current capability to evaluate it globally. Precipitation retrieval algorithms have been developed and refined over the few last years and their accuracy and reliability are becoming increasingly more important for Earth's energy and radiation budgets, as well as for human activities. Unfortunately, many issues still affect snowfall retrievals and algorithms' performances cannot be considered accurate and reliable enough yet. In particular, previous work showed that, within the Global Precipitation Measurement (GPM) mission, the Goddard PROFiling (GPROF) algorithm snowfall retrieval performances strongly depend on the snowfall type. Some type of snowfall, such as the shallow convective one, are detected with extreme difficulties and in most of the cases completely missed. Moreover, since the retrieval is based on Passive Microwave (PMW) data, the well-known issues of snow covered surfaces contaminating the signal arise, inducing false alarms in the precipitation estimates. The main reasons for GPROF behavior have been identified in the Bayesian nature of GPROF which relies on a-priori databases for its estimates. If the a-priori databases are not representative enough for a particular type of precipitation event, the estimates cannot actually find a 'perfect' match and miss or underestimate precipitation. Is representativeness the problem or is non-uniqueness i.e., the same TB signature make mean something in stratiform snow but another in convective snow? Some other details of GPROF (i.e. channel sensitivity, surface classification, etc.) could be modified to improve the retrievals and a classification flag that recognizes the snowfall type and makes the algorithm switching its characteristics would be particularly helpful. Many efforts have been made to partition rainfall between convective and stratiform, but very few efforts have been spent for snowfall and none of the methods developed can be applied to PMW retrievals.
Given the importance of convective snowfall type both globally (i.e. Northern Atlantic region, sea of Japan, Antarctic belt, etc.) and locally (i.e. lake-effect snow over the Great

Lakes), this proposal aims to partition snowfall type providing a flag able to activate a specific and dedicated setup of GPROF. This will be achieved through development of a new Deep Neural Network (DNN) model for snowfall class detection. Relying on the available CloudSat data, combined CloudSat-GPM dataset, and relevant ancillary products, GMI observations will be linked to a number of snowfall classes to offer a complementary information content to the existing PMW algorithms. In this effort, a newly developed GMI non-rain retrieval with surface-specific emissivity constraints will provide the necessary skill for precipitation detection. An evaluation exercise will be done, using part of the CloudSat dataset (mainly over ocean) and ground based sensors (Multi-Radar Multi-Sensor dataset over US, Finland and Great Lakes region radars).

Vasubandhu Misra/Florida State University
The Monitoring and the Predictability of Regional Tropical Rainy Seasons Using GPM Products
21-PMMST21-0018

The overarching goal of this project is to understand and monitor the variations in the evolution of the rainy season across various regions in the global tropics using NASA's GPM rainfall products. These regions that include nations in South Asia, monsoon core regions in South America and North America, Central America, tropical and subtropical Africa, and Northern Australia exhibit a robust seasonal cycle of rainfall. The current practices of monitoring the rainy seasons in these regions are not uniform, subjective, and do not necessarily recognize the importance of the variations in the length of the season. This project proposes to first assess the fidelity and the relationship of the variations in the onset/demise and length of the rainy season with other thermodynamic and dynamic variables of the atmosphere and ocean to develop an understanding on the evolution of the rainy season in relation to the proposed metric. It is also proposed to operationally monitor the rainy season with this uniform metric both at the regional (macro scale) and at the local scales. It should be recognized that these regions carry a substantial burden of the human population that critically depends on this seasonality. Several stakeholders have already expressed strong interest in this real time monitoring effort on the evolution of the rainy season.

Some of the strengths of the proposed metric to monitor onset/demise of the rainy season is that it is spatially scaleable to the application need, depends on a single observed variable i.e., rainfall, recognizes the importance of the variations in the length of the season at intraseasonal, interannual and longer time scales. Our earlier studies have indicated that the onset/demise date variations of the Indian and Northern Australian rainy seasons are strongly related to intraseasonal variations. Therefore, the S2S models that have archived their hindcasts will be investigated to assess their subseasonal predictability of rainfall around the evolution of their rainy season.

This project stems from considerable background work done by the PI, which bolsters the prospect to achieve the proposed goals. Our prior work has shown that variable length of the rainy season, for example, over India and Northern Australia exhibit a far stronger teleconnections than fixed length rainy seasons. In this study we will be exploring if the variations in the evolution of the rainy season in one region could affect the other? For example, the transition from the Indian to the Northern Australian season or the transition from the South American to the Central American and to the North American rainy season. Furthermore, our current effort to operationally monitor the evolution of the rainy season over Florida using the GPM rainfall products has been very well received by the water utility managers across Florida. We hope to replicate and expand this interest with a broader network of stakeholders with the proposed monitoring website.

In terms of the relevance to the call, the proposal directly addresses to the theme of "utilization of satellite/ground validation data products for process studies and model development". The IMERG products from GPM will be extensively used in this project to not only diagnose the evolution of the rainy season but also monitor it in real time. Furthermore, this study intends to make use of a number of NASA products besides GPM like MERRA2, NASA GMAO Ocean reanalysis datasets to ascertain the relationship of the thermodynamic and dynamic variables in the atmosphere and the ocean with the evolution of the rainy seasons.

Claire Pettersen/University of Wisconsin, Madison
High-Latitude Precipitation Characteristics During Atmospheric River Events Utilizing GPM and Ground-Based Observations
21-PMMST21-0026

Atmospheric Rivers (AR) produce extreme precipitation rates and winds that can lead to destructive flooding. During the cold season and in the high-latitude regions, AR-influenced precipitation events are more likely to produce rain-on-snow events, which lead to the rapid melting of snow, flooding atop the snow pack, and abrupt rises in river and lake levels due to run off. Utilizing GPM and ground-based observations to characterize precipitation phase and intensity during AR events will help to better predict impacts. Additionally, comparison of coincident values from GPM products with strategically located high-latitude ground-based datasets during ARs can evaluate satellite retrieval parameterization assumptions through assessment of precipitation phase and rates.

GPM Microwave Imager (GMI) products from the Goddard Profiling Precipitation Retrieval Algorithm (GPROF) co-located with identified ARs indicate that these events have higher rates as well as more frequent precipitation in the high-latitude regions. Furthermore, initial investigations from long-duration ground-based instrument observations suggest a significant increase in the frequency of surface rainfall during cold-season and high-latitude AR events. The abundance of available overpasses from GPM at high-latitude provide a unique opportunity to analyze precipitation evolution and phase during AR events at relatively high temporal resolution. Additionally, several high-latitude ground-based sites with long-duration surface observations can be leveraged to compare with simultaneous observations from GPM to assess the ability of GMI and Dual-frequency Precipitation Radar (DPR) to accurately obtain precipitation phase at the surface.

The proposed work fulfills the objectives stated in Research Category 2.2: Science and Process Studies. We will leverage GPM satellite observations and field campaign datasets in the high-latitudes to study precipitation and microphysical processes during high-impact AR events, with a focus on phase discrimination. We will utilize GPM and ground-based data to achieve the following objectives:

1. Exploit our recently developed high-latitude GMI and AR gridded product to assess precipitation phase during AR events.
2. Expand our high-latitude GMI and AR gridded product to include DPR observations and compare precipitation phase and rates between sensors, as well as examine profile characteristics during AR-enhanced rain events.
3. Leverage collaborations with several strategic, long-duration ground-based instrument sites near overpass maximum to assess GMI and DPR determined precipitation frequency, intensity, and phase.

Grant Petty/University of Wisconsin, Madison
A 70-Year Climatology of Ocean Precipitation from Shipboard Present-Weather Observations Calibrated Using GPM
21-PMMST21-0042

For most of the 20th century, there was little reliable information about precipitation amount or its geographic and seasonal distribution over most of the global oceans, especially at any significant distance from land-based rain gauges. Several notable efforts in the 1960s through 1980s undertook the construction of basic ocean precipitation climatologies, relying partly on coarsely categorical reports of precipitation type and intensity from ships of opportunity. However, the means did not exist to accurately calibrate or verify the resulting maps, nor did they cover a sufficiently long period of time to permit trends and other interannual variability to be studied.

Beginning in 1979, the Global Precipitation Climatology Project (GPCP) now provides monthly global precipitation maps based on combinations of satellite microwave retrievals, infrared imagery, land-based rain gauges. These have been widely utilized to explore interannual variability of precipitation in connection with climate change as well as various climate-scale cycles, such as ENSO. More recently, the Integrated Multi-satellitE Retrievals for GPM (IMERG) product is now available for years starting in 2000. It combines multi-sensor satellite precipitation data, including from the Tropical Rainfall Measuring Mission (TRMM, 1997–2015), the Global Precipitation Measurement (GPM) mission (2014 to present), and rain gauges where available, and it exploits geostationary infrared images to interpolate polar-orbiting microwave images of precipitation between overpass times for improved sampling.

Earlier work by the PI (Petty 1995) showed that it is possible to analyze ship observations of present weather to obtain climatological maps not only of precipitation frequency but also qualitative precipitation character (proportion of drizzle or heavy rain, showery precipitation, snowfall, thunderstorms, etc.). New work in progress is showing that it is also possible to detect significant trends in precipitation frequency. The objective of this proposal is to substantially extend the above work, not only by analyzing a longer record of ship reports (1950 through 2019), but also by reconstructing monthly maps of calibrated precipitation amount , not just frequency, over much of the world's oceans. Specifically, we will utilize GPM-era ocean precipitation estimates from IMERG and GPCP to develop and calibrate an algorithm for optimally estimating ocean precipitation amount from tabulated frequencies of ship-reported precipitation occurrence and type.

The result will be an an independent and reasonably homogeneous record of ocean rainfall spanning seven full decades, including the three decades prior to GPCP and more than six decades prior to GPM. Careful attention will be given to characterizing sampling and other uncertainties associated with the estimates, as required for significance testing of trends, for example. Because the analyses will be derived without reference to model-based estimates of ocean precipitation, they can potentially serve as independent validation for precipitation fields and associated trends and variability from standard reanalyses.

Derek Posselt/Jet Propulsion Laboratory
A Study of the Influence of Convection on Atmospheric River Genesis, Evolution, and Precipitation Production
21-PMMST21-0047

Atmospheric rivers (AR) constitute a critical component of the Earth’s water budget and produce a significant portion of the precipitation that falls along the western portions of middle-latitude continents. While ARs have been the subject of much study in recent years, significant questions remain as to their origin and evolution. Preliminary studies indicate that convection in the sub-tropics and lower mid-latitudes may exert a significant influence on the formation, development, and downstream impacts of ARs. However, a systematic and observation-based study has yet to be conducted.

The Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Mission (GPM) core observatory have made systematic active and passive measurements of precipitation in the tropics, sub-tropics and extra-tropics (lower middle latitudes in the case of TRMM) for more than two decades. In particular, the estimates of convective and stratiform rainfall and latent heating from the TRMM precipitation radar (PR) and GPM dual-frequency PR (DPR) allow a detailed study of the frequency and amount of convection in AR initiation regions, as well as its influence on the synoptic dynamics. The recent launch of the Cyclone Global Navigation Satellite System (CYGNSS) mission allows a joint study of precipitation and ocean surface winds and fluxes around convection. Along with reanalysis data that provide estimates of the thermodynamic environment and large-scale winds, a rich dataset exists with which to explore the evolution of ARs through their full life cycle.

In this research, we will study the relationships among convective precipitation and the initiation, development, and downstream impacts of ARs. We will quantify the incidence and amount of convective precipitation early in the AR development, then study the relationships between convection and AR features (e.g., integrated vapor transport) during development and finally the downstream impacts in terms of winds and precipitation. A well-proven AR identification and tracking database will be extended to cover times early in AR development (e.g., at the early stages of moisture organization, prior to the AR achieving necessary length/width and magnitude criteria for tracking), and well-tested cyclone identification and compositing techniques will be used to study ARs forming in various environments. The research will begin with an examination of several recent high impact AR events that were well-observed by Scripps Institution of Oceanography's Atmospheric River airborne reconnaissance program (AR Recon; 2016-2021) and occurred during the time both GPM and CYGNSS were on orbit. These cases will be used to develop objective means of identifying AR initiation regions, and also serve as the basis for detailed studies of the occurrence and morphology of convection and its relationship to ocean surface winds and fluxes in ARs. We will then proceed to composite analyses of ARs for the 20+ year time frame spanned by TRMM and GPM. Composite studies of precipitation type, intensity and latent heating profiles will provide an indication of the relationships that may exist between convective occurrence, timing, and location and the downstream AR impacts. These relationships will be examined using a multi-decade database of AR re-forecasts produced by Scripps.

The outcomes of our research will include: new knowledge of how convection influences AR development, evolution, and impact, and analysis of the potential mechanisms that drive the convection-AR relationships. This research addresses research category 2) "The use of satellite and ground measurements for physical process studies to gain a better understanding of precipitation, the global water cycle, climate, weather, and concomitant improvements in numerical models from cloud resolving to synoptic scales."

Kristen Rasmussen/Colorado State University
The Nature of Global Convection from GPM: Extratropical Cyclones to Tropical Convection
21-PMMST21-0073

The GPM satellite has ushered in a new era of global rainfall estimation as it provides a more global view of precipitation compared to TRMM, resulting in a wider variety of precipitation regimes from light rain to intense mixed-phase mid-latitude convection and snow. The proposed research is centered on three major objectives which seek fundamental understanding of storm processes, including the lifecycle and structural characteristics of extratropical cyclones (ETCs), comparing the nature of convection in GPM dual-precipitation radar (DPR) observations and high-resolution convection-permitting operational and regional climate model simulations, and evaluating precipitation estimation in extreme rainfall over the ocean and complex terrain, the latter leveraging a unique dataset on heavy rain.

In Objective A, we will validate and better understand the performance of GPM algorithms (GMI, IMERG, DPR) in regions experiencing heavy rainfall over land, ocean, and complex terrain regions using data from recent and planned field campaigns. Underestimates of GPM DPR compared to ground observations in the heaviest rainfall over both ocean and land regions of the western Pacific indicate that more research is needed to understand the bias in especially heavy rainfall, leading to improved satellite estimates globally. Under this objective, we will evaluate IMERG and DPR rain estimates using the PRECIP field campaign dataset to be obtained in summer 2022 and prior field campaign datasets of the western and eastern Pacific oceanic regions from the PISTON and SPURS campaigns respectively. Objective B will build on our previous work by continuing our investigation of the three-dimensional characteristics and life cycle of ETCs in the Northern and Southern Hemispheres using GPM DPR and IMERG datasets. Particular attention will be given to ETCs over storm tracks (including over land), the Southern Ocean, ETCs associated with atmospheric rivers, and land falling ETCs. We will evaluate specific ETC cases that occurred during the OLYMPEX field campaign to examine rain vs. snow estimation in complex terrain leveraging ground-based disdrometer and polarimetric and multi-wavelength radar observations. Finally, Objective C is an investigation of the global population of precipitation systems using both GPM DPR and high-resolution convection-permitting regional climate simulations to provide improved understanding of the global water cycle and representation of clouds and precipitation in current climate simulations. We will categorize different lifecycle stages of precipitating systems using both GPM DPR and simulated reflectivity model output to determine how well convection-permitting climate simulations represent the spectrum of precipitating systems in the U.S. and South America.

Our research will provide important insights that will improve understanding of the variability of the three-dimensional characteristics of global precipitating systems, validate satellite retrievals of precipitation over complex terrain and oceans, and evaluate how well convection-permitting NWP and regional climate models reproduce the storm structures viewed by GPM. Improving understanding of the global nature of clouds and high-impact weather is the primary motivation behind the proposed work, and thus, this research is a key focus of NASA's Earth Science Research Program. The proposed research directly addresses 4 out of 5 of the GPM Science Objectives. The proposed research objectives primarily address PMM Solicitation Research Category 2.2, by using satellite and field campaign data to study precipitation and microphysical processes, but also contribute to Category 2.1.

Courtney Schumacher/Texas A&M, College Station
Gravity Wave Impacts on Convection Near Complex Terrain (ROSES21)
21-PMMST21-0115

Land breezes that travel offshore from coastlines and mountain breezes that travel downslope from mountain ridges are important nocturnal circulations in regions of complex terrain and are often invoked to explain the formation and propagation of nighttime convective systems in these regions via low-level convergence with the large-scale winds. Gravity waves can be forced by convection and mountains and can modify the environment the convection is entering as well as the convection itself, so may also play a role in the evolution of nocturnal propagating convective systems near complex terrain. The relative importance of each of these dynamical forcings is unknown across much of the globe, with most results relying on short-term, regional modeling studies or

observational campaigns. For this proposed work, PMM satellite measurements will be used to observationally quantify the relative importance of land and mountain breezes and gravity waves on nocturnal propagating convective systems in regions of complex terrain in the tropics, such as over the Maritime Continent and the Himalayas. Environmental information from reanalysis will be used to assess the terrain-induced local circulations and gravity wave patterns in relation to the larger-scale circulation and its synoptic to interannual variability.
The TRMM precipitation radar (PR) and GPM dual-frequency precipitation radar (DPR) in conjunction with IMERG will provide the main observational data sets. IMERG will be used to identify propagating precipitation systems near complex terrain utilizing a proposed tool that can be oriented to any topographic angle and distance along the topography, while the PR/DPR measurements will be composited in space and time within the IMERG-identified events to provide a more direct measure of the convective properties. ERA5 reanalysis will be used to identify land and mountain breezes and their associated convergence using low-level wind and divergence fields and gravity wave features will be identified in temperature anomaly fields or with theoretical speed calculations. The overall outcome of this research will be a highly quantified set of propagation statistics of nocturnal propagating systems off the coasts of the major Maritime Continent islands and over the slopes of the Himalayas that will be used to assess the relative role of local terrain-induced circulations and gravity waves on the formation and evolution of the nocturnal propagating convection, especially in a variety of large-scale synoptic conditions. This framework can also be applied to many other regions of complex terrain across the globe.

Baijun Tian/Jet Propulsion Laboratory
Investigating the Double-ITCZ Bias in CMIP6 Models
21-PMMST21-0028

The double-Intertropical Convergence Zone (ITCZ) bias is a long-standing problem for fully coupled ocean-atmosphere global climate models (CGCMs). Most CGCMs have an excessive rainfall south of the equator and insufficient rainfall on the equator, especially over the Pacific and Atlantic. As a result, most CGCMs have two ITCZs in both hemispheres instead of one ITCZ over the northern hemisphere in observations over the equatorial central and eastern Pacific and Atlantic. Despite decades of model development and climate research, the double-ITCZ bias persists in all generations of CGCMs and still remains a serious problem in the latest CGCMs for Coupled Model Intercomparison Project (CMIP) Phase 6 (CMIP6).

Our recent work have quantified the annual mean double-ITCZ bias in 26 CMIP6 models. The double-ITCZ bias is well known for its strong seasonal variation and models with similar annual mean double-ITCZ bias could have very different seasonal manifestations. This project seeks to characterize the seasonal variation of the double-ITCZ bias in CMIP6 models that has not yet been explored in any published studies so far.

Because of the tight interactions and various feedback mechanisms in CGCMs, it has been proven challenging to identify the root causes of the double-ITCZ bias in CGCMs. Previous studies indicate that the double-ITCZ bias in coupled (CMIP) simulations can be traced back to their corresponding atmosphere-only (Atmospheric Model Intercomparison Project-AMIP) simulations. This project seeks an in-depth analysis of the CMIP6 models' coupled and atmosphere-only simulations to identify and understand the root causes of the double-ITCZ bias in CMIP6 models and to investigate what key errors in atmospheric models best explain the inter-model variation of the severity of the double-ITCZ bias in the coupled models in CMIP6.

This proposal will better characterize and quantify the double-ITCZ bias in CMIP6 models, especially its seasonal variation, will help us to decide which CMIP6 models should be used for IPCC AR6 and future climate projection, and will help better assess our confidence in the future climate projection and the fidelity of the IPCC AR6 based on CMIP6 models. The proposed analyses will help identify and better understand the root causes of the double-ITCZ bias in CGCMs, find ways to reduce the double-ITCZ bias in CGCMs, and guide the refinement and improvement of future CGCMs.

This proposal is directly responsive to the research category 2.2 “Science and Process Studies” of the NASA PMMST call. The NASA TRMM and GPCP satellite precipitation products will play a key role for the double-ITCZ bias diagnosis and quantification in this project. The PI has strong expertise of the double-ITCZ bias and climate model evaluation and analysis as well as the NASA TRMM and GPCP satellite precipitation products.

Francis Turk/Jet Propulsion Laboratory
Enhancements to Passive MW Algorithm Coverage and Representation of Vertical Precipitation Structure, Towards Future Improvements to Level-3 Precipitation Products
21-PMMST21-0020

In this proposal, four research objectives are addressed under Category 2.1, “Algorithm/Data Product Enhancement and Validation”, towards further enhancement of (1) passive MW inter-sensor product consistency, (2) capabilities across surface conditions, (3) passive MW coverage and (4) representation of light rain and snowfall. The capability of each passive MW sensor to replicate the DPR-observed vertical precipitation structure is used as a common metric across the respective four goals, specifically:

Goal 1: To assess and quantify the consistency in the surface precipitation rate and precipitation profile structure estimated across the Version 7 constellation passive MW sensor products. Several passive MW algorithm radiometer products will be evaluated towards replicating the DPR-observed precipitation height, which may provide a significant upgrade to a possible future IMERG update.

Goal 2: To assess and quantify the impact upon the surface precipitation and vertical precipitation structure derived from inclusion of the extensive record of 60-GHz oxygen absorption band channels. These channels bring in surface emissivity and lower tropospheric temperature information from the TB observations themselves, and whose incorporation into PMM radiometer algorithms may better guide the passive MW algorithms to “self-adapt” across a range of surface and weather conditions and across seasons.

Goal 3: To assess and quantify the precipitation estimation skill from a small satellite passive MW radiometer system. There is a fortuitous overlap of the GPM/DPR radar within the expected 3-year operations of the upcoming (late 2021/early 2022) ISS deployment of the COWVR+TEMPEST passive MW radiometer duo. The plentiful orbit coincidences between these two platforms provides a unique opportunity for rapid performance evaluation of Level-2 precipitation profile products, which would expand global passive MW coverage for IMERG.

Goal 4: To extend and update the existing PI-developed CloudSat-GPM (2BCSATGPM) and CloudSat-TRMM (2BCSATTRMM) satellite coincidence datasets. These datasets address DPR limitations in representation of light precipitation (snow and drizzle). Since DPR estimates populate the a-priori precipitation for the GPROF passive MW technique, these observations fill a significant missing component towards future updates to the suite of PMM algorithms.

Christopher Williams/University of Colorado, Boulder
Characterizing Precipitation Vertical Structure in the Satellite Radar Near-Surface Blind Zone
21-PMMST21-0051

Satellite-based radars have a near-surface ‘blind zone’ that prevents valid observations near the surface. Rainfall retrieval algorithms must use measurements far from the ground to estimate near-surface rainfall. For example, the NASA Global Precipitation Measurement Mission (GPM) Dual-frequency Precipitation Radar’s (DPR’s) lowest clutter-free off-nadir measurement is about 2 km above the Earth’s surface, yet, the DPR retrieval algorithms estimate rainfall at the surface. The overarching goal of this proposed research is to improve near-surface rainfall retrievals by characterizing rainfall vertical structure through the satellite-radar blind zone.

This proposed research has four main objectives. First, use vertically pointing radar (VPR) observations from NASA GPM Ground Validation (GV) field campaigns and collaborative partners to estimate raindrop size distribution (DSD) parameters from near-surface to several kilometers above the ground. Millions of DSD profiles from different rain regimes will be produced from several VPRs located across the globe. Then, describe DSD parameter vertical structure in different rain regimes by estimating DSD parameter evolution and identifying the physical processes, such as evaporation and raindrop breakup and coalescence acting on rain shafts. Next, identify rain -to- snow transitions in vertical DSD parameter profiles. Finally, develop relationships between DSD parameters and rain rate at altitudes within and above the blind zone. Accomplishing these objectives will help reduce retrieval uncertainties by providing physical-based relationships between DSD parameters and near-surface rainfall estimates.

This proposed research addresses the three research topics identified at the NASA GPM Cal/Val and Algorithm Virtual Workshop held in March 2020 and will immediately impact GPM precipitation products and GV research activities:

1. Improve estimates across the blind zone from the lowest resolved gate to the surface,
2. Improve DSD parameters retrieved in Radar, Combined, and GPROF algorithms, and
3. Improve phase discrimination in all GPM algorithms.

This proposed research will utilize the Doppler velocity power spectra from micro rain radars (MRRs) to retrieve DSD profiles in the lowest few kilometers of the atmosphere. MRR datasets are available both from collaborative partners with access to MRR datasets from around the globe and from NASA GPM GV program field campaigns including: MC3E, IFloods, IPHEX, OLYMPEX, and ICE POP; as well as several years of VPR observations at the NASA Wallops GPM Precipitation Research Facility.

As summarized above, this proposed research is responsive to GPM Scientific Objective (a) Advancing Precipitation Measurements from Space and to the PMM Research Category (2.1) Algorithm/Data Product Enhancement and Validation.

Daniel Wright/University of Wisconsin, Madison
Global Multiscale Uncertainty Estimation for Satellite Precipitation Products to Improve Hydrologic Prediction
21-PMMST21-0039

Predictions of hydrologic fluxes such as streamflow and evapotranspiration are at the heart of a vast range of research efforts and real-world decisions. While the potential of satellite precipitation to support these activities has been recognized for decades, the usefulness of products such as NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) can be hindered by relatively large errors. These errors stem from algorithm deficiencies, heterogeneous sensor properties, and insufficient spatiotemporal sampling and can depend on precipitation intensity, storm type, latitude, land surface type, and other factors. These deficiencies could be mitigated by robust uncertainty characterization—how right or wrong can we expect a satellite observation to be.

Robust global-scale characterization of uncertainty in satellite precipitation products has proven extremely difficult in practice, leaving both researchers and practitioners with limited information about retrospective and real-time uncertainties—which limits the credibility of subsequent hydrologic predictions. This proposal would address these

issues at a global scale through three interconnected objectives. These objectives cut across all three PMM research categories, but are motivated primarily by the need to improve GPM products for applications:
Objective 1— Develop a global parameterization and analysis of pixel-scale IMERG uncertainty: We will use a recent approach in which GPM Dual-frequency Precipitation Radar is used in place of ground-based data to train error models, which represent precipitation occurrence and magnitude uncertainty as statistical distributions. We will deploy this approach for the first time globally, creating a "pixel-scale" (i.e. single grid cell, single time step) error model parameter database that can be used to provide quantitative estimates of IMERG systematic bias and random error at any location and time.
Objective 2—Connect IMERG uncertainties across space and time to generate ensemble precipitation fields: Accounting for satellite precipitation error correlation structure at arbitrary spatiotemporal scales has been called a "grand challenge." We will address this using a combination of methods to create first-ever globe-spanning ensemble realizations of realistic precipitation spatiotemporal fields that remove IMERG systematic bias and encompass the range of autocorrelated IMERG random error. These methods combine pixel-scale uncertainty estimates from Objective 1 with nonstationary short-Fourier stochastic simulation and Lagrangian advection of uncertainty structures.
Objective 3—Assess value of satellite precipitation uncertainty in global-scale ensemble prediction of hydrologic fluxes: We will combine the results of Objectives 1 and 2 with a state-of-the art global-scale hydrologic model. Using probabilistic metrics and novel validation datasets, we will assess the value of IMERG uncertainty estimates to improve prediction of two critical fluxes: high streamflows (i.e. floods) and evapotranspiration. This assessment will cover diverse climatic regimes and watershed scales, and the combination of these two fluxes will "stress test" our uncertainty representations across a range of precipitation conditions, from zero to light and extreme rainfall.

As far as we are aware, this is the first global-scale effort to not only quantify uncertainty in a gridded multisensor satellite dataset such as IMERG (Objective 1) but also to make those estimates useful for hydrologic prediction by connecting them in space and time to span arbitrary spatial scales (Objective 2) and to demonstrate their value in such predictions (Objective 3). This addresses multiple PMM research objectives, helps support NASA’s goal of developing uncertainty estimates for IMERG, and will promote the uptake of satellite precipitation data in global applications such as flood and drought forecasting by providing more useful and reliable uncertainty information.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-DSCOVR
A.25 DSCOVR SCIENCE TEAM

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the solicited Deep Space Climate Observatory (DSCOVR) Science Team. DSCOVR is a multiagency (National Oceanic and Atmospheric Administration [NOAA], U.S. Air Force, and NASA) mission launched on 11 February 2015 with the primary goal of making unique space weather measurements from the first Sun-Earth Lagrange point (L1). The L1 point is on the direct line between Earth and the Sun located 1.5 million km from Earth. While the primary science objective of the DSCOVR mission is to provide solar wind thermal plasma and magnetic field measurements to enable space weather forecasting by NOAA, the secondary goal is to provide measurements of the Earth system.

NASA has integrated two Earth-observing instruments—the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology (NIST) Advanced Radiometer (NISTAR)—into the DSCOVR satellite.
Proposals were sought for analyses using existing algorithms to deliver EPIC Level-2 or higher science products—possibly with related algorithm maintenance and calibration activities. Proposals for enhanced or new Level-2 or higher product algorithm development were also considered.

NASA also sought proposals that use NISTAR Level-1 products to determine the Earth reflected and radiated irradiance with an accuracy of 1.5% or better, yielding the production of Level 2 shortwave and longwave flux products. Proposals to improve the NISTAR calibrations based on in-flight data were also considered.

In response to its announcement, NASA received 26 proposals and selected 13, reflecting the foci described above. Selected investigations will maintain production, enhance, and enable research investigations using these Earth science products. The total funding for these investigations, over a period of three years, is approximately $5.8 million.

Elizabeth Berry/Atmospheric & Environmental Research, Inc.
Enhancing the 2D DSCOVR-Derived Clouds and Radiation Products with 3D Information from CloudSat and CALIPSO
21-DSCOVR-21-0025

The distribution of clouds in the vertical column impacts the radiative heating of the atmosphere, directly modifying circulation and precipitation. Therefore extensive knowledge of this distribution and its variability in space and time is key to understanding and modeling weather and climate, yet that knowledge is currently incomplete due to limited spatial coverage provided by CloudSat/CALIPSO and various geostationary satellites. We propose to use the full disk 2-D cloud properties retrieved from the Deep Space Climate Observatory (DSCOVR) with collocated 3-D clouds from the CloudSat/CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellites to greatly expand the analysis of 3-D clouds beyond the narrow CloudSat track. We will use advanced Machine Learning (ML) techniques trained on collocated DSCOVR-CloudSat/CALIPSO observations and the atmospheric state to extend the far-reaching DSCOVR hourly cloud observations to three dimensions. In this way we can leverage the respective advantages of these platforms to essentially add a vertical dimension to the DSCOVR-observed clouds and fill in the time gaps of the CloudSat/CALIPSO observations.

Our objectives are to:
1. Characterize the vertical structure of clouds for DSCOVR pixels that are collocated with CloudSat/CALIPSO. This task will result in the creation of a 5-year (June 2015-August 2020) collocated DSCOVR-CloudSat/CALIPSO dataset that maintains the native resolutions of the cloud quantities.
2. Apply various ML methods to map the relationships between collocated DSCOVR-observed 2-D clouds and their atmospheric state and 3-D clouds from CloudSat/CALIPSO. Analyze the performance of the different ML approaches by comparing model results to blind test data.
3. Use the learned 2-D to 3-D relationships and the high temporal resolution of DSCOVR (~1-2hr) to predict a daytime cycle of vertically resolved clouds for DSCOVR pixels that are not collocated with the 13:30 UTC CloudSat overpass. Validate the predicted daytime cycle of 3-D clouds with observations from ARM (Atmospheric Radiation Measurement) ground sites, Global Precipitation Measurement (GPM) measurements of precipitating clouds, and a 3-D cloud analysis developed from GOES (Geostationary Operational Environmental Satellite) passive remote sensing data and the GFS (Global Forecast System) weather model.

With this extensive dataset, we will be able to address our scientific hypothesis that the interrelationships among top-of-cloud (as measured by DSCOVR), cloud vertical profile (CloudSat/CALIPSO), and atmospheric state characteristics remain consistent throughout the daytime diurnal cycle. The outcome of this project addresses several goals in the solicitation for DSCOVR science. One is the “integration of data from multiple spaceborne observation platforms to develop and utilize self-consistent global products.” The other is “the incorporation of new approaches that can lead to improvements in the products currently available.”

Simon Carn/Michigan Technological University
Enhanced DSCOVR/EPIC SO2 and Ash Products for Volcano Science Applications
21-DSCOVR-21-0024

Volcanic eruptions are rare events in the life-cycles of active volcanoes, but can have significant impacts on Earth’s atmosphere and climate, and represent rare opportunities to further our understanding of volcanic processes. This requires the acquisition of high-quality observations of volcanic emissions during such events. Global satellite measurements of volcanic sulfur dioxide (SO2) and ash emissions are crucial for detection of volcanic eruptions and for quantifying volcanic impacts on the atmosphere and climate, but the low temporal resolution of ultraviolet (UV) satellite measurements from polar-orbiters, and the low SO2 sensitivity of geostationary infrared (IR) sensors has limited our ability to study processes in transient volcanic eruption clouds. Since 2015, the Earth Polychromatic Imaging Camera (EPIC) aboard the Deep Space Climate Observatory (DSCOVR) has been making unique, high-cadence UV observations of volcanic eruption clouds from the L1 Earth-Sun Lagrange point. Under prior NASA support, our team at Michigan Tech and NASA Goddard Space Flight Center (GSFC) has developed and validated UV SO2 and aerosol index (UVAI) products that have successfully detected all significant volcanic eruptions during the DSCOVR mission to date and demonstrated the value of high-cadence UV imaging of volcanic clouds. However, some EPIC observations of recent, ash-rich volcanic eruptions highlight the need for further refinement of the EPIC volcanic SO2 products in the presence of high volcanic ash loading, which can cause underestimation of SO2 amounts, impacting the timely assessment of climate and other impacts. In this project we propose to continue development and maintenance of the EPIC SO2 algorithm and derived Level 2 products, with a special focus on improving the treatment of volcanic ash. We also plan to adapt and test our Principal Component Analysis (PCA) SO2 algorithm, which has proved successful at generating low-noise SO2 products from other UV satellite instruments, to retrieve SO2 from EPIC UV radiances and improve the existing EPIC SO2 product. We will also continue to conduct validation and scientific analysis of EPIC SO2 and AI data for recent (2015-2021) and future volcanic eruptions to advance our understanding of volcanic cloud processes and impacts. This proposal responds to the ROSES 2020 A.25 solicitation (DSCOVR Science Team) as it will 'exploit EPIC products to address one or more of the science questions articulated in 'SCIENCE 2020-2024: A Vision for Scientific Excellence' and will also conduct 'algorithm maintenance activities necessary to support the continued production of existing DSCOVR Level 2 products at the current level of quality.' Our plans to improve the treatment of volcanic ash in the L2 EPIC SO2 algorithm and test the PCA SO2 retrieval approach are consistent with the solicitation which states that 'algorithm enhancement involves making improvements to existing algorithms to respond to known shortcomings in currently available products and/or the incorporation of new approaches that can lead to improvements in the products currently available.' Regarding high-level NASA Science Mission Directorate (SMD) priorities, we address Exploration and Scientific Discovery by following guidance from recent National Academies and Decadal Survey documents within the NASA Earth Science focus area of 'Surface dynamics, geological hazards and disasters'. Our work with DSCOVR/EPIC contributes to NASA's exploration goals by testing novel observational techniques that could be deployed on the Moon in the future. The project addresses the NASA SMD Interconnectivity and Partnerships priority as it continues a long-term, successful collaboration between academia and a NASA Center and trains graduate students to engage with NASA missions.

Robert Frouin/University of California, San Diego
Ocean Surface Radiation Products from EPIC/DSCOVR Data

21-DSCOVR-21-0009

The proposal aims at developing from EPIC data a novel suite of surface radiation products to address science questions pertaining to biogeochemical cycling of carbon, nutrients, and oxygen as well as mixed-layer dynamics and circulation. These products include daily-averaged downward planar irradiance and scalar irradiance and average cosine for total light just below the ocean surface in the EPIC spectral bands centered on 317.5, 325, 340, 388, 443, 551, and 680 nm, and integrated values over the PAR and UV-A spectral ranges. Uncertainties (i.e., bias and standard deviation) will be associated to each product on a pixel-by-pixel basis. The daily mean radiation products will be generated on equidistant cylindrical "Plate Carrée" grid with 18.4 km resolution at the equator and in 18.4 km equal-area sinusoidal projection, i.e., they will be compatible with MODIS and VIIRS Level 3 NASA OBPG ocean-color products.
The sub-surface scalar fluxes and average cosines will be derived from the above-surface fluxes using LUTs of clear sky and overcast situations and the estimated cloud factor (the ratio of actual and clear sky irradiance reaching the surface). The sub-surface planar fluxes will be obtained more directly. Uncertainties will be assigned as a function of above-surface clear sky daily mean flux and cloud factor. ATBDs will describe the algorithms and their performance. The full processing line will be applied to generate a global time series of the various EPIC radiation products over the ice-free oceans, including the above-surface planar fluxes, since the beginning of the EPIC operational phase. The Langley ASDC will implement the algorithms, generate routinely the above- and below-surface products, and distribute them with documentation to the user community, in the same way as for the current EPIC daily mean PAR product.
Theoretical performance will be assessed using simulations with the SMART-G (GPU-accelerated) Monte Carlo code of the EPIC reflectance and corresponding radiation variables to estimate. Evaluation of the above-water quantities will be performed against in situ measurements at existing open-ocean sites (fixed platforms and moored buoys). A system collecting and transmitting continuously spectral UV and visible downward fluxes will be installed at the Bahia Blanca AERONET-OC site to provide complementary data. This activity will also contribute to further evaluate the current above-surface daily EPIC PAR product. For the sub-surface products (planar and scalar fluxes and average cosines), due to the lack of data our approach will be to propagate the above surface planar measurements to below the surface using SMART-G simulations with best information about the controlling parameters. Comparisons will also be performed with MODIS, VIIRS, and TROPOMI estimates and with OCI estimates of the PACE mission, which will generate starting in 2024 a similar suite of ocean surface radiation products.
The project responds directly to NNH21ZDA001N-A.25, which solicits "proposals for enhanced or new Level-2 or higher product algorithm development". The suite of EPIC daily mean ocean surface radiation products, above and sub-surface, spectral and wavelength-integrated over key spectral ranges, will be invaluable for a wide range of research applications, such as primary production and carbon export modeling, ecosystem dynamics and mixed-layer physics, photochemical transformations of dissolved organic matter, and control of stable soluble iron in marine waters. The time series of EPIC radiation products will complement existing datasets and help to bring about consistency across sensors, allowing a better description of light availability in the oceans that could

lead to new information about temporal and spatial variability of biological phenomena. The contribution of the project to understanding the role of the oceans in carbon cycling and climate change is expected to be significant.

Igor Geogdzhayev/Columbia University
Monitoring Calibration stability of DSCOVR EPIC VIS-NIR Channels Using Multiple Orbiting Radiometers
21-DSCOVR-21-0015

The first 6 years of operation of the Deep Space Climate Observatory (DSCOVR) Earth Polychromatic Imaging Camera (EPIC) at the Lagrange 1 point have produced results that uniquely complement the data from currently operating low orbit Earth-observing instruments. EPIC remote sensing observations have been used in such applications as the retrieval of aerosol, cloud, sulphur dioxide and ozone amount and vegetation properties, as well as ocean color. Most of the above applications rely on radiometric calibration of the EPIC measurements.
Previously we developed a unified approach to derive calibration coefficients and their trends by comparing EPIC observations to the measurements from polar orbiting radiometers. L1B reflectances from Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua and Terra satellites, Multi-angle Imaging Spectroradiometer (MISR) onboard Terra and Visible Infrared Imaging Radiometer (VIIRS) onboard the Suomi National Polar-orbiting Partnership (Suomi NPP) spacecraft were used to infer calibration coefficients for four non-absorbing EPIC visible and NIR channels: 443 nm, 551 nm, 680 nm and 780 nm Calibration gains for data to June 2019 were found to be in excellent agreement with independent published values. No significant changes in calibration were observed after the instruments exit from safe hold in March 2020.
The proposed work consists of two tasks. First, we propose to maintain a database of collocated L1B data from multiple LEO instruments and use it to implement a continuous monitoring of the calibration coefficients and trends. There is a significant advantage in using multiple instruments for EPIC calibration. It allows an independent assessment of the accuracy and stability, provides continuity in case one subset becomes unavailable or if one of the instruments reaches the end of life and facilitates inter-comparison of L2 EPIC products with other datasets. The database will also be used to update calibration once new releases of EPIC data become available. The calibration coefficients will be derived using two methods: regression (using both dark and bright scenes) and reflectance-to-counts (R/C) ratios for bright scenes. The incomplete overlap of the pixels employed in the two methods implies a degree of independence and provides an additional check of consistency of the results.
Second, we propose to implement several improvements to the calibration algorithm. For this purpose, we performed an analysis of parameters that may affect calibration. We found that using seasonal mean gains is appropriate for monitoring stability of calibration. Our radiative transfer modeling indicates that pixels which are very close to exact back-scattering may require special attention when used for calibration. In our current algorithm we use spectral adjustment factors to account for differences between position and width of EPIC and LEO instrument channels. These adjustments are based

on a static land cover type classification data. An implementation of time-dependent classification may help to improve the regression analysis by reducing the data spread. We also propose to investigate the geographical distribution of scenes used for calibration and implement adjustments to the selection process in order to improve stability and reduce the spread.

Olga Kalashnikova/Jet Propulsion Laboratory
Assessing Wildfire Induced Brown Carbon Evolution and Radiative Impacts Through the Synergistic Use of the DSCOVR EPIC Products, WRF-Chem Model, and In-Situ Observations
21-DSCOVR-21-0011

The frequency and severity of fire activity are projected to increase significantly in this century owing to a warmer and drier climate. The fire-emitted particle-phase compounds of smoke exert significant atmospheric impacts on climate, air quality, and health, especially in the downwind urban areas. Brown Carbon (BrC), emitted mainly by smoldering fires or biomass combustion, is one of the most important light-absorbing substances in the atmospheric aerosol. However, the extent of absorption by BrC particles for diffent types of fires and its effects of radiation balance are still largely unknown. Observational techniques alone do not provide enough constraints on the global BrC direct radiative forcing (DRF), and current representation of BrC in climate and regional transport models is either absent or overly simplistic, such that BrC optical properties are invariant with atmospheric processing or aging. The EPIC UV observations provide comprehensive coverage and a sufficint spatial and temporal resolution for improving representation of BrC processes in numerical chemistry models. EPIC MAIAC aerosol products combined with the regional-scale WRF-Chem model provide a unique opportunity for determining impacts of BrC-emitting smoldering fire phases on air quality and climate in globally-distributed target areas throughout US, Australia, and Canada.

The proposed research aims to develop robust parameterizations of aerosol production and aerosol optics in the recently developed version of the WRF-Chem model with new aerosol and fire schemes to improve understanding of temporal and spatial characteristics of BC and BrC by developing an approach combining EPIC L2 MAIAC absorbing aerosol products with the information from the BrC-aware WRF-Chem model constrained by the ground-based and field observations. In addition, the remote sensing observations collected during FIREX-AQ will be used to relate large-scale bulk optical properties of BrC, to chemical processes that are influenced by the identity, abundance, and evolution of individual BrC chromophores in fire plumes. EPIC L2 MAIAC aerosol products along with ground-based observations will be also used to characterize BC and BrC optical properties in downwind urban areas on seasonal and interannual scales. Results from this work will lead to the improved prognostic capabilities of the model, and the better understanding of temporal and spatial characteristics of BC and BrC, their evolution, and impacts on air-quality and radiation.

The key objectives are:

- Quantify the spatial and temporal variability of BrC and BC fractions, and their optical properties from the new EPIC L2 MAIAC absorbing aerosol speciation datasets for major fire events during the DSCOVR mission.
- Develop a new BrC chemical/optical representation in the WRF-Chem model including BrC property evolution, mixing, and aging derived from the EPIC L2 MAIAC absorbing aerosol climatology, field data analysis, and auxiliary satellite datasets;
- Assess and quantify radiative effects of BrC on the ambient environment and radiation budget for major fire events during the DSCOVR mission through reducing uncertainties in WRF-Chem model predictions.

This proposed work builds upon the existing capabilities of the proposal team in atmospheric chemistry modeling (J. Seinfeld and Y. Wang), remote sensing and satellite data analysis (O. Kalashnikova and Y. Wang) supported by the expert advise on EPIC MAIAC BC/BrC products (A. Lyapustin), WRFChem model development (J. Fan and M. Shrivastava), and in situ BrC analysis (R. Chakrabarty). This work will extend our previous and current collaborative research efforts in WRF-Chem model evaluation and development, numerical modeling of California wildfires, and BrC retrieval method development.

Yuri Knyazikhin/Boston University
DSCOVR EPPIC VESDR Product: Algorithm Maintenance, Refinement and Validation
21-DSCOVR-21-0007

The algorithm for generating Vegetation Earth System Data Record (VESDR) that provides Leaf Area Index (LAI) and diurnal courses of Normalized Difference Vegetation Index (NDVI), Sunlit Leaf Area Index (SLAI), Fraction of incident Photosynthetically Active Radiation (FPAR) absorbed by the vegetation, Directional Area Scattering Function (DASF) and Canopy Scattering coefficient (CSC) has been developed and implemented for operational use with the DSCOVR EPIC sensor. The VESDR parameters at 10 km sinusoidal grid and 65 to 110 minute temporal frequency are released at provisional quality level and available from the NASA Langley Atmospheric Science Data Center.

The primary objectives of this DSCOVR EPIC Science Team member proposal are to (a) maintain and minimally refine the standard Level 2 VESDR product by making improvements to the VESDR retrieval technique to respond to changing instrument conditions and its calibration, computer environments, quality of upstream generated inputs to the VESDR algorithm and resolving known shortcomings in the product (b) to comprehensively evaluate and validate the VESDR products and (c) reprocess the VESDR time series.

Natalya Kramarova/Goddard Space Flight Center
Continuing Total and Tropospheric Ozone Column Products from DSCOVR EPIC to Study Regional Scale Ozone Transport

21-DSCOVR-21-0003

The Earth Polychromatic Imaging Camera (EPIC) on the DSCOVR spacecraft measures Earth-reflected radiances from the sunlit portion of the Earth. The measurements from four EPIC ultraviolet (UV) channels are used to reconstruct global distributions of total ozone from sunrise to sunset with multiple observations over the same location each day at different local times. The tropospheric ozone column is then derived by subtracting an independently measured stratospheric column from the EPIC total ozone. The EPIC total and tropospheric ozone column products, sampled from sunrise to sunset, serve as a pathfinder and provider of intercalibration data for the constellation of existing and future geostationary missions, such as NASA's Tropospheric Emissions Monitoring Pollution (TEMPO), the Korean Geostationary Environmental Monitoring Spectrometer (GEMS) and ESA's Sentenial-4. These synoptic maps of tropospheric ozone column enable a more comprehensive study of the small, regional-scale variability of tropospheric ozone and its connection to the atmospheric chemistry and dynamics.
This is a renewal proposal aimed to continue the two existing EPIC ozone products: the Level-2 Total Ozone Column and the higher-level (Level-4) Tropospheric Ozone Column. To maintain the accuracy and stability of EPIC ozone products, we will continue to cross-calibrate EPIC radiances with those from Suomi NPP OMPS and compare total ozone values retrieved from the two instruments. To improve current EPIC ozone products, particularly at high solar zenith angles, we propose to investigate the accuracy of EPIC spectral calibrations and the quality of the forward model radiance simulations by comparing with the fully spherical models. One of the main focuses of this proposal is to evaluate EPIC ozone products for application in studies of small, regional-scale ozone variations by performing a comprehensive validation analysis. Our validation plan for the EPIC ozone products includes several steps. During the previous three years, we validated monthly and daily mean total and tropospheric ozone maps against the well-established satellite and ground-based measurements and demonstrated high accuracy of the EPIC ozone products. In this proposal, we will focus on validation of the regional scale variability in ozone as observed by EPIC. For these purposes, we propose to use model simulations in conjunction with available ozone sonde and aircraft measurements to facilitate attribution of observed patterns in regional scale ozone distribution to specific processes that control the ozone transport, such as stratosphere-troposphere exchange, lightning, biomass burning and air pollution. Results will be reported in peer-review publications and communicated to users to facilitate proper application and interpretation of EPIC ozone products in support of scientific research.

Alexei Lyapustin/Goddard Space Flight Center
Atmospheric Correction of DSCOVR EPIC Measurements
21-DSCOVR-21-0004

The DSCOVR EPIC provides continuous Earth observations from the first Lagrange (L1) point approximately 1.5 million kilometers away from the Earth since mid-2015. Our group has been responsible for the atmospheric correction of EPIC's observations. We adapted the NASA MAIAC algorithm to EPIC (version 1) and released the initial aerosol and surface reflectance dataset in May of 2018. In the past funding cycle we significantly improved the accuracy of the entire processing and developed the novel capabilities to retrieve spectral aerosol absorption from EPIC's UV-Vis measurements. These improvements were included in MAIAC v2 EPIC algorithm and v2 EPIC re-processing was performed recently. Furthermore, based on the retrieved AOD and spectral absorption, we developed capabilities to provide aerosol speciation information, for instance volume/mass concentrations of black and brown carbon for smoke, and of hematite/goethite for dust. This novel information, presently unavailable from the operational satellites, is in high demand in the climate modeling and the air quality communities. We propose to include these new developments in MAIAC v3 algorithm and conduct v3 EPIC re-processing, continue our validation analysis, and work with the land, climate modeling and air quality user communities supporting research based on MAIAC EPIC products.

Wenying Su/Langley Research Center
Determining the Daytime Earth's Radiative Flux from DSCOVR and Assessing the Diurnal Models Used in Estimating the Earth's Radiation Budget
21-DSCOVR-21-0018

Satellite observations of the Earth radiation budget (ERB) provide critical information needed to better understand the driving mechanisms of climate change. Currently, the Clouds and the Earth's Radiant Energy System (CERES) instruments have been providing continuous global top-of-atmosphere reflected shortwave (SW) and emitted longwave (LW) radiation since 2000. The NISTAR and EPIC instruments onboard DSCOVR observe the Earth from a new perspective, being the first Earth-observing satellite at the L-1 point, where it orbits the Sun at the same rate as the Earth and observes the sunlit side of the Earth continuously. Although these data cannot provide a full picture of ERB, these high-temporal-resolution data can be used to verify the temporal interpolation used in the CERES data production. Furthermore, while climate models are routinely tuned to CERES monthly products, they have yet to be confronted on shorter time-scales, and such testing would uncover whether models are correctly capturing the spatiotemporal scales of surface and cloud impacts on radiative fluxes. The Earth's surface and atmosphere are anisotropic reflectors and emitters resulting in a relatively complex variation of radiance leaving the Earth as a function of the viewing and illumination angles. Thus, converting radiances measured by NISTAR and EPIC to fluxes requires the use of angular distribution models (ADMs) to account for the emittance and reflectance anisotropies. We propose to continue characterizing the anisotropies for all EPIC pixels by using the CERES empirical ADMs, which are functions of scene types defined using many variables (i.e., surface type, cloud amount, cloud phase, etc). We will continue producing the EPIC cloud composite product by mapping cloud property retrievals from low Earth orbit (LEO) and geostationary (GEO) imagers and other ancillary data into the EPIC pixels to provide accurate scene type information. This processing framework will be used to produce SW fluxes from EPIC and SW and LW fluxes from NISTAR. These high-frequency SW fluxes will be used to examine the fluxes in the CERES SYN1deg and in climate models to investigate whether they capture observed temporal variations. Building upon the cloud composite, we will produce the multi-view composite for more accurate cloud phase determination and enrich the science community with the multi-angle dataset for a variety of studies. Finally, we will use EPIC observations to monitor MODIS instruments on Terra and Aqua as they drift towards the terminator, and to inter-calibrate VIIRS instruments. Specifically we propose to:

1. Produce the EPIC cloud composite product needed for characterizing the anisotropies of the radiance field. A new multi-angle dataset containing reflectances observed at different viewing geometries by LEO/GEO and EPIC will also be produced to explore new cloud phase retrieval methodology.
2. Produce global daytime mean SW fluxes from EPIC pixel observations. This product provides a direct comparison to the NISTAR SW flux and can be utilized to guide the development of the new version of NISTAR calibration.
3. Work with the NISTAR instrument team to produce new version of NISTAR Level 1 radiance data and produce flux product using the processing framework developed.
4. Assess the diurnal filling used by CERES product with the high-frequency EPIC and NISTAR data.
5. Continue monitoring the EPIC calibration stability using MODIS, VIIRS, and Earth invariant targets. Use EPIC to verify MODIS calibration stability when Terra and Aqua drift towards the terminator and as a transfer radiometer to enable calibration consistency across EPIC, MODIS, and VIIRS.
6. Determine if GISS ModelE, tuned with 35 LEO satellite observational constraints, captures the Earth's modes of variability in surface reflection and cloud albedo to produce realistic SW fluxes not just on monthly time-scales, but across time-scales ranging from sub-diurnal to inter-annual.

Omar Torres/Goddard Space Flight Center
EPIC Near UV Aerosol Algorithm: Maintenance and Upgrades
21-DSCOVR-21-0013

This proposal seeks funding for maintenance and upgrades of the currently operational UV aerosol algorithm that produces UV Aerosol Index (UVAI), aerosol optical depth (AOD) and single scattering albedo (SSA). Proposed activities include:

- Implementation of an improved UV aerosol Index that eliminates current spurious angular dependencies associated with the treatment of cloud scattering effects.
- Continuation of the operational implementation of aerosol layer height (ALH) from EPIC Oxygen-B band observations developed with NASA support in previous funding cycles.
- Extension of AOD/SSA retrieval capabilities of aerosol layers in the upper troposphere/lower stratosphere (UTLS) for the characterization of wildfire-generated high altitude carbonaceous aerosol layers.
- Validation activities to assess the effect of algorithm improvements on retrieved products.

Jun Wang/University of Iowa, Iowa City
EPIC Hourly Aerosol Optical Centroid Height (AOCH) Product: Mapping the Diurnal Variation of Smoke and Dust Vertical Distributions for Air Quality and Climate Studies
21-DSCOVR-21-0019

Among NASA's on-orbit fleet of satellites for Earth science, unique in many ways is the Deep Space Climate Observatory (DSCOVR) that carries the Earth Polychromatic Imaging Camera (EPIC) to observe the entire sunlit face of the Earth from the UV to the visible spectrum every 1-2 hours, thereby providing unprecedented opportunities to characterize the daytime diurnal variation of surface and atmospheric properties, globally, from a single instrument. Furthermore, by equipping both oxygen (O2) A and B absorption bands and their respective continuum bands, EPIC has shown great potential and uniqueness in retrieval of aerosol optical centroid height (AOCH) and aerosol optical depth (AOD) over dark surfaces, with hemispheric coverage at nearly every hour.

Since none of the EPIC's existing aerosol data products (including UV aerosol index data) provide any quantitative information of aerosol layer height (according to the current literature), we here propose to develop a new EPIC Level 2 product, namely, the hourly AOCH data product. This product will provide one piece of information of the aerosol vertical distribution, i.e., AOCH, as well as the corresponding AOD and other ancillary data (such as latitude and longitude) that are commonly needed by the scientific and application communities for aerosol studies. The project has three objectives, as follows.

1) Refine the AOCH research algorithm over dark (ocean and vegetated) surfaces for operational production and deliver the Algorithm Theoretical Basis Documents (ATBD) with NASA's Algorithm Publication Tool (APT). This task can be completed in the first half of the project. The refinement includes the improvement of dust and smoke aerosol optical properties; vicarious calibration of EPIC bands for aerosol retrieval; and an update to the treatment of surface reflectance.

2) Global validation study and scientific application demonstration of AOCH data. MISR and a wide range of lidar observations will be used to evaluate the AOCH retrievals. Scientific applications will demonstrate the importance of AOCH data for studying the climatology of hourly dust AOCH over the Atlantic Ocean and for estimating the surface PM2.5 from satellite-based AOD (during the 2018, 2020, and 2021 fire seasons in the U.S.).

3) Develop the research algorithm to retrieve AOCH and AOD over bright desert surfaces.

The proposed work fits the solicitation (NNH21ZDA001N-DSCOVR) that encourages "new product proposals … whose primary objective is to provide additional DSCOVR products beyond those currently available.".

Kai Yang/University of Maryland, College Park
Maintenance, Improvement and Validation of Ozone and Sulfur Dioxide Measurements from DSCOVR EPIC
21-DSCOVR-21-0017

With the support of the previous DSCOVR science team awards, we have adapted the direct vertical column fitting (DVCF) algorithm for processing Earth Polychromatic Imaging Camera (EPIC) UV measurements. The resulting EPIC O3SO2AI product, which contains total vertical column ozone (O3), sulfur dioxide (SO2), scene reflectivity, and aerosol index (AI), is publicly released and available at the Atmospheric Science Data Center at the NASA Langley Research Center. Analysis and validation studies have shown that the algorithm performance and the product quality are far beyond expectations. The accuracy of the total O3 retrieval is higher than or as good as those from satellite instruments with superior spectral coverage and higher signal-to-noise ratios. O3SO2AI often provides more accurate SO2 quantifications from large volcanic eruptions than other satellite retrievals because of the high SO2 accuracy achieved with the DVCF algorithm and EPIC's high-cadence observations that allow better identification of the peak loading of volcanic SO2 plume. These accomplishments support the continuing production and public release of the EPIC O3SO2AI product.

We propose to continue participation in the DSCOVR science team to maintain, improve, and validate the EPIC O3SO2AI product. Specifically,

1. We will update the processing algorithm in response to instrumental changes, with periodic application of soft calibration to maintain radiometric consistency over the lifetime of EPIC.
2. We have conducted thorough error analyses of O3 and SO2 retrievals from EPIC to identify observing conditions under which O3SO2AI has systematic biases or significant uncertainties. We will further improve the physics implementation in the DVCF algorithm to address these issues for higher accuracy and precision of O3 and SO2 retrievals from EPIC.
3. We will validate the EPIC O3 and SO2 measurements through comparisons with correlative data, including products from other satellite missions, ozone sonde data, and ground-based measurements.
4. We will generate a daily Level 3 EPIC O3 product by putting total and tropospheric O3 columns on an L3 grid cell sequentially in time.

Yuekui Yang/Goddard Space Flight Center
Continuous Improvement of the EPIC Cloud Products
21-DSCOVR-21-0012

Supported under prior selections, multiple versions of the EPIC L2 cloud products, which include cloud mask, cloud effective pressure/height, cloud optical thickness, etc., have been released. These products have been used in many applications, such as trace gas retrieval correction, surface solar radiation analysis, cloud system study, cloud diurnal cycle analysis etc.

This proposal seeks to continue participation in and support of the DSCOVR Science Team. We propose to continue the maintenance, improvement, and assessment of the EPIC cloud products. Main tasks of the proposed work include: (1) EPIC Cloud Product System maintenance and upgrade. (2) Refinement of the cloud mask product. (3) Improvement of the cloud effective height retrieval with improved look-up tables that include Earth's curvature in the radiative transfer simulations. (4) Continuous monitoring of the O2 A- and B-band channel performance and stability. We will use the EPIC observations over the Amundsen–Scott South Pole Station for this task. The Amundsen–Scott South Pole Station provides atmospheric profile and sky condition observations. The stable reflectivity of the snow surface provides an ideal condition for instrument stability check. (5) Continuous assessment of the cloud properties. We will continue our effort on assessing the new version of EPIC cloud properties using geostationary and low earth orbit satellite observations.

The proposed work will mitigate known shortcomings in the current EPIC cloud products. It will continue and further improve the EPIC cloud data record for climate study and for generating other geophysical products that require cloud properties as input.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences (ROSES) – 2021
A.26 CloudSat and CALIPSO Science Team Recompete
NNH21ZDA001N-CCST

The radar carrying CloudSat and backscatter lidar-carrying Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellites have provided unprecedented information on the vertical profiles of clouds, cloud liquid water, and aerosol particles over the globe in 2006. Taken individually, the CloudSat mission's primary science goal is to furnish data needed to evaluate and improve the way clouds are parameterized in global models, thereby contributing to better predictions of clouds and thus to the poorly understood cloud-climate feedback problem (http://cloudsat.atmos.colostate.edu/). For CALIPSO, the satellite was designed to help scientists answer significant questions and provide new information regarding atmospheric transport of airborne particles and air pollutants, as well as the effects of clouds and aerosol particles on Earth's changing climate (http://www-calipso.larc.nasa.gov/).

This solicitation requested proposals for the CloudSat/CALIPSO science team. While team members may pay strict attention to one satellite or the other, NASA considers this one consolidated science team and encourages cross sensor studies. Proposals were requested to enhance the state of atmospheric and climate science through the substantive utilization of CloudSat and CALIPSO data products, preferably in conjunction with other satellite (e.g., A-Train), suborbital campaign, ground-based, and/or model data. Example topics included:

- Phenomenological studies of fundamental cloud, precipitation and aerosol processes and evolution, as well as aerosol indirect effects and vertical transport;
- Development and validation of aerosol and cloud parameterizations for regional, global, and climate models;
- Use of CALIPSO and CloudSat products in the development of three-dimensional aerosol and cloud climatologies, spatial correlations, or trends;

- Seasonal or interannual variability of cloud and aerosol properties on regional to global scales;
- Fundamental studies of the information content of CALIPSO and/or CloudSat data products and their use for data assimilation;
- Use of CALIPSO and/or CloudSat in understanding the atmosphere's three-dimensional radiative environment;
- Aerosol/cloud interactions and their impact on cloud microphysics, optics, and radiation;
- Aerosol direct and indirect radiative effects;
- Effects of aerosols on precipitation;
- Development of new or significantly improved level two cloud and aerosol products;
- Development of innovative uses of CALIPSO and/or CloudSat data, such as for oceanography, meteorology, and land studies;
- Stratospheric aerosols and/or polar stratospheric clouds;
- Hydrologic processes in the context of weather and climate variability; and
- Assessment of cloud feedbacks in climate models.

NASA received a total of 65 proposals in response to this solicitation and selected 22 for funding. The total funding for these proposals over a 3-year period is ~12 million dollars.

Elizabeth Berry/Atmospheric & Environmental Research, Inc.
Implications for Cloud Feedbacks from the Evaluation of Low Cloud Properties and Radiative Effects in a GCM Using CloudSat and CALIPSO Observations
21-CCST21-0050

A robust feature of the CMIP5 models was a too few, too bright" tropical low cloud bias, an important issue since it impacts the amplitude of the low cloud feedback. In the latest generation of climate models (CMIP6) higher estimates of climate sensitivity have been attributed to low cloud feedbacks. Therefore, it is critical that we use observations to assess the validity of the cloud feedbacks. In terms of observed low-level clouds, the official CloudSat dataset for liquid cloud microphysical properties is 2B-CWC-RVOD, based on the CloudSat Radar. However, CloudSat is limited in its detection of some boundary-layer clouds, missing low-level clouds that are below its detection threshold or too close to the surface.

We propose taking advantage of the synergy of CloudSat and CALIPSO measurements to validate simulations of cumulus and stratocumulus clouds in the tropics and subtropics. To retrieve low cloud microphysical properties we will use a CloudSat-enhanced" algorithm, combining observations of CALIPSO lidar backscatter and CloudSat 94-GHz brightness temperature, in addition to radar reflectivity, to overcome the limitations of the radar alone. The retrieved profiles of liquid water content and effective radius will be assembled into a gridded dataset as monthly 2D histograms, preserving the basic statistics of the low cloud microphysics. From this dataset we will create observed cloud radiative kernels that quantify the cloud radiative effects as a function of the bulk cloud properties (e.g. optical depth, cloud top extinction, integrated radar reflectivity). To address the too few, too bright bias in the latest generation of climate models, we will use the observations to perform a detailed evaluation of the present-day low cloud fraction, microphysical properties, and radiative effects in the CAM6 model. We will investigate the potential of using the information derived from CloudSat and CALIPSO observations to identify models with credible low cloud feedbacks.

Our objectives are to:
1. Document the tropical low cloud fraction and microphysical properties from 40N-40S for 2007-2008, using a CloudSat-Enhanced retrieval. This task will result in the creation of a prototype cloud microphysical dataset, similar to official CloudSat level 3 products, that preserves the mean and sub-grid variability of the cloud properties as a quantitative metric for evaluating modeled low clouds.
2. Evaluate the representation of tropical low clouds in the latest generation of GCMs, using the CloudSat-Enhanced retrieval. Given advancements in cloud parameterizations, are the tropical low clouds still too few, too bright? This will include a detailed evaluation of CAM6 low clouds with the COSP CloudSat and CALIPSO simulators, and a broad evaluation of CMIP6 models with monthly mean ISCCP (International Satellite Cloud Climatology Project) simulator output.
3. Create an active-sensor" cloud radiative kernel as a diagnostic for evaluating models using COSP and investigate differences in cloud feedback from observed and modeled cloud radiative kernels. Test our emergent constraint, that the mean and sub-grid variability of the observed low cloud properties can be used to identify models that accurately simulate the low cloud radiative effects and hence have credible predictions for low cloud feedbacks.

The outcome of this project addresses several goals in the solicitation for CloudSat and CALIPSO science. We will make substantive use of information from the CloudSat radar and 94-GHZ brightness temperature, along with CALIPSO lidar to characterize boundary-layer clouds that have previously been a challenge. This will enable us to gain a better understanding of low clouds, which remain a large source of uncertainty in climate predictions. Ultimately, the work proposed here will make an assessment of low cloud feedbacks in climate models" with the use of an emergent constraint that is based on CloudSat and CALIPSO observations.

Gregory Cesana/Columbia University
Inferring Middle and High-Level Cloud Feedbacks Using A-Train Observations
21-CCST21-0046

How clouds will respond to global warming, which is the essence of cloud feedback, continues to be a leading source of climate sensitivity uncertainty in the two most recent Coupled Models Intercomparison Project (CMIP) generations. Such diversity impedes our ability to project the magnitude of future climate change and associated impacts. The simulated feedbacks from high-level clouds are somewhat less variable between models than those from low-level clouds and modestly contribute to the spread in intermodel equilibrium climate sensitivity (ECS). As a consequence, not much attention has been paid to constrain it with observations. However, a recent assessment under the auspices of the World Climate Research Program (WCRP) indicates that the best estimate of net high-cloud feedback is relatively large   about the same amplitude as tropical low-cloud feedback   but is distinguished in solely relying on climate model estimates. Yet, a lack of observational constraints has made it difficult to evaluate the representation of this cloud feedback in climate models and impairs our confidence in climate projections.

The synergistic use of lidar, radar and passive instruments onboard the A-Train satellite constellation makes it possible to better document cloud properties and quantify their associated radiative impacts globally. First, we will exploit different CALIPSO-CloudSat level1 and level2B orbital datasets (e.g., 2B-CLDCLASS-LIDAR, CALIPSO-GOCCP, 2B-FLXHR-LIDAR), supported by additional satellite and reanalysis datasets (e.g., CERES, MODIS, MERRA-2) to characterize short-term feedback from middle- and high-level clouds on a global scale. Because different cloud types can be driven by distinct cloud processes, there is no reason to expect they would exhibit similar cloud feedbacks. For this reason, we will separate contributions from different cloud types using CloudSat-CALIPSO datasets (stratiform, convective, optical thin or opaque, multilayer clouds&). We will then determine what environmental factors drive the variability of each cloud type and further document the interannual changes (i.e., sensitivities) of these clouds in response to the leading environmental factors (e.g., surface temperature, upper-tropospheric stability, large-scale vertical motion, and mid-tropospheric humidity). Building on these results and assuming different plausible future scenarios of environmental factor changes, we will use a novel approach based on the sensitivity of clouds to environmental factors to infer middle- and high-level cloud feedbacks on long time scales.

Finally, we will apply our framework to NASA GISS-ModelE3, exploiting its four configurations being submitted to Coupled Model Intercomparison Project phase 6 (CMIP6), comprising a generalized perturbed parameter ensemble, which together span a diversity of ECS and cloud sensitivities to environmental factors. To place our results into a broader context, we will also assess the middle- and high-level cloud feedback simulated by CMIP models. We anticipate that our results will advance understanding of the cloud-climate feedback mechanisms related to middle- and high-level clouds and provide useful metrics and constraints for both climate sensitivity and climate model assessments.

Richard Ferrare/Langley Research Center
Assessing and Improving CALIPSO Aerosol Optical Properties
21-CCST21-0021

Knowledge of the vertical profile, composition, concentration, and size of aerosols is required for assessing the direct impact of aerosols on radiation, investigating the indirect effects of aerosols on clouds and precipitation, attributing these effects to natural and anthropogenic aerosols, and assessing and predicting impacts on air quality. The multiwavelength aerosol optical depth (AOD) and aerosol backscatter and extinction profiles retrieved from data acquired by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor on board the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite provide valuable profile information for these activities. Current operational CALIOP aerosol extinction profile retrievals usually rely on accurately specifying the relationship between aerosol extinction and backscattering, which is expressed as a ratio (i.e. lidar ratio or Sa). Uncertainties in the assigned lidar ratios have been shown to be a major source of error (~30-50%) in these retrievals and are typically the largest source of systematic error in the CALIOP retrievals of aerosol extinction, backscatter, and aerosol optical depth.

In our previous CALIPSO projects, we have conducted studies to assess and improves these products. Under this project, we will extend these investigations using new techniques and algorithms that overcome the limitations of the current approach. Specifically, we propose to the following objectives:
(1) Assess and improve the CALIOP V4.5 aerosol retrieval algorithm using HSRL measurements. This will include investigating the CALIOP V4.5 aerosol classification and lidar ratios directly using the HSRL data as well as using the HSRL data with the CALIOP V4.5 algorithms. This will also involve investigating the presence and frequency of a new class of depolarizing sea salt aerosols using the HSRL and CALIOP measurements and determining how these can be added to the CALIOP algorithm.
(2) Assess and improve the CALIOP lidar ratios of the existing CALIOP aerosol types using constrained retrievals, such as from ODCOD and PARASOL. We use AOD provided by two powerful constraints; the new ocean-derived column optical depth (ODCOD) method provided in the new CALIOP V4.5 product (SDS names Ocean-Derived Column Properties ODCP) that retrieves AOD over water and the AOD retrieved by the PARASOL polarimeter over both land and water to constrain the CALIOP retrievals. We will use these constrained retrievals to assess and optimize the lidar ratios used by the operational CALIOP V4.5 algorithm.
(3) Use the constrained retrievals to provide better estimates of CALIOP aerosol types. This includes new aerosol types (e.g., sea salt) as well as regional and seasonal variations of lidar ratios (where warranted).
Our project will result in more accurate aerosol optical depth, extinction, and type products which will be useful to the community in all aerosol extinction, optical depth, and type applications, including estimating the direct and indirect radiative effects of aerosols and assessing/improving chemical transport models. These algorithm developments will also be valuable for the lidars, particularly the backscatter lidar, that will be part of future NASA ATMOS (formerly ACCP) satellite mission that will be used to study aerosols and clouds which NASA has called Designated Observables" in response to the National Academies of Science 2017 Decadal Survey for Earth Science and Applications from Space.

Yu Gu/University of California, Los Angeles

Integrative Analysis of Aerosol Effects on Convective Cloud and the Associated Lightning Characteristics Based on Satellite Retrieval, WRF Modeling, and Machine Learning
21-CCST21-0040

Among the deadliest meteorological phenomena, lightning can cause severe damage to infrastructure and serve as a major wildfire ignition source. The generation of lightning in convective clouds requires cloud microphysical and dynamical components like supercooled water, ice particles, and updrafts, all of which can be significantly regulated by aerosol effects. Previous observational and modeling studies have reported that aerosol tends to enhance lightning, but the aerosol lightning invigoration effect is not always expected, due to the nonlinear impacts of hygroscopic aerosols on cloud microphysics and/or the inhibition of absorbing aerosols on convections. Therefore, the sign of alterations in thunderstorm electrification and cloud discharging caused by aerosols is changeable, varying with aerosol types and thermodynamic background. In addition to the nonmonotonic response of lightning occurrence, aerosol effects on lightning characteristics, such as intracloud (IC)/cloud-to-ground (CG) ratio or lightning polarity (positive/negative flash fraction), remain controversial, leading to large uncertainty in lightning prediction and lightning dangerousness estimation. Also, the primary pathways through which the aerosols modulate cloud microphysics and charging could be significantly different for various aerosol types and depend on convective storm formatting mechanisms but are rarely explained in detailed physics. Moreover, aerosols can greatly modulate the evolution of convective systems by weakening or delaying warm rain processes and invigorating mixed-phase cloud processes, resulting in change in storm longevity and lightning timing, but, until now, limited quantitative assessment of the relative influence of aerosols versus meteorological parameters on convective storm lifetime are performed based on long-term satellite measurements. Convective storms with intensive lightning are usually accompanied with heavy precipitation, but the aerosol influence is not fully evaluated.

The objectives of our proposed research are to provide insights into aerosol microphysical and radiative effects on convective clouds and the associated lightning generation by integrating observational analyses focusing on satellite measurements and modeling studies with both statistical and physical models. We aim to answer the following fundamental scientific questions: 1) How does the aerosol effect on convective cloud microphysics and lightning activity and characteristics vary with aerosol types and meteorological regimes in long-term statistics? 2) What are the impacts of aerosols on convective storm longevity and lightning timing? 3) what are the primary physical mechanisms through which aerosol effects modulate convective cloud microphysical structure, cloud charge and discharge, and lightning generation potential?

To achieve the objectives, we will propose following tasks in this study, including: 1) to combine collocated the measurements of aerosol, cloud, precipitation, and lightning properties from satellites of CloudSat, CALIPSO, MODIS, TRMM, and GPM with ground-based monitoring networks to assess the long-term correlations between aerosol loadings and convective cloud properties, precipitation and lightning as well as their dependence on aerosol types and convective system formation mechanisms; 2) to construct machine learning models to quantify the relative importance of aerosols versus other meteorological parameters in determining convective cloud properties and lightning generation and characteristics, and evaluate the capability of these models in lightning forecasting; and 3) to perform cloud-permitting modeling sensitivity studies on representative thunderstorm cases using various aerosol-aware WRF versions configured with either explicit charging physics or a flash rate parameterization to improve the physical understanding of aerosol-lightning interactions in convective clouds.

Ute Herzfeld/University of Colorado, Boulder
High-Resolution Detection of Thin Clouds and Aerosols Facilitated by the Density-Dimension Algorithm for the Atmosphere: Development of New CALIPSO Level-2 Data Products
21-CCST21-0065

The objective of the proposed research is to develop and implement a fundamentally new algorithm that will enable significantly improved detection of tenuous atmospheric layers in the CALIPSO lidar data, including stratospheric smoke plumes, subvisible cirrus, Asian dust and volcanic ash from eruptions, which too frequently remain undetected using current CALIOP algorithms. The improved detection results will be used to to derive a new level two cloud and aerosol product. In this the proposed project meets one of the research needs stated in the ROSES call A.26 for the CloudSat and CALIPSO Science Team recompete.

Research using CALIPSO data has been very successful in a wide range of atmospheric and climatic science topics. But tenuous atmospheric layers with a low gradient and layers with poor signal-to-noise ratios are missed by the current detection algorithm. Such layers are typically very diffuse aerosols in the lower stratosphere and volcanic dust and sub-visible cirrus clouds in the upper troposphere and lower stratosphere. Detection of these features is important for assessment of air quality and pollution, airline safety, climate radiative forcing, monitoring of fires and volcanic eruptions, environmental safety, and weather forecasting.

To enable retrievals of heretofore undetected features we propose to utilize the mathematical core of an approach termed "Density Dimension Algorithm for the atmosphere" (DDA-atmos), which has been developed by the PI for the detection of layers in ICESat-2 atmospheric data. The DDA-atmos is the operational algorithm for ICESat-2 atmospheric layer detection, reported in the NASA ICESat-2 ATL09 Data Product. The DDA builds on concepts from Artificial Intelligence (AI) and spatial statistics. Core steps are calculation of a density field and application of a threshold function for signal-noise separation. The DDA is an auto-adaptive algorithm, in that is automatically adapts to changing background conditions of day times and reflectance. As a result, the DDA facilitates detection of tenuous layers in presence of optically thick layers, without creating false positives. Results of the DDA-atmos data analysis retain the full resolution of the data sets, thus enabling creation of a high-resolution data product (335m along-track, 30m heights for up to 8km, 1km along-track, 60m for 8-20km, etc.). The algorithm is computationally very efficient.

To demonstrate feasibility of the proposed CALIOP-DDA-atmos, first applications to CALIOP data have been carried out and result in detection of very faint stratospheric smoke plumes. Development of an operational algorithm will include sensitivity studies for optimal layer detection for all times and background conditions, uncertainty analysis/ quality assessment, and validation using simulated data. To more fully exploit the two-color, two-polarization measurements of CALIPSO, a generalized version of the DDA will be derived using a 6-dimensional kernel function. We aim to derive an operational Level-2 data product collaborative with the CloudSat/CALIPSO Mission. As a result of this project, a research product will be released, based on application of the DDA to one year of CALIOP data.

CATS data will be utilized for comparison with CALIOP data, facilitated by implementation of the DDA for CATS as well. This work component will aid in validation of CALIOP results, as well as lay the foundation for a CATS-CALIPSO integrated product. Cross-sensor studies are especially encouraged as a reached theme of the proposal call. The development of the same algorithm for CALIPSO and CATS is expected to allow integration of level-two data products across times and missions and can be extended to lidar data analysis future missions such as NASA's Atmosphere Observing System (AtmOS).

Meloe Kacenelenbogen/Ames Research Center
Effects of Aerosol and Cloud Variability on Satellite-Derived All-Skies Direct Aerosol Radiative Effects (DARE) Over the North and Southeast Atlantic
21-CCST21-0064

The Top-of-Atmosphere (TOA) Short Wave (SW) Direct Aerosol Radiative Effect (DARE) represents the global change in upwelling radiative flux due to aerosols. All-skies DARE depends on the Earth's surface albedo, cloud fraction, cloud optical properties, and aerosol optical properties in clear skies (i.e., non-cloudy) conditions as well as below, and above clouds. The NASA Atmospheric Observing System (AtmOS) project (which addresses the NASA Aerosol, Cloud, Convection and Precipitation, ACCP designated observable) proposes, as one of its minimum aerosol objectives, to reduce uncertainties in estimates of (&) global mean clear and all-skies SW DARE to ±1.2 Wm-2 at TOA (&)". Substantial progress is being made in the estimation of clear skies DARE from satellite observations. However, fewer studies use satellite measurements to attempt to estimate DARE above thick clouds, even less above any clouds (thick and thin) and, far less below thin clouds.

First, we will characterize cloud and aerosol optical and physical properties along the satellite tracks and averaged within three specific regions of the Atlantic Ocean from

2012 to 2016 -- the first region in the North, offshore from the Sahel, the second one in the South, offshore from Namibia and the third one encompassing the latter two. The first two regions are dominated by different aerosol and cloud regimes and the third one represents the transition between these two regimes. Second, we will characterize the observational TOA SW DARE along satellite tracks using the co-varying aerosol and cloud fields developed in the first step. Third, we will quantify the impact of assuming homogeneous cloud or aerosol fields in TOA SW DARE calculations.
Cloud properties will be characterized using mostly the CALIOP (Cloud Aerosol Lidar with Orthogonal Polarization), CPR (Cloud Profiling Radar), SEVIRI (Spinning Enhanced Visible and Infrared Imager) and MODIS (Moderate Resolution Imaging spectroradiometer) satellite sensors. Aerosol extensive properties will be characterized using mostly the CALIOP and CATS (Cloud-Aerosol Transport System) satellite sensors in all-skies conditions. Special attention will be dedicated to the characterization of aerosols below thin clouds. Surface-based lidars (on ships or on islands) will guide us on how to infer aerosol loading below thin clouds from satellite retrievals in near-by clear skies. Aerosol intensive properties will be characterized using MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications, version 2) simulations, coastal AERONET (Aerosol Robotic Network) and airborne campaign measurements. The resulting space-based all-skies aerosol vertical distribution and DARE calculations will be evaluated using airborne remote sensing observations (e.g., from the ObseRvations of Aerosols above CLouds and their intEractionS, ORACLES field campaign).
Well characterizing clouds, aerosol vertical distribution, aerosol types and associated all-skies DARE over the Atlantic Ocean will inform the AtmOS community on where, when, how, and how often the satellite-retrievals should be performed to most accurately estimate DARE and reduce all-skies DARE uncertainties. It will also identify the key regions and times when the AtmOS (or other ACCP-related) suborbital efforts should be implemented to evaluate and improve these AtmOS orbital observations and retrievals.

Ryan Kramer/University of Maryland Baltimore County
Investigating the Vertically-Resolved Radiative Constraints on Tropical Precipitation with CloudSat and CALIPSO
21-CCST21-0036

At a fundamental scientific level, precipitation is a medium for energy transport. On large spatial scales, radiative cooling in the atmosphere must be balanced by a source of heating, which comes mostly from latent heating associated with precipitation along with a small contribution from sensible heating. The balance is often met daily in the tropics, which will be our domain of focus. This constraint is a powerful first-order explanation of what controls precipitation, but details of the underlying physical processes are still unclear. Recent modeling work indicates that thermodynamic and radiative processes in the boundary layer play a key role in setting precipitation rates, whereby changes in low-level vertical mixing and stability influence radiation. In contrast, other work suggests precipitation is largely constrained by the free-atmosphere while the boundary layer more directly constrains sensible heat instead. The relative importance of these layers on precipitation, and the physical mechanisms that influence these relationships through radiation, have not been investigated in observations. While some relevant modeling studies have been conducted, they are inconclusive about important details that appear highly dependent on the model and its experimental setup, such as the role of clouds. Our preliminary work suggests differences in radiative cooling variability between convective and subsidence regions may be particularly relevant to tropical precipitation change. This also has not been thoroughly explored, especially in terms of the vertical distribution of radiative cooling. We propose to use a suite of products primarily from CloudSat and CALIPSO to diagnose vertically-resolved radiative cooling rates and how their variability drives tropical-mean precipitation.

CloudSat and CALIPSO (CC) are the only viable observing platforms for this work. We intend to use the CC Fluxes and Heating Rates product, various CC measurements of cloud properties, latent heating profiles from CloudSat and TRMM and reanalysis data for other non-cloud geophysical variables to a) develop a first-of-its-kind record of radiative cooling in the free-atmosphere and boundary layer, b) determine how differences in the variability of this radiative cooling between convective and subsidence regions influences tropical precipitation and c) identify how the vertical distribution of cloud versus non-cloud variables impacts these relationships. To delve further into the physical relationships between thermodynamic processes and radiation, we will develop a novel set of CloudSat and CALIPSO-derived radiative kernels defined specifically for radiative responses in the boundary layer, the free-atmosphere and for individual layers within them, to decompose total radiation changes into contributions from temperature, humidity and clouds with greater vertical detail than any previous work. Finally we will used these observed relationships to constrain well-documented biases and inter-model spread in present-day and future precipitation change.

This work is relevant to the CC Science Team call for proposals that investigate hydrological processes in the context of weather and climate variability" or that use CC to understand the atmosphere's three-dimension radiative environment". This work will also address two of the established Earth Science Mission Directorate focus areas: Climate Variability and Change" and the Water and Energy Cycle" and addresses multiple Science Questions from the 2017 Decadal Survey, including How do anthropogenic changes &modify the water and energy cycles at different spatial scales (H-2)?", What planetary boundary layer processes are integral to the air-surface exchanges of energy (W-1)?" and How to clouds affect the radiative forcing at the surface (W-10)?".

Guosheng Liu/Florida State University
Partitioning Solid and Liquid Precipitation Over Global Mountains Using CloudSat and TRMM/GPM Observations

21-CCST21-0025

Whether precipitation falls in the form of rain or snow is of great importance to glacier/snowpack accumulation and ablation, regional hydrological balance, water resources and economic activities. However, assessment of the phase-aware precipitation has been lacking over the most mountainous areas, due to the scarcity of quality surface-based measurements and the low quality of satellite estimates over complex terrains. Space-borne radars (CloudSat/CPR, TRMM/PR and GPM/DPR) are advantageous over passive sensors for observing precipitation over complex terrains because radar returns are determined for individual range gates. Snowfall estimation has been available from CPR since its launch in 2006, and precipitation estimation from PR and DPR has been available since TRMM satellite's launch in 1997 and GPM core satellite's launch in 2014. In response to this CCST21 call's research theme hydrologic processes in the context of weather and climate variability", we propose to study the solid to liquid precipitation ratio over global scale using CloudSat snowfall estimates and PR and DPR rainfall estimates with emphasis on global mountainous areas where the solid and liquid partition is particularly important (for glacier/snowpack and water resource), and yet the phase-aware precipitation is extremely difficult to estimate by other means. Specifically, we will perform the following research using CloudSat snowfall estimates as solid phase precipitation. 1. Develop a unified phase determination algorithm to be used for both CPR and PR/DPR data. We have developed a phase determination algorithm in the past (Sims and Liu, 2015). Further study indicates that there is a regional dependence of this algorithm, and some corrections are needed for several mountainous regions (for example, Himalayas, Rockies, etc.). We'll further improve this algorithm given the emphasis of this study on mountainous regions. 2. Perform CloudSat snowfall validation using SNOTEL and GHCND. Validation to PR/DPR rainfall product will also be conducted using MRMS data. The validation will particularly focus for mountainous regions. Biases found by the validation in snowfall and rainfall products will be corrected. 3. Derive solid to total precipitation ratio and make analyses. All CloudSat data from 2006 to 2017 will be used to estimate mean snowfall in 1ºx1º degree grid boxes to represent snowfall climatology global distributions. PR/DPR rainfall precipitation from 1997 to 2015 (for PR) and 2014 to present (for DPR) will be used to compute rainfall climatology in every 1ºx1º degree grid box. The following analyses on the precipitation phase partition will be performed: (1) the sensitivity of phase partition to temperature change, (2) the regional and seasonal differences in precipitation phase partition, and (3) the partition's variation with weather systems/cloud types.

Xiaomei Lu/Science Systems and Applications, Inc.
Innovative Uses of CALIPSO Data for Oceanography and the Ongoing COVID-19 Impacts Study
21-CCST21-0007

The CALIPSO mission is entering its 16th year of very successful operation, providing the first ever multi-year global record of high-resolution profiles of aerosols and clouds in

the Earth's atmosphere (Winker et al. 2010), which are critically important for Earth radiation budget estimation and climate model improvements. Although CALIPSO was not designed for ocean subsurface applications, its measurements over the Earth's oceans now provide a wealth of unanticipated opportunities for ocean biology and biogeochemistry studies (Behrenfeld et al., 2019, 2016, 2013; Churnside et al., 2013; Dionisi et al., 2020; Lu et al., 2016, 2014), which fill observation gaps in the passive remote sensing of ocean biology (e.g., MODIS ocean color) that occur when sensors are obscured by optically thin cloud and/or sea ice and during all nighttime observations. Based on years of experience conducting CALIPSO oceanic and atmospheric studies, we propose to investigate the internal feedbacks among sea ice, ocean, and atmosphere, making use of a suite of state-of-art satellite observed datasets acquired over the past decade. We propose three interconnected tasks to achieve the proposal's objectives:
Step 1. Generate the first decadal dataset of space-lidar derived global ocean results (e.g., subsurface attenuated backscatter profiles and bbp) by using CALIPSO (15+ years) and ICESat-2 (2+ years) observations, including high latitude regions and night times. The global scale and high vertical resolution profiles from CALIPSO and ICESat-2 provide new and unique information that augment the existing ocean color records acquired by passive remote sensors. This pioneering use of space lidars to retrieve ocean subsurface properties will provide a meaningful satellite lidar record to the ocean science community and an important preparatory data for the upcoming Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission.
Step 2. Based on the decadal space-lidar-derived ocean records from step 1, we will examine the variability at interannual and seasonal scales of phytoplankton dynamics in open ocean, coastal ocean and polar ocean, and analyze the dominant mechanisms (e.g., sea ice cover, water temperature, nutrient, ENSO, etc.) forcing seasonal and interannual changes in the upper ocean biomass. We will study the phytoplankton response to sea ice retreat and global warming, and its impact on atmosphere aerosol and cloud.
Step 3. Investigate the cryosphere - ocean - atmosphere interactions based on a large volume of datasets from multiple years of CALIPSO data collocated with other A-Train measurements.
While successfully completing the above tasks, we will investigate the following specific science topics: (1) How do the clouds and aerosols in the Earth's atmospheric respond to ocean biology activities and sea ice cover changes? (2) How do changes in clouds and sea ice cover affect the TOA and surface energy budgets? And finally, (3) what environmental consequences are evident as a result of the COVID-19 pandemic, e.g., have cloud droplet number concentrations and aerosol optical depths declined due to COVID-19?
The project is directly relevant to the A.26 'CloudSat and CALIPSO Science Team Recompete' by developing of innovative uses of CALIPSO data for oceanography and the ongoing COVID-19 impacts studies.

Zhengzhao Luo/City College of New York
Developing A Satellite-Based Convective Mass Flux Dataset for Evaluating and Improving GCM Cumulus Parameterization

21-CCST21-0020

Most current GCM cumulus parameterization schemes are based on the concept of convective mass flux. Yet, no global observations of this critical parameter exist at this time. To fill the vacuum, we developed a novel, satellite-based approach to retrieve convective mass flux (referred to as ML16 after Masunaga and Luo 2016). The ML16 approach combines, in a Bayesian manner, satellite observations from CloudSat/CALIPSO/MODIS, ambient sounding from AIRS, and plume model simulations (driven by the sounding) to estimate convective vertical velocity and convective mass flux. Comparisons with collocated, ground-based radar wind profiler observations at an Amazon site showed generally good agreement. The objectives of this proposal are 1) to continue to assess the ML16 method using A-Train observations and Observing System Simulation Experiments (OSSEs), 2) to extend the ML16 method to geostationary satellite observations to cover the convective life cycle and diurnal cycle, 3) to evaluate and improve cumulus parameterization in the GISS GCM, and 4) to improve the understanding of the convection-anvil relationship.

The proposed work is well aligned with the CCST themes. Development of an A-Train based convective mass flux dataset is an inventive combination of CloudSat and CALIPSO data with other sensors". Such a dataset is critical to evaluating and improving GCM cumulus parameterization. Study of the convection-anvil relationship using the new dataset enhances our process-level understanding of how convective mass flux ties to anvil coverage variation globally, which in turn facilitates improved assessment of cloud feedbacks in climate models". This study is also closely linked to the ACCP initiative, providing a bridge to connect future Doppler measurements to the present and past space-borne cloud radar observations.

Alexander Marshak/Goddard Space Flight Center
Near-Cloud Changes in CALIOP and MODIS/VIIRS Aerosol Observations
21-CCST21-0027

As stated in the 5th Assessment Report of the Intergovernmental Panel on Climate Change, Clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth's changing energy budget ... the quantification ... of aerosol cloud interactions continues to be a challenge." Aerosol observations in partly cloudy regions play a crucial role in understanding aerosol-cloud interactions and contribute significantly to uncertainties in the Earth radiation budget. Aerosol properties vary in response to nearby clouds and cloud-related processes, but the exact causes and radiative effects of these variations have remained elusive. Interpreting MODIS and VIIRS observations is especially challenging near clouds because of cloud contamination and cloud adjacency effects. Fortunately, CALIOP measurements show little sensitivity to cloud adjacency effects or uncertainties in surface properties that could exacerbate cloud contamination.

Our group combines experience in passive and active atmospheric remote sensing with expertise in statistical analysis and 3D radiative transfer. Here we propose to use CALIOP data enhanced by MODIS and VIIRS information to study the properties and radiative impacts of near-cloud aerosols. The two main goals of our proposed research are (i) using CALIOP to better understand the effects of clouds and cloud-related processes on aerosol properties, leading to better prediction of how aerosol radiative forcing will be changed if atmospheric composition is modified; and (ii) improving the interpretation of MODIS and VIIRS aerosol observations near clouds with the help of CALIOP observations and our theoretical models of cloud adjacency radiative effects. This proposal will use the excellent capabilities of CALIPSO to better understand the way aerosol populations are affected by clouds and cloud-related processes, and to help improve the interpretation of MODIS and VIIRS aerosol observations in partly cloudy regions.

Michael Pitts/Langley Research Center
Improved Characterization of PSC Processes Derived from a Third-Generation CALIOP and MLS Detection and Composition Classification Algorithm
21-CCST21-0051

We will continue to advance the understanding of polar stratospheric cloud (PSC) processes through a unique combination of data from the Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP) instrument on the CALIPSO satellite and the Microwave Limb Sounder (MLS) on the Aura satellite, in conjunction with supporting meteorological information and detailed modeling studies. We will adapt and implement a two-dimensional, multi-channel CALIOP feature detection algorithm (2D-McDA) for detection of PSCs and potentially stratospheric aerosol layers in the winter polar regions. We will develop an improved two-dimensional PSC composition classification scheme that will utilize multiple parameters (e.g., CALIOP 532-nm parallel and perpendicular scattering ratios, CALIOP 1064-nm total scattering ratio, MLS HNO3 and H2O, ambient temperature, and temperature histories) in a Bayesian approach to determine the most likely PSC composition and help constrain particle number density and size/shape. We will investigate possible trends in PSC occurrence and composition over the entire CALIOP data record and through further comparisons with the Stratospheric Aerosol Measurement (SAM) II PSC record from 1979-1989. Finally, we will validate the mountain-wave parameterization and PSC schemes used in the UM-UKCA (Unified Model coupled to the United Kingdom Chemistry and Aerosol module) chemistry-climate model through detailed comparisons with earlier CALIOP PSC data products and those developed under this proposal. Our research will further advance our understanding of the roles that PSCs play in ozone depletion and contribute significantly to meeting a major NASA science goal of providing an improved prognostic capability for the recovery of stratospheric ozone against a backdrop of global climate change.

Anita Rapp/Texas A& M, College Station
Constraining Cloud Feedback Responses Associated with Precipitating Cloud Distribution Shifts Under Changing Tropical Ascent Area
21-CCST21-0032

Cloud-precipitation-radiation feedbacks associated with the variations of convection and the shrinking of the broad regions of detrained high cloud in the tropics as surface temperatures increase has been hypothesized as one potential mechanism for regulating climate sensitivity. While climate models produce many aspects of the global mean precipitation and cloud radiative effects that are consistent with observations, they do not necessarily produce convection and rainfall that are consistent with cloud scale distributions, resulting in precipitation/latent heating and cloud radiative effects with large regional biases and widely varying cloud feedbacks in models. Some of the largest model biases in both precipitation and radiation are in the tropical ascent regions dominated by organized deep convection, likely due in part to model parameterizations that do not capture the relationship between the precipitation and the cloud extent.

Often these cloud-precipitation-radiation feedbacks are often examined separately (e.g., climate sensitivity or hydrologic sensitivity), when in reality, especially at the local and regional level, they are tightly linked. To support recent efforts toward developing parameterizations for prognostic anvil cloud area production and understanding variations in convection in tropical ascent regions that are expected to narrow with climate change, measurements from CloudSat and CALIPSO will form the basis of an analysis to constrain the cloud feedback response associated with precipitation shifts with variations in tropical ascent area. Building from the idea of cloud radiative kernels, a CloudSat-CALIPSO (C-C) cloud object identification dataset of cloud, radiation, and precipitation properties from C-C and other A-Train sensors will be used to determine the cloud and radiative response to changes in precipitation and the ascent area cloud feedback response to shifting precipitation distributions. The three main objectives of the proposed project are to:

1. Develop joint A-Train cloud object dataset for full timeseries of C-C observations
2. Compute radiative impact in response to precipitation changes
3. Determine ascent region cloud feedback associated with changing precipitating cloud distributions as the ITCZ width and tropical ascent area fraction changes

Outcomes of this proposal will further our understanding of the coupling across scales, linking the variations in the distribution of individual convective systems to large-scale phenomena like ITCZ ascent area narrowing and modulations of the radiative effects of the tropics. The project is also relevant for informing and evaluating prognostic anvil area parameterization development as the linkage between the cloud characteristics, cloud radiative effects and precipitation will lead to a better understanding of the physical or dynamical processes and parameterizations in the models that may be underlying the known model deficiencies in regions of deep convection and in capturing the ITCZ. The proposed research hits on a number of example topics listed in the solicitation, including 1) phenomenological studies of fundamental cloud and precipitation processes, 2) use of

CALIPSO and CloudSat products in the development of three-dimensional cloud climatologies, 3) seasonal or interannual variability of cloud properties on regional to global scales, 4) use of CALIPSO and/or CloudSat in understanding the atmosphere's three-dimensional radiative environment, 5) hydrologic processes in the context of weather and climate variability, and 6) assessment of cloud feedbacks in climate models.

William Smith/Langley Research Center
New Observational Constraints for Evaluating Aerosol-Cloud Interactions with the Use of Vertically Resolved CALIPSO Aerosol Properties
21-CCST21-0049

The interactions between aerosols, clouds, and precipitation simulated by climate models constitute one of the largest uncertainties in our current understanding of the anthropogenic radiative forcing. Improvements in estimates of aerosol indirect effects require tackling the problem of quantifying the dependence of cloud microphysics on atmospheric aerosols, and separating such effects from those driven by the atmospheric circulation. Current studies based on satellite observations have been advantageous at providing a global perspective, yet large observational uncertainties and retrievals limitations cast doubt on past climate model evaluations guided with satellite data in the context of the aerosol indirect effect. This is because satellite aerosol proxies (aerosol optical depth or aerosol index) can be severely affected by cloud contamination and 3D radiative effects, and because vertically integrated aerosol retrievals often poorly represent aerosol properties in the boundary layer. In contrast, CALIPSO aerosol retrievals can substantially remediate the aforementioned uncertainties. This calls for new methods of analyzing satellite data, emphasizing the physical link between aerosol and clouds, with retrievals representative of boundary layer processes. New observational constraints are key for validating numerical models, taking into account the 3-D structure of aerosols and clouds, and exploiting the strengths of specific remote sensing instruments/retrievals.

We propose to investigate aerosol, cloud, and radiation interactions in the marine atmospheric boundary layer (MABL) using novel observational constraints that combine vertically resolved aerosol extinction coefficients from CALIPSO with cloud retrievals from MODIS and precipitation information from CloudSat. The observed constraints will be applied further to the evaluation of aerosol-cloud interactions simulated by the state-of-the-art climate model Energy Exascale Earth System Model (E3SM). We hypothesize that a) refinements in the estimation of MABL aerosols using CALIPSO yield more physically meaningful aerosol indirect effect and ACI assessments than the standard approach of using aerosol optical depth (AOD) or aerosol index, with magnitudes differing from estimates from satellite passive only, and b) new observational constraints call for new assessments of climate models, which can be more thoroughly validated by incorporating 3D aerosol information.

Specific objectives of this proposal include:

1 Develop methods for reducing biases in aerosol and cloud properties of collocated datasets. Estimate height-specific aerosol properties relevant for the study of aerosol-cloud interactions in the boundary layer.
2 Compute aerosol-cloud interaction (ACI) metrics. Analyze the role of precipitation strength and large-scale atmospheric processes. Investigate the role of aerosol type using CALIPSO aerosol classification and optical properties.
3 Evaluate E3SM simulations of ACI at standard (~115 km) and high resolution (~25 km) using the new CALIPSO-based constraint. Assess the benefits of the high-resolution setting for simulating the aerosol indirect effect in MABL liquid clouds.
4 Analyze the importance of constraining the aerosol 3-D distribution in E3SM for simulating realistic ACI. Provide recommendations for the evaluation of climate models.
This project will lead to a more physical quantification of the aerosol indirect effect through the development of new methodologies for evaluating climate models, using observational constraints that more faithfully reflect the aerosol signature on clouds. Datasets and ACI metric maps will be available to the community for further satellite-model intercomparisons.

Brian Soden/University of Miami, Key Biscayne
Development and Analysis of Cloud Radiative Kernels Using CloudSat/CALIPSO Measurements
21-CCST21-0035

Radiative feedbacks regulate the response of the climate system to both internal variability and external climate change. Radiative kernels describe the differential response of radiative fluxes to perturbations in radiative state variables and have become the standard tool for quantifying radiative feedbacks in both models and observations. With previous funding from the CloudSat/CALIPSO project, the PI developed the first set of observationally based radiative kernels. These kernels highlighted the dominant role of surface radiative feedbacks in regulating the response of the atmospheric radiative cooling and the hydrological to changes in climate.

One limitation of radiative kernels is their ability to explicitly compute cloud feedbacks. There are currently two approaches: One is to adjust" the change in cloud radiative forcing by using kernels to account for the radiative impact of the changes in non-cloud variables (Soden et al. 2008). However, this approach does not provide information on the contributions of different cloud types or cloud properties to the total cloud feedback. The other approach is to use a set of cloud radiative kernels based on the ISCCP cloud property matrix (Zelinka et al. 2012a,b). However, this approach is only available for top-of-atmosphere (TOA) fluxes and requires models (and observations) to be post-processed using an ISCCP simulator.

Here we propose to extend the CloudSat/CALIPSO radiative kernels to include explicit kernels for cloud properties, including cloud amount, cloud altitude, and water content changes. The ability of CloudSat to resolve the vertical profile of clouds will enable us to compute cloud radiative kernels for both surface and TOA radiative fluxes, as well as to resolve the vertical contributions of cloud property changes at different levels. We will also extend the radiative kernel data set from 1 year to 4+ years to document the dependence of radiative kernels on the base state of the climate.

These Cloud Radiative Kernels will then be used to evaluate the representation of the feedbacks from changes in cloud properties in CMIP6 models and better understand how observable variability in these feedbacks on interannual time scales can be used to constrain their longer-term response to CO2 induced warming. Satellite measurements from NASA A-Train (and the follow on JPSS instruments) will then be used to evaluate the fidelity of the model simulated interannual variability and assess the their ability to provide emergent constraints on long-term cloud property feedbacks. By completing these tasks, this proposal directly addresses the program themes of Phenomenological studies of fundamental clouds" and Use of CALIPSO and/or CloudSat in understanding the atmosphere's three-dimensional radiative environment".

Hanii Takahashi/University of California, Los Angeles
Exploring A-Train Observations of Land-Ocean Contrast in Convective Cloud Characteristics and Their Ambient Environment Toward Improving GCM Cumulus Parameterizations
21-CCST21-0031

A series of analysis methodologies developed by the PI have successfully quantified convective cloud characteristics during different lifecycle stages of convective systems and documented the variables that are key to the convective processes, including convective core strength and size, level of maximum detrainment and deep convective outflow, and bulk entrainment and dilution. Now, a coherent picture emerges revealing a distinct land-ocean contrast in tropical convective cloud characteristics: tropical continental convective clouds, when compared to the oceanic counterparts, tend to have wider, stronger, and less diluted convective cores, as well as higher convective detrainment levels, enabling a more efficient convective vertical transport of cloud material to higher levels. What lies behind these contrasts are the differences in land-ocean environments in which convective clouds form and develop.

In this proposal, we will use the land-ocean differences in convective cloud characteristics as a framework not only to better understand atmospheric moist convection as a science subject, but also to develop methods and metrics for evaluating cloud-scale and global models in simulations of convection. First, we will use multi-year A-Train observations to explore what/how environmental factors control the land-ocean contrasts during different lifecycle stages of convective systems. Then, we will set up a framework to evaluate the representations of the land-ocean contrasts in large-eddy simulation (LES) with convective lifecycles to support GISS single-column model (SCM) parameterization. To analyze GISS SCM convection output utilizing a lifecycle approach is novel, and results will be compared with the typical approach of evaluating time-mean quantities.

Due to the coarse resolution of GCMs, direct comparison with the observations has been a challenge. However, the LES simulations will bridge the gap between the CloudSat/A-Train observations and the GISS GCM, which in turn will inform convective parameterization in the newest NASA GISS global climate model (Model-E3), which has an improved convective detrainment parameterization and a new cold pool parameterization, both of which have improved the representation of cumulus convection globally. The methods based on CloudSat/A-Train observations and LES model simulations will not only greatly enhance the process-level understanding of deep convective clouds, but also serve as novel diagnostic tools for evaluating and improving the representation of convective clouds in GCMs.

David Thompson/Colorado State University
Using CloudSAT and CALIPSO Data Products to Understand the Role of Clouds in Extratropical Climate Variability
21-CCST21-0001

Understanding two-way interactions between the atmospheric circulation and cloud radiative effects is a key Grand Challenge" in climate change research. The vast majority of previous work on such coupling has focused on tropical latitudes. Until recently, relatively little attention has been placed on understanding the role of such coupling in climate variability at extratropical latitudes.

The goal of the proposed research is to improve our understanding of two-way interactions between the atmospheric circulation and cloud radiative effects at extratropical latitudes using a range of CloudSAT/CALIPSO data products. The work builds on the track record we have developed in this area over the past decade. In the proposed research, we will build on that track record and focus on the importance of cloud/circulation coupling in two key but poorly understood aspects of extratropical climate variability. The work will explore: 1) the role of cloud radiative effects in atmosphere/ocean interactions over ocean frontal zones, including the western boundary currents; and 2) the role of cloud radiative effects in stratosphere/troposphere coupling.

The research will bring to the CloudSAT/CALIPSO team a proposal focused on the key role of clouds in large-scale climate dynamics. It fits under the auspices of numerous foci of the CloudSAT/CALIPSO Science Team Recompete, including "using CALIPSO and CloudSat (to) understand the atmosphere's three-dimensional radiative environment"; "the development of innovative uses of CALIPSO and/or CloudSat data for oceanography (and) meteorology)"; understanding the seasonal (and) interannual variability of cloud ... properties on regional to global scales"; and the assessment of cloud feedbacks in climate models".

The results are expected to lead to a much improved understanding of cloud processes in both extratropical atmosphere/ocean interactions and stratosphere/troposphere coupling, and thus of climate variability over large regions of the extratropics. The work will be lead by the PI (David W. J. Thompson) and a graduate student in the Department of Atmospheric Science at CSU.

Zhien Wang/University of Colorado, Boulder
Characterizing Polar Mixed-Phase Cloud Properties and Variations with CloudSat, CALIPSO, and Other A-Train Satellite Measurements
21-CCST21-0037

The Arctic is warming at approximately twice the pace of the rest of the globe, which is commonly known as Arctic amplification and is most pronounced during the late autumn and early winter. Cloud-ice-radiation feedback is a crucial mechanism in the observed rapid changes in the polar regions under a warm climate. Current climate models have significant uncertainties in polar regions, mainly due to errors in representing cloud and related feedback mechanisms.

Due to the cold environment, mixed-phase clouds play a critical role in the polar climate system. The co-exist of ice particles and supercooled liquid drops involves a complex set of cloud microphysical processes. Therefore, Mixed-phase clouds are especially poorly represented in climate models. Observations are needed to advance our understanding and to improve model parameterization to reduce climate forecast uncertainties.

Space-based observations of mixed-phase clouds in the polar regions are critically needed because limited surface-based and airborne observations are available. With the advancements in polar mixed-phase cloud retrievals and over 10-year multi-sensor measurements from CloudSat, CALIPSO, and other A-train satellites, it is a great time to focus on characterizing and understanding polar mixed-phase cloud properties and variations. Our three research objectives are:

1) A dataset to document polar mixed-phase cloud: By combining CloudSat, CALIPSO, and MODIS measurements, we developed new algorithms to determine stratiform mixed-phase cloud properties. Results from these algorithms will be combined to provide a consistent dataset to document polar mixed-phase cloud properties for model evaluations and process studies.

2) Characterize the annual cycle of polar mixed-phase clouds and their radiative impacts: Due to the dramatic annual cycles of solar insolation and temperature, mixed-phase clouds experience a significant annual cycle under different thermodynamics and aerosol conditions. Collocated TOA LW and SW flux measurements from the CERES satellite will be used to document mixed-phase cloud radiative impacts. We will understand factors and processes controlling polar mixed-phase cloud regional and season variations.

3) Understand interannual polar mixed-phase cloud variations: Other than aerosol and thermodynamic conditions, interannual sea-ice variations in the Arctic could result in significant mixed-phase clouds variations, which, in turn, impact sea ice formations. Also, dynamic processes associated with different weather patterns impact cloud developments. Since 2006, the arctic annual mean temperature increases about 1.5 degrees. How Arctic clouds, especially mixed-phase clouds, change with the warming will be evaluated. Interannual polar mixed-phase cloud variations offer opportunities to better understand critical processes controlling mixed-phase clouds.

Robert Wood/University of Washington, Seattle
Understanding Spatiotemporal Transitions in Marine Low Cloud Systems Using Observations From CloudSat, CALIPSO, MODIS, AMSR-E, and GOES
21-CCST21-0005

Earth's albedo is strongly sensitive to bright low clouds over the dark oceans. Marine low cloud systems are maintained by complex interactions between planetary-boundary-layer (PBL) turbulence and microphysical processes that are poorly understood. Marine low cloud systems typically organize at mesoscales (1-100 km), and systems can be classified using a relatively small number of archetypical organizational states. These mesoscale archetypes tend to be associated with particular cloud macrophysical properties (e.g., cloud cover and condensate distribution) and microphysical properties (precipitation, cloud droplet concentration and effective radius) that together determine a system's radiative properties. Mesoscale self-organization of low cloud systems is emergent in high resolution cloud-resolving models, yet is not accounted for in parameterizations used in climate models. Evidence from observations and modeling suggests that the selection of the mesoscale organizational state that a system adopts is sensitive to a range of meteorological drivers and also to changes in aerosol. Understanding how cloud-controlling factors influence mesoscale organization in the current climate can provide insights into how low clouds respond to increasing greenhouse gases and anthropogenic aerosol.
Central objectives: The proposed work aims to better understand processes controlling the spatiotemporal variability of marine low cloud systems through a focus on their mesoscale organization. A combination of active and passive satellite sensors is used to characterize key aspects of the macrophysical, microphysical and radiative properties of mesoscale low cloud systems to explore how these systems evolve on process-relevant timescales of hours to a few days. Compositing along Lagrangian air mass trajectories allows exploration of how environmental controlling factors determine transitions between archetypes. Separate components explore mesoscale organization in the tropics, subtropics, and midlatitude regions.

Methods/techniques: The research builds on previous work that developed a method to composite satellite data along Lagrangian air mass trajectories derived from meteorological analyses. Prior work explored factors controlling cloud cover, condensate, and microphysical properties, and established timescales for the evolution of these properties. We explored the influences of boundary layer depth and precipitation, for which we developed satellite observational estimates that use CALIPSO and MODIS to estimate boundary layer depths, together with CloudSat and AMSR to estimate rain rates. The proposed work will use these estimates and leverage a newly developed low cloud mesoscale classification dataset from a separate MEASURES project. This product classifies low cloud scenes into six different archetypes (stratus, closed cells, open cells, disorganized cells, aggregated cumulus, and suppressed cumulus), with a different subset of these types dominating in different regions. Active and passive satellite data will be composited along Lagrangian air mass trajectories to explore the time evolution of particular mesoscale states and the transitions between states. The high time resolution provided by geostationary data from the new ABI instruments on the current generation of GOES satellites will be used to explore cloud system evolution on shorter timescales than is possible using the A-Train alone.

Perceived significance of the proposed work: This proposed work is significant because the future warming of the Earth is strongly dependent upon how clouds respond to both greenhouse gases and anthropogenic aerosol. Low cloud feedback processes remain a major source of uncertainty in climate projections, and better understanding of marine low cloud systems and the processes controlling their mesoscale evolution on process-relevant timescales is needed in order to develop parameterizations for use in next generation climate models.

Kuan-Man Xu/Langley Research Center
Developing Neural Network Parameterizations of Volumetric Cloud Fraction Using CloudSat-CALIPSO Observations and GMAO Reanalyses
21-CCST21-0045

We propose to develop neural network parameterizations of volumetric cloud fraction (VCF), which is the fraction of volume occupied by clouds in a 3-D grid, not the traditional cloud fraction defined by area (ACF) at a height, for use in climate models using the merged CloudSat, CALIPSO, CERES and MODIS (CCCM) data and GMAO (Global Modeling and Assimilation Office) reanalyses. VCF can more accurately determine in-cloud condensate contents from the grid-mean values than ACF, thus improving cloud microphysics and radiative transfer calculations in climate models. To successfully develop such neural network cloud parameterization (NNCP) algorithms, the VCF profile data from high-resolution observations must be appropriately selected and collocated with the reanalysis data in addition to a careful design of the neural networks. Simple cloud parameterization algorithms have been developed to mimic the complex nature of cloud physical processes. After they are incorporated in a model, tuning of free parameters, for example, the threshold relative humidity (RH) for initiating a cloud, is needed to satisfy large scale physical constraints, such as the energy balance at the top of the atmosphere (TOA). The NNCP approach will minimize the need of tuning because it relates VCF empirically with multiple meteorological variables such as profiles of temperature, relative humidity, and three components of wind, and surface sensible and latent fluxes and thus represents comprehensive cloud formation processes. This approach is feasible due to the availability of vast amounts of satellite observations produced from matured algorithms, the rapid advances in machine learning (ML) techniques and the increasing use of ML in our field.

The main goal of this investigation is to develop three NNCP algorithms with increasing sophistications. They will allow climate models to simulate cloud macrophysical properties that are consistent with multiple meteorological variables, which leads to improve the assessment of cloud feedbacks in climate models. Neural networks are in principle a series of nonlinear functions with weights determined through training on data. That is, they are similar to a least square fitting but replacing linear polynomial with nonlinear neural network regressions. The NNCP algorithms intend to capture the best matching statistical relationships of observed VCF with meteorological variables over the entire globe. To achieve the goal, we propose four research tasks: 1) producing and refining the ML training data set from the merged CCCM data and collocating the satellite data with reanalysis in space and in time; 2) designing, training, optimizing, validating, and testing the ML algorithms such as random forest, feedforward, and mixture density neural networks, including validation of preliminary NNCP algorithms; 3) evaluating and improving the NNCP algorithms using a number of reanalysis and large-eddy simulation datasets; and 4) implementing, testing and evaluating the NNCP algorithms in a climate model. The uniqueness of this proposed investigation are twofold: its reliance on the state-of-the-art NASA satellite data for developing the NNCP algorithms and its utilization of multiple meteorological variables as predictors in the NNCP algorithms. The outcome of this research will contribute to improvement in the cloud physics parameterizations and radiation calculations in climate models, thus more accurate assessment of cloud feedbacks.

Ping Yang/Texas A & M, College Station
Global Distribution of Mineral Dust Load and Microphysical Properties Inferred From Synergistic CALIPSO Observations and State-of-the-Science Light-Scattering Simulations
21-CCST21-0002

Mineral dust aerosols constitute a unique and important atmospheric component. To improve our knowledge about the role of dust aerosols in the Earth's climate system, it is critical to reliably infer aerosol microphysical and radiative properties from space-borne observations on a global scale, particularly the effective particle size, dust mass load, optical thickness, the asymmetry factor associated with the scattering phase function, the single-scattering albedo, and direct radiative forcing effect.

Fused active and passive observations provide a wealth of information for robust inference of airborne dust aerosol properties. We propose to use thermal infrared observations made by the Imaging Infrared Radiometer (IIR) and the backscattering depolarization measurements made by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite to retrieve dust aerosol properties. The proposed retrieval method will not rely on an empirical assumption of the lidar ratio to avoid degrading the accuracy of lidar-based aerosol property retrievals. Furthermore, we will include a fast radiative transfer model for the forward radiative transfer simulations to facilitate retrievals of dust properties in a computationally efficient way. To successfully implement a retrieval method based on collocated observations made by active and passive sensors, reliable single-scattering properties of dust particles must be used. In this effort, we will develop an optimal bulk dust optical property model based on an existing single-scattering property database of mineral dust particles that we previously developed and published using state-of-the-science light-scattering computational capabilities.

Through this project, we will demonstrate the applicability of the proposed IIR-CALIOP based dust property retrieval. Although the proposed retrieval will NOT require an empirical assumption of lidar ratio, the proposed optimal bulk dust optical property model will be able to provide information about the lidar ratio and the backscattering depolarization ratio under dust conditions for other existing aerosol retrieval algorithms including the operational CALIPSO aerosol retrieval algorithm.

With use of the results from the proposed CALIOP IIR mineral dust optical property retrievals, we will investigate the spatiotemporal distributions of mineral dust aerosol associated with dust plumes on a global scale from 2006 2021. In particular, we will focus on the distributions of the mineral dust load and the variability of dust microphysical properties, and develop a decadal dust aerosol climatology, towards a better understanding of seasonal and interannual variability of aerosol properties on regional to global scales. The outcomes of this project will benefit 1) validating dust transport simulated in climate models and 2) estimating the amount of mineral dust aerosol transported inter-continentally across the Atlantic and Pacific oceans.

Lauren Zamora/University of Maryland, College Park
Aerosol Microphysical Effects on Clouds in a Warming Arctic
21-CCST21-0026

The Arctic is warming quickly, affecting infrastructure, commerce, and human safety, as well as regional ecology, sea level rise, and weather even outside of the Arctic. Even though clouds have a major influence on this warming, they are not simulated very well in climate models, especially in the Arctic. Clouds can be very sensitive to airborne particles, yet the concentrations of these particles and the ways in which they affect cloud ice formation are not well known. Therefore, we still do not have answers to even basic questions such as whether aerosol indirect effects cool or warm the Arctic, and how aerosol impacts on clouds will change in a warmer future.

Our team aims to better understand the aerosol effects on Arctic cloud microphysics. We will address two central topics that have been highlighted by a series of recent review papers as highly important directions for future research:

1) When and to what degree do aerosol effects on clouds warm or cool the Arctic?
  a) What are the most important ways in which aerosols affect Arctic cloud droplets and ice particles?
  b) How do these cloud particle changes affect cloud properties across the Arctic?
2) In what ways will aerosol effects on cloud change in a future warmer, more humid Arctic?

We will use the millions of vertically resolved CloudSat/CALIPSO cloud observations over the Arctic as the primary data for characterizing cloud properties. We will also leverage data from AIRS satellite instrument, the FLEXPART aerosol model and MERRA-2 reanalysis to represent meteorological state and aerosol amount and type. Ground, ship, and aircraft data will fill in aerosol property details, a radiative transfer model will simulate the energy balance, and the CESM2 Earth system model will project future conditions. Our approach builds upon our previous work (Zamora et al. 2016, 2017, 2018; Tan & Storelvmo, 2019; Zamora & Kahn, 2020) to combine these data sources to account for co-varying meteorology and determine the likely aerosol effects on clouds. Ground- and aircraft-based evidence for different aerosol-related mechanisms will help isolate the causes for aerosol-related changes in cloud properties as observed by satellite, and discern to the extent possible the conditions under which different particle-related mechanisms dominate aerosol impacts on Arctic cloud microphysics. We will compare the satellite-based results with predicted effects from an Earth system model to help improve model parameterizations of aerosol-cloud interactions and to identify likely near-future changes to aerosol impacts on Arctic clouds.

This work contributes toward addressing some of the key science priorities identified in the most recent Decadal Survey and Intergovernmental Panel on Climate Change report. The work will enable a better understanding of the way aerosol-cloud interactions produce indirect radiative effects in the Arctic climate system, and it will help improve future aerosol freezing process parameterizations. As such, the work will provide new insights into the meteorological conditions that are most likely to be affected by aerosols, now and possibly in the future, and it will contribute to better forecasts of sea ice loss and cloud-related amplification of Arctic warming. It will also enable us to provide valuable information for ongoing and future large-scale field campaigns, such as NASA's upcoming 2024 ARCSIX aircraft campaign.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2021
NNH21ZDA001N-WATER21
A.34: Applied Sciences - Water Resources
Abstracts of Selected Proposals

The National Aeronautics and Space Administration (NASA) Science Mission Directorate solicited proposals for the Water Resources program within the Earth Science Division. The solicitation sought proposals to support the research, development, and deployment of applications using Earth observations for water resources management.

NASA received a total of 141 Step-1 and 67 Step-2 proposals and has selected 30 proposals for funding at this time. The total funding to be provided for these investigations is approximately $22 million over 3 years. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided. Co-investigators are not listed here.

Daniel Ames/Brigham Young University
Advancing the NASA GEOGloWS Toolbox for Regional Water Resources Management and Decision Support
21-WATER21-2-0088

The GEOGloWS initiative of the Group on Earth Observations (GEO) seeks to enable earth scientists to solve challenges associated with achieving Global Water Sustainability including improving water resources management by local and regional agencies worldwide   in support of the UN's Sustainable Development Goals (SDGs). Water management is a key component of the UN SDGs and is fundamental to food security, climate, health, and energy. Earth Observations (EO) provide an expanding resource to support water science and are vital achieving these goals.
As EO data increase in frequency, resolution, and availability, there is a growing need within the earth science community for flexible analysis tools that empower users and developers to explore, analyze, and model big data in a software-as-a-service cloud" environment. Brigham Young University (BYU), in collaboration with NASA, NOAA, and GEOGloWS partners, has developed a prototype open source software system called the GEOGloWS Toolbox to meet this need. The GEOGloWS Toolbox includes a collaborative web application development and management platform, the GEOGloWS App Store, and several modular web applications for discovering, visualizing, and analyzing EO and locally collected water data to support on-the-ground decision making for flood management, drought preparedness, food security, and energy planning. The GEOGloWS Toolbox components have attained an Application Readiness Level (ARL) of between 5 and 7 through previous NASA support and are now poised to be improved and elevated to advanced ARL levels through strategic collaboration with professional software engineering firms and a well-defined user community. Our stakeholder collaborations include established relationships with multiple water management agencies in South and Central America, Western Africa, and Central Asia as well as existing and new anticipated connections with regional and county water agencies in the

U.S., NASA's Western Water Applications Office (WWAO), the World Meteorological Organization (WMO), and the U.S. Agency for International Development (USAID).
The GEOGloWS Toolbox was developed to overcome the limitations of storage capacity, processing speed, transmission bandwidth, and platform dependency associated with desktop computing. User-friendly web applications   or web apps"   provide a medium for visualizing and conveying scientific data and concepts to stakeholders and decision makers. These web apps give access to complex computational back-end services, distributed data stores, modeling systems, and modelling workflows to support decision-making needs. Although the technical expertise required to develop web apps can be a barrier for earth science researchers, our GEOGloWS App Store, built on Tethys Platform, helps lower this barrier for new app development while providing decision-makers access to the existing tools already included in the GEOGloWS Toolbox.
Data are provided to the GEOGloWS Toolbox web apps from several data sources including the Global Earth Observation System of Systems (GEOSS) data broker, the European Centre for Medium-Range Weather Forecasts (ECMWF) Global Streamflow Services, WaterOneFlow data services from local government agencies, and from NASA Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs). Combining data from such a variety of data sources with their distinct and often incompatible file formats and data structures, into usable, functional, decision support tools for local and regional water managers is the hallmark of the GEOGloWS Toolbox effort. This proposal will build on the GEOGloWS Toolbox, increasing its components' ARL levels to 8 or 9.

Edward Beighley/Northeastern University
A Well Water Surveillance and Response System for North Carolina
21-WATER21-2-0032

Private wells are a prominent source of drinking water in North Carolina, with 1 in 4 residents relying on these wells for drinking water. A combination of lacking consumer awareness and minimal state/federal oversite has led to drinking water contamination problems in these systems, ultimately resulting in adverse health outcomes. At the 2015 NC Safe Water from Every Tap summit, participants recommended the development of an interactive mapping tool to enable local health departments to identify at-risk private wells to enable more targeted outreach and monitoring campaigns. Building on our exiting efforts and collaborations in NC, we are joining our project partners, the NC Department of Health and Human Services (DHHS), to deliver this recommendation. We will expand on our existing platform to integrate a multi-hazard well water surveillance and response system (WSRS) into DHHS's Environmental Health Section private water supply wells program. The project's strategy for user engagement builds on existing and past projects involving DHHS and the project team. To facilitate the implementation of the WSRS into DHHS decision-making activities full-time co-op students, working at DHHS, will support the project team in pilot testing, integration of the WSRS onto DHHS web platform, and assessment of WSRS performance in terms of value added.

WSRS will provide near real-time insights on stresses and pulses that are impacting private wells. The WSRS will provide the Project Partner with CAPABILITIES to: (i) Identify spatial-temporal fluctuations in well water quality associated with changes in environmental conditions (e.g., landcover, water availability); (ii) Enhance preparation strategies based on forecasted natural hazard (i.e., droughts, floods) extents/severities derived from existing global and national monitoring platforms; (iii) Optimize recovery target locations based on near real-time estimates of natural hazard (i.e., droughts, floods, fires) extents and severities; (iv) Generate insights on well water impacts from stresses and pulses (i.e., wells in areas with significant landcover changes; within/near hazard extents; accessing shallow water); (v) Evaluate county-level well construction data (e.g., type, depth, water quality) to inform future well data needs and limitations of current well water assessments.

The WSRS will enable health departments and the general public to detect and respond to stresses (changing environmental conditions) and pulses (natural hazards) that are impacting private wells. The WSRS will utilize a suite of satellite observations from (MODIS, VIIRS, LandSat, Sentinel, SMAP, TRMM/GPM, GRACE/GRACE-FO); NASA's LANCE system for near real-time access to MODIS/VIIRS derived data products; NOAA's National Water Model; and the multi-agency U.S. Drought Monitoring System.

To deliver and transition the WSRS to DHHS, the specific project OBJECTIVES are: (1) Generate geospatial data repository using remotely sensed data and integrate into our exiting vulnerability platform to launch the WSRS; (2) Characterize stressors and pulses driving spatial-temporal variability in well water quality; (3) Characterize how race and socioeconomic status influence well construction and water contamination susceptibility; and (4) Pilot test the WSRS with NC DHHS to assess value added and plan for statewide application.

The WSRS is being developing using results from roughly 50,000 existing NC well water samples for total coliform and/or E. coli. For overall performance assessment, we will use additional well water samples being collected by the state of NC (2,000 to 3,000/yr) and targeted well water samples collected through this study (50/yr); bringing the total number of samples used for performance assessment to roughly 10,000.

The project category is Category 2: Demonstration/Validation for Decision-Making. The WSRS is starting at ARL 3 and will be advanced to ARL 6 or 7 by the end of the project.

Paul Block/University of Wisconsin
From Forecasts to Action (F2A): Enabling Proactive Societal Responses to Hydrological Extremes

21-WATER21-2-0039

Climate and weather-related disasters are increasingly expensive and deadly, leading to $165 billion in direct losses and 50,000 causalities on average per year. Hydrologic catastrophes are especially devastating, accounting for over half of all disasters and global disaster victims. Trends of severe drought followed by flooding, as well as intensification of heavy rainfall due to climate change, are expected to continue well into the future.

Novel approaches are desperately needed for vulnerable communities subject to hydrologic and water-related crises. Post-disaster assistance is a crucial component of disaster relief, however the potential for reducing humanitarian impacts through anticipatory, pre-disaster planning and actions cannot be overstated. Short-term early warning systems are common, yet hydrologic forecasts at monthly or seasonal scales are relatively underused to guide preparatory actions, despite their potential value. Empirical evidence suggests that pre-disaster actions can reduce loss of life and property and result in cost savings for relief and governmental organizations. Such interventions often flow through water management systems, such as water distribution, reservoir operations, agriculture/irrigation, energy, sanitation, and treatment. This highlights the central role of water resources decision-making in hazard resilience.

The International Federation of the Red Cross has recently developed operational early action protocols (EAPs), conditioned on forecasts and risk analysis, outlining trigger criteria and identifying early actions. Concurrently, an extensive number of subseasonal-to-seasonal climate forecast products are now available which may be coupled with state-of-the-art land surface modeling frameworks to derive hydrologic forecasts. Thus there exists significant potential to tailor subseasonal-to-seasonal hydrologic forecast products, enhanced with Earth observations, to appropriately trigger a suite of water resources oriented preparedness actions and decisions across multiple lead times.

We propose to geographically focus on floods and droughts in Peru and Ethiopia. The Earth observations, forecasts, models, and alternative EAPs proposed here can provide managers with an improved set of tools to better protect lives and livelihoods, specifically a clear protocol for what action to take and when to trigger action.

Methods include integrating customized ensembles of subseasonal-to-seasonal meteorological forecasts (e.g. SubX, NMME) with a hydrologic forecast system to produce multi-scale hydro-climatic and streamflow ensemble forecasts; constructing alternative EAPs (e.g. triggers, actions) based on these ensemble forecasts to reflect the large and uncertain decision space; assimilating forecast products and characteristics into digital platforms; and projecting how disasters and predictability may change and implications for the design of future EAPs schemes. Earth observations play a critical role in these forecast-to-action efforts.

This project responds to the strong demand for large-scale, multi-sectoral hydrologic forecast and management tools to enable early preparedness for anticipated drought and flood extremes. We anticipate outcomes to represent a major step forward in anticipatory planning, not merely a marginal improvement. We expect to realize significant gains over existing preparedness and decision-making strategies regarding integration of earth observations; longer and more skillful prediction lead times; tailored prediction variables to inform distinct actions; an expansion of the suite of preparedness actions; refined triggers and probability of exceedance levels; superior protection for households and communities; and engaged and informed users.

Xiaobo Chao/The University of Mississippi
Integrating Remotely-Sensed Data and Numerical Models into a Web-Based Decision Support System for Agricultural Watershed and Water Quality Management
21-WATER21-2-0114

The water quality in a receiving waterbody is significantly influenced by upstream land use which may produce large amounts of sediment, nutrients, and other pollutants. Linking information of upland watersheds, channel networks, and receiving waterbodies is critical for developing an effective approach to pinpoint causes for water quality issues and target solutions to improve water resource management.

An online data and watershed/water quality modeling support system, Agricultural Integrated Management System (AIMS), has been developed by the National Center for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi (UM) in collaboration with the USDA Agricultural Research Service (ARS) National Sedimentation Laboratory (NSL). AIMS provides geospatial databases of any watershed in the United States, and it also provides input data for the Annualized Agricultural Non-point Source Pollution (AnnAGNPS) watershed model developed by USDA ARS to simulate runoff, nutrients and sediment loads exported from the watershed.

The proposed project will integrate remotely-sensed data and numerical models into AIMS for agricultural watershed and water quality management. In this project, AIMS will be improved by: 1) integrating remotely-sensed data, such as land use/land cover (LULC), soil moisture, soil temperature, evapotranspiration (ET) and vegetation indices into the system to provide more reliable input data for numerical models; 2) integrating the USDA AnnAGNPS watershed model, NCCHE CCHE1D channel network model and NCCHE CCHE-WQ water quality model to simulate the physical/chemical processes of different scales in the upland watershed, channel network and receiving waterbody systematically; 3) expanding the decision-support system (DSS) capabilities of AIMS to evaluate the response of water quality in a receiving waterbody to the upland pollutant loads, and analyze the effects of climate change induced temperature and precipitation variations on water quality.

Three main components are included in this improved AIMS: an enhanced AIMS database, a new AIMS integrated modeling system, and an enhanced AIMS-DSS. The

AIMS database with integrated remote sensing data will be used to provide geospatial, meteorological and land surface properties data for any watershed in the United States. The integrated modeling system will be used to simulate the flow, sediment and water quality constituents in upland watersheds, channel networks, as well as downstream receiving water body. Based on the simulation results, the AIMS-DSS will be applied to analyze the effects of pollutant loads from upland watersheds, LULC and climate change on the water quality of a waterbody.

Improvements in the AIMS technology will be validated and applied to several river basin/watersheds in Mississippi, including Beasley Lake Watershed (BLW), Goodwin Creek Watershed (GCW), Upper Pearl River Basin (UPRB). The project team will work closely with end users, include Mississippi Department of Environmental Quality (MDEQ), the Pearl River Valley Water Supply District (PRVWSD), ARS NSL, USGS, and other federal/state agencies to identify their requirements for WQ management and evaluate the decision-making activities implemented in those river basin and watersheds using the improved AIMS.

Wade Crow/USDA ARS
Applying Radar and Thermal Remote Sensing for Irrigation Decision Support in Vineyards and Almond Orchards
21-WATER21-2-0024

Irrigation plays a large and growing role in global agricultural production. However, the expanding water-use footprint for irrigated agriculture is increasingly coming into conflict with competing uses. To reduce the economic impact of recent drought, and risk associated with over-reliance on tenuous surface water resources, Californian producers of high-value perennial crops increasingly rely on groundwater extraction for irrigation. However, at current levels of pumping, there are grave concerns about the long-term sustainability of groundwater resources in the Central Valley of California. Reflecting this concern, California enacted the 2014 Sustainable Groundwater Management Act, which mandates that sustainable groundwater management plans be developed for critical agricultural basins. Achieving such sustainability in an economically viable way will require more efficient irrigation management and, therefore, improved techniques for monitoring crop-water loss (i.e., evapotranspiration; ET) and soil water availability (i.e., root-zone soil moisture, RZSM) at sub-field scales. In response, this Category II project proposal describes the innovative application of data assimilation, modelling, and remote sensing tools to operationally derive and deliver 30-m/daily RZSM and ET products to Californian almond and grape growers. ET and RZSM products will be operationally delivered as both an analysis (describing current conditions) and 7- to 14-day RZSM forecasts (assuming business-as-usual irrigation strategies). Resulting ET and RZSM products will be integrated into existing irrigation decision support systems maintained by our two targeted end users: E&J Gallo Winery (for grapes) and Olam Food Ingredients (for almonds). In addition to these two core end users, the project will leverage on-going collaborations with the National Grape Research Alliance and Almond Board of

California to promote the adoption of any realized advances within the broader California grape- and almond-growing communities.

Michael Durand/The Ohio State University
Adopting SWOT Measurements to Improve Decision Making for Currently Ungaged Basins: Decision support for Alaska
21-WATER21-2-0103

River discharge is fundamental to a wide range of decision-making activities, but is under-observed globally. Alaska exemplifies these issues, with stream gage density significantly less than in the conterminous United States. River remote sensing capabilities are evolving rapidly, and remote sensing is an obvious candidate technology to improve calculations of river discharge in under-gaged areas. A NASA Water Resources funded project (PI: Jack Eggleston) is currently exploring use of remote sensing measurements to observe river discharge in Alaska with key end users in the USGS Alaska Science Center, NOAA Alaska-Pacific River Forecast Center, Alaska Department of Transportation, USFWS, and Alaska Department of Fish and Game, and is currently in its final year. The project has successfully developed remote sensing datasets and software applications to enable a USGS hydrologic technician rating curve development workflow analogous to the workflow for in situ monitoring. Despite the success of that proposal, challenges precluding full-fledged adoption of remotely sensed streamgaging technology persist. The Surface Water and Ocean Topography (SWOT) satellite mission will launch in late 2022 and is designed to overcome the limitations in existing datasets. SWOT will record stage, width and slope measurements to a higher precision than currently possible. SWOT measurements are expected to enable discharge estimates with an accuracy of 10-15%, on average, when calibrated against in situ streamflow. Because SWOT temporal resolution improves at high latitudes, and because of Alaskan needs for streamflow data, Alaska is a perfect place for agencies to adopt remotely sensed discharge for decision making purposes.
In this project, we will partner directly with state and federal agencies to demonstrate adoption of SWOT measurements for both stage and discharge monitoring by agencies. Specifically, we will work with newly established remote-sensing streamgaging sites established as part of the previously mentioned Water Resources funded project, as well as work with end users to identify new sites in Alaska that are currently ungaged and could be adequately monitored by SWOT. We will create a workflow using CUAHSI's HydroShare to host discharge and stage data collected by partners and general users, and will leverage the SWOT discharge data processing software (Confluence") created by University of Massachusetts as well as USGS-developed software applications built to support rating curve development. Final discharge and stage time series, and field measurements will be hosted on HydroShare. This primary" discharge application (i.e., rating curve development and remote sensing discharge predictions) begins at Application Readiness Level 7, and is expected to advance to Level 8 by end of project. Along with the primary" discharge application, we will also create software services to

use SWOT data to support three secondary" decision-making applications: river forecasting, glacial dammed lake monitoring, and structure design.
Focusing on Alaskan agencies already interested in adopting SWOT data for monitoring stage and discharge is the perfect next step in transitioning from ongoing efforts to SWOT-powered efforts proposed here. The web-based service we create will enable any user anywhere to seamlessly estimate discharge, by uploading to HydroShare and using Confluence derived tools and publicly available SWOT data. We envision the focus on Alaska to serve as a flagship project to illustrate how NASA measurements can meet real needs by establishing virtual gages on high priority targets across the state, as well as illustrate the potential for adoption in other states, and other countries, globally. We will partner with the Brazil National Water Agency to expand and test capabilities for remote sensing of discharge in the Amazon basin to prove this potential, expanding the range of hydrogeographic settings that can be observed.

Joshua Fisher/Chapman University
Water Management for the State of New Mexico
21-WATER21-2-0143

This is a Category 3 proposal (Proven Application and Full Transition to Operational Partner) moving an established set of prototype hydrological remote sensing tools in use (ARL 7) and demand by the state operational water agency for New Mexico the Office of the State Engineer (NMOSE) into full operations and transition to the partner (ARL 9). NMOSE has the authority over the appropriation and distribution of all surface and groundwater in New Mexico, which is the only state that is in the top-10 driest and poorest states in the US.

The remote sensing water management system enables the State to use remotely sensed data for decision-making across water rights management and agriculture, forest and ecosystem monitoring, and drought response and mobilization. NMOSE accesses a unique 7.3 TB, 30+ year record of Landsat (5, 7, and 8)-based evapotranspiration and evaporative stress data developed and produced specifically for the State, including continuous near real time updates for the State, which are visualized in a dashboard co-designed by our technical team and NMOSE to match NMOSE and downstream NMOSE partner requirements. The data and tools save the State over hundreds of thousands of dollars per year and facilitate a more accurate and precise management of precious water resources.

The technical data system, as it currently stands, runs on NASA servers accessible only by the NASA technical team, and data are pushed to NMOSE storage and to individual NMOSE users by NASA. Here, we propose to transfer the technical system entirely to NMOSE, as required by NASA for full transition ARL 9 (Year 1). Moreover, we propose to conduct numerous in person and online trainings for the many NMOSE users, as well as complete thorough documentation and user guides (Year 2). Finally, we will conduct a quantitative and qualitative impact assessment of the system and develop extensions for potentially scaling the system to other states (Year 3). Years 2 and 3 will also provide stand-by technical support to ensure that the system is running smoothly for NMOSE, and if there are any other refinements that emerge.

Renato Frasson/Jet Propulsion Laboratory
Harmonizing Multiplatform Spaceborne Water Surface Observations to Support the US Army Corps of Engineers-Engineer Research and Development Center Water Intelligence Assessments
21-WATER21-2-0004

Timely information on global water availability is indispensable for the identification of water supply stressors with potential to cause social unrest. The US Army Corps of Engineers-Engineer Research and Development Center (ERDC) supports the National Geospatial-Intelligence Agency (NGA) by providing intelligence assessments of surface water stores (lakes) and fluxes (rivers). The current source of lake surface area observations is based on the dynamic surface water extent product by the U.S. Geological Survey, which leverages data collected with the MODerate resolution Imaging Spectroradiometer (MODIS). However, MODIS' resolution is not fine enough to track river surface area changes in time and space. Therefore, assessments on surface water fluxes through rivers are solely based on river routing model results. Because the intelligence is most valuable where in situ data is not easily accessible, either because such data is not collected or because of data sharing barriers, information derived from routing models tends to carry exceedingly large uncertainties.
Our project aims to fill the need for river observations by implementing a low latency river processing system that will make use of the water masks produced by the Observational Products for End-users from Remote sensing Analysis (OPERA) project. The OPERA project will initially process optical data collected by Sentinel 2 A/B and Landsat, generating observations at higher spatial resolution than MODIS, thus enabling the tracking of surface area change in rivers. While the OPERA water masks get us close to producing the data needed by our collaborators and ERDC and our end users, the NGA, a critical step is missing, the processing of raster-based water masks extracted from the optical imagery to produce time series of river widths along the river network used by our partners. By building the processing infrastructure needed to translate the water masks into actionable information, we will enable a complete assessment of basins' surface water stores and fluxes in areas where little to no in situ information is accessible and help our end user fulfill its mandate to produce worldwide assessment of water resources conditions, gaging the potential for famine, social unrest, or flooding. During the first two years, we will rely on data produced by OPERA, with the intent of using the third year to explore two promising Synthetic Aperture Radar (SAR) platforms: the Surface Water and Ocean Topography (SWOT) mission and the NASA-ISRO SAR (NISAR) mission.
Our project has three main goals defined to fill critical knowledge gaps:

G1: Create a framework for harmonizing observations from multiple satellites to enable high frequency observations of river width and surface area and integrate such observations to the ERDC's Water Intelligence system.
G2: Process state-of-the-art long-term surface water observations, e.g. Pekel et al. (2016) to facilitate the historical contextualization of river width.
G3: Prepare the system to ingest data produced by future missions, including the Surface Water and Ocean Topography mission (SWOT) and the NASA-ISRO SAR (NISAR) mission.
The proposed work is responsive to this solicitation's category 1 priority target to leverage multi-sensor technology with implications to the following encouraged topics: drought response, cascading threats to water supply, infrastructure assessment using multi-sensor technology. Our project will start at an Application Readiness Level (ARL) of 2 (definition of application concept), and end at ARL of 4 (verification of application integration) in this funding cycle.

Chandana Gangodagamage/University of Maryland
Tracking Fresh Water from Space for Congo River Water Resources Management and Water Related Decision Making
21-WATER21-2-0104

Managing freshwater is an essential requirement for healthy terrestrial life. Yet the knowledge of the change in the volume of water stored and flowing in the stream networks, wetland, and lakes is extremely poor in the Congo Basin, the second largest basin in the world, and the deepest river in the world. Better quantification and management of water resources are intimately linked to our ability to measure riverflow rates throughout the basin. This task is inherently challenging in the Congo basin geographically as it spans nine countries. Additionally, much of the Congo Basin is frequently under cloud cover, making many remote sensing techniques difficult to use for studying the basin and quantifying water resources. Further, security concerns and lack of transport infrastructure make the basin difficult to access for field campaigns, particularly its large central swamp named 'Cuvette Centrale' which is covered by dense rainforest and occupies the heart of the basin. Recent developments in satellite remote sensing, particularly the availability of radar and other microwave data, and the advancement of hydrological and land surface modeling and high-resolution streamflow routing promise more accurate quantification of water resources and better prediction of riverflow rates, floods, and droughts for water-related decision-making processes.
This proposed category 1 pilot project will be a collaboration between NASA, USGS, and the Congo Basin Water Resources Research Center (CRREBaC) at the University of Kinshasa. The CRREBaC will coordinate with the International Commission for Congo-Ubangi-Sangha basin (CICOS) and other basin-wide water resources organizations to advance the usage of streamflow discharges among basin stakeholders in the largely ungauged basin using our observations and model implementations from ARL 2 to ARL 4 by the end of the project. Our longer-term objective is to partner with the broader community involved in research and management of the Congo Basin to advance

multiple aspects of the CRREBaC Congo Basin Water Resource and Modeling Tool and associated decision-making in the basin.
We believe we are uniquely suited to provide and integrate microwave and other remote sensing data sets in a modeling framework to enable improved river flow rate estimates. Microwave-based remote sensing is critically important for the Congo Basin, to see through" the persistent cloud cover of the basin. Proposal team members are currently in the early stages of producing global river width measurements from ESA Sentinel-1 SAR data as part of a NASA ACCESS project, and a member of the team has unique expertise and long experience in deriving reservoir and river surface elevation measurements from microwave altimetry data. These are key inputs to improve the representation of river flow rates in the NASA LISHydro model, which the PI was instrumental in developing. The proposal team will also leverage the publicly available geoBAM model, developed by NASA investigators (funded by the NASA SWOT mission) specifically for enhancing river flow rate information using river height and width information.
In addition to advancing the ARL of the components and integrated system needed for improved river flow rate estimates of the Congo Basin, proposed activities include (1) working with our CRREBaC partners to better understand the Congo Basin Water Resource and Modeling Tool and how improved river flow rate information (and potentially other NASA products) can be integrated into the tool to ultimately can improve decision making, and (2) investigating partnerships with other stakeholders in the basin (for instance the Transborder Water Management in the Congo Basin project of the German Organization for International Cooperation, the Trans-African Hydro-Meteorological Observatory, the Congo Basin Catchment Information System project, on-going related NASA research, and USAID and World Bank interests and projects in the basin.

Auroop Ganguly/Northeastern University
Remote-Sensing Data Driven Artificial Intelligence for Precipitation-Nowcasting (RAIN)
21-WATER21-2-0052

Quantitative precipitation forecasting (QPF) at short time scales, while crucial for flash floods and river management, has remained challenging over the last several decades. However, recent advances in remote sensing (including NASA satellite data products) and machine learning, as well steady progress in hydrometeorology, suggest the possibility of a significant advance. This proposal focuses on flood preparedness and river basin management, at nowcasting time scales of hours to a few days, with a focus on the short term (0-6 hour). A key use-inspired hypothesis animating this proposal is that improved predictive understanding of hydrological and meteorological variables, with a comprehensive characterization of uncertainty, can lead to risk-informed decisions for water resources engineering. A related hypothesis is that new developments in Machine Learning (ML) and data-driven sciences, along with the availability of remotely sensed satellite data products in recent years, when systematically integrated with state-of-the-art scientific knowledge and existing data science methods, can lead to enhanced predictive understanding of hydrometeorology. The fundamental science question at the core of this proposal is as follows: What combinations of hydrometeorological variables and their spatiotemporal dependence structures produce hydrological extremes, especially heavy precipitation, and flash floods, and to what extent are these predictable and relevant for stakeholders? This science question corresponds to objectives H-1, coupling of the water and energy cycles", H-2, prediction of changes", and H4-c forecast short-term impacts more accurately" in the NASA's Decadal Survey. We will work closely with a set of diverse stakeholders for this Category 1 proposal, including a government agency, a non-profit and a private sector startup, to develop prototypical use cases related. This Category 1 proposal will explore how adaptations of spatiotemporal machine learning methods with the latest geostationary and processed satellite data from NASA can improve hydrological predictions and water resources risk assessments in a way that is relevant for stakeholders. The knowledge, data and software products generated from the project will be shared widely through peer-reviewed publications, NASA Earth eXchange (NEX), as well as open-access software portals. Our team of four PIs/Co-Is has been strategically selected to include researchers in remote sensing, hydrology, and machine learning from NASA's Ames, RTI International, and Northeastern University, along with three stakeholder organizations: Tennessee Valley Authority (TVA), US DOE's ORNL (with affiliations to NASA's ORNL DAAC), and risQ. The TVA, ORNL and risQ will bring to bear stakeholder and decision maker perspectives in the areas of river management, hydrological modeling, and urban resilience.

Huilin Gao/Texas A&M University
Satellite Assisted Operational Reservoir Evaporation Monitoring and Forecasts for the Western U.S.
21-WATER21-2-0115

Accurate reservoir evaporation estimates are essential for supporting the U.S. Bureau of Reclamation's water resources management mission. Currently, Reclamation and its partners largely rely on outdated evaporation data that lack accuracy and are not readily accessible to the public. In addition, while subseasonal to seasonal (S2S) evaporation forecasts can benefit water resources management, an operational product is not yet available. Producing reservoir evaporation estimates that are spatially and temporally consistent, based on the best available science, well documented, and readily accessible to end users, including local, state, and federal agencies, is a key priority for Reclamation. Therefore, the overall objectives of this project are: 1) to refine recently developed and validated evaporation algorithms to generate historical, near real-time, and forecasted evaporation estimates; 2) to develop an automated and operational software architecture that will link and integrate reservoir-specific property databases, place-based weather, and remote sensing datasets to estimate reservoir evaporation and explore options and requirements to disseminate results to the public via an application programming interface (API) and a web map user interface (UI); and 3) to conduct stakeholder engagement, outreach, and trainings across Reclamation offices and other federal agencies and state water resource agencies.

We propose to develop place-based operational reservoir evaporation estimates at a daily time step for all 287 Reclamation reservoirs and 188 Texas reservoirs using newly developed algorithms in combination with gridded weather and satellite remote sensing data. The reservoir evaporation monitoring and forecasting system (ReVap) will leverage NASA and NOAA weather products, S2S forecasts, and satellite observations for operational reservoir evaporation and forecasting, with automated data processing and delivery via an API and UI. This project will expand the validation of operational evaporation estimates using Reclamation and other in-situ micrometeorological evaporation estimates from previous and ongoing studies. We will conduct stakeholder outreach campaigns to increase awareness and understanding of reservoir evaporation information that will be made freely available. The project team includes scientists from Reclamation, Texas A&M University and the Desert Research Institute. The team has extensive basic and applied research experience related to reservoir evaporation algorithm development, remote sensing of reservoirs, in-situ data collection, UI and API software development, and collaboration experience with federal and state agencies, and local conservation districts.
The proposed concept aligns with Category 2: Demonstration/Validation for Decision-Making. This proposal directly addresses three highlighted priority topics - Adaptation to climate change impacts on water supply or water demand; Drought response; and Other topic areas relevant to water resources management." The current Application Readiness Level of this project is at an ARL of 3 as we have already established a proof-of-concept for the application and assessment of the feasibility and potential viability of this proposed work. The proposed deliverables include: 1) A reservoir evaporation database which includes archival and operational evaporation estimates that are continually updated; 2) A remotely sensed reservoir elevation, area, and storage variation product for locations where in-situ data are either incomplete or non-existent (at monthly and at 5-day time steps); 3) A reservoir evaporation forecast system which provides operational S2S evaporation ensemble forecasts; 4) A web-based geodatabase and data processing interface compatible with the Reclamation Information Sharing Environment (RISE); and 5) a series of outreach activities and trainings focused on the co-development and use of ReVap.

Mekonnen Gebremichael/University of California, Los Angeles
Satellite-Based Information System for Improved Crop Production in Gezira Scheme, Sudan
21-WATER21-2-0127

RATIONALE: A number of surface irrigation schemes in many countries are constrained by lack of cost-effective and reliable performance monitoring indicators, and this can be solved by employing remote sensing to improve the performance of surface irrigation schemes. The Gezira Irrigation Scheme in Sudan, which is the world's largest irrigation scheme under one management, similarly lacks irrigation performance monitoring system, resulting in the scheme's low water use efficiency and crop yield. Hence, there is a need for addressing this gap by developing reliable and near-real-time irrigation advisory service.

OBJECTIVE: To set up an operational irrigation advisory service for Gezira based on the utilization of satellite observations of crops with the goal of increasing water use efficiency and crop yield. The project will provide the following operational and high-resolution (30-m, every 5 days) data products and information: (1) potential crop evapotranspiration (ETc; crop water requirement), (2) actual evapotranspiration (ETa; amount of water consumed), (3) crop stress factor (ETa/ETc; a direct indicator of plant water stress), and (4) irrigation advice to farmers. Web portals will be developed to disseminate the spatio-temporal datasets to extension advisors, and other stakeholders. SMS service will be used to provide weekly information to farmers with personalized irrigation advice (that is, whether or not there is need to irrigate a field). The irrigation advice will also be sent to farmers with internet via telegram notification and web push notifications.

METHODOLOGY: Pillars of the methodology are: (1) use of geostationary satellite data over Africa (MSG/SEVIRI) and reanalysis model (ERA-5) output to calculate ETc based on the Slob-De Bruin algorithm, (2) use of harmonized Landsat and Sentinel-2 data, along with ERA-5 output and MSG/SEVIRI to calculate ETa based on SEBAL model, (3) estimation of crop water stress index using ETa and ETc products, (4) validation of models and components based on field validation data, and refining associated empirical constants, (5) development of a web-based irrigation advisory service software package that provides an automated end-to-end service, and (vi) development of service tools (web portal and SMS service) to communicate data products and irrigation advice to farmers and stakeholders.

IMPLEMENTATION: The irrigation advisory service will initially be implemented on pilot farms, and later extended to the entire Gezira scheme. We envision that the irrigation advisory service can be applied in other climatologically similar regions of the Nile Basin, such as, Egypt, South Sudan, and Ethiopia.

BENEFITS: The irrigation advisory service is expected to bring the following benefits, among others, increased water use efficiency, increased crop yield, and frequent irrigation advice via SMS regardless of farmers' location. We will measure the performance of the advisory service in terms of water use efficiency and crop yield collected from the pilot farms.

LOCAL WATER RESOURCE PARTNER: The work will be done in close collaboration with the Hydraulic Research Center (HRC) of the Sudanese Ministry of Irrigation and Water Resources. The HRC is responsible for developing irrigation water requirement and scheduling guidelines, and advising organizations directly involved in the operation of the Gezira scheme. The HRC researchers will also contribute their expertise during the development, implementation, follow-up evaluation, and sustainable use of the irrigation advisory service.

ALIGNMENT WITH SOLICITATION: By integrating a suite of satellite observations and solving practical water management issues in Africa, this project is aligned well with the objectives of the NASA Applied Sciences, and NASA WRA. The project fits into Category 2: Demonstration/validation for decision making, and addresses one of the WRA priority topics, irrigation water management.

Bin Guan/University of California, Los Angeles
Subseasonal-to-seasonal Prediction of Winter Precipitation: Determination from Innovative Spatiotemporal Analyses of Observations for Facilitating Improved Management of Water Resources in the Western U.S.
21-WATER21-2-0083

Prediction of winter precipitation in the western United States (U.S.) at subseasonal-to-seasonal (S2S) timescales has drawn considerable public/policy attention lately as the region becomes resource stressed. Rapid population and economic growth have led to significant land-use land-cover changes, and heightened demand for fresh water and energy. This environmental backdrop and the livelihood concerns of the population generate the demand for more accurate, longer-lead precipitation predictions, especially considering California's recent and frequently occurring drought conditions. On one hand, the skill of numerical weather prediction has remained marginal and stagnant on S2S timescales. On the other hand, sources of predictability premised on influential atmospheric, oceanic, and land-surface components with long-term memory offer unique avenues for improving S2S predictions and remain to be fully explored in light of recent advances in statistical and machine learning methods.

Exploring and demonstrating the utility of S2S prediction of winter precipitation to water management in the western U.S., rooted in scientific understanding of long-lead predictors (such as large-scale patterns of sea-surface temperature variability, the Madden-Julian oscillation, sudden stratospheric warming, etc.) and leveraging additional insights from recent advances in statistical and machine learning methods, is the subject of the proposed project. The specific objectives are to:

I. Design, validate, and implement a prediction model for western U.S. precipitation at S2S lead times based on novel statistical and machine learning applications;
II. Generate and communicate experimental S2S precipitation forecasts to the partner user organization (California Department of Water Resources) at the beginning and midway through each winter season per requirements of the user organization;
III. In this context, evaluate the representation of key sources of S2S predictive skill in currently operational weather/climate prediction models, and assess model strengths and shortcomings.

Objectives I and II will make use of data products from NASA and non-NASA Earth-observing satellites, in-situ observations, reanalyses, and other related data products, and will leverage an innovative statistical analysis technique, namely, the partial-least-squares regression, that identifies an optimal set of discrete predictors and generates forecasts while maximizing the variance explained by them. Additionally, the above objectives will utilize machine learning approaches (random forests, gradient boosted decision trees, and neural networks) to improve forecast performance by providing pathways for non-linear interactions between the identified predictors. Objective III will involve analysis of a suite of dynamical models being made available by the WWRP/THORPEX-WCRP Subseasonal-to-Seasonal Prediction Project, and the North American Multi-Model Ensemble (NMME) Project. These objectives will be undertaken in close partnership with the California Department of Water Resources, the water management agency of the State of California.

Faisal Hossain/University of Washington
Improved Reservoir Management with Simultaneous Monitoring of Water Quantity and Quality using Multiple Satellites, SWOT and RAT-WQ2
21-WATER21-2-0001

This project is driven by the need to develop user-ready solutions for six water agencies to address two key problems commonly faced in water management today. The first problem is the limited monitoring of reservoir water quantity (flux and storage) that undermines end-users from using water wisely. The second problem is the lack of simultaneous monitoring of water quantity and quality that prevents management decisions optimized for both quantitative need and ecosystem health. Applied economists have long argued that the key benefit of joint management of water quantity and quality is the ability to incorporate multiple trade-offs when allocating water among end-users into decision-making while safeguarding ecosystem health. We believe both problems can now be addressed using a wide array of remote sensing sensors in optical, infrared (near & thermal) and microwave (altimeter, SAR) wavelengths and advancements in cloud computing infrastructure and distributed modeling. It is timely for NASA Applied Science Program (ASP) to promote this capability of joint monitoring of water quality and quantity of reservoirs because of the planned Surface Water Ocean Topography (SWOT) mission (launch planned in 2022). SWOT is expected to improve water management and will be accompanied with a NASA ASP Early Adopter program that has been spearheaded by the PI since 2018.

The proposed project is a Category-2 project (Demonstration/Validation for decision-making). The objective is to raise the Application Readiness Level (ARL) for our identified and already-engaged six end-user agencies spanning water management, fisheries science and tribal communities in the USA and in developing regions. From the USA, we are engaged with Columbia River Inter-Tribal Fish Commission (CRITFC), NOAA Fisheries and Texas Water Development Board as end-user agencies. From the developing world, we are currently engaged with the national government water agencies of Egypt, Pakistan, Kerala (India) and Mekong nations (via Asian Disaster Preparedness Center). The project will raise ARL from 4 to 6-7 and be poised for acceleration to ARL9 at the end of the project for these end-user agencies. Our key decision support template is called Reservoir Assessment Tool-Water Quality & Quantity (RAT-WQ2). Specifically, the project will engage SWOT Early Adopters (EAs) that the PI has mentored closely since launch of the NASA EA program in 2018. By leveraging the community-driven SWOT Applications Landing Portal built by the PI's team, the project will accelerate success stories on SWOT's societal impact after its launch in 2022. The specific project objectives are:

1) Demonstrate to six end-user agencies and the broader water community the added value of decision making with simultaneous nowcast and hindcast of water quantity and water quality conditions of reservoirs using multiple satellites, SWOT and RAT-WQ2.
2) Prepare SWOT Early Adopters that have critical need for improved reservoir management to operationally use (ARL 9) SWOT lake and river data in RAT-WQ2 after SWOT's launch.

The project is a collaboration among five investigators representing the domains of water management/end-user engagement (Hossain), computational hydrology and SWOT discharge algorithm (Andreadis), fisheries sciences (Holtgrieve), geodetic remote sensing (Lee) and hydropower and reservoir management (Galelli). The project will support three PhD students with two additional students supplemented from NSF-Future Rivers Graduate training program at the University of Washington. The team has previously worked successfully together on inter-disciplinary freshwater issues using remote sensing and modeling for end-user water agencies.

Shruti Khadka Mishra/Sandia
NASA LIS Hydrologic Forecasts for Hydropower Optimization in the Upper Colorado Basin
21-WATER21-2-0043

Water in the Colorado River Basin (CRB) provides the needs of approximately 35-40 million people in seven states. The snow-fed rivers in the basin generate a number of ecosystem services that supports the economy of the western U.S., namely food and energy production, provide water for municipalities and industries, and recreational and cultural services. Because the quantity of ecosystem services depends on the allocation of water among multiple uses by the water resource managers of the region, accuracy in hydrologic inflow forecast has important economic implications. The forecast errors translate into inefficient allocation of water for hydropower generation, agricultural production, and ecological function. Improved accuracy in prediction of the western U.S. snowpack, which plays a critical role in regional hydroclimate and water supply, could influence the region's heavily water-dependent economy.
To that end, we propose to demonstrate, and implement NASA Land Information System (LIS) hydrologic forecast model coupled with water and hydroelectricity management models in an integrated assessment framework to support decisions of Bureau of Reclamation (Reclamation) and Western Area Power Administration (WAPA). Analyses will focus on the Green and Gunnison River Basins of the CRB. Also considered is the Upper Rio Grande Basin (URGB) that is connected to the CRB through the San Juan-Chama Project (an interbasin transfer). LIS is a flexible land surface modeling framework that has been developed with the goal of integrating satellite- and ground-based

observational data products and advanced land surface and hydrologic modeling techniques to produce optimal fields of hydrologic states and fluxes. The fine spatial modeling capability and dynamical resolution of LIS allows it to take advantage of the EOS-era observations, such as MODIS leaf area index, snow cover, and surface temperature, at their full resolution. Retrievals of soil moisture, skin temperature, snow water equivalent and snow cover, and terrestrial water storage have been assimilated into land surface models using LIS-DA. LIS output runoff forecasts at 1km and finer spatial resolutions, and at one-hour and finer temporal resolutions will be used to simulate WAPA's mid-term seasonal planning that includes WAPA's decisions regarding available hydropower offers to its customers and monthly firm power purchases in coordination with Reclamation. The objective function of the GTMax model is to maximize the economic value of hydropower while maintaining the release required by Reclamation. We will assess the changes in WAPA's requirements to buy short-term capacity and sell the excess to meet FES energy requests under current and LIS forecasting systems to assess the potential economic reduction in costs attributed to use of LIS. In a similar fashion water resource models in the URGB will be used to evaluate socioeconomic impacts from improved system operations due to LIS forecasts.

The societal benefits of using remote sensing observations to manage water resources in the CRB are expected to be significant. The value of accurately forecasted flow at short, medium, and longtime horizons quickly adds up in terms of increased value from day-ahead electricity market, increased efficiency in power purchase agreements, improved water deliveries while meeting environmental flow targets. Our effort leverages past and on-going NASA-sponsored activities that will be brought to bear on the CRB. Our results will demonstrate and quantify the value of NASA-supported datasets to the issues of critical importance to water resources management for hydropower generation and environmental performance. The results will improve the decisions of water resource managers and energy producers in the Basin. The information generated from this work will be useful to scientific communities as well as water resource managers, energy stakeholders, and decision makers in the western US.

Ayse Kilic/University of Nebraska
Accelerating Adoption of Irrigation Scheduling With Satellite-Based Precision Evapotranspiration from OpenET
21-WATER21-2-0066

The proposal is responsive to the program element: Agriculture related topics such as irrigation scheduling and management or soil moisture and crop yield," and is submitted as a Category 3 effort. Our objectives are to extend the data reach and impact of the national OpenET program by constructing conduits to infuse OpenET forecasted evapotranspiration (ET) data into the domains of operational irrigation scheduling system (ISS) applications. The ingestion and transformation will bolster the capabilities of irrigation systems to manage water on a field-by-field basis through the use of accurate spatial water consumption information. Six universities and one private company are combining efforts to infuse OpenET forecasts into three operational ISS in the western

US to improve accuracy of the applications and, as a result, more widespread use and acceptance. The result will be better efficiency in management of scarce irrigation water. OpenET (https://openetdata.org/) is a national consortium of six ET modeling groups involving NASA centers (ARC, JPL), other U.S. government agencies, several universities and research institutes. OpenET development is supported by large philanthropic organizations and NASA research and application programs to ensure sustained service as a national repository for historical, real-time and forecast spatial ET information. One of OpenET's products that is under development and testing is the provision of near-real-time (NRT) and forecast daily ET at 30 m resolution for 17 western states, and ultimately for the entire CONUS. This project's expansion and extensive testing of OpenET's ET and vegetation index (VI) data serving is in response to requests by OpenET stakeholders for ET information that is useful for ISS. NRT and forecast ET information is generated in OpenET from at least four independent surface energy balance models and one VI-based ET model to provide ensemble ET forecasts having enhanced data accuracy and robustness.

This project will work with the OpenET consortium to test and expand their application programming interfaces (API) for transfer of forecast data into the domains of operational ISS applications with training and substantial testing with field data. Our three operational ISS operations are CropManage, Irrigation Scheduler and Jain Logic. We will produce a data access and conduit system that enables easy and rapid access to and ingestion of OpenET data into ISS. We will assist the ISS with transforming their data flow and means of projecting water consumption needs to irrigation water users (farmers and managers). Those ISS operations have committed to ingest OpenET data into their systems and to conduct extensive field testing and accuracy assessment in collaboration with the CO-I's. The work is significant in that lack of field-scale spatial information and ready access to ET information is a current impediment and source of uncertainty to current ISS operations. We will provide feedback to OpenET to further evolve the ET forecasts. As part of the project, we will develop a new and simple "on-the-fly" ISS with low information requirements other than OpenET to serve as a broad back-stop. Our developments will pave the way for use of OpenET data by a number of additional ISS.

Lu Liang/University of North Texas
Multi-Source Imaging of Long-Term Irrigation Status and Type Changes in the Mississippi Alluvial Valley
21-WATER21-2-0054

The Mississippi Alluvial Valley (MAV) is a highly productive yet vulnerable agricultural region that encompasses nearly four million ha of irrigated croplands. The most critical water resource management issue is the severe groundwater depletion that is due to substantial increases in irrigated land. The use of water in agriculture is synergistically related to whether the land is irrigated and what irrigation practice the farm operator uses. Critically important to stakeholders and managers, a comprehensive assessment of long-term irrigation status and changes in irrigation system type in this high-impact agricultural hotspot is needed to understand and manage water resources.

The overarching goal of this proposal is to quantify the long-term irrigation status and system type changes in the MAV region for an advanced understanding of irrigation-induced water resource changes by integrating multi-source earth observation data, machine learning techniques, artificial intelligence, and cloud computing. To achieve this goal, we will integrate multi-source earth observation data, artificial intelligence techniques, cloud computing, and test the method's scalability, with three objectives:

Objective 1: Develop an annual field boundary and sub-field irrigation management boundary dataset and a quality-controlled, annotated image database CropNet for remote sensing solutions. We will generate an annual dataset that contains the delineated boundaries of relatively stable fields and the further divided sub-field irrigation management units using a two-level mapping strategy. We will also create a benchmark image database by visually annotating irrigation status and types on very-high-resolution imagery to provide high-quality training samples for classification.

Objective 2: Use multi-source land imaging strategies to quantify annual changes and long-term trends in the annual irrigation status of agricultural fields for the period 2000-2020. We will enhance recently developed techniques to perform continuous change detection on irrigation status from dense stacks of Landsat and Sentinel. Improvements will be centered on conducting classification at the field level and training the algorithm with CropNet ground truth data to achieve better performance.

Objective 3: Apply deep-learning methods to assess irrigation types and their changes for the period 2000-2020. We will couple deep-learning analysis of 1-m NAIP imagery with CropNet training samples to quantify the spatial-temporal pattern of irrigation practice. We will apply the developed methods to detect similar changes in different geographic regions and apply the methods to imagery acquired from NASA Commercial SmallSat Data Acquisition Program.

Our aims are in direct response to the NASA ROSES 2021 A.34 Earth Science Applications: Water Recourses solicitation. Completion of these aims will deliver insight into the processing of multi-source remote sensing data through state-of-art deep learning techniques and time-series analysis. By partnering with stakeholders such as USGS and OpenET team, this project will enhance the baseline performance of water use estimates in a dynamic and hard-to-estimate region. Partnering with the NRCS will enable an assessment and potential reprioritization of their outreach and conservation incentive efforts. It will contribute to water resources research through the new remote sensing mapping paradigm and data-intensive research for an improved understanding of the long-term historical dynamics of irrigation management on water conservation at a broad scale.

Christoph Nolte/Boston University

LakeSense: A Portal for Nationwide Remotely Sensed Lake Water Quality Indicators to Inform Benefit-Cost Analyses for Federal and State-Level Rulemaking 21-WATER21-2-0027

This project will develop the prototype of LakeSense: an automated data pipeline that derives high-quality time series of lake water quality indicators (LWQI) from remote sensing data for lakes e5 hectares in the contiguous United States (CONUS) and that makes the data publicly accessible through an interactive web portal. Reliable, consistent, temporally dense, and nationally representative LWQI time series are necessary to close known information gaps in decision support tools developed by the U.S. Environmental Protection Agency (US-EPA) to support federal and state-level water resource rulemaking. Existing tools that (i) predict policy-induced changes in water quality and (ii) estimate the costs and benefits of such changes at regional and national scales currently do not explicitly represent lake-specific water quality processes and benefits. The development of reliable and nationally representative models for lake water quality prediction and valuation is currently severely constrained by the absence of LWQI datasets that are reliable, consistent, temporally dense, and nationally representative. LakeSense will combine imagery from Sentinel 2A-B, Landsat 8, and the ECOSTRESS mission to develop high-quality time series of LWQI that are remotely observable and known to be valued by lake users: water clarity, turbidity, color, algal blooms, and temperature. The LakeSense pipeline will automatize the processing of the imagery using an adaptive procedure that involves: (i) imagery acquisition, (ii) optimal atmospheric correction of the imagery using state-of-the-art methods for aquatic systems to retrieve lake-water remote-sensing reflectance spectra, and (iii) the implementation of reliable algorithms to retrieve LWQI from these spectra. We will develop and calibrate the adaptive procedure based on a nationwide sample of 100-120 lakes with rich in-situ LWQI data that are purposefully selected to represent the wide variety of lakes in CONUS (lake size, climate, region, water quality conditions and trends). Upon successful calibration, the LakeSense prototype will be deployed to generate remotely sensed LWQI (RS-LWQI) time series for all resolvable lakes e5 hectares in two pilot regions with large numbers of lakes, lake users, and in-situ measurements (Minnesota-Wisconsin, Florida-Georgia-South Carolina) to prove scalability and facilitate data scrutiny. The resulting data will be made available via an interactive web portal that allows users to observe lake-specific conditions and trends and to download data in bulk.

To facilitate integration into decision making, the project team will conduct hedonic valuation studies to (i) establish whether RS-LWQI time series generated by LakeSense are a reliable substitute for in-situ LWQI data in water quality valuation, and to (ii) establish whether the enhanced spatial and temporal coverage of RS-LQWI data enhances the transferability of estimated relationships between changes in lake water quality and property prices across diverse settings. In collaboration with partners at US-EPA's National Center for Environmental Economics, we will develop the prototype of a tool to estimate effects of (observed and simulated) changes to lake water quality on property values, laying the foundation for an operational integration of RS-LWQI data into US-EPA's valuation and decision support tools.

Responsiveness: this project develops innovative solutions in satellite-based quality monitoring of optically complex waters. It synergistically integrates multiple sources of

Earth observations and information, specifically satellite, in-situ, socioeconomic data, and operational models, and lays a novel data foundation for seasonal-to-subseasonal water resource forecasting. The inter-disciplinary team combines expertise in aquatic remote sensing, environmental economics, large-scale computing, and spatial data science, and is led by two early-career scientists.

Julie Padowski/Washington State University
Aiding Water Managers through a Predictive Ecohydrological Modeling tool for Assessing Disturbance-Induced Runoff and Water Quality Challenges
21-WATER21-2-0031

Wildfire events will become more common as climate changes and are a major cause of increased erosion, runoff, ash, suspended sediment, and debris flows in forested watersheds. An increased risk of wildfire is of particular concern to municipal drinking water utilities in the Pacific Northwest (USA) that rely on forested watersheds as high-quality water sources. Yet, these utility managers have little information to plan for, or capacity to respond to, water quality threats when fires do occur, as evidenced by the 2020 wildfires in western Oregon that burned more than 1 million acres and damaged more than 50 drinking water systems.
This Category 2 proposal seeks to provide water utility managers with a decision-support tool that will make it possible to incorporate Earth observation (EO) data into a predictive modeling framework that can directly aid in management decisions that impact millions of water customers. Our project will integrate two existing modeling efforts- one that predicts shorter-term responses to fire including changes in post-fire erosion, ash transport, and runoff and the other that models long-term fire regime trends, vegetation regrowth, and nitrogen leaching- into an easy-to-use decision support tool (WEPP-PUFF). This tool will be able to simulate watershed processes and feedbacks, including changes to water quality, with wildfire activity.
We will work with a team of nine end-user partners to guide tool development and promote end-user adoption. With this tool, water managers will be able to use EO data to map likely fire risk scenarios in their watershed, generate information about potential post-fire water quality threats, and explore the impact of different pre- or post-fire mitigation strategies. Through model-informed decision-making ,water utilities will have the information they need to more efficiently and effectively reduce the negative impacts of fire on water quality potentially saving customers and agencies millions of dollars in damage control and response.

Adnan Rajib/Texas A&M University
HydroFlame: An Earth Observation-Integrated Hydrologic Modeling Framework for Post-Wildfire Water Resource Management

21-WATER21-2-0118

This Category 2 project aims to establish an innovative web-based framework HydroFlame" for post-fire water resource management across large river basin scales. Using the 49,500 sq. km Clark Fork Basin in Montana, United States for prototype application, this project will equip end-users with an operational framework that can perform four tasks: (i) instantaneous download of Earth observations from multiple open sources; (ii) post-processing fire disturbance indicators and their seamless integration into a hydrologic model Soil and Water Assessment Tool (SWAT); (iii) simulation of streamflow and sediment transport; and (iv) interactive scenario runs and input-output data visualization through a map interface.

HydroFlame will automatically extract Landsat Burned Area extents for a user-defined time-period. Using geostatistical models, it will estimate fire-induced changes to LAI, ET, and soil moisture considering MODIS MCD15A3H, MOD16A2, and SMAP-based Crop-CASMA datasets. These burn area-representative LAI, ET, and soil moisture estimates will be the main indicators of fire disturbance in the Clark Fork SWAT model. The framework will also integrate TerraClimate future climate projections. For instant evaluation of simulated scenarios, the framework will be dynamically coupled with USGS data repositories. The prototype framework will be deployed through the Google Earth Engine and NSF-supported XSEDE cloud computing platform.

To quantify improvements in end-users' decision-making activity, this project will demonstrate four application areas: (i) predict streamflow and sediment load at actionable post-fire time-scales, e.g., immediately (30 days, considering data latency) and over the long-term (wet period following a drought spell, seasons, years) after fire event(s); (ii) compare before- and after-fire scenarios to identify priority areas that may need management interventions for post-fire streamflow recovery; (iii) quantify the uncertainty in traditional post-fire streamflow predictions; and (iv) simulate the compound impact of recurring wildfire events and projected future drought severity on surface water storage. With this new information, HydroFlame will offer consolidated fire and water analyses via a single user-friendly interface, a well-informed, data-driven response mechanism to post-fire flood and debris flow hazards, insights on the true extent of climate change impacts considering the fire-water interactions, and a novel planning tool to support water security and environmental justice in rural western United States communities. These benefits can be reproduced for any basin once HydroFlame becomes fully operational.

The investigators have extensively tested the conceptual components of HydroFlame (ARL 3). During a 3-year period, this project will make the prototype HydroFlame operational, and enable its integration into the end-users' workflow through targeted dissemination and training efforts (ARL 7). The financial and logistic support already acquired through Co-I organizations will enable HydroFlame's continued evaluation, maintenance, and transition up to two years after project completion. Importantly, the end-user partners/Co-Is involved in this project, including the Montana Department of Natural Resources and Conservation, Army Corps of Engineers-Seattle District, Missoula

County of Montana, The Clark Fork Coalition, and The Nature Conservancy, have committed to coordinating an interagency pathway for full-scale operationalization, potential expansion, and sustained adoption of HydroFlame.

Despite research demonstrating that Earth observations can be used to assess the impact of fire disturbances on water quantity and quality, this kind of research has not yet been operationalized nor been accessible to water resource managers. The new end-to-end data-to-decision information flow proposed here will be the first to address this critical need.

Matthew Reiter/PRBO Conservation Science
From 2D-3D: Leveraging Space-Based Sensors to Track Water Depth and Volume in Wetlands of the Central Valley of California
21-WATER21-2-0137

Water is a limited resource throughout the arid western portion of the United States, and has become increasingly managed over the last 100 years through extensive systems of reservoirs and water conveyance structures to support the needs of human communities, agriculture, and ecosystems. Model projections suggest that water may become even more limited as the result of climate change and increasing frequency and severity of drought are pushing water management programs to their limits. The Central Valley of California is a semi-arid region, larger than nine other U.S. states, that is a nexus for water resources and epitomizes the challenges facing water systems in the West. Balancing multiple needs with water management in the Central Valley, particularly during recent extreme droughts, requires data with high spatio-temporal resolution and extent for optimization that only satellite-based Earth observations can provide. Effectively quantifying water use has become particularly relevant with the passing of the Sustainable Groundwater Management Act (SGMA) which requires all users of groundwater in California to develop Groundwater Sustainability Agencies (GSAs) which in turn complete Groundwater Sustainability Plans (GSPs) for a specific groundwater basin which defines how water, specifically groundwater, will be managed to achieve sustainably over the next 20 years. The development of GSPs has led to an increase in the development of water budgets. Managed wetlands, an essential component of water use, have a paucity of data with which to populate water budget models. Although satellite remote sensing has been shown to effectively track surface water inundation in the Central Valley across different wetland and flooded agriculture types, a critical missing piece remains - water depth. We propose a Category 1 project that will take a multi-sensor, multi-scale approach to assess water resources, using a combination of ground, UAV, and satellite data. This project will test the sufficiency of multiple remote sensing datasets and demonstrate the utility of NASA and other Earth observations to estimate water depth and volume in order to guide managers developing wetland water budgets for decision-making and monitoring as part of GSPs. We will take advantage of existing in situ data combined with satellite-based sensors to develop and deploy a methodology for tracking water depth and volumes in managed wetlands of the

Central Valley to inform the parameterization of wetland water budgets. Specifically, we will: (1) test the sensitivity of water volume estimates in managed wetlands to different sources of space-based topography / DEM data (e.g., ICESat-2; TanDEM-X; WorldView photogrammetry) using UAV- and ground-based data; (2) develop a repeatable workflow to remotely derive and track water depth and volume in managed wetlands; and (3) work with GSAs to incorporate these new data into their decision-making and monitoring. We will use multiple radar-based satellite sensors to test this approach, including the Sentinel-1 Interferometry Synthetic Aperture Radar as well as the soon to be launched NASA-ISRO Synthetic Aperture Radar. Point Blue recently developed a Wetland Water Budget Tool (WWBT) and is testing it in partnership with wetland water managers from the Grasslands GSA. We will use the WWBT to test the sensitivity of changes in water depth measurements on overall water budgets. The WWBT will serve as the foundation for evaluating the science and prototype workflow developed in the proposed project. In addition to supporting water management decisions and monitoring in GSPs that will be the foundation for sustainable groundwater over the next 20 years in the Central Valley, this project will address important questions from the ESAS 2017 Decadal Survey such as how changes in land management will affect water use and how water use varies across extreme events particularly drought and flood.

Karl Rittger/University of California, Santa Barbara
Advancing Domestic and International Water Management Capabilities with a Global Daily Snow Cover and Albedo Product
21-WATER21-2-0096

Water managers need accurate observations of snow cover and albedo to make decisions for a diverse set of applications. Remotely sensed snow cover and albedo products that are currently available do not meet operational requirements for several reasons. First, the most widely available snow products from MODIS use an index algorithm developed in 1989 that employs two spectral bands, one in a visible wavelength and one in the shortwave-infrared, which together provide limited information to estimate fractional coverage or snow albedo. Second, cloud cover is difficult to discriminate from snow and causes data gaps that can be filled using techniques that rely on accurate cloud masking. Third, MODIS is an elderly system that continues to operate well beyond its design life, and the successor to MODIS, the Visible Infrared Imaging Radiometer Suite (VIIRS), do not gap-fill the snow cover product and there is no snow albedo product. Fourth, standard snow cover and snow albedo products do not account for off-nadir observations that introduce uncertainty and additional data gaps. Fifth, no widely distributed product accounts for the darkening of snow caused by light absorbing particles and their impact on snow albedo.

The NASA Jet Propulsion Laboratory (JPL) Snow Data System (SnowDS) currently creates and hosts snow cover products from MODIS made with algorithms using all seven visible through shortwave-infrared spectral bands. However, these products still suffer from some of the issues described above. As SnowDS is not an operational entity, users regularly report intermittent outages and issues. Such interruptions compromise reliable data availability for integrating these remote sensing products into near real-time decisions. There is no outward facing interface to request and access data. Critically, financial support for continued processing will be discontinued and there is no planned transition to process VIIRS measurements. As a result, many users rely on coarser resolution snow maps from the Interactive Multisensor Snow and Ice Mapping System (IMS) that requires operator interpretation. The resulting operational bottleneck limits practical use of remotely sensed snow products.

For this proposed project, we have partnered with snow remote sensing end users who serve diverse needs of national and international water resource decision makers. With their guidance, we will create and provide daily gap-filled snow cover and snow albedo, including impacts of light absorbing particles. The products will account for off-nadir views, snow under the forest canopy, and use cloud filtering techniques not employed in existing products. Using algorithms shown to perform consistently across sensors specifically Landsat 8/9, MODIS, and VIIRS we will process the historical daily record and produce data in near real-time with a sub-daily latency period for both MODIS Terra and VIIRS Suomi. This project will complete the transition of the data processing, archiving, and distribution from JPL to the National Snow and Ice Data Center (NSIDC). The transition will ensure the continued production of snow cover and snow albedo products for the lifetime of these sensors.

Our partner organizations are decision makers poised to directly benefit from accurate and timely snow cover and snow albedo information. These collaborators are globally distributed in North America, New Zealand, the Andes, High-Mountain Asia, and the European Alps. The historical and near real-time snow and albedo products will enhance decision-making processes to better inform stakeholders in a range of applications, including streamflow forecasting, agriculture, and water futures planning. An advisory board composed of science, applications, and operations experts will help guide decisions by the investigator team during the project to provide the best outcome for NASA, collaborators, and stakeholders.

Matthew Ross/Colorado State University
Real-Time Satellite and Sensor Fusion for Predicting and Understanding Water Quality Threats to Water Supply Networks of Northern Colorado
21-WATER21-2-0038

Rivers, lakes, and reservoirs   together inland waters"   are dynamic systems connected in hierarchical and spatially heterogeneous networks. Managing these critical water supply systems requires observation platforms that can match their dynamic and connected nature. Remote sensing is (and has been) a promising tool to enable these new insights because satellite data can yield repeated, consistent, simultaneous, whole-network observations of water quantity and quality across most large rivers and lakes (Fig. 1). Despite the long history of work on estimating water quality from imagery, general use of remote sensing of inland waters for scientific discovery and decision support systems has been frustratingly limited. Though many research groups use remote sensing of inland waters as a foundational tool for understanding environmental change at large spatial scales, far more inland water scientists and mangers would benefit from remote sensing.

The objective of this proposal is to overcome historic barriers that prevent water resources managers from using remote sensing to more deeply integrate these datasets into decision making process of water resource management in Northern Colorado (Fig. 1). To accomplish this task, I will continue to build on existing, robust collaborations with all of the major water suppliers and utilities in the region including: Northern Water, the Cities of Fort Collins, Greeley, Thornton, and the Solidier Canyon Water Authority. Together these water suppliers help control the water supply to over 2 million residents in Northern Colorado. However, like most of the Western United States, our water supplies are dually threatened by impacts to water quantity and quality. Intensifying drought, wildfires, land use change, and other impacts have historically been studied primarily for their impacts to water quantity, however, water suppliers of Northern Colorado, and the Arid West more generally, increasingly recognize that water quality is rapidly changing as well. Harmful algae blooms, increased sedimentation of supply reservoirs and highly varying concentrations of dissolved organic carbon (DOC), can all interfere with a water suppliers ability to provide clean drinking water to their customers. Here, I propose a project to use machine learning, remote sensing, and live-streaming sensors to build a system that predicts water quality at seasonal and weekly timescales. This work will build on my decade of experience using this kind of data, and deeply leverage existing partnerships with local water suppliers and similar initiatives in the USGS remote sensing of water and data science branches. The format of the proposal follows the guidance for the Step-1 Proposals.

Tirthankar Roy/University of Nebraska-Lincoln
Enhancing the Hydrological Drought Monitoring Capability of the US Drought Monitor
21-WATER21-2-0135

Droughts are considered to be the most detrimental natural hazard in recent decades, impacting a variety of sectors spanning society, economy, environment, and health. Factors such as the unclear onset and termination, non-structural damage, large spatiotemporal spans, etc., complicate drought assessment. The US Drought Monitor (USDM) is the state-of-the-art drought information system, which produces weekly drought maps for the entire US. The monitor captures current conditions using a percentile ranking method and a convergence of evidence" approach, which allows for multiple indicators of the hydrologic system to be integrated into the final map. The current USDM system, with some exceptions, is primarily based on inputs from unmanaged or natural systems and land surface conditions.

In this proposed research, we will significantly enhance the hydrological drought monitoring capability of the USDM by incorporating the impacts of improved terrestrial hydrologic process representations and streamflow hydrologic response. Streamflow will be realized through the NASA LIS-supported Land Surface Models (LSMs), which are capable of assimilating remote sensing surface observations, coupled to the WRF-Hydro hydrologic model that supports managed streamflow through the assimilation of USGS streamflow (LIS/WRF-Hydro). This will be a novel and impactful addition to the present USDM since the current system, with some exceptions, is primarily based on inputs from unmanaged or natural systems at point locations and land surface conditions. The proposed LIS/WRF-Hydro system will also incorporate the contributions of groundwater to the system to get a more realistic representation of the drought events. The proposed system will both be validated for regional drought events and a CONUS-wide implementation as well as in a prototype environment in which the value of the addition to the decision-making process may be evaluated. The hydrological responses of the managed systems will be derived from LIS/WRF-Hydro, where a wide range of observations, including several from NASA sources (e.g., IMERG, SMAP), will be assimilated using NASA's Land Information System (LIS). Thus, the proposed work will synergistically combine satellite datasets with in-situ observations.

The enhancement to the USDM's hydrological drought monitoring, which builds upon multiple currently operational capabilities, will thus combine NASA's observation datasets with modeling capabilities and leverage feedback from the stakeholder base and user community of the UDSM. The NDMC will use social science focus group and survey methods to gather data from key stakeholders (USDM listserv, which includes the USDM authors as well) about the utility of the product for operational drought monitoring. This stakeholder community includes 450 individuals and groups that either directly or indirectly participate in the weekly production of the USDM. Thus, the proposed research falls under Category 2 to reach ARL 6.

Kimberly Slinski/University of Maryland, College Park
Earth Observation-Based Monitoring and Forecasting of Rangeland Water Resources
21-WATER21-2-0098

This project partners with the United States Agency for International Development's (USAID) Famine Early Warning Systems Network (FEWS NET, https://fews.net/) to develop new capabilities for monitoring and forecasting water availability in rangeland ponds in East and West Africa using satellite remote sensing data. The overarching goal of the new system is to provide timely data on rangeland water availability, increasing the operational capacity of FEWS NET to provide early warning of food insecurity in pastoral communities and, subsequently, the capacity of government and relief agencies to take appropriate actions to mitigate the impact of drought events. Specifically, this project develops an Earth Observation (EO) and Earth system model-based Rangelands Water Point Monitoring and Forecasting System (Rangelands Water MFS) covering food-insecure areas of East and West Africa. The proposed work consists of four tasks:

Task 1: EO-based water point classification: Employ machine learning methods using high-resolution synthetic aperture radar (SAR) and multispectral data (Landsat, Sentinel 1 & 2, NISAR) to identify rangeland water points and generate an observation-based time series of water point area.

Task 2: Water balance model development, calibration, and validation: Simulate water availability at each water point with a satellite data-driven water balance model. The model will be forced using satellite- and Earth systems model-based meteorological data, and calibrated using the observation-based time series.

Task 3: Water stress forecasts: Forecast water availability at each water point using the calibrated model driven by bias-corrected spatially downscaled meteorological forecasts at the weather, sub-seasonal, and seasonal scales.

Task 4: Stakeholder engagement: Engage stakeholders at critical points in the project cycle, including needs assessment, verification of new water points, system pilot testing, and during the development of the web interface. This task also includes stakeholder training on the final Rangelands Water MFS and associated web-based outputs to ensure their full integration into stakeholder water stress and food security assessment and prediction workflows.

This work will significantly expand and improve FEWS NET's existing Water Point Viewer, increasing the locations monitored and improving overall model physics. This will lead to development of the most substantial contribution of this work: new predictive capabilities for forecasting water point stress. Predictive capabilities are needed to provide early warning of drought impacts on water availability in pastoral communities. Existing climate services in East and West Africa currently lack this capacity. The proposed system will fill this gap, forecasting water point stress at weather, sub-seasonal, and seasonal time scales. The advanced data streams provided by the new Rangelands Water MFS will allow disaster response agencies to better plan for and implement mitigating actions, including ensuring access to alternate water supplies through water trucking or increased maintenance and repair of groundwater pumping stations. Mitigating actions also include limiting herd size to a number that can be supported by rangeland conditions (de-stocking). These actions are costly to implement. Therefore, good data on current and forecasted conditions are essential to the decision makers responsible for implementing drought-response actions.

The proposed work is submitted to the NASA Water Resources Program as a Category 2 project and is directly relevant to four Category 2 primary topics: 1) adaptation to climate change impacts on water supply or water demand, 2) drought response, 3) infrastructure assessment and planning, and 4) agriculture-related topics such as irrigation scheduling and management or soil.

Eric Small/University of Colorado, Boulder

Development of a Colorado-Wide Data Assimilation System to Provide Snow Water Equivalent Data and Water Supply Forecasts to Water Managers
21-WATER21-2-0094

Colorado water managers rely on information about mountain snow water equivalent (SWE) and water supply forecasts (WSF) to balance the demands of reservoir operations, irrigation, municipal use, and recreational interests. However, the SWE and WSF information required is either not available or not adequately synthesized to inform decisions. The water management challenge is thus to generate and distribute the information water managers need to make better operational decisions based on the conditions of Colorado's snowpack and forecasted streamflow. We will develop a Colorado-wide SWE and WSF product that leverages the strengths of available Earth observations and state-of-the-art tools. The products will be available through a decision support system (DSS) that will enable water managers to (1) compare the new SWE and WSF products with baseline datasets; and (2) make decisions considering both the conditions and uncertainty of hydrologic states. The project team consists of scientists from academia and Lynker   a company that develops hydroinformative products to integrate data in modern decision supporting toolkits. Together, the team has the expertise required to integrate Earth observations, WSF models, and decision support, guided by collaborations with water managers partners.

This is a category 1 proposal. The starting application readiness level is ARL 2, although some components are at ARL 3. The proposed ending ARL is 4. The effort will expand an existing data assimilation (DA) system that blends Earth observation to yield a spatially and temporally complete characterization of SWE with uncertainty. The proposed application system will integrate existing NASA Earth observations (MODIS snow cover area and past JPL ASO airborne lidar snow depth) with non-NASA airborne and ground-based datasets. Thus, the effort relates to the category 1 priority topic Approaches multi-sensor and multi-scale assessments of water resources". The DA system will provide SWE estimates to a machine learning algorithm (Long Short Term Memory, LSTM) to produce daily water supply forecasts throughout the melt season. Thus, the effort relates to the category 1 priority topics of application of machine learning" and seasonal-to-subseasonal water resource forecasting". WSFs will include uncertainty from (1) SWE estimates via DA; and (2) possible future weather, as informed by an ensemble of historical conditions. The WSFs will be generated for all active USGS stream gauges in Colorado, which monitor basins ranging in area from 100 to > 10,000 km2.

The SWE and WSF products will be distributed through a centralized DSS. The DSS will be developed in collaboration with three partners that span the diversity of stakeholders in Colorado: a large municipal supplier, an irrigation/flood control agency, and a recreational entity. This component of the project will be completed by scientists from Lynker. Developing the DSS will leverage an ongoing statewide effort led by Lynker to more completely characterize the decision-making process used by water resource managers, specifically as it relates to snowpack information.

We will address two questions: (1) How does the use of various Earth observations, integrated into a DA and machine learning system, change the characteristics and uncertainty of SWE and WSF, compared to baseline datasets? (2) How do SWE and WSF based on assimilated Earth observations influence water management decisions, compared to decisions informed by currently-used baseline datasets? We will sequentially reconfigure the application system to include different combinations of Earth observations to quantify how the use of each type of observation affects SWE and WSF, using retrospective analyses for water years 2010-2021. Then, the SWE and WSF products generated using different combinations of Earth observations will be queried via the DSS to evaluate how this would influence decision-making by the partner organizations.

Marouane Temimi/Stevens Institute of Technology
Synergistic Use of Multisatellite River Ice Remote Sensing and Hydraulic Modeling to Enhance Operational Streamflow Forecast in Northern Watersheds
21-WATER21-2-0059

There are six northern River Forecast Centers (RFCs) out of the total 13 RFCs across the USA under NOAA National Weather Service (NWS) that are impacted by river ice every year which represents a considerable fraction of the US territory that requires accurate mapping and monitoring of river ice dynamics to forecast streamflow accurately. The current streamflow forecast models used regionally by NWS RFCs and the CONUS-wide National Water Model (NWM) still lack this capability and operationally simulate streamflow in northern watersheds without considering the effect of ice. In addition, in the absence of an operational river ice mapping system, forecasters can only rely on collected local in situ observations or visual inspection of satellite data.
The overarching goal of this project is to implement a prototype of an enhanced operational streamflow forecast system across the northeast that integrates satellite river ice information. This project leverages existing river ice remote sensing systems, developed by PI Temimi, that use MODIS and VIIRS imagery. The focus in this project is to develop a multisatellite river ice system that integrates images from different sources. The system will generate maps of river ice extent, concentration, thickness, and volume. Then, the generated river ice products will be used to adjust the parameters of streamflow routing schemes to enhance the forecast. The feasibility of the assimilation of the river ice information from earth observations in operational streamflow forecast systems will be assessed. Hence, the project, at this stage, falls under Category 1: Proof of Application Concept.
This project will be conducted in partnership with NOAA NWS Northeast River Forecast Center (NERFC) which covers a geographic domain that includes the states of Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York with several ice prone rivers. The domain includes the nation's largest water supply system that is managed by New York City Department of Environment Protection (DEP), the water supply division. They rely on streamflow forecast from NERFC to manage their reservoirs and streams which are impacted by river ice every year. The project will test

the deployment of the proposed system over various watersheds before expanding it to the entire NERFC domain.

The effort will focus on assessing the assimilation of river ice information in two models, namely, the HEC-RAS model and the WRF-Hydro model. The latter is the engine of NOAA National Water Model. The HEC-RAS model is used by our partners at the NERFC. The latest version of WRF-Hydro does not account for river ice in streamflow simulation. We will compile a modified version of the code to introduce a new calculation of streamflow and account for the additional roughness introduced by ice. HEC-RAS is limited to the steady flow conditions in presence of ice which is not realistic. The HEC-RAS model will be coupled with a controller to automatically adjust roughness and cross-section parameters as new information on river ice is inferred from satellite observations. The integrated system will be deployed operationally over specific ice-prone river sections. The enhanced WRF-Hydro version will be deployed regionally to cover the entire NERFC domain. We expect to achieve a significant improvement in streamflow forecast compared to the baseline system which will have a strong positive impact on decision-making and water resources management in northern watersheds which will be quantified and assessed by our partners at NYC DEP. The proposed effort holds the potential of maturing to category 2 and 3 with an expansion of the domain to include all NOAA RFCs that are impacted by river ice and assimilate the satellite-inferred data in an operational nation-wide streamflow model like the National Water Model.

Enrique Vivoni/Arizona State University
Managing the Colorado River as an Infrastructure Asset: Fusing Remote Sensing and Numerical Modeling in the Operations of the Central Arizona Project
21-WATER21-2-0072

A prolonged drought in the Colorado River Basin (CRB) and recent shortfalls in snowmelt runoff have led the U.S. Bureau of Reclamation (USBR) to issue an unprecedented Tier 1 shortage for 2022. For Arizona, a Tier 1 shortage will reduce water allocations to agricultural users served by the Central Arizona Project (CAP) by 500,000 acre-feet in that year. This crisis is Arizona's most significant drought stress test to date and water managers must shift into an anticipatory framework that prepares for the worst-possible cases. In this proposal, Arizona State University and the Colorado River Programs division at CAP have partnered to address the impending drought crisis by building on a hydrologic remote sensing and modeling system. We propose a novel framework to manage the biophysical system and its sociopolitical institutions as infrastructure assets whose resilience to drought stress is quantified. Infrastructure is defined as the interacting components of the biophysical and sociopolitical system in the Colorado River that must work together to reliably deliver water and protect against extreme drought risk. This framework is based on the Variable Infiltration Capacity (VIC) model and the operational Colorado River Simulation System (CRSS). We will conduct simulations of two types: (1) long-range scenarios to identify drought stress periods in retrospective and future climate and land use-land cover (LULC) change periods, and (2) short-range projections that mimic the 24-month study issued by the US Bureau of Reclamation using seasonal climate forecasts and rapid detection of LULC. For both activities, we will conduct an iterative process of model testing and improvements in VIC using in-situ networks and satellite platforms, including from commercial Cubesat observations. Remote sensing data will be used to detect land surface conditions, including land surface temperature, snow, and vegetation indices, and assimilate snow observations into VIC for short-range simulations. We will transform our hydrologic remote sensing and modeling system into an infrastructure asset framework by: (1) identifying through basin stakeholder interactions the key triggers in the biophysical system leading to varying levels of risk, (2) quantifying through modeling the retrospective behavior and future projected conditions associated with key triggers, and (3) building a quarterly reporting system using remote sensing and modeling to monitor short-range changes in the key triggers. Visualizations in the form of charts, traffic signals, critical risk levels, and similar tools will be constructed to represent the retrospective, current, and future projected system performance at key asset locations and assembled into quarterly reports that will be delivered to the CAP Board of Directors and other CRB water management agencies. This is a Category 2 proposal that addresses the following priority areas mentioned in the solicitation: (1) drought response, (2) cascading threats to water supply, (3) adaptations to climate and land cover change impacts on water supply, and (4) infrastructure assessments. We estimate starting at ARL-3 and advancing to ARL-7 by the end of the project. This effort is anticipated to become an important management tool for both short and long-term planning of the Colorado River for a broad set of basin stakeholders and a paradigm shift with respect to the baseline management system. A large set of stakeholder interactions will also demonstrate the value added of NASA Earth Science products to a large number of policy makers and technical staff who can adopt similar approaches in their water management organizations.

Danielle Wood/Massachusetts Institute of Technology
Supporting Drought Management in Angola using Integrated Modeling of the Environment, Vulnerability, Decision Making and Technology (EVDT)
21-WATER21-2-0009

This project seeks to improve the use of satellite-based Earth Observation as an input to a Drought Decision Support System to inform the response to drought and floods in southern Angola. Specifically, the government of Angola needs to make decisions to evaluate the effectiveness of three categories of interventions to determine if these interventions are delivered to the regions in which residents face high vulnerability based on their sensitivity, exposure and adaptive capacity to drought hazards. The three interventions include: 1) Sending water trucks to deliver water to residents impacted by drought; 2) Providing funding, equipment and personnel to improve boreholes; and 3) Investing in long term infrastructure improvements in the Cunene River to allow catching and pumping of water during rainy periods. In addition, the Angola Drought Decision Support System contributes to a capability for the Government of Angola to organize information about the various entities that provide drought relief (included national government, regional government and non-profit entities such as UNICEF) and determine whether the combination of drought response efforts is delivered collectively to the regions with high vulnerability. To summarize, the government of Angola needs to use the Drought Decision Support System to make four high level decisions: 1) What routes & schedule should trucks use to deliver emergency water supplies to High Vulnerability regions? 2) What locations should be prioritized for borehole improvement projects to serve High Vulnerability regions? 3) What region of the Cunene River should be prioritized for long term infrastructure improvements to serve High Vulnerability regions? and 4) How should work on the three interventions be divided among government and nonprofit agencies to ensure that high vulnerability regions are served?

The project applies a foundational framework guiding the project called Environment-Vulnerability-Decision-Technology" (EVDT), which allows a structured process to created integrated, spatially presented views of complex scenarios in which environmental state, human experience, policy decisions and the use of technology as a source of information play a key role. The Project also uses tools from Systems Architecture to collect and organize data about the social and technical context of Angola. For this project, the US team led by PI Danielle Wood will collaborate with the Unfunded Collaborator led by Dr. Zolana Joao, Director of the Angolan Management Office of the National Space Program (the acronym is GGPEN in Portuguese). At the request of Dr. Joao, the US-team proposes to collaborate with GGPEN to build an Angola Decision Support System offering an interactive website, based on the Environment-Vulnerability-Decision-Technology Integrated Modeling Framework. The project uses satellite and in-situ earth observation data, including data on precipitation, soil moisture, surface water, land use, population and weather parameters. The outputs of the Decision Support System assess and guide drought response efforts.

Samuel Zipper/Kansas Geological Survey
Managing Temporal Trade-Offs through Irrigation and Yield Forecasting to Advance Groundwater Conservation
21-WATER21-2-0050

Groundwater depletion threatens the future of aquifers around the world. Despite widespread recognition of negative short- and long-term impacts of groundwater depletion, it remains an intractable problem in many regions as pumping reductions are often the only viable pathway to sustain groundwater resources, which can threaten local communities and regional economies rely on irrigation-driven agriculture. Effective groundwater conservation strategies such as pumping reductions require farmers to balance considerations spanning temporal scales from days (should I irrigate today and, if so, how much?) to decades (how will my actions affect the future viability of irrigation for myself and my children?). Despite the existence of intra-seasonal irrigation scheduling and yield forecasting tools, there is a need for decision support systems in areas experiencing significant aquifer decline that also incorporate inter-seasonal objectives for sustaining long-term water availability.

This Category 1 proposal will use diverse Earth observation and in situ data to fill this irrigation decision support gap by spanning intra-seasonal and inter-seasonal considerations and specifically tailoring tools to the decision heuristics of real-world producers. Project outcomes will allow water users to better manage the trade-offs between intra- and inter-seasonal decision factors by integrating Earth observations with crop models, meteorological data, and in situ hydrological monitoring data to provide near-real-time forecasts for the end-of-year and multi-year agronomic and hydrologic outcomes (yield, water use, groundwater and streamflow depletion) and associated uncertainty. These forecasts will be conditioned on the decision processes, information needs, and risk preferences of end-user farmers with regard to trade-offs between short-term crop profit and sustaining long-term water supply.

The proposed work is at application readiness level 2 (ARL2; application concept/invention) and seeks to advance to the ARL4 (prototype/plan) within the three-year project period. We will accomplish this through two parallel objectives: (1) assess end-user decision needs, concerns, and heuristics; and (2) develop a subseasonal to seasonal yield and water use forecasting framework. There will be information flow between these two objectives that will evolve throughout the project. To advance from ARL2 to ARL3, analysis of decision approaches and heuristics will inform the variables and indicators that will be output from the forecasting framework, and the development of the forecasting framework will provide estimates of forecast accuracy and timeliness that can be used to assess whether the tool meets user needs for key decision indicators. To advance from ARL3 to ARL4, we will develop a prototype web-based decision support system which will include forecasts and associated uncertainty for an existing groundwater conservation area as an engagement point with stakeholders, and assess how this information and tool can be integrated into farmers' decision workflows with other existing decision support systems (e.g., in-field soil moisture probes, crop consultants).

This project will focus on parts of Kansas, Colorado, and Nebraska with ongoing groundwater conservation programs and leverage extensive experience by our project team working in these regions. We will work closely with two groups of end-users: (1) agricultural producers who make irrigation water-use decisions, and (2) local groundwater management districts and state water management agencies responsible for advocation or enforcement of general groundwater supply stewardship strategies. Both groups are already partnered with our team on other projects focused on groundwater modeling to assess aquifer sustainability, looking primarily at multi-year timescales. This proposal would serve as the foundation to provide decision support across all important irrigation water-use decision timescales.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences (ROSES) – 2021
NNH21ZDA001N-SERVIR
A.35 SERVIR Applied Sciences Team

NASA's Research Opportunities in Space and Earth Sciences (ROSES) 2021 included an Applied Sciences Program solicitation to select a new SERVIR Applied Sciences Team. The Principal Investigators constitute the core of the team and their co-investigators and collaborators constitute the broader team. Each PI has an individual project developed in collaboration with a SERVIR hub, and, as SERVIR Applied Sciences Team members, each investigator will also be available to advise SERVIR on issues that may arise in their areas of expertise during their service on the team. The solicitation included a two-step selection process and a total of 49 Step-2 proposals were received. Through NASA Headquarters' peer review process, NASA has selected 20 proposals for funding, based on the panel review and the programmatic need to balance the needs identified in the thematic service areas by the five regional hubs in Eastern and Southern Africa, Hindu Kush-Himalaya, Mekong, West Africa, and Amazonia regions. Funding amounts to $4,495K for the first year and a total of $13,492K over the full 3 years of the grants. The selected PI's, their institutions, thematic areas, and titles for their selected work are listed below.

Julius Anchang/New Mexico State University
Supporting Index-Based Livestock Insurance Initiatives (IBLI) in East and Southern Africa Through Earth Observation for Forage Biomass and Associated Risk Factors
21-SERVIR21_2-0074

For this SERVIR Applied Science Team (AST) project we propose to work with the East and Southern Africa (E&SA) SERVIR hub on earth observation data applications relating to food security and agriculture (Thematic Service Area 1). We propose applications that complement SERVIR E&SA hub priorities on rangeland biomass monitoring and drought monitoring and disaster risk financings through innovations such as index-based livestock insurance (IBLI). Livestock production critically supports the basic livelihood of millions of people in the pastoral zones of East and Southern Africa, contributing significantly to the agricultural gross domestic product (GDP) of most countries in the region. However, livestock production systems in these countries are also vulnerable to chronic and acute risk factors originating from natural and human-induced processes.
This proposal will focus on collaborative development (with the SERVIR E&SA hub and regional/local pastoral stakeholders) of new and improved Earth Observation (EO) data products on annual rangeland forage productivity and quality, and how relevant processes such as climate variability and land degradation influence risk assessment within a livestock insurance framework. It will also focus on extensive regional capacity building for tools and services developed as part of the project, and support the establishment of a sustainable ground-based rangeland data collection initiative. Four (4) main activities are proposed. Activity 1: Mapping annual/seasonal forage biomass (kg/m2) and anomalies based on 20 years of partitioned MODIS Leaf Area Index in E&SA. This will be the

primary basis for assigning ex-post risk to relevant livestock production areal units. Activity 2: Mapping native/invasive species distribution and impacts on E&SA rangelands, as a means to create forage quality masks. Activity 3: Mapping land degradation as a contributor to risk assessment uncertainty in E&SA. Activity 4: Coordinate the establishment of local rangeland field data collection network for sustained monitoring and assessment of rangeland productivity and quality that complements EO-based risk assessment.

We will work with the SERVIR hub to tailor our plans to E&SA stakeholder needs, and will emphasize locally driven verification and uncertainty analysis of EO data products. We anticipate that this collaborative AST project will contribute to E&SA Service Areas relating to supporting rangeland decision-making, notably as direct inputs to the emerging drought risk financing mechanisms such as IBLI and management of diverse private, communal and publicly owned rangelands across the East and Southern Africa region.

The PI (Anchang) is currently a Co-Investigator on a NASA SERVIR E&SA project focused on improving existing rangeland decision support tools with EO based forage monitoring and forecasting applications. Co-I Kahiu has experience working on theoretical and applied ecological research in African savannas. She has pioneered algorithms for partitioning satellite aggregate leaf area index into woody and herbaceous components which form the basis of our existing rangeland monitoring applications. She has also contributed broadly within the drought risk financing agenda across Africa through rangeland innovations such as IBLI. Co-I Hanan is an experienced dryland ecologist who has spent decades working in African savannas. He is the PI on a current NASA SERVIR E&SA project and has broad research interests on the ecology, management and earth observation of the rangelands and savannas. Co-I Kenduiywo is a geospatial scientist with experience in using EO data for crop mapping and modeling, and crop insurance. He is also a long time educator and capacity builder within regional institutional and stakeholder networks. He joins the project as the primary liaison between the AST and SERVIR E&SA Hub.

Mauricio Arias/University of South Florida, Tampa
Subseasonal-to-Seasonal Forecasting for Informed Decision-Making in the Mekong River Basin
21-SERVIR21_2-0029

The goal of this project is to develop a decision support tool that provides subseasonal forecasts of water availability for the Mekong River Basin using NASA s subseasonal-to-seasonal (S2S) forecast system. Currently, the Mekong River Commission (MRC) forecast system provides 1-5 day river level forecasts along the Mekong s main stem. The temporal and spatial scope of this forecast, however, is insufficient for comprehensive basin management, as it excludes river tributaries and hydrological alterations caused by reservoirs. Using well-established tools and published research by our team, this project will work directly with the SERVIR-Mekong hub to enhance the capabilities of their systems to:

1) Increase temporal coverage from 5 to 30 days;
2) expand spatial coverage to include Mekong tributaries;
3) accounting for reservoirs and their operations;
4) improve overall subseasonal forecast skill.

The proposed application builds upon published research and tools with high readiness level. At its core is the Global Earth Observing System real-time S2S forecast system by NASA s Global Modeling and Assimilation Office. 30-day ensemble forecast meteorology from this system will be bias-corrected and used to drive NASA s Catchment Land Surface Model offline. The resulting arrays of total water runoff will be used within our team s well-proven reservoir model, which accounts for infrastructure and operations of major dams along the Mekong and its tributaries. Resulting forecasts of water discharge and levels at multiple locations throughout the basin will be shared with the MRC and other critical stakeholders through an online application co-designed with the SERVIR hub. The application of this project will be guided by SERVIR s Service Planning approach and a Theory of Change, with feedback from MRC and other key regional stakeholders. This process will be facilitated through a series of 3 stakeholder workshops.

The primary thematic service area of this project is Weather and Climate. By developing a reliable, basin-wide subseasonal forecast, this project will produce a tool that generates actionable knowledge to National Mekong Committees, governmental and non-governmental organizations, the media, and the public. The proposed application would be instrumental in all other thematic services areas; in particular, it will help in drought resiliency, dam safety, hydropower production, and it will help maintain water needs of riverine ecosystems. It should also give disaster preparedness centers more time to plan emergency relief operations to protect life, property, public health and safety. Moreover, the application could help farmers, for example, reach short- and medium-term decisions about crop types and planting schedules, potentially resulting in larger and more profitable crop yields. In a broader sense, by boosting disaster risk reduction and effective water resources management, accurate subseasonal forecasts should provide overall societal benefits and enhance economic prosperity.

The proposed activities will lead to two umbrella outcomes: 1) Integration of NASA s S2S forecasting platform with well-tested water models for the entire Mekong River Basin; 2) Prediction of subseasonal variations in river flows on the Mekong s main stem and tributaries through the joint consideration of S2S forecast runoffs and dam operations. Proposed deliverables include application integration, validation and demonstration, 3 stakeholder workshops, scientific publications, and a online application compatible with existing SERVIR and MRC tools. Our project team consists of a diverse group of experts with a solid record of contributions to the Mekong s state of knowledge, and a history of collaboration on applied research related to modeling land surface processes, watershed hydrology, reservoir operations, water resources management, seasonal forecasting, and stakeholder engagement.

Gregory Carmichael/University of Iowa, Iowa City
Bringing Multi-Sensor Exposures to Respiratory Health and Crop Yield Studies
21-SERVIR21_2-0069

Air pollution contributes to an estimated seven million deaths worldwide annually [1] and reduces yields of major crops by up to 20% [2]. Even with this knowledge of human health and food impacts and commitments for action, progress towards reducing the impacts of air pollution is slow in many parts of the world. To effectively mitigate the hazards of air pollution on health and food security, we need better estimates of exposure of humans and crops to air pollutants. In the case of human health ongoing studies are identifying a broad set of effects of exposures to air pollutants across the lifespan, from low-birth-weight neonates to increased risk of dementia in the elderly. We know that air pollution influences lung immune function following both acute and long-term exposures and serves as a modifier in infectious disease spread and progression [3,4]. The understanding of these linkages is hampered by insufficient information to produce robust exposure estimates at desired spatial and temporal scales needed to assign individual-level air pollutant exposures. This is a formidable limitation in many health outcomes studies, as inaccurate exposure assignments result in exposure misclassification reducing statistical power or biasing effect estimates. Similar arguments can be made for the importance of better exposure estimates in assessing the impacts on crop yields.

The scientific basis for acute and chronic disease linkages and reduced crop yields with air pollution is increasingly robust but progress in control of air pollution sources is slow, especially in developing nations. Exposure estimation tools based on combination of remote sensing, deterministic modeling, surface observations, and statistical data-driven approaches are increasingly powerful yet underutilized in the study of the impacts of air pollution. We propose to leverage NASA remote sensing assets to engage public health organizations, healthcare practitioners and patients, and air pollution managers and citizens in a collaborative effort to improve the exposure science that supports the linkages between air pollutants and specific diseases and crop yields. We hypothesize that this information will lead to improved and innovative public health and air quality interventions.

We propose to work with the SERVIR-Mekong hub on a project where we will make complex exposure estimates more accessible to physicians, scientists, public health officials, and crop scientists performing health and food security outcomes research by developing 1-km spatial resolution exposure estimates. This proposal directly addresses the SERVIR APPLIED SCIENCES TEAM stated priority in the RFP to use Earth observations to support public health and air quality management. And directly addresses two of the SERVIR-Mekong stated priorities: 1) Food Security through use of existing and new capabilities to address sustainable agricultural practices, including impacts to air quality and the food-energy-water nexus; and 2) Weather and Climate by providing actionable information for regional entities through building on and expanding current activities that connected global air quality model forecasts with the available ground observations in the region.

Sean Healey/Forest Service
Documenting Forest Emission Reduction Through Both Statistical Estimation and Improved Resource Mapping
21-SERVIR21_2-0028

The Paris Agreement explicitly recognizes the slowing or reversal of emissions caused by deforestation and forest degradation as an important contribution in the fight against climate change. Remote sensing has tremendous potential as a globally consistent, freely available source of critical monitoring data, but there can be no further delay in translating that potential into practical, theoretically defensible data systems. Monitoring needs related to maturing Nationally Determined Contributions (NDCs) under Paris have become more urgent, while new sensors and computing platforms have greatly increased the reach and acuity of our observations. We propose a multi-sensor (GEDI, Sentinel-1, Landsat) forest emission monitoring application that leverages the statistical inference framework developed for the GEDI mission. Pilot studies at different scales in Oregon, Paraguay, and Nepal have demonstrated the feasibility and value of transparent, sustainable carbon monitoring from space.

Our proposal addresses the SERVIR Hindu Kush Himalaya (HKH) region under the Land Cover and Land Use Change and Ecosystem theme. We have worked with ICIMOD (SERVIR s regional hub organization) to plan for a regional instance of OBIWAN, an online tool that leverages GEDI s measurements, statistics, and biomass models to produce customized carbon reports. This tool will be specifically calibrated with local inventory data provided by ICIMOD partners, a step our experience in Paraguay has shown to be important both in establishing the tool s local credibility and improving its actual accuracy. OBIWAN-HKH will represent a system for documenting trends in forest-related emissions at both national (Nepal, Pakistan, Bangladesh) and sub-national scales.

We will collaborate with ICIMOD stakeholders to develop regionally consistent spatial layers related to: land cover class; ecosystem degradation; and forest structure (height and cover). In some cases (land cover and forest change), existing SERVIR products will be augmented through the use of Sentinel-1 C-band radar data. In the case of forest structure, GEDI canopy profile information will be modeled across space and time in ways that address needs identified by ICIMOD. These layers will be produced and validated in ways that allow their sustained use with SERVIR s RLCMS decision support platform. We will also partner with the SilvaCarbon program to ensure that techniques we develop are: 1) appropriate in the HKH context; 2) thoroughly understood by our partners; and 3) supported beyond the scope of a 3-year SERVIR grant. We believe the science of making statistical inferences from space has now advanced to the point where it can fill important roles in monitoring national commitments and supporting results-based payments. We outline here service components that would make the HKH hub a leader in this field.

Michael Keller/Forest Service
A Service to Quantify Forest Carbon Stock Changes in the State of Mato Grosso, Brazil
21-SERVIR21_2-0027

In Amazonia, human activities take many large- and small-scale forms including agriculture, livestock raising, logging, and mining. These practices contribute synergistically to deforestation, forest fragmentation, and fires causing forest degradation and losses of carbon and biodiversity. One of the approaches to slowing the pace of forest destruction is to make standing and regrowing forest more valuable through policies that compensate forest owners for the carbon storage services that they provide. However, any plan to account for the value of ecosystem carbon needs reliable estimates of carbon stock and carbon stock change.

The State of Mato Grosso in the Brazilian Amazon has identified the need for quantification of emission reductions (ERs) and incorporating forest degradation in the estimates and analysis of errors and uncertainties as top challenges for monitoring reporting and verification related to REDD+. Working together with the SERVIR Amazon hub we propose to develop a service to estimate forest carbon stock and stock change using ground-based, airborne, and satellite remote sensing data. We will adapt research already completed by our group that estimates these quantities at a global scale with coarse (10 km) resolution to function annually in Mato Grosso State with a relatively fine resolution (500 m). This leap in resolution is possible because of new satellite data resources from the NASA Global Ecosystem Dynamics Investigation (GEDI) and other new, freely availability resources such as composite high-resolution multispectral data from Planet through the NICFI initiative.

Our planned applied science development takes three steps. The first step based on already published studies takes data from ground-based forest inventories and recently acquired airborne lidar data to produces local aboveground carbon (AGC) models. Those models from airborne lidar data together with simulated GEDI metrics from the lidar will be used to develop AGC products across the forested region of the state for calibration of a temporal-spatial machine learning model that will produce time series of AGC and, with an additional modeling step, below ground carbon. All data are in the public domain. All models supporting the service will be transferred to be operated by the implementing partner in Mato Grosso.

We will consult extensively with stakeholders to co-develop services that increase access to information for stakeholders and enhance their capacity to support REDD+ monitoring, reporting, and verification. To do this, we will work closely with the hub to build capacity. All data used by the models from the ground-based surveys through the satellite information are in the public domain and freely available for download. The service we develop including all source code and products will be freely and openly available both to increase transparency and to ease the transfer of the developed service to other jurisdictions. At the end of our project, we aim to have transferred a sustainable service to provide carbon stock and change estimation in Mato Grosso in support of REDD+ and other environmental values.

Today our technological capabilities nearly match the societal demands to confront climate change. Natural climate solutions including avoiding deforestation and degradation and recovery of forest carbon stocks present a desirable and economical pathway to mitigate climate change. Development of a high-resolution satellite driven forest carbon accounting system in Mato Grosso will facilitate this pathway for the state and can be a pathfinder for tropical forest jurisdictions across the world.

Robert Kennedy/Oregon State University
Harmonizing for Carbon: Scalable Earth-Observation Frameworks to Facilitate REDD+ Objectives in the Lower Mekong Basin
21-SERVIR21_2-0081

Although the forests in the countries of the Lower Mekong Basin (LMB) are under significant development and extraction pressure, carbon-based management regimes may incentivize appropriate levels of development and conservation. The REDD+ (Reducing Emissions from Deforestation and Degradation in Developing Countries; https://red.unfccc.int) framework of the United Nations Framework Convention on Climate Change (UNFCCC) provides structures for countries to report and potentially benefit from appropriate carbon-based conservation. Simultaneously, the rapidly emerging voluntary carbon credit markets may provide significant resources to actors operating at sub-national levels. In our existing SERVIR Applied Science Team work as well as with related capacity building efforts with developing countries, it has emerged that conducting statistically defensible cross-scale harmonization is a key goal and challenge to ensure trust of carbon management systems.

We propose to work with the SERVIR Mekong Hub to build tools and capacity around improved REDD+ scaling and accounting. Our first objective focuses on improving monitoring of forest loss by integrating an ensemble of forest disturbance algorithms, providing both improved discrimination of forest loss events as well as scalable estimates of uncertainty in maps. These will reduce the overall uncertainty of estimates and allow for scaling of national-scale maps to local scale. Our second objective focuses on improving the estimation of forest carbon reference levels. We attack this on two levels. First, we will integrate spaceborne lidar observations to improve labeling of forest types, allowing separation of types with divergent biomass profiles. Under current stratification-based sampling protocols, the improved strata will reduce variability in biomass estimates and allow for more targeted sampling efforts. Second, we will develop improved biomass mapping tools that can produce either improved pixel-based biomass maps to be used under newer revised protocols, or that can be used to further tighten biomass estimation under traditional protocols. These mapping methods adapt Bayesian Hierarchical Spatial Modeling approaches we have built for forested systems in the U.S., and incorporate statistically defensible estimation approaches that can scale from local to national scale.

We have engaged collaborators engaged in carbon-management activities at the level of community forests, regional REDD+ projects, and national agencies. These users and other new users we hope to engage in the course of the project will help ensure that our tools serve their needs.

We anticipate development of web-based services managed by the SERVIR Mekong Hub to facilitate REDD+ objectives by users operating all of these scales. One service will focus on disturbance algorithm harmonization to improve monitoring of forest loss. The second will focus on improved land cover and biomass estimation within forests.

Ultimately, our impact will be on livelihoods and conservation. By making carbon-based management more accessible, reliable, and scalable, we anticipate that our tools can facilitate forest management that spreads wealth more equitably and provides real incentive for conservation.

Our proposal is responsive to the land cover and land use change and ecosystems element of the SERVIR call, and is aimed at the Mekong Hub. Through our first SERVIR project, our team has shown effective adaptability in co-production of services that respond to end user needs. We intend to continue this collaborative spirit, and ideally be able to host workshops and learning sessions in person during the life of the proposed new project. We believe our tools can empower local groups to take more ownership of conservation and sustainability goals, and improve trust by donor entities in the establishment of sustainability frameworks.

Rajesh Kumar/University Corporation For Atmospheric Research
Enhancing Air Quality Decision-Making Activity in Eastern and Southern Africa
21-SERVIR21_2-0031

Ambient air pollution leads to 23,310 premature deaths per year, exacerbates respiratory ailments of millions of residents, and causes economic loss in millions of dollars in Eastern and Southern Africa (E&SA). For example, poor air quality is estimated to exacerbate respiratory ailments of about 20 million Kenyans and cause an economic loss of $349 million in Rwanda alone. To reduce such losses, this project aims to co-design and co-develop a regional air quality forecasting system for E&SA together with local scientists that will provide near-real-time and next-two-days information about air quality to the public and decision-makers, as well as past changes in air quality over E&SA from 2003-2022 via a dissemination system. The following tasks will be carried out to achieve this objective.
Task 1: Determine the needs of stakeholders in E&SA together with E&SA SERVIR hub and align project activities with the identified needs.
Task 2: Collect and process all available multi-platform observations for assimilation and model validation.
Task 3: Develop a Weather Research and Forecasting model coupled with Chemistry (WRF-Chem)-based Air Quality Forecasting system that includes:

? A system for assimilating National Aeronautics and Space Administration (NASA) satellite aerosol optical depth (AOD) and carbon monoxide (CO) retrievals.
? A near-real-time evaluation system based on available multi-platform observations in E&SA.
? A source attribution system to help with the design and implementation of emission control measures.
Task 4: Develop an information dissemination system to disseminate short-term air quality products and a regional air quality atlas from 2003-2022 for E&SA, and its integration into E&SA SERVIR hub s Early Warning Explorer (EWX).
Task 5: Capacity building and transition of the new system to E&SA to ensure sustainability.

The proposed system, providing both the past and short-term future air quality information, will help decision-makers issue timely alerts and warnings about upcoming air pollution events to the public, who then can make informed decisions about protecting their health. If air quality alerts in E&SA can reduce air pollution impacts even by 1%, we will be able to save 233 lives per year, prevent exacerbation of respiratory illnesses of about 200,000 people, and help save millions of dollars. Furthermore, the generation of long-term gridded air quality information through a combination of regional atlas and air quality forecasts in unmonitored areas of E&SA can help environment management agencies in this region make informed decisions for designing future air quality monitoring systems in the region. By improving the air quality decision making activity, this project will directly contribute to the NASA SERVIR mission of fostering the applications of Earth observations to help developing countries assess their environmental conditions and, as such, improve their planning and decision-making activities.

Hyongki Lee/University of Houston
Strengthening Regional and National Capacity for Operational Flood and Drought Management Services For Lower Mekong Nations via Mekong River Commission and SERVIR-Mekong
21-SERVIR21_2-0003

This proposal builds on a current SERVIR project (2019 2022) titled Operational Services for Water, Disaster and Hydropower Applications for Lower Mekong Populations using NASA Earth Observations and Model which has experienced tremendous success in unexpected directions with Mekong River Commission (MRC) via SERVIR-Mekong: (1) Operational Reservoir Assessment Tool (RAT)-Mekong system officially adopted by MRC to support MRC s Strategy on Flood Management and Mitigation 2021 2030 and Drought Management Strategy 2020 2025, implemented in SERVIR-Mekong s website; RAT-Mekong bulletins to be officially published in MRC s portal by June of 2022, (2) Operational Forecasting Inundation Extents using REOF analysis (FIER)-Mekong, flagged as a timely tool for 2-D (inundation extents) and 3-D (inundation depths) flood management service needs of MRC and Vietnamese stakeholders. These recent successes have identified more time-sensitive institutional and

societal priorities of Lower Mekong countries when it comes to floods and droughts in the context of an increasingly impounded Mekong river.
Accordingly, we propose to expand and integrate the skills of current RAT-Mekong and FIER-Mekong as an individual and integrative operational decision support systems as follows: (1) Ultra High-Frequency Operational RAT-Mekong System With Outflow Forecasting Skill for All Key Mekong Reservoirs; (2) Operational FIER-HYDRAFloods-Mekong as Inundation Forecasting System Without Reservoir Operations; (3) Operational RAT-FIER-HYDRAFloods-Mekong as Inundation Forecasting System With Existing Reservoir Operations; (4) Operational RAT-IROS(Integrated Reservoir Operation Scheme)-FIER-HYDRAFloods-Mekong as Inundation Simulation System With Existing and Planned Reservoir Operations. We will adopt a scalable participatory approach for engaging MRC, Vietnam s NAWAPI, VNUA, and NCHMF as end-user agencies toward achieving high ARLs. Our proposed services are expected to be a unique and highly scalable decision support system for holistic water management with and without existing and planned upstream reservoir operation, and provide important recommendations for basin-wide reservoir operation policies toward sustainable allocation and management of water resources across time, space, and sectors of water-energy-food nexus. For example, we have assessed the economic impact of FIER-based decision making by estimating flood-induced rice crop loss in Cambodia and Mekong Delta that could have been prevented or mitigated using FIER during 2020 harvest time, which was about USD 450 million.
Due to COVID-19, we have followed a virtual Training for Trainers (ToT) protocol using hackathon-like features for the current project. These protocols were already well-developed as part of the NASA Applied Sciences Early Adopter program for the SWOT mission. In particular, our previous engagement for building capacity during COVID-19 was based on four essential features: MEDically safe, SCAlable, Rapidly-deployable, and Focused on learning outcomes (MEDSCARF). We will follow a similar virtual format in the proposed project at a quarterly (3-month) frequency and blended with hybrid features of annual in-person training. This blended ToT in hackathon-like training will allow us to be in lockstep with the evolving needs of the stakeholders as well as make rapid knowledge and technology transfer to SERVIR-Mekong with close interactions with the Hub Co-I. For each of the services proposed, the project team will contribute to SERVIR-Mekong s service planning and service design documents. Especially, we will actively participate in the Monitoring and Evaluation and Learning (MEL) process that captures the Theory of Change for the service proposed in order to ensure the lasting impact on the stakeholders and Lower Mekong region. The project will support two PhD students in total at U of Houston (UH)   a Hispanic-Serving Institution (HSI), and U of Washington.

Hongxing Liu/University of Alabama, Tuscaloosa
Water Quality and Storage Monitoring Services for the Great Lakes Region of Eastern and Southern Africa by Integrating Multi-Sensor Satellite Observations, Machine-Learning Models and Cloud Computing Platform

21-SERVIR21_2-0002

This project will provide lake water quality and storage monitoring services for management decisions in the Great Lakes region of Eastern and Southern Africa by integrating multi-sensor Earth observations, machine-learning models, and cloud computing technology. Specific objectives include: 1) Establish well-calibrated and validated algorithms/models and associated software tools for monitoring and mapping lake water quality parameters (chlorophyll-a, toxic algal blooms, turbidity, suspended sediment concentration, colored dissolved organic matter, water temperature), invasive water hyacinth, lake water level and volumetric change for three of the largest African Great Lakes in this stage of the project, with the potential to extend such services by applying the calibrated models to other major lakes in Eastern and Southern Africa in the future. 2) Conduct joint field surveys to collect to collect on-lake measurements on various water parameters, and co-develop remote sensing algorithms with the personnel of the regional hub at RCMRD, and other regional professionals. 3) Implement water quality and quantity algorithms/models into open-source software tools, and transfer the source codes and software tools to the regional hub-RCMRD through technical workshops and co-development activities. 4) In partnership with RCMRD, develop training materials and hold training workshops for regional professionals and end users to build their capability in using multispectral, thermal, radar altimetry Earth observations and geospatial information technologies for water availability and water quality monitoring, assessment, and prediction. 5) Develop online maps and a visualization website with RCMRD, provide user-tailored services, and organize user conferences for stakeholders, policy makers and resource managers to use Earth observations and geospatial tools for water resource management and decision-making activities.

We will greatly expand previous SERVIR s Lake Victoria Water Quality and Ecosystem Management project to include the three largest lakes (Lake Victoria, Lake Tanganyika, Lake Malawi) of the African Great Lakes as focus lakes for field and in situ measurements for satellite model calibration and validation. Besides lake water quality parameters, lake water quantity variables (lake water level, water storage volume) will be derived and monitored by applying innovative remote sensing algorithms/models to multiple Earth observations. Our team has many years of on-the-ground-and-water field experience in different countries/continents. The three Points of Contact at the regional hub RCMRD in Nairobi, Kenya will serve as co-Is of this project.

This project will address SERVIR s priority thematic topic Water Resources and Hydroclimatic Disasters . Data products, calibrated models, software tools, and web-based maps from this project will help the regional hub personnel, professionals, and users to document lake water level and storage volume change, harmful algal blooms, sediment plumes, and other threats to their freshwater resources. Lake water level and storage information will meet the regional needs for drought and flooding early warning as well as for water availability and supply assessment for human drinking, agriculture, aquaculture and food security. The satellite-based lake water quality information will benefit Eastern and Southern Africa by providing the early warning and monitoring of toxic algal blooms and invasive water hyacinth outbreaks to protect approximately 25%

of Earth s unfrozen freshwater resources and the health of millions of people in the African Great Lakes region. Our project will build and improve the capacity of regional professionals, government policy makers and resource managers in using new generation of Earth observations and geospatial technologies to support water resource management, lake aquatic ecosystem protection, natural hazard mitigation, and decision-making activities.

Franz Meyer/University of Alaska, Fairbanks
Combining SAR Remote Sensing and Machine Learning to Advance Flood Monitoring and Landslide Hazard Assessment in the HKH
21-SERVIR21_2-0063

This proposal addresses the Water Resources and Hydroclimatic Disasters focus topic formulated in the 2021 NASA ROSES A.35 solicitation for the SERVIR Hindu Kush Himalaya (SERVIR-HKH) Hub. Specifically, we propose to develop the HydroSAR Next Generation (HydroSAR-NG) service to advance SERVIR-HKH needs for flood inundation mapping and forecasting and estimating landslide probabilities, by combining SAR and interferometric SAR (InSAR) remote sensing with machine learning. The key expected outcomes of our work are 1) high-accuracy daily flood extent forecasts and 2) low-latency maps of unstable or anomalously behaving slopes, which are susceptible to initiating cascading hazards such as debris flows and outburst floods. The proposal is coordinated with previous SERVIR (AST members Meyer, Kirschbaum, Nelson) and previous and ongoing NASA High Mountain Asia projects and will build capacity and train end users to employ machine learning and (In)SAR to generate hazard assessments.

To address SERVIR-HKH information needs in daily flood mapping and forecasting, we will enhance existing SERVIR-HKH abilities currently provided by ICIMOD s HydroSAR service (https://geoapps.icimod.org/flood2021/) by developing operational daily inundation extent forecasting capabilities (HydroSAR-NG d-INX30 product). To achieve this goal, we will integrate SAR with daily streamflow data using machine learning and deep learning techniques. We will use SAR data from the Sentinel-1 and NISAR missions as well as 10-day forecasts of the SERVIR-HKH Streamflow Prediction Tool as primary inputs. Our machine learning approach will mature an existing prototype solution that is based Rotated Empirical Orthogonal Functions (REOF). We will complement this solution with a deep learning approach that will devise and train a forecast tool based on a long-term short-term memory (LSTM) convolutional neural network. We will evaluate the performance of both approaches separately for each hydro basin and operationalize daily inundation forecasting for basins that show sufficient product quality.

To address SERVIR-HKH information needs regarding estimating landslide probabilities, HydroSAR-NG will create technology to derive low-latency 30-meter resolution maps of slope motion (SLOPE30 product) and identify unstable slopes. To generate the low-latency (6-12 days) maps, we will leverage the PI s affiliation with the JPL OPERA (Observational Products for End-Users from Remote Sensing Analysis) project, which is implementing a high ARL processing chain for the generation of surface displacement information from InSAR data. We will adapt OPERA technology to the conditions in the HKH, initially focusing on high-altitude regions. An interactive cloud-based web interface will let the user create maps of long-term slope motion and accelerating slopes. The processing and detection parameters will be adjustable, allowing the workflow to be adapted to a specific region. The interface will be co-developed with SERVIR-HKH end users to maximize its usefulness for disaster management and mitigation.

To maximize the benefit of the developed tools to the HKH, we will develop an end-user engagement plan. First, all developed data analysis and machine learning tools will be open source following the NASA Earth Science Data Systems Open Source Software policy. Second, we will transition all developed tools to the SERVIR-HKH Hub to support their needs in flood and landslide forecasting and mapping. Third, we will provide end-user trainings to enable in-region partners to adopt our tools and use InSAR and machine learning for a range of environmental monitoring tasks.

While our work will be focused on the needs of the SERVIR-HKH region, analytical tools combined with targeted engagement and outreach activities will make the developed services accessible to the entire SERVIR network.

Aaron Naeger/University of Alabama, Huntsville
Enhancing Air Quality Applications in the Hindu-Kush Himalaya Region using Synergistic Remote Sensing, Modeling, and Machine Learning Techniques
21-SERVIR21_2-0052

This proposal addresses the Weather and Climate thematic service area of the A.35 SERVIR Applied Sciences Team (AST) solicitation, with a specific focus on SERVIR-Hindu Kush Himalaya (HKH) region. Air pollution in the HKH region of south-central Asia is a severe issue, as increases in emissions and pollutant levels over the past two decades have degraded air quality (AQ) across the region, which poses major threats to the ecosystem, human health, climate, and agriculture. A diversity of anthropogenic and natural emission sources including transportation, power plants, industries, open biomass burning of crop residue, forest fires, cooking and heating fires, and dust storms can contribute to the elevated pollution levels in HKH. Transboundary pollution is a major concern in the region, as high emissions from regional sources such as fires can lead to complex influences on local AQ.
The overarching goal of this proposal is to build a fully customized and sustainable AQ toolkit for advancing AQ monitoring, forecasting, and management decisions in the HKH focus countries. Application of our enhanced AQ toolkit will aid in characterizing and quantifying diurnally-varying source emissions and attributions on the AQ state, providing critical information to the SERVIR-HKH hub and partner agencies on transboundary pollution and local-scale AQ issues in the region. Specific objectives of the proposed project are as follows: (1) Develop cutting-edge algorithms and machine learning (ML) techniques from satellite data to deliver near real-time products and tools

with advanced precision and detail on emissions, transboundary pollutants, and local-scale AQ; (2) Implement newly customized model solutions with updated emission inventories and assimilation procedures for improving AQ forecasts and decision-making activities; (3) Actively engage with the SERVIR-HKH hub and partners in the region through workshops and training to tailor new product solutions/tools to specific stakeholder needs in each HKH focus country, maximizing the application impact and sustainability of our AQ toolkit.
Our ML algorithms will utilize spectral, spatial, and temporal information from different band combinations on new-generation geostationary satellite sensors to accurately classify dust and smoke in the HKH region. The dust and smoke classifications will be used to develop an enhanced aerosol optical depth (AOD) product and surface-level particulate matter estimates for the region. We will also operationalize a threshold-based approach using geostationary satellite data to provide fire hot spot locations throughout the daytime and nighttime. The AOD and fire detection products will be used as input into a high-resolution Weather Research and Forecasting model with Chemistry (WRF-Chem) configuration over the region. The operational WRF-Chem model will also be updated with a new anthropogenic emissions inventory based on a satellite-based adjustment method. Lastly, the fire detection locations, dust classifications, and aerosol layer height products will be used to initialize an automated HYSPLIT dispersion forecasting system over HKH for rapidly warning the public of AQ exceedances related to dust and smoke episodes. To tailor our AQ products to stakeholder needs in HKH, we will actively engage the community through workshops and customized trainings over the course of the project, supporting long-term sustainability of our products. We aim to achieve an Applications Readiness Level of 8, application system completed and qualified by the regional partners through testing and demonstration in targeted decision-making activities. Our proposed work will build upon the health and AQ focus area of the NASA Applied Sciences Program through enabling impactful applications for societal benefit, building knowledge, and expanding partnerships in the region.

Catherine Nakalembe/University of Maryland, College Park
EO-Enabled Regional and National Agricultural Monitoring in West Africa
21-SERVIR21_2-0057

Food security is the most important development objective for many countries on the African continent, yet has remained an elusive target. The increasing frequency and severity of extreme climatic events and their impacts on food systems continue to impact farmer livelihoods negatively. FAO estimated a 2.3% increase in global production in 2019 compared to 2018; however, in Africa, they estimated an overall 4.6% reduction due to conflict, socio-economic conditions, natural hazards, climate change, and pests that affected multiple countries. Although big strides are being made across the continent, poor agricultural production (due to poor access to inputs and being largely rain-dependent) remains a major driver of food insecurity. Communities in West Africa continue to struggle to recover from recurring failed cropping seasons compounded by insecurity, conflict, and the associated large-scale population displacements, which have caused an increase in staple cereal prices and persistent food insecurity in the region. The impacts of COVID-19 are expected to continue through 2022 and possibly beyond. These events, combined with COVID-related challenges, underscore the need for timely early warning and the adoption of scalable, data-driven approaches to improve decision-making for agriculture and food security in Africa. Governments in West Africa urgently need to strengthen early warning systems for food and nutrition security, providing actionable information for better and more timely decision-making. However, one of the major challenges remains the absence of reliable information on crop production prospects to support informed decisions and coordinated responses. This project will focus on capitalizing on the work-streams SERVIR West Africa is building capacity to deploy complementary models and approaches that have been applied in SERVIR E &SA and tested in Mali for strengthening operational national agricultural monitoring systems. This project will focus on Senegal and Mali, potentially expanding to Burkina Faso. The project team will work with the SERVIR West Africa Hub to improve regional agriculture monitoring and assessments leveraging Earth observations data. Building on the lessons learned in E&SA, the project will aim to launch a regional crop monitor while improving critical spatial information on crop conditions, yield forecasts, and cropland/crop-type maps that feed into crop monitoring. We will strengthen existing early warning systems through capacity development training and systems adaptation. The project team will leverage our partnership with Lutheran World Relief (LWR) in Mali and Burkina Faso to improve systems.

Jim Nelson/Brigham Young University
Integrated Global and Local Hydrologic Models for Flood Early Warning and Water Resources Management
21-SERVIR21_2-0007

We propose to engage with scientists in the Eastern and Southern Africa hub to extend global hydrologic services tools in the region with the goal of improving water resources management and reducing loss of life and property due to flood damage. This effort capitalizes on Earth Observation data, state-of-the-art hydrologic modeling, in-situ observations, and integration with local and regional expertise in the region to produce and validate the best possible hydrologic forecasts, flood impact projections, and water quality and sediment analysis. Our effort will result in a set of open source, open access, web-based tools and applications that provide ready visualization and access to all the contributing data sets. Our project builds on a successful effort to develop a streamflow prediction service through the Group on Earth Observation Global Water Sustainability (GEOGloWS) initiative and previous SERVIR and other NASA applied sciences programs. With the support of the World Bank, it is now accessible to stakeholders globally for water resources decision support and has already had some application in Africa, including countries that are part of the Eastern and Southern Africa hub. We will help scientists from the hub integrate their own existing models and services into their plans for supporting the broader stakeholder community in their region. While the global streamflow forecasts are already freely available, we will develop hub and stakeholder capacity to use and integrate the forecasts for their prioritized local needs. This will include developing applications in additional areas such as for community-based warning systems where foot bridges are critical for access and livelihood, impact-based flood mapping useful in programs like forecast-based financing, sediment and water quality analysis in watersheds and receiving bodies, as well as other priorities identified by the hub for which our expertise is relevant. Such applications will be evaluated and piloted in priority areas as determined by the hub in collaboration with their stakeholders. These water resources flood forecasting tools will be validated and improved by in-situ observations and Earth observation of flooding in real-time, and for which we will provide additional tools and training so that, where available, they can be incorporated. Our applications and tools are developed using free and open-source software, are deployed as web applications which minimizes the bandwidth and compute resources required at the hub level, and will be deployed online for hub partners as well as the broader SERVIR network. We will also provide documented source code and operational tools with the intention that hub scientists will eventually take over development and management of the system. Resulting deliverables are expected to have immediate significance for emergency responders, water resources managers, and community leaders who can benefit from water resources and flood impact predictions that could lead to improved resiliency for the often devastating effects stemming from water resources and hydroclimatic disasters. Longer term benefits to hub partners will be derived from their ability to access, update, and improve the tools and techniques at a source code level even after the current SERVIR project ends.

Efthymios Nikolopoulos/Florida Institute of Technology
Machine Learning Based Flash Flood Forecasting in West Africa with Satellite Observations
21-SERVIR21_2-0047

Information on heavy rainfall and flash flood characteristics (such as intensity, timing, and geographical occurrence) is very important for guiding preparedness and response to flash flood disasters. The currently available flood forecasting system (FANFAR) in West Africa, does not have the capacity to predict flash floods that develop at small spatial and over short temporal scales. The overarching goal of this project is to develop a flash flood forecasting system that will rely on available satellite observations and weather forecasts to deliver timely information on flood predictions at a range of spatial scales (i.e., from small urban catchments to large basins related to dam operation) and thus significantly advance the current capacity of West Africa Hub to deal with flash floods.

Our proposed flash flood forecasting system will include precipitation information from a) Near-real time satellite observations, b) numerical weather prediction models and c) Nowcasting estimates derived from a machine learning-based algorithm. The various precipitation estimates will propagate in a distributed hydrological model that will provide hydrologic predictions at every point in the river network and at the national/regional scale. Precipitation and flood prediction outputs will be integrated into the existing FANFAR platform that is available at AGRHYMET and will assist in the decision-making and management of flash flood risk.

The proposed forecasting system will provide critical information for the design and operation of relevant water infrastructure (e.g., levees, storm drainage, dams), flood insurance, and flood plain management and will ultimately assist climate adaptation and hazard mitigation strategies. The expected outcomes of the proposed development and capacity building activities of this project, include i) development of a regional end-to-end flash flood forecasting system, ii) improved utilization of forecasts for decision making through co-design with stakeholders, iii) enhanced human and institutional capability to reduce flash flood related impacts.

Izaya Numata/South Dakota State University
Monitoring Forest Carbon Dynamics in Response to Disturbances in the Southwestern Amazon
21-SERVIR21_2-0086

Amazonian forests contain one of the planet s largest biomass carbon stocks and harbor 25% of global terrestrial biodiversity. However, increasingly frequent drought events and land use intensification in the region threaten these ecosystems. The Southwestern Amazon has been the one of the most affected regions by these disturbances within Amazonia. For example, Acre in the Brazilian Amazon has shown large scale forest degradation due to drought-mediated fires, as well as the increase trend of deforestation after 2019. In the case of Madre de Dios, Peru, forest loss has been increasing due to mainly illegal gold mining. While these conditions substantially impact carbon dynamics and can destabilize forest conditions in this region, our ability to quantify carbon dynamics associated with these disturbances is limited in this region.
Our proposed project will provide stakeholders a new dataset and tool to monitor forest carbon dynamics derived from the new NASA satellite lidar GEDI in combination with other remotely sensed data for the Southwestern Amazon (Acre in Brazil, Madre de Dios in Peru). The products derived from our project will be used to answer two main questions: Q1) How do forest disturbances (deforestation, fire, drought, logging and fragmentation) impact carbon dynamics (loss and sequestration) in the southwestern Amazon? ; and Q2) how are carbon dynamics different inside and outside protected areas and by different conservation units (Indigenous Reserve, Strict Protection and Sustainable Use)? The knowledge and products generated during this project will help policymakers and natural resource managers to manage biodiversity conservation and ecosystem services and strengthen the monitoring capability of the SERVIR-Amazonia hub. The proposed project is directly responsive to the thematic service area Land Cover and Land Use Change and Ecosystems for SERVIR-Amazonia and provide support for MRV for REDD+ as well.
Our proposed project will address three major objectives
Obj1) Develop current and historical forest ACD data for carbon dynamic assessment over the southwestern Amazon for 2000-2023 using NASA optical and lidar data.
Obj2) Assess forest carbon dynamics in response to disturbances (deforestation, fragmentation, fire and drought) and recovery.
Obj3) Conduct training and capacity building to transfer knowledge and products to partners in the regional natural resource management sector.

Pontus Olofsson/Boston University
Continued Support for Estimation and Monitoring of Land Change and Forest Degradation in West Africa
21-SERVIR21_2-0041

The availability of usable satellite data in West Africa is considerably less than in many other parts of the tropics including other regions of Africa. The lack of data prior to 2017 is severe and has greatly limited our understanding of how the West African landscape has changed in the twentieth first century. The ability of decision-makers to curb and mitigate environmentally destructive processes such as the conversion of forestlands to plantations, farmlands, and mines, and the extraction of wood for fuel and charcoal, is hard (if not impossible) without geographical and statistical data. Here we propose to continue the work of AST member Pontus Olofsson to map and estimate land cover, land change, and forest degradation. We are proposing a multi-tier system that will allow us to monitor change from 2000 onwards across the whole West African Hub, including the coastal areas for which deliverables are currently missing. The proposed monitoring system uses Landsat, Sentinel-1, and Sentinel-2 data but adapts to the amount of data available. Different monitoring methods are used depending on the variability of data density in space and time. An added benefit of the multi-tier system is support for near-real time monitoring of forest disturbance. Further, the current project is limited to the analysis of land change to deforestation and forest degradation without attribution -- here we propose to identify the forest disturbance driven by establishments of plantations, agricultural expansion, mining activities, and logging for fuel and charcoal. We will rerun the workshop series focused on sampling and inference of area and map accuracy with the new Hub. We aim to physically implement these techniques across West Africa; an activity that has been hard to complete online as and will require in-country work to be successful. We aim to provide the West African Hub the capacity for monitoring based time series analysis of multi-sensor data and comprehensive support for sampling-based estimation of map accuracy and area of land cover and land change. The proposal team has a proven record of international collaboration and knowledge of working in West Africa which will increase the likelihood of proposed effort having societal impact.

Naiara Pinto/Jet Propulsion Laboratory
Unlocking the Power of NISAR for Mapping the Amazon's Forest-Agriculture Interface
21-SERVIR21_2-0021

Last century was marked by accelerated expansion of the Amazon s agriculture frontier, catalyzed by government-sponsored migration, the establishment of roads, and integration with international commodity markets. The resulting land use dynamics and deforestation rates have critical impacts on social inequalities and ecosystem services. Remote sensing has emerged as a critical tool to design and evaluate sustainability goals in the Amazon. Yet, decision makers face a major capability gap: the lack of operational systems to monitor perennial crops and their expansion in forested areas. This project aims to support subnational initiatives that work with local land owners to improve livelihoods, while shifting the balance away from deforestation by promoting plantation establishment in degraded lands, supporting sustainable agroforestry practices, and increasing supply chain transparency. In coordination with the SERVIR/Amazonia Hub and Latin American stakeholders, the PI for this project has led a research effort to operationalize oil palm mapping at the sub-national scale in Peru and Brazil. Building on these efforts, we propose to address the following objectives: (1) to increase the service s Applied Readiness from Level 6 to 8 by improving integration with local platforms and expanding list of crop species to meet stakeholder needs and (2) to transfer knowledge and technology to end-users and catalyze the incorporation of SAR observations to address locally-relevant questions.

Aditya Singh/University of Florida, Gainesville
Integrating Socio-Economic and Remotely Sensed Information to Characterize Conflict Precursors and Land Degradation Dynamics in Ghana
21-SERVIR21_2-0071

Project Summary
Processes driving land cover change are inherently complex and reflect spatio-temporal dependencies. Efforts at understanding land cover change therefore necessarily require the need for disentangling the underlying socio-political and environmental forcings. This is largely because factors influencing landscape dynamics at regional scales reflect outcomes of decisions made at the household-to-community scales. Landscape-scale changes in land cover patterns, therefore, reflect changes in economic activities that are, in turn, influenced by regional-scale land management policies. Recent land cover dynamics in Ghana offer a case study into how regional-scale policies can affect land cover change.
Policymaking aimed at mitigating land degradation and resolving land utilization conflicts, therefore, needs data on land cover and socioeconomic dynamics at high spatiotemporal resolutions. These data are not currently available in a consistent manner, especially in developing countries. In this project, we aim to leverage recently developed methods of spatiotemporally downscaling socioeconomic data (funded by the NASA Land Use Land Cover Program), identifying objects using high-resolution imagery (funded by the National Science Foundation), and combining socioeconomic and geospatial datasets (funded by the NASA-USAID SERVIR Program) to generate a fine-scale framework for identifying precursors to land degradation and conflict resolution in the greater West African region.
This proposal is aimed at SERVIR s Land Cover and Land Use Change and Ecosystems focus area. This project will advance stakeholders skills in regional land cover mapping, land planning, deforestation precursor assessments, and assessments of forest degradation linked to charcoal production and illegal mining. In addition, this project will also directly contribute to the understanding of the causality between changing socioeconomic dynamics, land cover and land use change. The goal of the proposed project is to develop a land use conflict and degradation mitigation framework by integrating high-resolution

socioeconomic data with localized information on drivers of land degradation. The framework will integrate remote sensing and GIS-based modeling, and use historical trends and causal linkages among deforestation, urbanization, and agricultural expansion. Specific objectives of the project are to 1) Development of an operational method for the detection and monitoring of artisanal mines (galamsey) and charcoal-production activities in a user-in-the-loop data fusion strategy. 2) Modification and adoption of an existing deep learning-based AI model to downscale socio-economic data on livelihoods and poverty indicators across Ghana, 3) Linking land degradation with socioeconomic indicators in a causal modeling framework, and 4) broad dissemination of training, data, code, and technology products to the SERVIR community. Primary outputs of the proposed project are 1) spatially-downscaled socioeconomic indicators, 2) operational techniques for fusing moderate- and high-resolution satellite data with high-resolution imagery obtained using custom open-source Unmanned Aerial Vehicles (UAVs) for monitoring and mapping land degradation, and 3) the generation of a webGIS-based decision-making framework to integrated socio-economic data with land degradation assessments to help minimize conflict.

Raghavan Srinivasan/Texas A&M AgriLife Research
A Satellite-Based Crop Monitoring and Forecasting System to Enhance Food Security in Nepal
21-SERVIR21_2-0056

The Hindu-Kush Himalayan (HKH) region is highly vulnerable to climate-related disasters (e.g. droughts); often leading to low agriculture production and food scarcity, which affects rural livelihoods. Furthermore, climate-driven risks of extreme weather events are expected to continue increasing in near future, and increase the risk of food insecurity and enhance the potential for civil unrest. It is thus crucial to have the ability to produce accurate subseasonal-to-seasonal (S2S) forecasts to drive crop forecasts and 2) provide reliable within-season crop conditions and yield outlooks with actionable lead-time. Such forecasts offer early warnings on impacts of extreme events and help stakeholders make sound decisions that can improve risk management and enhance policy making, and interventions. The role of such predictive tools for food security and resilient practices can hardly be overemphasized.
Responding to recurring extreme events and food security concerns in Nepal, governmental and non-governmental agencies have undertaken various initiatives to build effective monitoring and forecasting systems; e.g., Nepal Food Security Monitoring System (NeKSAP) operated by Ministry of Agriculture and Livestock Development and Agriculture Drought Warning System of International Centre for Integrated Mountain Development (ICIMOD). Even though these systems have been effective as early indicators of crop production status, they can be further improved to produce more reliable and frequent production forecasts at finer resolution. As a contribution to the NASA-Harvest food security program, we have developed a satellite-based agriculture monitoring and forecasting (SAMF) framework to provide within season crop condition and yield outlooks. This framework uses remote-sensing-derived crop variables (e.g., leaf area index), and S2S forecasts in the crop model Environmental Policy Integrated

Climate (EPIC), to simulate crop condition and crop yields periodically during the growing season.
Considering the need for comprehensive monitoring and forecasting framework to strengthen the existing systems and to contribute to the food security programs in Nepal, the overall goals of this proposed project are to 1) co-develop, in partnership with ICIMOD, an operational web-based tool using SAMF framework to provide in-season crop condition and yield outlooks at sub-district (i.e. palika) level for rice and wheat production systems with acceptable accuracy, and integrate into the existing ICIMOD s Food Security Information System, and 2) engage with various stakeholders to deliver technical knowledge of framework s usage and strengthen the existing food security programs in Nepal. Specific objectives are to 1) develop annual rice and wheat masks early in the season using a combination of SAR and optical imagery, 2) downscale and bias correct Subseasonal Experiment (SubX) forecasts to 5km using spatial disaggregation with bias correction (SDBC) downscaling approach, 3) Develop web interface to implement SAMF at the palika level over Nepal to estimate monthly crop condition and yield outlooks for rice and wheat and evaluate its performance for previous years (2021-2022) and automate the web system to create operational SAMF tool, and 4) Engage agencies involved in the Nepal food security programs to integrate SAMF tool in their programs, and conduct training program to transfer the knowledge. We will also share our products with NASA Harvest and other NASA application programs to use in their capacity building programs.
Ultimately, the research will deliver an operational web based SAMF tool and requisite training for Nepal. This tool is expected to improve the estimates of food security metrics currently produced by NeKSAP and ICMOD, and thereby help strengthen the existing systems. Contribution to SERVIR training programs will build the capacity of local agencies in the use of SAMF web tool in decision-making related to food security.

Benjamin Zaitchik/Johns Hopkins University
Subseasonal-to-Seasonal Forecast of Hydro-Ecological Extremes in the Amazon Basin
21-SERVIR21_2-0035

Hydro-ecological extremes, including high and low flows, floods, droughts, and fires, have significant impacts on ecosystems and human well-being in the Amazon. There is an expectation that the ability to forecast the probability of such extremes at subseasonal to seasonal (S2S) timescales (weeks to months) can contribute to improved preparedness and the ability to mitigate impacts. In the Amazon there is, indeed, an ability to forecast: while S2S forecasts always include significant uncertainty, both statistical and dynamically-based hydrological forecast systems have demonstrated skill in the region out to several months in some areas, thanks to a combination of reliable teleconnections and persistence of initial hydrological conditions. Statistical skill in a forecast, however, is a necessary but far from sufficient condition for actionable S2S climate services. Decision-making under the uncertainty of a probabilistic S2S forecast--even a good forecast--is a substantial challenge, and to be effective an S2S forecast platform needs to be designed to meet the information and communication needs of boundary organizations and stakeholders.

Recognizing this need for a transdisciplinary approach to S2S forecast, we have assembled a team of investigators and collaborators with deep experience in forecast-based decision making, including members who are already involved in disaster and health preparedness and response in Peru, Ecuador, Brazil, and Colombia. This team, together with members of the SERVIR-Amazonia hub and its existing network of partners and stakeholders, will [1] convene at the outset of the project to establish priority decision targets and communication strategies. We will then [2] work back from these targets to customize an S2S hydro-ecological forecast system that several of our team members have already developed for the SERVIR-Amazonia region. This customization will include evaluation and refinement of our existing platform as well as [3] coupling the system to existing climate services developed by our collaborators and by the SERVIR-Amazonia hub. Through [4] iterative design and case study applications pursued with key collaborators, we will [5] integrate forecasts to existing or newly developed planning and communication tools for fire risk, hydropower management, health early warning, food security, and disaster preparedness. In parallel, we will [6] develop our own standalone S2S hydro-ecological forecast information portal that can be hosted by the SERVIR-Amazonia hub or relevant operational partners. Ultimately, [7] the full forecast system and post-processing and visualization tools will be transferred to hydrometeorological service providers in the region. Communication channels established during the project will then be maintained by those operational partners.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences-2021
NNH21ZDA001N-HAQ
A.37 Earth Science Applications: Health and Air Quality

The Earth Science Division/Applied Sciences Program (ASP) promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science research and applications projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products in practitioners' decision-making, and transition the applications. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained uses of and sustained benefits from the Earth observations. For more information visit the Applied Sciences Program website at http://AppliedSciences.NASA.gov/.

The Health and Air Quality applications area of the ASP supports the use of Earth observations in air quality management and public health, particularly regarding infectious disease and environmental health issues. The area addresses issues of toxic and pathogenic exposure and health-related hazards and their effects for risk characterization and mitigation. The area promotes uses of Earth observing data and models regarding implementation of air quality standards, policy, and regulations for economic and human welfare. The Health and Air Quality Applications area also addresses effects of climate change on public health and air quality to support managers and policy makers in their planning and preparations.

This solicitation called for results-oriented proposals focused on the integration of Earth observations into decision making activities related to all focus areas of Health and Air Quality applications. The objectives of a proposed project must have been to a) develop and prove the potential enhancements of an application of specific Earth observations to one or more decision-making activities and b) transfer and enable the adoption of this application by one or more specific end user organizations in a sustainable manner (i.e., without continued NASA financial support post-project). NASA received a total of 68 proposals in response to this NRA element and selected 10 for support, representing a total investment of $10.2M over three years.

The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided.

Assaf Anyamba/Goddard Space Flight Center
MEDINA: Machine Learning, Climate Variability and Disease Dynamics
21-HAQ21-0027

Background:

Vector-borne and zoonotic pathogens comprise at least two-thirds of top infectious disease threats to Department of Defense (DoD) personnel and global public health, and account for more than 17% of all infections with more than 700,000 deaths per year. Current DoD and global public health surveillance systems track individual infectious disease cases to report trends across the Joint Force and the public, but these are retrospective and do not provide predictive information that could identify high-risk areas to better protect deploying service members and the global public. At present, we have the capability to leverage environmental data which underpin patterns of vector-borne disease transmission to forecast disease risk in space and time. In this proposal we describe a novel machine learning (ML) based system that synthesizes biosurveillance data, satellite climate measurements, and environmental data to serve real-time worldwide risk maps for an array of prominent and military-relevant and global public health vector-borne diseases. Epidemiologies of many vector-borne pathogens are driven by environmental conditions that critically influence vector survival, reproduction, biting rates, feeding patterns, pathogen incubation and replication, and the efficiency of pathogen transmission among multiple hosts. Specific patterns of climate and weather anomalies preceding increased vector populations and resulting disease outbreaks are extensively documented for key vector-borne diseases such as dengue, chikungunya, Rift Valley fever, Zika and hantavirus among others.

Objectives:

We propose to develop and enhance risk mapping and forecasting of a suite of vector-borne disease models driven by extreme weather/climate conditions, i.e., dengue, Rift Valley fever, Zika, hantavirus, through prototype ML methods that integrate disparate climate, model, environmental, and disease outbreak data to deliver timely disease risk maps in a unified platform called MEDINA. This platform will build on our ongoing work supporting the DoD in vector-borne disease risk mapping to serve a package of critical disease information, including historical disease outbreak distributions, baseline risk maps, and current and forecasts risk maps. Such a platform will support the dynamic needs of our collaborating partners including the Global Emerging Infections Surveillance (GEIS) Branch - Armed Forces Health Surveillance Division, Pan American Health Organization (PAHO), USDA-Center for Medical, Agricultural, & Veterinary Entomology (CMAVE), World Organization for Animal Health (OIE) and Food and Agriculture Organization of the United Nations.

Perceived Significance:

Enhancing vector-borne disease risk mapping and forecasting through use of NASA Earth Science data and model outputs we address the Decadal Survey science priorities. These priorities are also addressed by using Earth Science Mission data variety on NASA platforms in monitoring and assessments of droughts, agricultural productivity, and public health related concerns (e.g., vector-borne diseases)

Methods:

We will leverage various ML approaches that we previously developed for chikungunya and apply them to dengue, Zika, and Rift Valley fever to predict the magnitude and geospatial extent of transmission risk probabilities using a combination of climate, biosurveillance, population density, and vector distribution data. Models will be calibrated to disease presence and pseudo-absence data derived from historical outbreaks. Model selections will be based on the evaluation of validation dataset using metrics such as root mean squared error, area under the receiving operating characteristic curve, and Akaike's Information Criteria. We have employed such an approach to develop our chikungunya risk map with 0.85 accuracy (95% CI: 0.83   0.89). Outputs will be ML-based algorithms that derive risk maps for dengue, zika, Rift Valley fever, and hantavirus

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Jesse Bell/University of Nebraska Medical Center
Identifying Public Health Applications of Satellite-Derived Drought Indicators: Improved Monitoring for Respiratory Health (ROSES21)
21-HAQ21-0069

Health departments and healthcare professionals need reliable information to effectively prepare and warn constituents of pending natural disasters. Warning systems for drought are a high priority for federal and local agencies. Drought presents a complex health issue that public health agencies are beginning to identify as a serious health threat. The Centers for Disease Control and Prevention (CDC) provides public health guidance documents and other tools to help public health agencies address drought. Unfortunately, these materials are not completely effective as the linkages
between drought and health are not fully understood. To improve the capacity of state and local public health agencies in addressing drought, tools need to be developed based on regional health outcomes associated with regional droughts. A thorough evaluation of health outcomes over large spatial extents is necessary to assist health officials understand outcomes. We hypothesize that health outcomes based on drought will vary for different regions of the United States because of changes in populations demographics, local environment, and overall drought exposure. Certain underlying health disparities (e.g. race/ethnicity, age groups, occupation, rural or urban status, and access to existing health care) may give rise to greater vulnerability to drought. In addition, there are multiple environmental exposures that can occur because of drought. One of the greatest concerns is drought's ability to reduce air quality, which has been established as a key pathway for potential health outcomes. The proposed research will consider the role of drought in reducing air quality. As we evaluate various satellite-derived drought indices with satellite-derived air quality metrics, we will also identify health outcomes associated with these variables and the health disparities. Satellite-derived measures provide a key strength as an exposure source with a robust temporal and geographic coverage that exceeds limited ground monitoring data. We will apply multiple satellite-derived drought indices and satellite-derived air quality products to analyze the impacts on several health outcomes. We also propose to identify potential regional health outcomes associated with reduced air quality from drought events. Our findings will benefit public health professionals by showing utility of drought indicators in predicting health outcomes and enable the production of specialized messaging for at-risk populations. Findings will be synthesized at the state and regional level to assist with dissemination. We will present our results through prepared materials to be provided to the National Integrated Drought Information System (NIDIS) and CDC. These two agencies and public health departments will help us reach end users such as emergency managers, public health officials, and others who need such data to inform specific warnings on health threats. Summary of Work: This project will take a multidisciplinary

approach to improve understanding of drought impact on human health, particularly among at-risk populations in the United States. This will be completed in six parts: 1) Evaluation of changes in air quality caused by historical droughts using satellite-derived indicators; 2) Using national mortality records to identify the health risk associated with changes in air quality during drought events; 3) Characterize the spatial and temporal differences in associated health outcomes throughout the United States; 4) Estimate the risk of increased mortality from drought exposure and potential vulnerabilities; 5) Summarize health risks to help officials determine populations susceptible to drought; and 6) Provide information and products to NIDIS and the CDC. Project Scope and Purpose: The proposed project will use existing satellite-derived drought and air quality monitoring tools to better understand drought's role in worsening air quality and the resultant impact on human health.

Kenneth Davis/Pennsylvania State University
Improving Air Quality State Implementation Plans Using Land Surface Remote Sensing
21-HAQ21-0039

This project will enhance the performance of the air quality simulations used in California and Pennsylvania's air quality State Implementation Plans by 1) integrating state-of-the-science land surface remote sensing, specifically NASA's Land Information System (LIS), into their numerical weather models. These modeling systems are used to design the State Implementation Plans (SIPs) used to attain the National Ambient Air Quality Standards (NAAQS). We will apply the NASA LIS in the NASA Unified Weather Research and Forecast model (NU-WRF) to these state's air quality simulation needs. We will then 2) assess the performance of this modeling system by comparing with state-of-the-science observations, including observations of land surface fluxes, atmospheric boundary layer properties, and pollution concentrations. We will explore options within our numerical modeling system that 3) optimize system performance across the expanded spectrum of evaluation metrics, with the aim of improving air quality simulations as a robust tool for guiding decisions concerning emission mitigation. Finally, we will 4) implement the improved simulation systems in the state air quality modeling systems.

The project addresses documented challenges in simulating air quality conditions in both states. California's San Joaquin Valley (SJV) is a nonattainment area in particulate matter of 2.5 microns and smaller diameter (PM2.5) and ozone (O3). The land surface is highly heterogeneous and includes intensive agriculture and irrigation. The simulation of air quality in the SJV has been demonstrated to be highly sensitive to the method of simulation of land surface fluxes. The heterogeneous, dynamic surface makes surface fluxes very difficult to simulate without direct observations of time-varying land surface properties such as are available through NASA's LIS. Pennsylvania's Allegheny County, which includes Pittsburgh, is currently a PM2.5 nonattainment area. Lancaster County may become a PM2.5 nonattainment area, and Philadelphia is likely to be declared a moderate nonattainment area in O3. These landscapes are also complex, including forests, agriculture and urban development. Neither state's air quality simulation system currently uses the advanced land surface remote sensing available via NASA's LIS.

We anticipate that this work will improve the simulated land surface fluxes and ABL properties in the nonattainment areas in both states, which will in turn improve the air quality modeling used to develop their SIPs. The improved atmospheric modeling will result in more robust estimates of future emission targets needed to attain the NAAQS. A more robust atmospheric modeling system will also provide better understanding of how non-linear interactions in pollution transport and chemistry will affect the combined effects of policy actions, and which portfolio of policies will be most cost-effective in achieving the air quality standards. As air quality improves with more stringent policies over time, our proposed model advancements will meet the need of future SIPs to assess the effectiveness of further air quality improvements at increasingly lower ambient pollutant levels.

Our research team will work closely with both the California Air Resources Board (CARB) and the Pennsylvania Department of Environment Protection (PA DEP) in all steps of the process. CARB and PA DEP observational and modeling teams will work closely with Penn State personnel to implement the NASA LIS / NU-WRF meteorological modeling system, merged with the Community Multiscale Air Quality model (CMAQ), in the state air quality modeling frameworks. The states will gain well-tested, state-of-the-science remote sensing inputs resulting in more physically robust air quality models, and updated, comprehensive observational assessment systems, both of which will support more robust air quality management that can serve as a model well beyond these two states.

Julia Gohlke/Virginia Polytechnic Institute and State University
Quantifying Distributional Health Damages of Extreme Weather Events
21-HAQ21-0034

The overall goal of the proposed work is to improve current methods for estimation of health costs of flooding and extreme temperature events. Current benefit-cost analyses related to extreme weather events used in decision-making in federal regulatory environments rely on spatially aggregated mortality dose-response functions to estimate health damages, with minimal incorporation of differences in health damages across affected communities or morbidity-related health costs. The proposed project addresses these gaps in current methods by: (1) spatially disaggregating exposure and estimated health costs to assess distributional impacts and, (2) incorporating health outcomes that do not result in death, by estimating healthcare costs associated with emergency department (ED) visits for injuries, diarrheal disease, cardiovascular and respiratory disease exacerbation events, and pregnancy complications. Local and federal end-users (Houston Health Department, EPA National Center for Environmental Economics, NOAA Billion Dollar Disasters) have been identified. Engagement with end-users will be supported by a partnership with Environmental Defense Fund, with ongoing projects in Houston and at the federal level, through organization of twice-yearly meetings to identify optimal routes for incorporation into relevant end user decision-making systems.

With the use of EO data and synthetic population modeling of human movements, we propose to improve estimation of proximity, and hence exposure, to extreme temperatures and flooding, while also accounting for air pollution exposures, during and following extreme weather events. First, use of gridded EO data products allows us to standardize exposure estimates across urban and rural locations despite differences in ground-level monitoring. Gridded exposure estimates of temperature extremes, flooding, and air quality will be derived from MODIS/VIIRS, NLDAS, Sentinel-1 SAR estimates, OMI and TROPOMI and MODIS/MISR and existing hybrid products. Second, modeling of differences in daily movements and evacuation decisions during extreme events will allow us to differentiate how human behaviors influence exposures within urban and rural environments.
Current extreme weather health damage functions rely on mortality-temperature and mortality-flood event relationships, as morbidity data is often not readily available, making it difficult to apply to models that need to account for health damages at a national or global scale. This is evident, for example, in NOAA's Billion Dollar Disaster reports, which do not include health impacts when estimating the economic impacts of disasters. We propose damage estimates can be improved through application of emergency department (ED) visit data currently collected through health department surveillance systems, to incorporate morbidity and quantify direct health care costs associated with extreme weather events.
Spatially resolved exposure and associated health damage estimates will allow for better estimates of the distribution of health damages associated with environmental exposures during extreme temperature and flooding events, allowing impacts to be quantified in terms of health equity. We propose to apply these improvements for estimation of exposure and associated health damages across urban and rural areas in the State of Texas from 2015-2021./ Specific objectives include: 1) Comparison of estimates of mortality associated with temperature extremes and flooding across urban and rural areas in Texas between 2015-2021, accounting for differences in air pollution exposure, 2) Determination of contributions of movements outside of home census tract to health effects associated with extreme temperatures and flooding, and 3) Determination of morbidity contributions to health costs associated with extreme temperatures and flooding, accounting for air quality differences across urban and rural landscapes.

Antarpreet Jutla/University of Florida
Assimilation of Earth Observations to Improve and Enhance Global Predictive Ability of Forecasting Risk of Cholera Outbreaks
21-HAQ21-0019

Cholera, a diarrheal disease caused by drinking contaminated water containing bacterium Vibrio cholerae, remains a global threat to public health. While cholera is not a new disease and is preventable by ensuring access to safe drinking water and adequate sanitation facilities, it is the only ongoing water-borne pandemic (since 1961) with high mortality rates. The outbreak of cholera requires two components: the trigger and the transmission. The trigger component defines conditions under which cholera bacteria survive in the environment, and the transmission component can provide pathways for the spread of vibrios in human populations. Our previous research has resulted in a calibrated and validated regional (at country scale) cholera trigger model with four weeks of forecast lead time. This model is currently operational in Yemen.

The critical challenge towards its global implementation is the earth observation-based quantification of the transmission, which is crucial to understand how cholera will spread in human communities. Historically, epidemiological models such as variants of the susceptible-infected- recovered (SIR) architecture has been used to understand how diseases like cholera spread in human communities. While the simulative properties of SIR models are unquestionably strong, the predictive abilities of these models are minimal. The reason is that these models need incidence dataset which are seldom available prior to an outbreak and have assumed boundary conditions. It translates to high uncertainties and poor decision-making abilities during cholera outbreak. We argue that a transformational approach, integrating earth observations through data-rich and adaptive theory, is needed to understand and predict the transmission potential of cholera in humans. Focusing on a global scale, this proposal aims to develop a comprehensive satellite-derived, population-based operational global cholera prediction system such that it can provide a unified trigger and transmission information for anticipatory decision-making activities for end-users.

Within this context, three specific research objectives are to: (i) Enhance the predictive ability of the cholera risk model through integration of transmission component with trigger component. (ii) Develop earth observation-based data architecture for effective dissemination and communication of cholera risks, and (iii) Develop an Anticipatory Decision Making (ADM) toolkit for the deployment of cholera modeling systems on global scales. United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA) and the United Kingdom's Foreign, Commonwealth & Development Office (FCDO) will participate as official end-user organizations. UNOCHA is responsible for releasing Central Emergency Response Fund (CERF) to the United Nations Children's Fund and World Health Organization during disasters which include disease outbreaks. The agency has provided CERF grants toward mitigating cholera in Zimbabwe, Mozambique, Yemen, and other locations in the world. However, UNOCHA requires information on when and where funding from their resources should be released on global scales to optimize resource allocations. Outputs from the proposed research will answer when and where the budget should be released by integrating knowledge from epidemiology, hydroclimatology, microbiology, and sociological processes that govern the trigger and transmission of cholera. We propose using data from multiple sensors, including GPM, TRMM, VIIRS, MODIS, and gridded products such as the MERRA-2 dataset. Deliverables include one of the first earth observation-based apps for predicting cholera, a web hub to monitor the risk of trigger and transmission, and an anticipatory decision-making framework for cholera on a global scale. We will start with ARL 7 and reach ARL 9 milestone by the end of the performance period.

Peter Kalmus/Jet Propulsion Laboratory
Neighborhood-Scale Extreme Humid Heat Health Impact
21-HAQ21-0035

Steadily worsening anthropogenic global heating is causing steadily worsening heatwaves. In coming decades, deadly heat will intensify but will be unevenly distributed in space and wealth, disproportionately affecting the tropics and vulnerable urban populations with limited or no access to reliable air conditioning (AC). Using global climate models (GCMs), high-resolution remote sensing data sets, and health data, we will create projections of humid heat to 2100 and connect them to human health impacts.

Our work will target the world's major urban centers and provide humid heat impact projections at the neighborhood scale (375 meters), capable of resolving urban heat islands and providing precise spatial guidance to enhance decision-making activities around urban climate planning for mitigation and adaptation such as cooling centers, air conditioning capacity, cool roofs and surfaces, urban forests, and parametric insurance. We will provide unprecedented spatial specificity, as well as demographic specificity by resolving impacts to vulnerable subpopulations such as the elderly and people with pre-existing conditions. In addition, our heat-health impact model could potentially enhance heat early warning systems.

We will accomplish these objectives through the use of high-resolution remote sensing data and advanced data science methods and analysis strategies developed previously. Our analysis pipeline will collect GCM projections of near-surface temperature (NSAT) and relative humidity (NSRH). Next, long-record, coarse-scale observational data sets will be used to skill-weight the GCM ensemble, and high-resolution VIIRS NSAT (modeled from the 375 m land surface temperature product) and MODIS NSRH (at 5 km resolution) will be used to statistically downscale the skill-weighted coarse-scale projections. These downscaled projections will then be converted into projections of appropriate humid heat metrics and coupled to human health at each 375 m location to 2100 using: (1) A threshold of wet-bulb temperature of 35°C, the upper limit of human thermoregulatory capacity (Raymond et al. 2020); (2) A threshold of empirical deadly humid heat, above which at least one heat-related death is expected as modeled from historical data (Mora et al. 2017); (3) Heat-related morbidity and mortality rates, modeled from hospitalization data and AC penetration data. We will produce high-resolution maps of urban centers showing the number of days per year above thresholds, and annual morbidity and mortality rates, for each year to 2100.

The JPL-led science team has partnered with the Los Angeles County Chief Sustainability Office and the international Red Cross Red Crescent. We will utilize a phased approach to operationalizing the models and projections. We will first integrate and test the application systems in data-rich Los Angeles County and California. We will then nationalize, and subsequently internationalize, the systems, focusing in particular on major urban centers in the Global South where heat-health risk is highest.

In the worst-case climate scenario, prior low-resolution studies have shown that extreme humid heat could directly affect most of the world's population, and cause widespread migration and death. Building capacity to understand precisely when and where these impacts are likely to occur is therefore important.

Katherine Emma Knowland/Goddard Space Flight Center
Supporting Local Government Public Health and Air Quality Decision-Making with a Sub-City Scale Air Quality Forecasting System from Data Fusion of Models, Satellite, In Situ Measurements, and Low-Cost Sensors
21-HAQ21-0024

This proposal will address the needs of three end-user groups for sub-city scale air quality (AQ) estimates and forecasts: 1) In Dakar, Senegal, Director Drame of the Ministry for Environment and Sustainable Development requires information to assess the impacts of new regional rail and bus rapid transit policies on spatial and temporal AQ distributions; 2) In Rio de Janeiro (Rio), Brazil, President Fajardo of the Instituto Pereira Passos (the city government's data hub) would like to expand on an existing partnership with the NASA GMAO in order to provide AQ forecasts across the city with early warnings to city hospitals to prepare for poor local AQ events; and 3) In select US cities, the Environmental Protection Agency (EPA) seeks to guide state, local, and tribal AQ managers on how to best incorporate data from low-cost sensors (LCS) into their AQ management decision-making.
To meet these needs, we propose to expand an existing AQ data fusion tool (currently ARL 6) implemented in Google Earth Engine (GEE) by our project team members at Sonoma Technology, Inc. (STI), a private AQ data company. We propose to expand the capabilities of this tool using new methods developed by the NASA GMAO (currently ARL 3) which will give it the capability of providing sub-city scale resolution and hourly frequency estimates and forecasts of three key AQ indicators: surface-level fine particulate matter mass (PM2.5), nitrogen dioxide (NO2), and ozone (O3). We will enable this capability by combining a variety of Earth Observations, some of which are already available through GEE and others which will be incorporated into GEE through this proposal. These include global AQ forecasts from NASA's GEOS-CF and ECMWF's CAMS Earth system models, satellite data from instruments such as NASA MODIS and ESA TROPOMI, and local data from regulatory-grade monitors (RGM) and/or LCS. We will implement the new data fusion capabilities into the existing GEE tool in consultation with our end-users to best address their needs for sub-city scale AQ estimates and forecasts, combining global Earth Observations with local RGM and/or LCS where available.
Our project team includes US EPA and the United Nations Environment Programme (UNEP), national and international organizations with mandates to work with end-users to effect AQ policy development and action. These organizations will facilitate our cooperation with the named end-users by leveraging existing connections. US EPA and UNEP will also ensure the sustainable operation of our GEE tool by incorporating it into their ongoing provision of AQ decision-making support to end-users in the US and globally. This will allow the adaptation and scaling of the tool in other cities and regions, increasing the project's impact and growing a global end-user community who will continue to employ, adapt, and expand the tool beyond the lifetime of this project.
The project team has expertise in atmospheric chemistry forecast modelling, satellite data, statistics, AQ data management, and policy development and evaluation which will

contribute to the project's success. The project team, including our collaborators at LDEO and Clarity Movement -- a global LCS provider -- have experience with LCS and we will work to incorporate LCS data in our proposed GEE tool. Our collaborator from WUSTL will guide our integration of various Earth Observations in our proposed GEE tool. Besides meeting the AQ estimation and forecasting needs of our end-users, this project addresses the priorities of the Health and Air Quality Applications area by creating a tool which integrates Earth Observations to address the AQ management and public health decision-making needs of our end-users. Our project's objectives are to develop and implement this tool in consultation with our end-users, apply and validate the tool through their applications, and transfer the tool to US EPA and UNEP to ensure its sustained use beyond the end of the project.

Rajesh Kumar/National Center for Atmospheric Research
Enhancing Air Quality Decision-Making Activity in Indian Megacities through Assimilation of NASA Earth Observations and Development of a Decision Support System
21-HAQ21-0020

The Ministry of Earth Sciences (MoES), India is mandated to develop air quality early warning systems (AQEWS) to timely alert the public of forthcoming air pollution episodes and implement temporary emission control measures to reduce the predicted air pollution events. As a pilot, the Indian Institute of Tropical Meteorology (IITM), the Indian Meteorological Department (IMD), and the National Center for Atmospheric Research (NCAR) have collaboratively developed an operational AQEWS for Delhi that has been providing 72-h air quality forecasts daily since 01 Oct 2018. The system assimilates the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) retrievals to improve initialization of aerosol chemical composition. The assimilation of MODIS AOD retrievals is shown to improve the accuracy of fine particulate matter (PM2.5) forecasts in Delhi by 70-86% during the crop-residue burning season. Decision-makers have found these air quality forecasts useful in imposing and/or lifting-off temporary restrictions on targeted emission sources to improve air quality in Delhi.

To expand air quality decision-making activity beyond Delhi and impose science-based temporary control measures, the decision-makers have demanded the development of similar AQEWS in other Indian megacities along with a decision support system (DSS) that will provide information about the sensitivities of predicted air quality to a set of target emission sources (e.g., construction activities, traffic, power generation, and industrial production) predefined in the Grades Response Action Plan. This project aims to meet these needs through the following:

1) Develop a machine learning based decision support system (DSS) that will help decision-makers to assess the relative importance of controlling target emission sources predefined in GRAP and implement the most effective control measures.

2) Develop high-resolution (400 m x 400 m) AQEWS for five additional Indian megacities namely Ahmedabad, Bengaluru, Pune, Indore and Bhubaneswar.
3) Integrate new capabilities in the information dissemination system.
4) Transition new capabilities to IITM and IMD.

We will define new model domains to simulate air quality in the aforementioned five cities at 400 m grid spacing and explore the feasibility of improving aerosol chemical initialization via additional assimilation of the MAIAC AOD retrievals available at 1 km resolution. Since Terra and Aqua satellites are aging, we will also develop the capability to assimilate VIIRS AOD and TROPOMI carbon monoxide (CO) retrievals in the AQEWS (including for Delhi) to ensure that air quality forecasts continue to benefit from NASA satellite observations beyond the lifetime of the MODIS sensors. The proposed DSS will be tied to the GRAP and through a machine learning algorithm that will be applied in such a way that ozone and PM2.5 can be predicted as a function of tagged CO tracers representing various emission sectors and regions, which is a computationally efficient approach to track various emission sources and regions. All the new capabilities will be integrated into the AQEWS dissemination system using the concepts of usable science. The Indian and US scientists will closely collaborate to co-design and co-develop the AQEWS and DSS to build local capacity in both chemical data assimilation and source attribution during the project itself to ensure that these skills can be used to develop AQEWS and DSS for other cities in India by Indian scientists themselves.

William Pan/Duke University
Getting to Zero: Satellite Informed System to Support Elimination of Malaria in the Americas (SISTEMA)
21-HAQ21-0026

MOTIVATION: Eradication of infectious diseases is a shared global health goal that involves: (1) management of known cases; (2) prevention of onward transmission; (3) early detection of emerging cases; and (4) management of transmission foci. These strategies were successful in eradicating smallpox and have moved the world close to eradicating polio and Guinea Worm. However, global and regional elimination efforts for any disease significantly under-utilize the power of environmental monitoring to improve identification of locations and time periods of elevated risk. This has been the case for malaria, an environmentally-driven disease for which eradication and elimination efforts have existed since 1955, yet, efforts to leverage environmental monitoring data are sparse. Since 2000, only 12 countries have achieved Malaria Elimination Certification including 2 island nations, 8 with low biodiversity or arid climates, and 1 high income country compared to 27 prior to 2000 (24/27 before 1980). Progress toward malaria elimination has stalled due to rapidly changing environmental conditions, increasing human population and mobility, social inequalities, and pathogen and mosquito adaptation. In Central America and the Caribbean, nine countries joined the Regional Malaria Elimination Initiative (RMEI) in 2018, supported by the Inter-American Development Bank and the Gates and Carlos Slim Foundations. However, RMEI

strategies do not use environmental monitoring to inform strategic response, a recognized gap by key stakeholders.
OBJECTIVE: The primary goal of this project is to develop real-time, satellite-informed tools to perform early and enhanced detection of novel malaria cases that improve the timing and spatial deployment of malaria interventions and speed progress toward malaria elimination. This project directly addresses priority topics of the NASA HAQ Area by developing earth observation (EO) tools to improve public health and contribute to the elimination of one of the most important infectious diseases in human history. This project addresses knowledge gaps described by our primary end-user the Clinton Health Access Initiative (CHAI), who collaborate on the RMEI with National Malaria Control Programs (NMCP) in the region.
APPROACH: We combine multiple streams of data--including historical malaria vector, case, and intervention data from the 1970s to the present--to produce malaria elimination support models (MESM) informed by: (1) Hydrometeorology, which consist of dynamic real-time and forecasted climate models using a Land Data Assimilation System (LDAS); (2) Pan-Tropical Climate Metrics, which quantify the propagation of multiple weather anomalies through teleconnections between pan-tropical ocean basins; and (3) Land cover analysis, which uses synthetic aperture radar (SAR) and other landcover monitoring products to characterize disease ecology. We leverage our prior experience developing a malaria early warning system (MEWS) to develop and validate new, higher-resolution Bayesian Machine Learning algorithms that combine the above data streams into risk metrics at the village level and 12-20 weeks in advance. These risk metrics will inform when, where, and what type of active interventions should be deployed to prevent onward transmission, detect cases early, and manage malaria foci. This project benefits from an experienced collaborative team that successfully developed an Amazon MEWS that integrated LDAS and landcover data to forecast malaria outbreaks at the district level.
IMPACT: Our system will be tested in Panama and Honduras, leveraging strong local presence and government collaborations of CHAI. We expect our tools to significantly improve operationalization of malaria elimination strategies by NMCP and CHAI, ultimately leading to more rapid progress towards elimination. Given our experience and strong collaboration with end-users, we start at ARL4 and expect to achieve ARL8.

Jun Wang/University of Iowa
Enrich and Enhance the Application of TEMPO and GEOS Data Products for Regional Air Quality and Public Health Management Under Smoke Conditions
21-HAQ21-0031

To be launched in 2022, the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission will provide unprecedented measurements for characterizing atmospheric composition at hourly temporal resolution over greater North America. While there are plans to make TEMPO data products operational in near real time (NRT) for regional air quality managers, what has not been planned at the time of this writing is the TEMPO aerosol optical centroid height (AOCH) and aerosol optical depth (AOD) product for operational applications. The AOCH data product was originally planned as a research product, but by leveraging Level 1B data from EPIC/DSCOVR and TROPOMI as proxy data for TEMPO, the research algorithm now has a theoretical basis in the literature, has been evaluated with sufficient case studies, and is ready for operational use.

The proposed project will first make the TEMPO AOCH research algorithm operational so the AOCH and AOD products from TEMPO can be ported to a new website for Fire and Air Quality (FireAQ) in NRT. FireAQ will leverage the software engineering structure as part of the Midwest Real-time Earth System Modeling Complex (ESMC, https://esmc.uiowa.edu) and is proposed to be an interactive online mapping system to provide decision support for our collaborators on air quality forecast and public health management. It will not only integrate TEMPO AOCH and AOD data but also the VIIRS research-grade, in-house fire combustion efficiency product with the GEOS-FP (forward processing) forecast of surface PM2.5 and GEOS-CF (composition forecast) of O3, all in NRT. This interactive tool will allow users to pinpoint any location within the TEMPO domain to obtain surface PM2.5 and O3 forecasts and AOCH data at their fingertips. Valued-added surface PM2.5 data uniquely enabled by the AOCH product will also be archived online and accessible to end users for applications such as exceptional event analysis. Intensive engagement with stakeholders is planned to evaluate the NRT value of AOCH data for air quality forecasts in the late spring and late fall when fires in TEMPO's field of regard are most likely. Consequently, applied research including exceptional event analysis will be conducted primarily in winter and early spring.

The proposed efforts will bridge application needs and TEMPO's operational data production. Published machine-learning tools will be used to provide NRT estimates of surface PM2.5 forecast bias corrections, with inputs from TEMPO AOCH and AOD data, as well as GEOS-FP meteorological and aerosol fields. Back-trajectory analysis together with the GEOS-Chem adjoint model will facilitate exceptional event analyses for our collaborating stakeholders. Aerosol profiles from the surface observation network and space-borne lidar will be used to assist the analysis of uncertainty that will be conveyed to regional air quality managers. AOCH mapping will be used to support fire exceptional event demonstrations that require satellite imagery of plume with evidence of the plume impacting the ground."

The interdisciplinary team for this project consists of satellite data product developers, air quality modeling experts, regional air quality and public health mangers, and visualization experts. They will work together to develop the FireAQ system for decision-making related to air quality and public health management. The proposed project fits well with the solicitation (NNH21ZDA001N-HAQ) that (a) encourages project teams to consider and use products from upcoming, near-term missions such as the Tropospheric Emissions: Monitoring Pollution mission (TEMPO)," (b) strongly encourages the use of Earth system science models and coupled models," and (c) aims to enhance the performance of existing decision-making activities or to develop new capabilities for decision making where the need and activity can be clearly defined."

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2021 Instrument Incubator Program
NNH121ZDA001N-IIP

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals, for the Instrument Incubator Program (IIP-21) in support of the Earth Science Division (ESD). The IIP-21 will provide instruments and instrument subsystems technology developments that will enable future Earth science measurements and visionary Earth-observing concepts.

The ESD is awarding 17 proposals, for a total dollar value over a three-year period of approximately $50 million, through the Earth Science Technology Office (ESTO).

The Instrument Incubator Program (IIP) supports the development of innovative technologies for new Earth observing instruments, sensors, and systems in support of Earth science. The technologies and measurement concepts developed under the IIP may extend through to field demonstrations, with a longer-term aim for infusion into future ESD research, applications, and flight programs.

The goal of the IIP is to promote innovation in the research, development, and demonstration of new measurement technologies that:

- Enable new or greatly enhanced Earth observation measurements, and
- Reduce the risk, cost, size, mass, and development time of Earth observing instruments

Fifty Six IIP-21 proposals were evaluated of which 17 have been selected for award.

They are:

Alexander Akins/Jet Propulsion Laboratory
Separated Thinned Array for Sensing of Ice Sheets (STASIS)
21-IIP21-0019

The key objective of the Separated Thinned Array for Sensing of Ice Sheets (STASIS) concept study is to demonstrate feasibility of a constellation microwave interferometer approach to derive high resolution 3D maps of ice sheet temperature. Ice sheet temperature with depth is a fundamental parameter for ice process models and important to studies of ice mass balance and rheology. Accurate measurements of ice sheet temperature can benefit efforts to predict changes in ice mass balance and sea level over time, a high priority for NASA. However, only limited observations of these parameters exist due to the practical difficulty of in situ sampling. Passive microwave instruments are uniquely sensitive to thermal emission from deep within ice sheets. Observations at these wavelengths require up to 10-100m diameter antenna apertures to resolve variations in subsurface properties at 10km resolution, which is impractical for a real-aperture system. Interferometric aperture synthesis, or the correlation of measured intensity from several independent radiometer instruments, within a satellite constellation could be used to obtain high spatial resolution measurements of ice sheet state while bypassing the challenges associated with a single, large antenna. We propose a ICD modeling and feasibility study of disconnected interferometric radiometric techniques for long-wavelength remote sensing of polar ice sheets. In this concept, signals from 2 or more small satellites with broadband antennas are correlated to form interferometric baselines. Given a relatively time invariant target like the deep ice temperature of Antarctica, the complete set of interferometric baselines can be measured over many weeks to months, making a distributed array formation a feasible solution. We will develop a simulation to generate synthetic interferometric images of polar ice structure for a given constellation geometry and instrument design. This simulation will then be used to 1) parameterize the relationship between constellation design and the spatial/temporal resolution for ice sheet observations; 2) assess the contribution of systematic uncertainties to the absolute accuracy and precision of the derived polar images; and 3) study mission systems engineering trades. The measurement method discussed above represents an order of magnitude improvement in the spatial resolution of long wavelength passive remote sensing of the Antarctica ice sheet. The emergence of small satellites and low-cost ride-share options to space make this approach an attractive alternative to a 10-100m deployable real-aperture that would otherwise be needed. Measurements of deep ice sheet thermal structure at this enhanced spatial resolution would significantly improve estimates of geophysical parameters relevant to ice sheet modeling (e.g. deformation/sliding contributions to ice flow, geothermal heat flux). The proposed concept has the potential to provide a novel data product that will significantly improve the predictive power of ice sheet modeling by reducing uncertainties in ice flow parameterizations and is therefore relevant to the NASA Earth Science Focus Area of Climate Variability and Change. The duration of the proposed study is 18 months, and the entry and exit TRL of the concept are TRL 1 and TRL 2, respectively

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Darmindra Arumugam/Jet Propulsion Laboratory
Rydberg Radar: A Quantum Architecture Covering the Radio Window for Multi-Science Signal of Opportunity Remote Sensing with Focus on Land Surface Hydrology
21-IIP21-0020

We propose a concept for a high sensitivity, dynamically tunable, and ultra-broad-band radar system, named Rydberg Radar, that dramatically improves over the state-of-art radar using quantum Rydberg atomic sensing. The Rydberg Radar instrument concept vastly improves the existing radar capability to study dynamics and transients of the Earth system by enabling a single-detector-based measurement covering the entire ‘radio window’ (0-30 GHz) in a small form-factor deployable-free architecture. This fundamentally novel technology has the potential to enable multi-science applications covering various bands and applications on a single platform, including in focus areas of planetary boundary layer (PBL), surface topography and vegetation (STV), surface deformation and change (SDC), and sub-surface structure and change (SSC). The high sensitivity and very low-noise (ultimately limited by quantum-projection noise), ultra-broadband (10kHz-1THz), quantum down-conversation of radio signaling (no antenna, RF front-end, or mixers), and compact form-factor of the quantum Rydberg atomic detector (detection volume <1cubic-cm) makes the Rydberg Radar a vast improvement over traditional radars with potential for high-impact in all radar missions of the future.

The objective of this proposal is to develop the Rydberg Radar instrument concept for a CubeSat platform as part of a coordinated multi-satellite signal of opportunity (SoOp) concept to address dynamics and transients in land surface hydrology (LSH) science. The benefit of this concept is that it dynamically retrieves soil moisture content (SMC) from canopy to deep-root-zone using collocated detection from C- to I-band, which are sensitive to variables including canopy water content, vegetation water content, as well as near-surface and deeper root-zone soil moisture. The proposed work develops integrated models to study the performance of Rydberg Radar in LSH science and conducts a proof-of-concept SoOp detection. In addition, specific component level requirements for the Rydberg Radar system is developed.

The concept studied is composed of multiple coordinated CubeSats, where each CubeSat instrument concept architecture is composed of a dual-polarization fiber-coupled-laser Rydberg detector node with excitation, detection, and digital systems. Specific bands addressed for the LSH science in this concept are SoOps at 137MHz/260MHz/360MHz/1.5GHz/2.3GHz/3.9GHz (I/P/L/S/C bands), although the technology can be tuned to higher frequencies for other science applications. The concept has an entry level TRL of 2, with many critical components and subsystems at a considerably higher TRL. We will raise to TRL 3 over the 18-month effort.

Srinivas Bettadpur/University of Texas, Austin
Quantum Gravity Gradiometry In Hybrid Architectures with Satellite-to-Satellite Tracking for Spaceborne Earth System Mass Change Measurements
21-IIP21-0036

A hybrid architecture is envisaged for obtaining high-spatial-frequency mass change data from cross-track gradiometers in conjunction with the twin constellation of GRACE-like satellite to satellite tracking mission. A JPL/SURP-sponsored effort has shown the benefits of the cross-track gradient configuration at 10 micro Eotvos precision.

Quantum gravity gradiometry (QGG) uses ultracold atoms as test masses for absolute gradient measurement. However, the accuracy of baseline for gradient measurements, i.e., the separation of atomic clouds, has not been demonstrated to meet the demand of future QGG sensitivity requirements. Specifically, for a nominal 1500 Eotvos cross-track gravity gradient in GRACE orbit, a 10 micro Eotvos resolution requires a baseline stability of <10^-8, which is < 10 nm for a 1-m baseline.

Through this IIP-ICD effort, we propose to develop observation mathematical modeling for the hybrid architecture, address challenges such as spacecraft pointing, and technically demonstrate the feasibility to obtain baseline resolution to support the measurement concept. Through the results of this effort, a TRL-1 to TRL-3 transition is anticipated. The period of performance is expected to be between Feb 1, 2022 and September 30, 2023.

William Blackwell/Massachusetts Institute of Technology
Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR)
21-IIP21-0007

Recent advances in deployable, rigid, panelized antennas and low-noise RF silicon-on-insulator (RFSOI) integrated circuits now make possible a new class of instruments that offer low-power, low-mass, low-cost, high-performance, and compatibility with ESPA-class small satellite systems. In this proposal, we demonstrate system-level technologies supporting a Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR), and we develop a complete ProtoType (PT) of this instrument (PT-CREWSR) that demonstrates all the needed core technologies of a large-aperture CREWSR instrument that would benefit many earth science focus areas that rely on microwave imaging and sounding.

The PT-CREWSR instrument that we propose to build and test will operate at 23.8, 31.4, and 50-58 GHz and will include a 0.6 m x 0.9 m lightweight thin-panel configurable reflectarray that can electronically scan the antenna beam over a 45-degree field of view in two dimensions. The PT-CREWSR instrument will demonstrate all the core technologies needed to realize a very-large-aperture (1.8 m x 1.8 m) system comprising six of these panels, which can be folded up into an ESPA-class small satellite and deployed to achieve a factor of ten improvement over current state-of-the-art microwave temperature sounder spatial resolution. The single panel to be built as part of the PT-CREWSR instrument will consume less than 3W of average power with a mass less than 3 kg and will provide the performance of a phased array system with a factor of 100 reduction in power consumption, as no amplifiers are needed in the reflectarray surface – only low-power FET switches are used in each of approximately 20,000 elements in the panel to select one of 16 different phase states. Simulations of the antenna feed, reflectarray antenna elements, and the custom 45RFSOI beamformer radio frequency integrated circuits (RFICs) developed as part of this work yield excellent performance with antenna beam efficiencies of approximately 95 percent over the entire scanned field of view. The ultracompact feed module at the focus of the reflectarray comprises an entire tri-band radiometer with antenna feeds, calibration network, filter bank, and digital processing and control electronics. A computer board operates the radiometer and controls the reflectarray surface to permit switching of the antenna beam state on the order of a microsecond. The noise performance of the PT-CREWSR demonstration instrument proposed here will be at least as good as current state-of-the-art sensors such as the Advanced Technology Microwave Sounder, as the losses in the reflectarray surface (approximately 3 dB) are completely counteracted by the fact that PT-CREWSR can observe the field of view four times as long as a constant-velocity, mechanically cross-track-scanned system with a +/-45-degree field of view.

In addition to the realization of very large apertures from an ESPA-class small satellite platform, the electronic beam steering capability opens up a broad new trade space of how satellite-borne radiometers can be operated, both in low-earth and geostationary orbits. The beam can be pointed at any point in the field of regard at any time, and this permits much more sophisticated spatial and angular sampling of the scene to be achieved. The spatial sampling could be dynamically optimized based on the characteristics of the scene being viewed, and super-resolution techniques could be used to focus on a region of interest to further improve spatial resolution by a factor of two with no increase in noise.

The project is led by MIT Lincoln Laboratory, who will provide the reflectarray and system integration and test in collaboration with U. California-San Diego, who will provide the phase shifter and beam forming RFICs. Entry TRL is 2 and exit TRL is projected to reach 5.

John Conklin/University of Florida, Gainesville
Simplified Gravitational Reference Sensors for Future Earth Constellations
21-IIP21-0012

Our team led by the University of Florida, in collaboration with Caltech/JPL, Ball Aerospace, and Embry-Riddle Aeronautical University propose to elevate a Simplified Gravitational Reference Sensor (S-GRS), an ultra-precise inertial sensor for future Earth geodesy missions, from TRL 3 to TRL 5. These sensors are used to measure or compensate for all non-gravitational accelerations of the host spacecraft so that they can be removed in the data analysis to recover spacecraft motion due to Earth's gravity field, the main science observable. They consist of a dense metallic test mass that is free-falling inside an electrode housing. When operated as an accelerometer, small electrostatic forces are applied to the test mass to keep it centered in its housing. The applied force provides information about spacecraft acceleration. In a drag-compensated scheme, spacecraft propulsion is used to directly compensate for atmospheric drag, reducing the electrostatic force needed to keep the test mass centered and also the force noise on the test mass. Low-low satellite-to-satellite tracking missions like GRACE-FO that utilize laser ranging interferometers are technologically limited by the acceleration noise performance of their electrostatic accelerometers, as well as by temporal aliasing associated with Earth's dynamic gravity field. The current accelerometers, used in GRACE and GRACE-FO have a limited sensitivity of ~1E–10 m/s^2 Hz^1/2 around 1 mHz. The S-GRS is estimated to be at least 40 times more sensitive than the GRACE accelerometers if operated on a GRACE-like spacecraft bus and more than 500 times more sensitive if operated on a drag-compensated platform. The improved performance is primarily enabled by (a) removing the small test mass grounding wire used in the GRACE accelerometers and replacing it with a non-contact UV photoemission-based charge management system, (b) increasing the mass of the sensor's test mass, and (c) increasing the gap between the test mass and its electrode housing.

The S-GRS concept, as well as two candidate mission architectures, were developed in our current IIP Instrument Concept Demonstration (ICD) project. During our ICD effort we have shown that this level of improvement allows future missions to fully take advantage of the sensitivity of the GRACE-FO Laser Ranging Interferometer (LRI) in the gravity recovery analysis. The S-GRS concept is a simplified version of the flight-proven LISA Pathfinder GRS. Our performance estimates are based on models vetted during the LISA Pathfinder flight and the expected low Earth orbit spacecraft environment based on flight data from GRACE-FO. The relatively low volume (~5,000 cm^3), mass (<13 kg), and power consumption (<20 W) enables use of the S-GRS on ESPA-class microsatellites, reducing launch costs or enabling larger numbers of satellite pairs to be utilized to improve the temporal resolution of Earth gravity field maps.

Our approach to advancing the technology readiness will follow two primary paths. The first will be to develop a Metrology and Charge Management Testbed at the University of Florida that will be used to demonstrate S-GRS readout sensitivity, charge management performance, and test mass and drag-compensation control system performance in a hardware-in-the-loop configuration. These tests will first be done on a bench-top in air (TRL 4), then a higher fidelity unit will be tested in the UF thermal vacuum chamber (TRL 5). The second path will be to produce a Structural, Thermal, and Optical prototype and test it in the relevant environment through shock and vibration testing and thermal vacuum chamber testing. This TRL 5 prototype will be designed and fabricated by Ball Aerospace with oversight from UF. This programmatic choice expedites technology transfer to industry allowing earlier flight readiness. The success of this project will allow the S-GRS to be ready for a flight demonstration in the second half of this decade.

Madeline Cowell/Ball Aerospace & Technologies Corporation
Multi-Functional Lidar Measurements to Identify and Characterize Marine Debris Using Time-Resolved Fluorescence
21-IIP21-0035

Current remote sensing systems are not optimized to monitor the exponential increase of marine debris pollution, nor quantify its impact to ocean health. While passive imaging spectrometers with near infrared (NIR) and shortwave infrared (SWIR) bands provide some limited utility in identifying debris floating on the surface, most debris is submerged and these systems cannot “see” below the water’s surface. Building on the near/below surface studies of phytoplankton using CALIPSO, we propose to investigate the capability of a fluorescent lidar system, to both identify and characterize near-surface and submerged marine debris.

Our goal is to characterize the laser induced fluorescence (LIF) return of marine debris both in the spectral and time domain. We will include measurements from naturally occurring targets, such as phytoplankton, to demonstrate sufficient differentiation in aquatic scenes between biogenic and anthropogenic material. Time-correlated single photon counting (TCSPC) will provide a measure of fluorescence lifetime of the various targets. After having success measuring fluorescence spectra and fluorescence lifetime independently, we propose to expand upon this research to feed into this study. The laboratory measurements will consist of a tunable pulsed laser as the excitation source, a photon-sensitive fast detector, and spectral filters tuned to the target's peak emission wavelength. To ensure high probability of classification, machine learning algorithms will be developed and tested. The results of this study will define the sensitivity of the fluorescence return for future performance modeling necessary for developing an effective space-based lidar system. Ultimately, this will inform a mission architecture to achieve global coverage for marine debris identification, characterization, and monitoring.

Our team includes leading lidar technologists from both industry and NASA and research and application scientists from Academia and NOAA, all focused on addressing the marine debris problem. The PI and technology team are from Ball Aerospace, with participation from NASA LARC. Research and applications support is provided by collaborators from Woods Hole Oceanographic Institution (material experts studying the change in plastic characteristics as they decay in the ocean) and NOAA (application scientists who target and remove marine debris).

Antonia Gambacorta/Goddard Space Flight Center
Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI)
21-IIP21-0033

Our Team's Hyperspectral Microwave Photonic Instrument (HyMPI) breaks away from 40-year old microwave sounding technology and breaks through to a new era of advanced measurements of Earth's atmospheric temperature and water vapor profiles.

Hyperspectral (a few hundred to a few thousand channels) microwave sensors have been strongly advocated by numerous space and meteorological agencies worldwide, to augment Earth atmosphere sounding capability of temperature and water vapor from space. In general, the strength of a microwave sensor rests in its high cloud penetrability, which enables retrieval of temperature and water vapor under all sky conditions. However, the current Program of Record (POR), (e.g., the Advanced Technology Microwave Sounder (ATMS), the Time Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)) only have a couple dozen sparsely sampled channels. This hinders vertical resolution and accuracy in the retrieved temperature and water vapor soundings, limiting data utilization. The Earth's planetary boundary layer (PBL) is the most affected region, due to the opacity introduced by the overlaying atmospheric layers.

The reason for stalled progress in hyperspectral microwave technology rests in the numerous technological challenges associated with simultaneously processing an ultra-wide bandwidth (20-200 GHz) at hyperspectral resolution (< 1 GHz), while maintaining a feasible instrument size, weight and power consumption, and cost (SWaP-C). Traditional microwave radiometers are based on radio-frequency (RF) technology whose constraints limit the capabilities of current spectrometers. However, SWaP-C can be improved by means of photonic signal processing techniques, enabled by up-conversion of a microwave signal to an optical carrier.

This proposal aims to solve the SWaP-C challenge of current RF technology by combining Photonic Integrated Circuits (PICs) and Application Specific Integrated Circuits (ASICs) into a “PICASIC” module, the heart of the hyperspectral microwave spectrometer. The results will yield a low mass, low power, high spectral resolution and wide band instrument. The PICASIC modular approach enables full-spectrum (20 – 200 GHz) and contiguous spectral coverage with a tunable capability to measure the spectrum with higher resolution where higher structure in the signal is exhibited.

The proposed PICASIC is the missing puzzle piece, the critical technology element, needed to realize HyMPI, a first of a kind combined hyperspectral microwave imager and sounder.

The NASA Planetary Boundary Layer (PBL) Incubation Study Team Report lists hyperspectral microwave sensors as an “Essential Component” of the future global PBL observing system, to provide “accurate PBL and free tropospheric 3D temperature and water vapor structure context”. We studied a Hyperspectral Microwave Photonic Instrument (HyMPI) design configured to respond to the requirements outlined in the PBL Study Team Report. One of the primary goals of this proposal is to finalize instrument design trade studies and derive a final optimal configuration ready for follow-on airborne flight demonstrations.

Key to improved retrieval thermodynamic structure are the HyMPI’s enhanced spectral coverage and resolution, uniquely enabled by the PICASIC technology. Thanks to the reduced SWaP-C also enabled by the PICASIC technology, HyMPI can meet the 5km spatial resolution requested by the PBL Study Team Report and achieve a Smallsat/Cubesat deployable capability, key to provide high temporal refresh for weather applications.

Following the proposed research effort, the PICASIC can be proposal-ready for the first in-space demonstration of an integrated hyperspectral microwave photonic system with science-grade performance.

The period of performance is February 1, 2022 to January 31, 2025. The entry TRL is 2, the exit TRL is 5.

Patrick Gatlin/Marshall Space Flight Center
Combining Distributed RF and Multi-Spectral Optical Observations for a Spaceborne 3-D Lightning Measurement Concept

21-IIP21-0042

The goal of this proposal is to advance key components of the CubeSpark measurement concept to prepare it future satellite demonstration or Earth Venture opportunities for obtaining novel, global 3D measurements of lightning. The CubeSpark concept is to use a constellation of small satellites with combined optical and RF lightning instruments to retrieve the 3D location (latitude, longitude, and altitude) of lightning flashes within thunderstorms around the globe with a spatial resolution of at least 1- to 2-km. This will make use of fast, high-resolution bispectral lightning imagers, which can be assembled using commercial-off-the-shelf (COTS) CMOS-based detectors, and a recent ESTO-funded ACT project to design a CubeSat-based RF antenna/receiver, which has a planned exit TRL of 4-5, for detecting lightning. The organizations involved in this proposal have a long heritage of developing space-based lightning instruments and missions and have demonstrated success obtaining novel and impactful measurements of lightning on a global scale.

The objectives of this work are as follows: 1) establish that a bispectral lightning imager can enhance the performance and science return of space-based optical detection of lightning for CubeSpark; 2) demonstrate a space-based time-of-arrival approach capable of measuring the 3D location to address CubeSpark science questions; 3) determine a baseline concept of operations for CubeSpark. The tasks we are proposing to meet these objectives will be completed within the time frame of 18 months. The entry TRL is 2 with an expected exit TRL of 4.

Sarath Gunapala/Jet Propulsion Laboratory
Compact Fire Infrared Radiance Spectral Tracker (c-FIRST)
21-IIP21-0025

Remote sensing and characterization of high temperature targets on the Earth’s surface is required for many cross-disciplinary science investigations and applications including fire and volcano impacts on ecology, the carbon cycle, and atmospheric composition. For decades this research has been hindered by insufficient spatial resolution and/or detector saturation of satellite sensors operating at short and mid-infrared wavelengths (1-5 μm) where the spectral radiance from high temperature (>800 K) surfaces is most significant. To address this critical need, the Jet Propulsion Laboratory and partnering institutions propose to develop and validate a compact modular high dynamic range (HDR) multispectral imager concept, with the flexibility to operate in the short, mid- or long-wavelength infrared spectral bands. The goal of this IIP project is to demonstrate this novel technology through the maturation of a mid-wavelength infrared (MWIR) imager, the Compact Fire Infrared Radiance Spectral Tracker (c-FIRST), which leverages digital focal plane array (DFPA) development from the Advanced Component Technology (ACT) Program. The DFPA is hybridized from a state-of-the-art high operating temperature barrier infrared detector (HOT-BIRD) and a digital readout integrated circuit (D-ROIC), which features an in-pixel digital counter to prevent current saturation, and thereby provides very high dynamic range (>100 dB). The DFPA will thus enable unsaturated, high-resolution imaging and quantitative retrievals of targets with a large variation in temperatures, ranging from 300 K (background) to >1600 K (hot flaming fires). With the resolution to resolve 50 m-scale thermal features on the Earth's surface from a nominal orbital altitude of 400 km, the full temperature and area distribution of fires and active volcanic eruptions and the cool background are captured in a single observation, increasing science content per returned byte. The use of a non-saturating detector is novel, overcomes previous problems where high radiance values saturate detectors (which diminishes the science content and usefulness of the data), and demonstrates a breakthrough capability in remote sensing – one with broad applicability in both terrestrial and planetary settings. By incorporating this technology, c-FIRST is suitable for quantifying emissions from fires and volcanic eruptions of different temperatures and intensities, which is critical for establishing their impact on ecosystems, carbon fluxes, and air-quality at local scales and climate at global scales. c-FIRST will incorporate artificial intelligence (AI) approaches to identify events of high scientific value (e.g., wildfires and volcanic eruptions) while limiting the need for significant onboard storage or high bandwidths for data downlink, which is a particular handicap for high-spatial resolution satellite sensors. When deployed in a future constellation (not proposed as part of this work), multiple instruments could communicate directly with one another to perform continuous tracking and focused quantitative characterization of the thermal emissions from fires and volcanoes. This modular, AI-enhanced instrument design will enable and accelerate the development of constellations of intelligent, interacting Cube- or SmallSats. The period of performance of the project is 3 years, with an entry TLR of 3 and a planned exit TRL of 5.

Felipe Guzman/Texas A&M Engineering Experiment Station
Compact Optomechanical Accelerometers for Space Geodesy
21-IIP21-0014

GRACE has fundamentally improved our understanding of the surface anomalies in Earth's gravitational field and its dynamics. However, GRACE has shown that certain technologies, such as low-frequency high-sensitivity accelerometers, require improvements in both sensitivity and reliability to ensure future high quality science outputs. Significant progress in the development of optomechanical sensing technologies has been achieved by the scientific community over the past decade. Building upon these advancements, we target the development of compact optomechanical low-frequency acceleration sensors with sensitivity levels that enable mass change and geodesy observations.

Monolithic inertially-sensitive optomechanical sensors yield high mechanical quality factors and, therefore, high acceleration sensitivities. Readout of these sensors is performed by laser interferometry. Careful selection of materials is necessary to ensure low internal mechanical losses. Furthermore, these materials are non-magnetic resulting in a measurement system that is less sensitive to external electromagnetic fields that typically affect electrostatically readout sensors.

Material selections include low-loss glass ceramics – such as fused-silica – and crystalline silicon or silicon-nitride, among others. The materials used to fabricate the mechanical oscillators and the built-in optical components – which constitute the compact test mass sensing interferometers – are inherently compatible with vacuum operations and show low susceptibility to radiation and magnetic effects. Moreover, the materials selected typically exhibit very low coefficients of thermal expansion (CTE), in the order of 10^-7 K^-1. The design of mechanical oscillators and laser interferometer topologies are designed such that the impact of thermal effects and temperature fluctuations can be minimal. Laboratory optical sensor prototypes have demonstrated displacement sensitivities of the order of 10^-13 – 10^-15 m/rtHz over measurement frequencies of 2 mHz up to 100 Hz, respectively. Also, micro-fabricated oscillators with natural frequencies around 10 Hz and below demonstrated mechanical quality factors above 270,000; indicating acceleration noise floors at levels below 10^-10 m s^-2/√Hz, within the observation bandwidth of interest for mass change.

The Mass Change Designated Observable has identified strategic value in this technology and has funded a Category 3 effort to advance it to a level where it can be more vigorously supported by a NASA technology development program. Furthermore, it is worth mentioning the value in the realization of a US-sourced low-SWaP low-frequency accelerometer that enables Earth science applications. Presently, no similar US-sourced alternatives exist.

The Laboratory of Space Systems and Optomechanics (LASSO) research group at Texas A&M University, led by Dr. F. Guzman, will develop this instrument. LASSO will collaborate with Dr. Christopher McCullough at JPL, who will assist the research program by providing scientific expertise to help steer the technology development in a direction that maximizes scientific output, as well as by conducting gravity field recovery simulations using our experimentally determined instrument performance as determined at progressive stages in the development process.

David Harber/University of Colorado, Boulder
Compact Total and Spectral Solar Irradiance Sensor (CTSIS) Mission Concept Study
21-IIP21-0006

We intend to propose an Instrument/Measurement Concept Demonstration (IIP-ICD) to develop a detailed mission concept for a next-generation solar irradiance observation system that employs a robust and affordable mission architecture to provide future continuity of the measurement of total solar irradiance (TSI) and spectral solar irradiance (SSI). Solar irradiance, along with Earth reflected and emitted radiance, is one of the longest and most fundamental of all climate data records derived from space-based observations. Measurement of TSI and SSI, and the monitoring of small long-term changes, is necessary for the understanding of Earth’s climate.

The LASP-built Total and Spectral Solar Irradiance Sensor (TSIS-1) instrument has been operating on the ISS since 2018, and LASP is currently building the TSIS-2 instrument with an anticipated launch in late 2023. With the understanding of the need to make these measurements in perpetuity, and the advent of advanced technologies which allow for equivalent and better measurement accuracy on CubeSats and SmallSats, LASP and ESTO have embarked on the design and launch of pathfinder missions which have and will prove the ability to provide solar irradiance measurements using smaller, low cost, reliable platforms. The first demonstration was the launch of Compact Solar Irradiance Monitor (CSIM) which demonstrated the ability to make equivalent measurements with a CubeSat form factor. The next demonstration will be the ESTO-funded Compact Total Irradiance Monitor (CTIM) mission with a planned launch in 2022.

The natural technical evolution is to develop a single, compact system, which includes both the Total and Spectral Irradiance sensors. This new platform, which LASP is calling the Compact Total and Spectral Solar Irradiance Sensor (CTSIS) will enable robust, long term, low cost, resilient measurements. During the first phase of the planned 12-month study two to three distinct mission architectures will be identified, such as a small constellation of 12U CTSIS CubeSats with a two-channel CSIM and a four-channel CTIM versus a 50 kg class CTSIS SmallSat with a three- channel CSIM and a four-channel CTIM. In parallel, we will summarize desired modifications to future CSIM and CTIM instruments based on lessons learned during the CSIM flight and the CTIM I&T, and the estimated impact of these modifications on the cost and performance of future CSIM and CTIM instruments. Next, the team will work through a manufacturing, build, calibration and storage plan of the different mission architectures, followed by the development of a mission timeline for each architecture. Finally, these inputs will allow us to estimate the lifecycle cost, and the resiliency of each architecture. These results will be compared directly against the estimated cost and resiliency of a “build to print” implementation using the heritage TSIS-1 instrument designs, similar to TSIS-2. These results will be summarized in a final report at the conclusion of the study. The ultimate goal of this study is to identify and document a new mission architecture, leveraging the CSIM and CTIM instruments, which will provide solar irradiance measurement continuity at a significantly lower cost, and greater or equal resiliency, than a TSIS-1 rebuild. Entry TRL at the CTSIS system level is TRLin = 2 with a planned exit TRLout = 3.

Yunling Lou/Jet Propulsion Laboratory
Flexible Configuration Distributed Synthetic Aperture Digital Beamforming Radar (FlexSAR)
21-IIP21-0028

We propose to develop technologies for a flexible, scalable, and adaptive distributed architecture for implementing synthetic aperture radar (SAR) systems, hereinafter referred to as “FlexSAR,” to address a number of targeted observables (TOs) identified by the 2017-2027 Decadal Survey. Considering the diversity of products needed to accommodate the Surface Topography and Vegetation (STV) TOs, and the resulting observational frequencies and modalities, a fundamentally new approach to realizing this vision must be developed. We therefore propose the FlexSAR technology such that multiple observational needs can be realized within the same unified architecture. The proposed technology hinges on digital beamforming electronics that are (1) flexible and scalable across a large frequency range including P-band, L-band, and beyond, (2) reconfigurable for different imaging modalities such as polarimetry, interferometry, ScanSAR, and spotlight mode SAR, (3) reconfigurable for resolution and spatial coverage. This architecture will be suitable for implementation on low cost distributed platforms such as CubeSats, achieving a large synthesized aperture via docking of multiple CubeSats that provides high signal-to-noise ratio, high effective spatial resolution, reduced overall system risks and potentially overall system costs, unprecedented flexibility and reconfigurability, and increased resilience compared to traditional one-off SAR systems.

We will demonstrate the FlexSAR architecture with L-band and P-band SAR. L-band is chosen due to its commonality amongst multiple STV and Surface Deformation and Change (SDC) observables. P-band is chosen due to its ability to penetrate dense vegetation, an advantage in solid Earth and vegetation structure observations as the majority of the land surface is covered by vegetation. Spaceborne P-band radar concepts have long been hindered by the lack of spectrum allocation for Earth exploration and the need for very large antennas. We plan to employ spread spectrum techniques to work around restricted bands, while this distributed aperture approach eliminates the need of very large deployable antenna structures.

New technologies are needed to enable digital beamforming across multi-platform elements of the distributed aperture. We propose to (i) design a distributed aperture architecture that will minimize grating lobes of the sparse array while optimizing radar performance, (ii) develop clock synchronization and calibration scheme for cross-platform antenna elements necessary to facilitate digital beamforming across the distributed aperture, (iii) conduct multi-frequency and imaging trade study, an incubation activity highlighted in the STV Incubation Study Report, to guide the FlexSAR design optimization and architecture, (iv) develop novel synthetic wideband waveforms to address fragmented spectrum availability in P-band, (v) develop a flexible simulation environment for multi-frequency radar retrieval of STV/SDC observables, followed by proof-of-concept science product development. To validate the multi-platform distributed aperture technology, we propose to develop Software Defined Radar electronics with clock synchronization, internal calibration, digital beamforming, and synthetic wideband waveform generation capabilities in a compact form factor. We will utilize UAVSAR's L-band active array antenna front-end to conduct airborne demonstration to further test the proposed technologies in a relevant environment. By modifying UAVSAR, NASA/JPL's airborne SAR testbed, we will simultaneously demonstrate FlexSAR's feasibility and prepare UAVSAR to help mature technology and science algorithms in support of STV studies.

The proposed development is a 3-year effort. We will enter at TRL 2 and plan to exit at TRL 5.

Richard Lynch/Atmospheric & Environmental Research, Inc.
Metamaterial-Based Super Spectral Filter Radiometers for Atmospheric Sounding of Temperature and Water Vapor
21-IIP21-0041

Through metamaterial filter development, building and testing of a benchtop prototype sensor, and atmospheric retrieval studies, the concept of an ultra-compact IR sensor for measurements of temperature and water vapor in boundary layer will be built and its capabilities demonstrated. Metamaterial-based spectral filtering offers narrow passband spectral channels in a fast-optical system to provide performance matching that of a much larger spectrometer or interferometer-based systems.
Retrieval studies using measured prototype sensor characteristics and a sensor model determined from benchtop analysis offer a way to test the application of this technology to sounding of the boundary layer and free troposphere. Optical tests on a fabricated filter array with scores of spectral bands will quantify its spectral characteristics, stray light levels, and spectral sampling performance when paired with an appropriate focal plane array. Use of the device measurements in a sensor performance model then give high-fidelity predictions of a space-based sensor using a metamaterial based super spectral sensor. Development of retrievals for sounding with a super spectral sensor and sensitivity studies using the measured prototype sensor optical characteristics produce a verification of the measurement approach for atmospheric sounding and a quantitative picture of its capabilities.

Matthew McLinden/Goddard Space Flight Center
Microwave Barometric Radar and Sounder (MBARS)
21-IIP21-0017

Atmospheric surface pressure and pressure profiles are essential variables in weather modeling and forecasting. Pressure gradients generate atmospheric motion and are essential to the air-sea heat exchange feedbacks within the planetary boundary layer (PBL) that lead to convective storms and heavy precipitation. Despite the importance of pressure and pressure gradients on meso-, synoptic-, and global-scale weather patterns, current technology relies almost entirely on buoy measurements over the majority of the ocean. These measurements are too sparse to capture pressure gradients of even many synoptic scale events, and leave models starved of information.

Data assimilation studies have demonstrated that ocean surface pressure data contain a more useful information about the large-scale atmospheric circulations than observations of surface wind or temperature. Research at the NASA/GSFC Global Modeling and Assimilation Office (GMAO) shows that assimilation of a potential wide-swath satellite-based surface pressure retrieval product significantly impacts forecasts of ocean winds and temperature from the PBL through the mid troposphere.

This joint team of NASA/GSFC, NASA/LaRC, and Remote Sensing Solutions proposes to develop a Microwave Barometric Radar and Sounder (MBARS) for surface air pressure and pressure profiles, especially over oceans. MBARS is a combined active/passive microwave sensor in the O2 absorption V-band (64-70 GHz). This instrument consists of an innovative scanning multi-channel differential absorption radar (DAR) to provide an estimation of total atmospheric column oxygen content and thus the surface air pressure. MBARS also provides radiometric temperature profiling that enables vertical pressure profiling based on the hypsometric relationship between pressure and temperature.

The proposed system leverages significant Small Business Innovation Research (SBIR) program investments, including a software-defined radar/radiometer (SDRr) and a highly efficient power amplifier. A future spaceflight instrument may also leverage one of several SBIR technologies advancing deployable antennas. Various cutting-edge communication and radar technologies used in the sensor development enable the exacting precision and stability requirements for pressure retrieval.

The proposed effort will develop and demonstrate the innovative MBARS sensor on the NASA ER-2 high-altitude aircraft. This three-year Instrument Incubator Program (IIP) Instrument Development and Demonstration (IDD) project will start on February 1, 2022, and end on January 31, 2025. The sensor development, laboratory experiment, and flight test will raise the Technology Readiness Level (TRL) of the pressure measurement concept from 3 to 5, paving the way for future spaceborne missions on SmallSat platforms.

Paul Siqueira/University of Massachusetts, Amherst
SNOWWI Snow Water-Equivalent Wide Swath Interferometer and Scatterometer
21-IIP21-0013

In this response to the 2021 ESTO Instrument Incubator Program research announcement, the University of Massachusetts (UMass), the University of Michigan (UMich), Boise State University, and Capella Space are partnering to create an advancement in using snow surface and volume scattering characteristics for estimating the snowpack characteristics of Snow Water Equivalent (SWE), snow density and snow depth, all Essential Climate Variables (ECVs) that are used to quantify water resources, land- and ice-surface albedo. The basis of the work is centered around four basic activities: 1.) airborne instrument development, 2.) ground calibration and validation campaigns, 3.) theoretical development, and 4.) the transition of these activities into a realizable spaceborne design. The fundamentals of the remote sensing technology development are the use of high-resolution volume and surface scattering signatures that occur in a dual-frequency Ku-band regime and can be expanded upon through the use of ancillary sensors, such as ESA’s Sentinel-1 C-band mission which has demonstrated a useful sensitivity to deep snow, and changes in snow cover in mountainous regions

Carl Weimer/Ball Aerospace & Technologies Corporation
Quantum Parametric Mode Sorting (QPMS) Lidar
21-IIP21-0030

Lidars and laser altimeters have demonstrated that they can bring the third dimension to satellite remote sensing for Earth Science (ICESat, ICESat2, CALIPSO, GEDI, ADM Aeolus). For future lidars to increase scientific knowledge of our planet there will need to be new technologies and new techniques. Trending is important, but new understanding of our Earth using remote sensing requires new technologies. Some key lessons learned from these past lidars/altimeters are 1) solar background light always decreases their effectiveness during the day, and 2) scenes are easily obscured by cloud, blowing snow, or turbid water - again reducing measurement quality e.g., lowering detectability of objects below and introducing biases in the science products. With next generation systems in pre-phase A development, we need to look forward now to what will follow - development cycles are lengthy.

The Quantum Parametric Mode Sorting (QPMS) lidar technique draws from developments created for Quantum Information Science (QIS). The technique uses a laser system tailored to emit in a unique Temporal-Frequency mode, a laser pulse made up of many photons all phase coherent within a pulse. The lidar receiver uses a nonlinear crystal carefully chosen to have a phase matching bandwidth smaller than the laser pulse bandwidth. This effectively creates a temporal/spectral filter, only photons in the correct mode are converted all other photons are rejected. This creates the perfect filter against background light. It also identifies signal photons that have passed through dense obscurations and still carry the precise time-of-flight to Earth scenes to allow mapping under a wider range of conditions. This is because highly multiple scattered photons will lose their intrapulse coherence and thus not be detected by the QPMS receiver. This is similar to Low-Coherence Interferometry, the basis to Optical Coherence Tomography, that allows imaging and ranging into dense tissue for medical applications.

The system is currently at TRL 4 for 1550 nm having proven out the precise ranging even through optically dense obscuration and in the presence of strong background light. The most serious of limitations of traditional up-conversion technique have been addressed with funding from ESTO (ESTO ATI-QRS-20). For it to be useful for a broader range of Earth scenes the system must be adapted to the visible spectrum where there is much lower absorption, setting the entry of the proposed development to TRL 1 The proposed effort will extend the techniques to the visible and perform lab testing in snow and water scenes. For snow the objective is to precisely measure (mm resolution) snow depth up to 0.8 m and potentially characterize snowpack properties such as grain size/shape and snow water equivalent (SWE) a critical parameter as called out in the Decadal Survey. For water it is to increase the depth at which bathymetry can be performed in turbid water. The path to a packaged system for field demonstrations and eventual space application will be evaluated. This will advance the technique to TRL 3 and prepare it for actual Earth missions at NASA, e.g., for the future snow/hydrology missions and Surface Topography and Vegetation mission.

Lauren Wye/Aloft Sensing, Inc.
HALE InSAR for Continual and Precise Measurement of Earth's Changing Surface
21-IIP21-0055

Interferometric synthetic aperture radar (InSAR) is a proven technique for observing wide-area surface deformation and topographic change at sub-cm vertical scales. However, the limited temporal resolutions of current InSAR techniques preclude the detailed study of dynamics that occur on timescales of days or hours. Substantially improved revisit times and long durations for InSAR are achievable at low cost from high-altitude long-endurance (HALE) platforms such as solar-powered aircraft and stratospheric airships. Aloft Sensing proposes to develop a high-performance compact InSAR instrument that, when hosted on these platforms, offers continual and precise collection of surface deformations and topographic changes that are unattainable with any other existing method.

Objective and Benefits: Aloft will develop and demonstrate a low-SWaP InSAR payload (<7 kg and <250 W) that enables continuous and accurate surface deformation (millimeter) and topographic measurements (centimeter) from HALE platforms. Operation from these platforms present three key challenges for InSAR: 1) limited payload size, weight, and power, 2) low platform velocities, and 3) coarse trajectory control. As a result, existing InSAR instruments and algorithms are incompatible with HALE-based operations. This work addresses all three challenges and enables new science by extending the benefits of InSAR to the stratosphere. Revisit times improved from weekly to sub-hourly (a 100x benefit), coupled with flight durations of months to years, enables the thorough capture of geophysical and topographic processes (e.g., glacier dynamics, earthquakes, volcanoes, landscape erosion), as well as real-time responsiveness to events on the ground.

Outline and Methodology: Newly available RF system-on-a-chip (RFSoC) and front-end module RF integrated circuit (RFIC) components enables a breakthrough level of integration and power efficiency for a software defined radar (SDRr) with an active electronically steered array (AESA). Once developed, the tightly integrated prototype instrument is hosted on the nimble, low-cost Swift Ultra Long Endurance (SULE) aircraft for stratospheric demonstration. Innovative processing algorithms that achieve micron-level position and milli-degree orientation overcome the challenges associated with stratospheric InSAR operation. In the first year of the program, the RFIC-based AESA is redesigned and prototyped, the payload bay of SULE is modified to accommodate the AESA, the interfaces of the RFSoC-based SDRr are verified, and the processing algorithms are defined and tested. In the second year, the SULE, SDRr, AESA, and onboard algorithms are fully integrated and verified at low altitude before initial stratospheric flight testing. In the third year, additional payload system units are manufactured for continued HALE InSAR testing and demonstration in the stratosphere, and the algorithms are efficiently embedded into a GPU/FPGA-based onboard processing solution for future operations.

Period of Performance: A three-year effort: 1 Jan 2022 to 31 Dec 2024.

Entry and Exit TRL: (Entry TRL: 3, Exit TRL: 6) Aloft has previously demonstrated SAR from HALE platforms, but the concept of InSAR from HALE is new and unproven. We have identified the hardware challenges and formulated the algorithmic approaches for InSAR, but they have not been applied experimentally. Hardware components exist at TRLs ranging from 2 to 8, but as a complete ultra-low SWaP instrument, the composite HALE-InSAR system has yet to be developed and tested. Therefore, the instrument system has Entry TRL 3. This work provides the analytical and experimental critical functioning, as well as performance validation of the tightly integrated low-SWaP hardware required for operation in a stratospheric environment. This establishes the instrument system Exit TRL at level 6.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-DSI
A.45 Decadal Survey Incubation Program: Science and Technology

The National Aeronautics and Space Administration (NASA) solicited Decadal Survey Incubation proposals to accelerate readiness of high priority observables in Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) Targeted Observables (TO) as outlined in the 2018 Decadal Survey, which are not yet feasible for cost-effective flight implementation. PBL and STV science goals call for exploring next-generation measurement approaches that could be ready for spaceborne implementation perhaps in the next decade. This program element supported the development of Earth observing instrument sensor systems, advanced information systems, and enabling science studies to further advance PBL and STV. The ultimate intent of DSI is to enable the next generation of possible measurement approaches, system architectures, and mission concepts to address PBL and STV needs. NASA received a total of 76 proposals in response to this NRA and selected 35 for funding. The total funding to be provided for these investigations for the first year of work is approximately $9.5 million. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided.

Chi Ao/Jet Propulsion Laboratory
High Resolution PBL Profiling with LEO-LEO Occultation (HiPPO)
21-DSI-21-0018

The planetary boundary layer (PBL) has been recognized in the 2017-2027 Decadal Survey for Earth Science and Applications from Space [ESAS 2017] as a key Earth science targeted observable essential across multiple discipline areas. ESAS 2017 specifically called out high-resolution vertical profiles of temperature and water vapor as well as PBL height as the most important physical parameters to measure from space. While existing remote sensing technology such as GNSS radio occultation (RO) can provide high vertical resolution refractivity (which is a combination of temperature and water vapor), it cannot disentangle temperature and water vapor within the PBL without a priori information. Emerging technologies such as DIAL (Differential Absorption Lidar) and DAR (Differential Absorption Radar) can potentially yield high resolution water vapor profiles, but they are still at low TRLs and are limited to clear and cloudy sky conditions, respectively. The technological challenges and the motivation for placing PBL observations in the incubation program are recognized by ESAS 2017 and detailed in the NASA Incubation Study Team Report for the PBL.

We propose to study a new instrument concept that offers the potential to simultaneously profile water vapor, temperature, and possibly liquid water content with high vertical resolution within the PBL. The concept is based on an emerging remote sensing technique known as LEO-LEO occultation where amplitude changes in microwave signals in multiple bands (e.g., Ka/Ku/X) are transmitted and received between two low Earth orbiters (LEO) to yield absorption due to water vapor and other atmospheric constituents. The objective of this study is to mature this concept by quantitatively assessing the expected accuracy, sampling and resolution of temperature and water vapor profiles retrievable from LEO-LEO occultation for various PBL regimes covering subtropical ocean, mid-latitude land, and the Arctic. As a result of this study, we will determine the optimal frequencies, component hardware maturity, feasibility of smallsat/cubesat implementation, and orbital configurations to achieve the desired spatial and temporal coverages.

The study will consist of three key parts. First, we will perform a theoretical study to quantify the retrieval accuracy, resolution, and depth penetration for different instrument (e.g., choice of frequencies, SNR) and PBL scenarios. Second, we will characterize the spatial and temporal sampling of these measurements with different orbital configurations, including constellations of smallsats comprised of a few to tens of satellites in varying altitudes and inclinations. It is expected that different orbital configurations will be optimal for the study of different PBL regimes and associated science objectives. Third, we will document instrument performance requirements and assess the current hardware sub-component maturity level, with a goal to enable a smallsat/cubesat class instrument concept. Successful completion of the proposed research will bring this instrument concept, which we refer to as High Resolution PBL Profiling with LEO-LEO Occultation (HiPPO), from an entry TRL of 2 to an exit TRL of 3. Furthermore, we will identify the paths required to mature the technology beyond TRL 3.

The HiPPO instrument concept is a compelling extension of RO signals of opportunity. While similar concepts have been previously proposed to both NASA and ESA, the significant and unique application of such a technique to PBL profiling has never been rigorously explored. The proposal team consists of instrument and retrieval experts in RO and microwave technologies that will ensure that the study objectives are met and to support the technology developments in the PBL Incubation Program.

Avelino Arellano/University of Arizona
Advancing Capabilities for Systems Analysis of PBL and Its Interactions with the Earth System
21-DSI-21-0051

As new concepts to observe the planetary boundary layer (PBL) from space are being planned and current observing systems are subsequently advanced, the ability to integrate these observational constraints into numerical models of weather and climate correspondingly needs to be developed.In response to the NASA ROSES 2021 A.45 Decadal Survey Incubation (DSI) program (2.1.1 PBL Science), we propose to: a) develop and advance ensemble-based approaches to assimilate current and potential future observations of PBL properties within a coupled numerical prediction system (Program Element 2.1.1.2); b) conduct observing system experiments (OSEs) for program of record (POR) datasets to assess how these sensors can be better exploited including their synergies; (Program element 2.1.1.1); and c) conduct sensitivity studies to identify potential gaps and investigate how best to augment the POR infrastructure with new observation concepts. We focus our analysis on systems over the United States using a high-resolution configuration of the NASA Unified Weather and Research Forecasting (NU-WRF) model and an ensemble-based data assimilation software (Data Assimilation Research Testbed, DART). We explore new advances and introduce refinements to contemporary multi-scale data assimilation strategies that would be more practical yet most effective for PBL observations. For example, ensemble-based systems, such as DART, can represent flow-dependent covariances and add new (complex) observation operators without the need of building their adjoints. This is especially relevant for PBL height (PBLH) observations since PBLH is a diagnostic variable in WRF and other NWP systems that needs to be related to the atmospheric state vector through an observation operator and its adjoint. In this work, we take advantage of ensemble covariances between atmospheric states and PBLH variable to construct the necessary observation operator. We conduct a suite of observing system experiments (OSEs) using NU-WRF/DART to demonstrate the impact of PBL height (PBLH) retrievals on short-to-medium range weather forecast. In particular, we assimilate into WRF: 1) lidar backscatter PBLH retrievals from the Automated Weather Service (AWS) network of lidar-based ceilometers, 2) thermodynamic profile retrievals from Atmospheric Emitted Radiance Interferometer (AERIoe), along with 3) GNSS-RO, and 4) conventional meteorological observations (e.g., radiosondes). This observing system (while upward looking) mimics the combination of space-based lidar and hyperspectral IR components for the targeted observables (T,Q profiles+PBLH) identified in the NASA PBL Incubation Study Team Report. First, we analyze their corresponding impacts and synergies using high-quality measurements from 2015 PECAN field campaign. We will then evaluate and assess their constraints on land surface states, especially in updating estimates of surface fluxes, and soil moisture and temperature. Lastly, we assess the robustness of these impacts by conducting short DA experiments on sensitivity to model physics schemes, sampling resolution of PBLH and AERIoe, and regional DA using PBLH across the Unified Ceilometer Network along I-95 corridor. Our emphasis will be on building this capability and creating a robust methodology in exploiting observational synergies across the land atmosphere interface, while addressing inherent (and unique) challenges in assimilating PBL datasets, which exhibit characteristics of nonlinearity, non-Gaussianity, and greater degree of inhomogeneity.

Rory Barton-Grimley/Langley Research Center
Combining Lidar Profiles of Aerosol and Water Vapor to Determine PBL Height
21-DSI-21-0076

The 2017 Decadal Survey for Earth Science Applications from Space (ESAS) as well as the PBL Incubation team report identified the planetary boundary layer height (PBLH) as a Most Important" observable. High resolution observations are required, 5-to-10-fold improvement over the Program of Record (PoR), to improve model representation of key exchange and feedback processes that contribute uncertainty in our understanding of weather and climate systems. Lidar was identified as an optimal measurement candidate in both reports to overcome observational gaps and provide high spatial resolution distributions of PBLHs compared to the PoR. Water vapor (WV) differential absorption lidar (DIAL) was specifically identified for its additional cross-cutting capabilities beyond 'standard' backscatter lidar, providing high resolution WV profiles. Techniques and airborne instrumentation for WV DIAL and for High Spectral Resolution Lidar (HSRL) profiling of aerosol properties have been developed and deployed at NASA Langley Research Center (LaRC) for decades. This airborne PoR forms the foundation of our proposal to combine cross-cutting and synergistic observables of aerosol optical properties and atmospheric state parameters to improve the spatial resolution, coverage, and retrieval accuracy of PBLHs compared to traditional aerosol gradient methods.

The HSRL and DIAL data sets form a rich PoR for advancing PBLH algorithms and determining priorities for future space-based PBL lidar. The LaRC airborne lidar PoR will be leveraged to optimize the accuracy and spatial coverage of a heritage Wavelet Covariance Transform (WCT) PBLH algorithm, remove the need for manual optimization when measurements span diverse atmospheric and geographic conditions, and provide uncertainty estimation. Performance of this heritage algorithm is fundamentally limited in certain environments as current methods employ only lidar backscatter profiles as input. To further constrain the traditional PBLH algorithm to improve accuracy and coverage, additional lidar observables from the airborne PoR will be incorporated, namely depolarization and color ratio as these are advantageous for PBLH determination and are tractable elements for most lidar architectures (i.e., not exclusively HSRL or DIAL).

We propose a threefold approach to optimizing lidar PBLH retrievals and informing the design of a future space-based PBL observing system. First, we will incorporate additional aerosol intensive variables (depolarization and color ratio) into the PBLH algorithm. We will evaluate the extent to which variables independent of aerosol loading intensity can help improve retrievals of PBLH in cases where aerosol gradients confound traditional methods. Second, we will incorporate WV DIAL profiles to further constrain the PBLH retrieval. It is anticipated that high vertical resolution profiles of atmospheric state variables like WV will significantly improve the coverage and accuracy PBLH retrieval over clean open oceans or heterogeneously loaded PBLs where lofted aerosol gradients are adjacent to the surface-connected layer. A sensitivity study will also be performed utilizing the DIAL retrieval's precision-vs-resolution trade space to determine the upper limit on PBLH retrieval resolution; the first work of its kind. To bookend the advances in the PBLH retrieval and inform the formulation of a future space-based PBL optimized lidar, we propose to employ the optimized algorithm to simulated space-based lidar scenes using both airborne and reanalysis data to generate the scene. We will employ a flexible instrument forward model, novel signal processing techniques, and a combination of lidar observables to evaluate the improvement to the coverage and accuracy of PBLHs retrieved from space-based lidar compared to the PoR. These improvements will be documented and help the formulation of a future PBL optimized space-based DIAL. The period of performance for this project is 36 months.

Ruben Delgado/University of Maryland Baltimore County
Quantifying the Accuracy of Combined Artificial Intelligence Microwave/Optimal Estimation Infrared Single Footprint All-Sky Retrievals in the Planetary Boundary Layer
21-DSI-21-0033

We propose to assess the accuracy of thermodynamic retrievals in the Planetary Boundary Layer (PBL) using the current generation of satellite-based microwave (MW) and infrared (IR) instruments. When compared to measurements from aircraft and continental US ground based lidar/ceilometers (L/C)networks and global sonde database, will allow us to carry out the assessment over all seasons and under a variety of climate conditions. An important parameter, namely the PBL height (PBLH), will be computed from satellite instrument retrievals using the derivative of the relative humidity with respect to pressure.

The combined MW and hyperspectral IR sounder thermodynamic retrieval will work at the single field of view IR horizontal resolution (currently 15 km) under heterogeneous cloud conditions. The microwave sounder will provide thermodynamic profiles even if the conditions are cloudy; the infrared sounder will improve the vertical resolution of the retrieved products. The core of the retrieval will be a combination of MIIDAPS-AI, an Artificial Intelligence (AI) based algorithm for the microwave (MW/IR) retrievals, fed into a physically based Optimal Estimation Method (OEM) algorithm coupled to a fast scattering radiative transfer algorithm (RTA) for the infrared retrievals. The novelty of the single footprint infrared (SFPIR) retrieval is the cloud initialization (cloud loading, cloud top/bottom, cloud fraction), using a combination of best initial fit" clouds from a Numerical Weather Prediction (NWP) model and cloud profiles obtained from the AI/MW retrieval. Two (randomly overlapping) clouds can be handled in each retrieved column, either or both of which can consist of ice particles or water droplets.

The flexibility of the AI retrieval will allow us to switch between generating AI MW only, AI MW+IR or AI IR only profiles as initialization for the physically based SFPIR retrieval. The modular design of the AI(MW/IR)/SFPIR code will allow us to easily switch between sensor pairs such as NOAA's Cross Track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) on the Suomi and JPSS satellites, or the Atmospheric Infrared Sounder (AIRS) and the Advanced Microwave Sounding Unit (AMSU) on board NASA's Aqua satellite. We anticipate that our methodology will immediately achieve the following improvements over existing IR sounder products (AIRS L2, AIRS and CriS NUCAPS): (a) retrievals at the native resolution of the sounders (15 km) instead of the 3x3 45 km footprint currently achieved using cloud clearing (b) improved yield of retrievals (currently 60% globally) and easier quantification of quality assurance (using the degrees of freedom).

Validation and quantification of PBL parameters will use a combination of radiosondes, aircraft and ground based (L/C) data. Thermodynamic profile validation will include radiosonde data (from Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)), DOE Atmospheric Radiation Measurements, profiles from ground-based (L/C) and MW radiometer data, lidar profiles from airborne instruments and AIRS and CriS L2 products.

Importantly, in line with the requirements of this call, we will also have access to water vapor and aerosol extinction profiles from the NASA Langley's aircraft-borne High Altitude Lidar Observatory (HALO). We have combined experience in using AI based algorithms to detect boundary layer thickness from lidars and will apply this knowledge to studying the thermodynamic retrievals from the combined AI(MW/IR)/SFPIR retrieval.

The proposal is highly relevant to the A.45 Decadal Survey Incubation" solicitation, as it will generate a new data set that quantifies how well a novel all-sky thermodynamic retrieval using data fusion from the current generation MW/IR instruments, can capture properties of the planetary boundary layer, in particular the PBLH.

Timothy Dixon/University of South Florida, Tampa
DEMs from Satellite and Ultra-High Resolution UAV platforms: Mitigating Trade-Offs for Arctic Permafrost and Sub-Tropical Coastal Wetland Applications
21-DSI-21-0062

Improving Digital Elevation Models (DEMs) in terms of spatial resolution, vertical accuracy, and frequency of coverage, would help to address a host of scientific and practical applications. A satellite-based global model would be especially useful, but of course would be unable to meet some of the more demanding requirements, presumably the domain of more detailed local surveys. NASA's recent Surface Topography and Vegetation Study Team report (Donnellan et al, 2021) examined many of the trade-offs, but gaps remain in assessing requirements for certain environments.

Here we propose detailed studies in two such environments, Arctic permafrost and a sub-tropical coastal wetland. In both cases a two meter DEM already exists, but more detailed information is required to maximize the science. In both areas the ability to separate bare earth elevation from vegetation height is crucial. The Arctic environment in particular would benefit from improved vertical accuracy to measure elevation change as the volume difference between ice and water means that areas undergoing permafrost thaw generally experience significant elevation loss. Both environments are also evolving rapidly due to climate change, and the Arctic environment has the potential to accelerate this change via feedbacks in the carbon system. Preliminary work suggests that simply improving the vertical accuracy of existing DEMs would enhance utility in both environments. Such improvements in DEMs would facilitate change detection, improve vegetation change measurements, and allow merging with more precise local data. Our preliminary work also suggests that some LiDAR products considered to be bare earth do not reliably return bare earth elevation in regions of dense vegetation.

We propose to generate a series of ultra-high resolution and accuracy DEMs (~ 5 cm 3-D RMS) using UAV-based Structure from Motion photogrammetry, airborne or UAV-based LIDAR, and high precision GPS-GNSS tracking. Our short-term goal is to measure and understand elevation change in the two test areas. Our long-term goal is to provide guidance on cost-effective high resolution elevation measurement techniques in these two contrasting environments.

Andrea Donnellan/Jet Propulsion Laboratory
High-Resolution Stereophotogrammetry and Analysis for Achieving STV DSI Goals: 3D and 4D topography
21-DSI-21-0003

We will mature the airborne Quantifying Uncertainty and Kinematics of Earth Systems Imager (QUAKES-I) into an end-to-end operational system. This includes maturing data processing, understanding optimal experiment design, quantification of uncertainties, and developing information tools for analysis of QUAKES I data products. This project will analyze and create information system tools, primarily from airborne QUAKES-I data collected with an 8-camera array that flew in June 2021 over the Grand Canyon and along numerous fault and wildfire-modified features in California totaling over 7500 km of 12 km wide swaths. The two flights produced over 9.6 TB and 480,000 images. Challenges exist in processing and managing the large volumes of data. Tools are needed to extract scientific information from the data products, manipulate and preprocess the raw imagery, and extend existing stereophotogrammetry techniques to incorporate the multiple stereo views provided by QUAKES-I in the computation of the data products. Entry and exit TRLs are 5 and 7.

The key technological need fulfilled by this project is a robust processing and analysis workflow for diverse and large-scale optical photogrammetry data. It will enable the production of high-resolution topographic data and its application to three-dimensional and four-dimensional multitemporal analyses. Deployment of overhead optical imaging sensors has increased dramatically in recent years and stands as the most rapidly collected form of high-resolution data available following seismic, volcanic, and environmental hazard events. Algorithmic and technological development is required to process and manage these rapidly acquired data sets, along with recent and legacy collections to baseline pre-event characteristics, to generate rapid analysis of landscape change, and to develop topographic metrics required to understand solid earth, earth-surface, and ecological changes across landscape scales.

The objectives of this work are threefold. 1) Improve processing speed and algorithms for stereophotogrammetric products, in particular those derived from QUAKES-I and follow-on systems, 2) Quantify uncertainty and improve accuracy of the data products, and 3) develop tools to compute geomorphic metrics, detect change, and carry out science analyses using stereophotogrammetric products. We expect to improve significantly the production, accuracy, and availability of stereophotogrammetric data products of Earth's land surface for science studies. This work addresses gaps in information systems and stereophotogrammetry identified in the STV Study Report (Donnellan et al, 2021). Information Systems and Stereophotogrammetry are both essential technologies identified in the STV Study Report necessary to collect the data and to produce useful data and knowledge products. We will develop tools to extract science information from single baseline measurements and to measure change and quantify uncertainty from repeat measurements from the same or different platforms. These tools and prototype data products will be developed with practical application and usability in mind given the broad experience of the proponent team.

This project addresses NASA's Earth Surface and Interior Program goals and will improve understanding of land surface processes including earthquakes, landslides, and post-wildfire effects. The project supplies complementary observations to UAVSAR. Information Systems and Stereophotogrammetry are technologies identified in the STV Study Report. Sub-meter baseline measurements and ability to measure change over time are key needs identified. We will develop tools to extract science information from single baseline measurements and to measure change and quantify uncertainty from repeat measurements from the same or different platforms. These tools and data products will be developed with practical application and usability in mind given the broad experience of the proponent team.

Antonia Gambacorta/Goddard Space Flight Center
A Combined Passive-Active, Multi-Sensor Approach to Earth's Planetary Boundary Layer (PBL) Sounding
21-DSI-21-0040

The overarching goal of this proposal is to develop and demonstrate a novel passive-active multi-sensor data fusion retrieval algorithm of thermodynamic (temperature and water vapor) profiles with improved structure in the PBL. The proposed work builds upon state-of-the-art expertise in active (BSL) and passive (infrared; IR, microwave; MW) operational sounding algorithms to address three fundamental objectives: 1) harness information content in the PBL vertical structure and depth from active measurements where passive measurements are lacking; 2) verify and quantify the enhanced 3D thermodynamic structure achieved by this data-fusion approach in the PBL; 3) perform signal/noise trade studies and simulation sensitivity experiments intended to inform future pathways (e.g., enhanced passive and active sensors) to filling technology and uncertainty gaps. To this end, the proposed algorithm is a modular design intended to be expandable to future sensors to build the algorithm infrastructure needed for future integrated observing systems architectures and will have long-term viability for PBL Incubation regardless of specific instrument development paths.

This work integrates Artificial Intelligence/Machine Learning (AI/ML) tools to harness PBL information content in existing Program of Record (POR) left underutilized by the complex nature of the data-fusion processing. Conceived with a user's application focus, a significant part of the proposed research is the verification that the scientific requirements expressed in the NASA PBL Study Team Report Science and Applications Traceability Matrix are met by this algorithm.

The proposed work is relevant to the program element because it aims to develop algorithms, approaches to sensor fusion using POR data" and harnesses content in existing POR data sets for PBL information content via data mining, machine learning techniques". It proposes feasibility investigations to leverage the POR to harmonize different PBL observations towards a merged product (e.g., active and passive measurements).

This work should be funded now because it proposes to exploit POR datasets for making advancements to prepare for measurements from the space environment and provide information for future space-based architectures". It proposes key activities that are important to accomplish early in the incubation period" such as: determining gaps, exploiting the POR, simulations, and trade studies" (A.45 proposal announcement, Section 2-1, page 4).

Craig Glennie/University of Houston
Characterizing Expected Uncertainty in Spaceborne High-Resolution Terrain Models for Examining Surface Processes
21-DSI-21-0030

The Decadal survey and the surface topography and vegetation study report both highlighted the uncertainty in the requirements for horizontal resolution and accuracy of a future high-resolution topography mission. A primary cause of this uncertainty is the unknown linkage between the scale and magnitude of surface processes proposed to be studied and the raw satellite observations required to sufficiently observe these processes. The linkage is difficult to define because the nature of the surface being observed will have a direct effect on the requirements for accuracy and resolution rough terrain and/or the presence of vegetation cover will require higher resolution and lower uncertainty to model at the same magnitude and scale as for a smooth and non-vegetated surface. This proposal seeks to fill these fundamental knowledge gaps by: (1) examining the relationships that link surface parameters such as slope, roughness and vegetation cover to uncertainty in the modeling of that surface, (2) developing a rigorous model to estimate the uncertainty in surface locations due to space-based lidar observing system errors, and (3) determining the capacity of a high-resolution STV mission to estimate surface change from temporally spaced high-resolution surface models. This characterization of expected targeted observable errors will elucidate the connections between the achievable accuracy for observing surface processes and the uncertainty in the raw satellite observables, enabling a better understanding of the observing platform specifications required to meet the STV mission science and applications goals, objectives and product needs.

Richard Hodges/Jet Propulsion Laboratory
Deployable MetaLens for G-Band Earth Science Applications
21-DSI-21-0073

This proposal addresses the Decadal Survey Incubator (DSI) call for disruptive technologies that enable innovative SmallSat-based measurement techniques to meet Planetary Boundary Layer (PBL) science objectives. The key objective is to develop a deployable G-band high gain antenna that reduces instrument size, weight and power (SWaP) to enable a new measurement capability that is not currently feasible. Specifically, the 2019 NASA decadal survey incubation program focused on priority PBL science and technology components that require advancement and development prior to implementation. The PBL Study Team Report, Toward A Global Planetary Boundary Layer Observing System" identified G-band Lightweight Deployable Antennas" as one of the five key technologies needed to enable a PBL mission.

The proposed antenna technology is a unique new artificial dielectric lens. Lenses have long been favored as a simple and effective method to focus light because they are less sensitive to tolerances than a reflector antenna and have no aperture blockage. Despite these advantages, lenses are rarely used at microwave or mm-wave frequencies due to size, mass, and fabrication challenges. This proposal brings lens advantages to the mm-wave band by using an artificially engineered metal particle dielectric lens, or MetaLens, that overcomes these limitations. We will develop a deployable multi-layer MetaLens antenna design that enables future PBL missions. This breakthrough in antenna technology is needed because solid composite reflectors are currently the only large (~2 m) G-band antennas available. These composite reflectors are very expensive and do not stow compactly, which limits their applicability for PBL missions. MetaLens is an innovative new technology that will provide a lightweight and comparatively low-cost and antenna that can meet SmallSat stowage requirements.

The MetaLens fabrication concept uses multiple layers of polyimide sheets, each with a pattern of photoetched copper disks. This three-dimensional array of disks creates an artificial dielectric that can produce a wide range of permittivity values, and supports inhomogeneous and/or zoned lens designs. The mechanical concept is to stack closely spaced (< lambda/5) sheets on a frame, which permits the lens to be folded for deployment. A related antenna concept, the tensioned membrane reflectarray, was successfully demonstrated at 32 GHz by John Huang at JPL, but the practical utility of his innovative antenna was limited by reflectarray tolerances. A tensioned membrane MetaLens effectively eliminates this problem because surface positioning tolerances are relaxed by an order of magnitude, so that membrane displacement errors do not significantly degrade or modulate RF performance. Moreover, unlike a reflectarray, the artificial dielectric is not a resonant electromagnetic structure   the permittivity is determined by volume density of the disks etched on each sheet, which means that transmission phase is not highly sensitive to Kapton sheet separation distance. Periodic laser cut polyimide sheets can be bonded to the layers to insure proper nominal separation. The entire assembly can be folded for stowage using a mechanism. A similar deployment mechanism was recently demonstrated on the JPL LADeR deployable reflectarray.

Radar instruments are currently in development that address the key PBL science objectives. However, a breakthrough in antenna technology is essential to realize the potential of these new radars. This proposal will leverage recent investments in lens technology in order to provide an innovative new technical approach to G-band radar antennas.

Entry TRL=2. Exit TRL=4

Fredrick Irion/Jet Propulsion Laboratory
Boundary Layer Measurement with Combined Near and Thermal-Infrared Observation
21-DSI-21-0005

Hyperspectral thermal-infrared instruments have good sensitivity to temperature and water vapor through the free troposphere, but can often lack sensitivity in the planetary boundary layer. Near-infrared instruments have good sensitivity to water vapor and temperature in the boundary layer over land and ocean glint, in clear and near-clear conditions using reflected daylight, but can lack sensitivity through the free troposphere.

We propose a study of boundary layer to free troposphere measurement of temperature and water vapor profiles by combining near-infrared spectra from the Orbiting Carbon Observatory-2 (OCO-2) with single-footprint, thermal-infrared spectra from the Atmospheric Infrared Sounder (AIRS) in a joint retrieval system. Combining these programs-of-record measurements can provide a consistent information content analysis and error estimation. Results will help guide decision-making and resource allocation in the development of remote sensing for the planetary boundary layer and its interactions with the free troposphere above.

Robert Knuteson/University of Wisconsin, Madison
Refining Planetary Boundary Layer Remote Sensing Requirements Using Merged Orbital And Sub-Orbital And Merged Active And Passive Observations From The Program Of Record
21-DSI-21-0031

The overarching goals of the DSI program are to promote (1) innovation in the research, development, and demonstration of new measurement technologies in preparation for future integrated observing system architectures, and (2) science activities that support maturation of measurement concepts, retrieval algorithms, models, data assimilation, and/or integrated observing system approaches. We propose to exploit datasets from the Program of Record (POR) sensors to create new merged passive and active, orbital and sub-orbital products along with validation truth data that can be used to refine remote sensing requirements of the Planetary Boundary Layer (PBL) thermodynamic state and PBL height. The ultimate goal is to help define the next generation of sensors that can probe the PBL over all climate regimes to augment future Earth observations from operational weather satellites.

Five tasks are proposed to address the four PBL science goals:
G1. PBL, Convection and Extreme Weather.
G2. Cloudy PBL.
G3. PBL and Surface Interaction.
G4. PBL Modeling, Mixing and Air Quality.
The global daily coverage of hyperspectral infrared and microwave sounders will be merged with 1) ground-based hyperspectral infrared data, and 2) active sensor profiles from radio occultation. These data will be used to quantify the spatial, vertical, and temporal uncertainties in the Program of Record and inform the future of space-based observations to monitor the PBL.

The expected significance of this project is that the PBL science team will have early access to quality merged datasets that can be used to test and refine PBL retrieval algorithms and OSSE data assimilation techniques. In addition these merged datasets will provide the basis for simulation studies of hyperspectral infrared channel selection and information content for refinement of future measurement requirements from space.

Keith Krause/Battelle Memorial Institute
Globally-Derived Measures of Structure Informed by Ecological Theory and Observation
21-DSI-21-0027

Lidar is an invaluable remote sensing tool for 3d measurement. However, instruments have platform constraints and are typically driven by what technology is currently available rather than by science requirements or data quality/utility. Informed by ecological knowledge gaps and model limitations, and focusing on the next generation of lidar-based products, the project objectives are to:
1. Identify the suite of next generation" lidar derived data products, akin to LAI, that are broadly useful to advancing and improving modeling application and fundamental ecological knowledge across scales;
2. Assess the capabilities and limitations of current lidar systems to produce ecologically meaningful next generation data products;
3. Determine the instrument parameters of future systems needed to derive next generation lidar products;

4. Evaluate the accuracy and uncertainty of next generation data products across several spatial scales including change with time.

The high-level work plan is broken into three categories: ecological relevance, existing data sets, and simulation. All categories will begin with an evaluation of common lidar derived data products, such as those listed in the STV Study Report. The ecological relevance aspect of the project will aid in the identification and development of next generation structural indices of broad interest to ecologists, modelers, and remote sensing scientists. Candidate structural indices will be selected based on ecological criteria, with prioritization given to indices that correlate with ecological processes at multiple spatial scales and across ecoregions. The indices will be produced from existing data sets (if possible) and/or will be developed from simulated lidar data sets. Existing data sets include but are not limited to: GEDI, ICESat2, LVIS, MABEL, Sigma Space MPL, G-LiHT, NEON AOP, UAS, and TLS field data. Coincident data collections of most of these sources exist for a few instances and those sites will be prioritized, however, comparisons for a subset of data sources will be necessary from other sites/times in order to span the variety of measurement techniques, sampling strategies, and instrument parameters. Simulations will be performed using Rochester Institute of Technology's DIRSIG software where inputs of scene geometry, optical properties, and instrument/collection parameters can be controlled and modified. DIRISG has a long heritage of simulating linear mode discrete and full-waveform lidar and is capable of simulating Geiger-mode lidar. In addition to evaluating existing instruments and next generation systems/platforms, DIRSIG provides significant flexibility for trade studies of instrument and collection parameters plus contains truth information about the physical vegetation structure in the scene. For all three work plan categories, tasks will include evaluation of data quality/utility, assessment of accuracy/uncertainty, and analysis at different spatial scales.

The proposed research contains Science activities to support the objectives of the targeted observable Surface Topography and Vegetation as described within the NASA ROSES2021 A.45 Decadal Survey Incubation Program Element, with a core focus on vegetation structure (including underlying surface topography) and will address knowledge, methodology, algorithm, and measurement gaps. The work plan has applicability to all 6 vegetation structure knowledge gaps identified in the STV Study Report, although the focus will be on current plus needed quality/accuracy of 3D vegetation structure, understory, and structural diversity products evaluated across a variety of different ecoregions (including sparse and low vegetation). A technology gap related to sampling density and footprint size is also relevant. This study will assess the quality, accuracy, and uncertainty of lidar instruments, collection methods, and resulting data products necessary to address several questions from the Decadal Study.

Rachael Kroodsma/University of Maryland, College Park
Hyperspectral Capability for CoSMIR: Enhancing Capability for Future PBL Suborbital Campaigns and Enabling PBL Science from Space

21-DSI-21-0041

The NASA Planetary Boundary Layer (PBL) Incubation Study Team found that hyperspectral microwave sounders are an Essential Component" of a future global PBL observing system due to their perceived ability to capture the three-dimensional structure of temperature and water vapor in the free troposphere. As such, significant resources have been directed at building this capability as part of a comprehensive technology portfolio targeting PBL science. In this proposed effort, we will upgrade the Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR) with new hyperspectral receivers including wideband application specific integrated circuit (ASIC) spectrometers developed under SBIR (80NSSC18C0102). Subsequent test and engineering flights with the new CoSMIR Hyperspectral (CoSMIR-H) will provide airborne validation of the hyperspectral architecture and demonstrate advancement in high-resolution measurement of the thermodynamic structure of the boundary layer by using hyperspectral microwave radiometry.

Recent modeling studies performed internally at Goddard and elsewhere have supported the assertion that hyperspectral microwave radiometry can provide temperature and humidity profiles with vertical resolution superior to traditional microwave sounding architectures. The fine spectral resolution over wider bandwidth translates to this improved vertical resolution while also reducing uncertainty. Additionally, when compared with infrared sounding, microwave sounding is less sensitive to trace gasses with better penetration through clouds. These benefits of hyperspectral microwave sounding are what led the PBL Incubation Study Team to emphasize the value of these observations.

To address the needs of the PBL science community, our team aims to deliver a highly capable airborne hyperspectral microwave sensor that will demonstrate high spectral resolution profiling and support future suborbital campaigns probing the PBL. Moreover, CoSMIR-H will validate the critical 4-GHz spectrometer ASIC technology. The effort will modify the V-band (temperature) and G-band (water vapor) receivers of the well-regarded CoSMIR with hyperspectral capability using the ASIC spectrometers as an enabling component. Importantly, our team will implement a new data system that can capture and process the finely resolved spectra. Laboratory and airborne demonstration will raise the Technical Readiness Level (TRL) of the hyperspectral profiling technique from 2 to 6.

Marco Lavalle/Jet Propulsion Laboratory
An OSSE Framework for STV Multi-Mission Design and Performance Evaluation
21-DSI-21-0001

Multiple and simultaneous synthetic aperture radar observations taken from different look angles (i.e., operating in multi-baseline interferometric or tomographic mode) have the potential to provide high-resolution, gap-free maps of vegetation structure and underlying topography with characteristics reported in the 2021 Surface Topography and Vegetation (STV) Study Report. We propose to develop a scalable community-based Observing System Simulation Experiment (OSSE) Framework to evaluate the multi-mission STV observational needs, and implement a multi-static Radar OSSE Component to quantify the end-to-end TomoSAR/PolInSAR performance of distributed smallsat radar formations for STV. The specific goals of our proposal are to: (1) Architect and implement a modular and scalable OSSE framework for STV with the required flexibility to support multiple OSSE components associated with different observational technologies and measurement approaches; (2) Design and implement a specific OSSE component for end-to-end simulations of multi-static/tomographic and polarimetric-interferometric radar measurements; and (3) Conduct a rigorous and comprehensive trade study using the radar OSSE component to design a multi-static radar mission concept for multiple STV needs.

Stephen Leroy/Atmospheric & Environmental Research, Inc.
Profiling Water Vapor in the Planetary Boundary Layer using GNSS RO in Data Assimilation
21-DSI-21-0049

The planetary boundary layer (PBL) has been designated a high priority for theoretical investigation and remote sensing by the NASA Earth Science Decadal Survey of 2018 because the uncertainties in the workings of the PBL and the inadequacies of its parameterization are driving large, unresolved and under-addressed uncertainties in a wide range of fields in the atmospheric and climate sciences. For the Decadal Survey Incubation (DSI) program, we will initiate a project that will advance the science of the retrieval of water vapor in the PBL, will test and validate two candidate retrieval schemes with program-of-record (POR) data, will finalize the development and implement an accurate and extremely efficient tool to find collocations of RO data and scanner data types, and will implement the retrieval schemes and collocation algorithm in a data preprocessor for infusion of high vertical resolution profiles of water in the PBL into the GEOS-5 data assimilation system.

First, two PBL water vapor retrieval schemes will be tested and validated, one that fuses GNSS radio occultation (RO) data with passive nadir microwave soundings (MW), and another that fuses GNSS RO with the forecasts of a numerical weather prediction system (NWP). The schemes will be tested with POR GNSS RO data (Metop and COSMIC-2) and POR MW data (Suomi-NPP, NOAA-20, Metop) and validated against high vertical resolution radiosonde profiles of water vapor. The PI recently completed a project that showed that both schemes can theoretically retrieve water vapor with 2% precision, near perfect accuracy, and with 100-meter vertical resolution. Second, we will finalize a fast and accurate algorithm to find RO+MW collocations and will implement it for operational retrieval and data assimilation. Mature development already shows the algorithm to be 98% accurate and 1,000 times faster than a standard, brute force approach. Finally, we will implement the retrieval schemes and the collocation tool into a data preprocessor for the GEOS-5 data assimilation system. The data to be assimilated will be retrievals of water vapor in the PBL, making the assimilation of RO data much more likely to positively impact PBL water vapor than previous attempts at assimilating RO data. This project is a continuation of two other projects, one funded by the U.S. Air Force, and the other funded by the National Science Foundation. Theoretical demonstrations of the retrieval algorithms shows that both greatly exceed the performance of other proposed retrieval algorithms according to their theoretical performance because of the robustness of the MW and NWP soundings and the amount of information mined from these data. This work responds directly to the DSI call by advancing GNSS RO retrieval by fusing it with other data and by developing tools that will enable these retrieval schemes to improve the analysis of PBL water vapor in data assimilation.

The work to be done is to be considered PBL Science", addressing the advancement of retrieval algorithms, testing on POR data, and developing tools needed for mission architecture studies. We have assembled the team necessary to the successful completion of this work, mentoring a graduate student in the process. Dr. Stephen Leroy (PI; AER) and Dr. Rob Kursinski (Collaborator; PlanetiQ) are well-known experts in GNSS RO and its application to atmospheric and climate research, possessing over 50 years of experience in the field. Prof. Kerri Cahoy (Co-I; MIT) is a leader in the design and development of RO and MW nano-satellites and the science of fusing GNSS-RO data with MW data. Dr. Mohar Chattopadhyay (Co-I; SSAI/GMAO) is an expert in data assimilation and is responsible for the assimilation of new data types into the GEOS-5 system. Dr. Kursinski (PlanetiQ) is the progenitor of RO retrieval algorithms that correct for super-refraction thus enabling the unbiased, precise, and high vertical resolution retrieval of water vapor in the PBL.

Zhen Liu/Jet Propulsion Laboratory
Assessing the Sensitivity and Measurement Needs of Surface Topography Towards the Study of Earthquake and Fault Creep Processes
21-DSI-21-0006

This proposal aims to understand the effects of high-resolution topography and change on earthquake and fault displacement science by exploiting existing digital elevation models (DEMs), optical imagery, lidar and interferometric synthetic aperture radar (InSAR) data. We will test the resolution and accuracy needs on deformation measurement and geophysical studies of earthquakes and fault creep through global earthquake simulation and selected target studies.

We have three objectives:
1) Quantify the resolution and accuracy needed for capturing earthquake related topography change. We will do so through a global analysis along with selected focused studies (objective 2). For global analysis, we will use SRCMOD, a global compilation of finite-fault earthquake rupture models of past earthquakes (http://equake-

rc.info/srcmod/), which occurred over a diverse range of tectonic settings, vegetation coverage, magnitudes of ~4.5-9.1 and variable focal mechanisms (strike-slip, thrust, normal, mixture), to simulate topography changes from these earthquakes, perform trade-studies between desired topography resolution/accuracy, and instrument measurements needed from a future STV mission.
2) Assess the impact of high-resolution topography measurements on details of earthquake rupture and postseismic deformation mapping using the 2019/07 Ridgecrest earthquake sequence and the 2013/09/24 Mw7.7 Baluchistan earthquake as target events. Our preliminary results from the topography difference of optical-derived digital surface models (DSMs) reveal complex fault geomorphology and near fault deformation including non-negligible vertical displacements for both events (see 1.1.1.2 for details). We will use the two events as case studies to assess the sensitivities of lidar and photogrammetric techniques and existing data to 3-D differential topography displacements associated with earthquakes, and examine the impact of detailed topography change on earthquake models. We will use the Ridgecrest earthquake as a selected example, thanks to the availability of a hybrid set of post-earthquake airborne lidar and high-resolution satellite optical images, to develop the integrated analysis of multi-sensor data for mapping the topography change and 3-D deformation following the earthquake. We will assess the capability improvement by leveraging the strengths of complimentary measurements (lidar and stereo photogrammetry).
3) Assess the sensitivities of fault slip studies to the resolution and vertical accuracy of global baseline topography and repeat measurements. The bare earth DEM is essential in InSAR processing (e.g, topography phase correction, image co-registration, geocoding) to obtain reliable deformation measurement from InSAR. How different DEMs, as a function of resolution and accuracy, affect InSAR mapping of near fault creep processes is not well understood. We will use the central San Andreas fault as a target area, where NASA UAVSAR measurement with high spatial resolution of ~5x7m at 3x12 range x azimuth looks, a suite of bare earth DEMs with various spatial resolution/accuracy are available to test the sensitivities of fault creep and off-fault deformation to different DEM products. In addition to baseline DEM effects, we will also exploit the joint use of lidar and high-resolution stereo photogrammetry data for 3-D differential topography displacement rate estimates, uncertainty characterization and reduction in rate of change for fault creep study. We expect the insights from this study will help inform the architecture design and observing strategy of a future STV mission towards global mapping of fault zone landscape change and creep processes.

Paul Lundgren/Jet Propulsion Laboratory
STV Volcano Science and Applications Observation
21-DSI-21-0002

Volcanoes experience some of the largest and most dynamic topographic changes of any Earth surface process, spanning a wide range of spatial and temporal scales. Processes include creating topography through extrusion of new lava flows or domes, or removing topography by explosive eruptions, caldera and sector collapse. During eruptions,

volcanoes also change topography by depositing ash or pyroclastic flows or even between eruptions through remobilization of deposits from lahars and landslides. The highly variable nature of these processes in space and time places stringent constraints on the spatiotemporal requirements for topography data products.
We will focus on three mutually linked topics relating topography and its change to hazard assessment and mitigation: 1) Dynamical models of volcanic eruptions; 2) The effects of topography quality on lava flow dynamics, slope instability and pyroclastic flows; 3) Assess candidate observing methods and architectures based on data analysis and simulations in topics (1) and (2).) the 2018 K+lauea, eruption, Hawaii, featuring caldera collapse and large basaltic lava flows; 2) silicic lava flows and dome eruptions: Cordón Caulle and Nevados de Chillán, Chile; Ibu, Indonesia; La Soufrière, St. Vincent, West Indies; and Great Sitkin, Alaska; 3) slope stability at Sinabung, Indonesia, and pyroclastic flows at Fuego, Guatemala. Datasets will include: TanDEM-X (TDX), GLISTIN-A, EarthDEM, Planet, Pleiades, and locally acquired Lidar and photogrammetry.
Dynamic volcano source modeling will build off of existing models for caldera collapse-effusion (Roman and Lundgren, 2021) and lava dome extrusion (Delgado et al., 2019). Flow simulations will use existing software for lava and pyroclastic flows (e.g. VolcFlow, Kelfoun and Vallejo-Vargas, 2016; DOWNFLOW, Favalli et al., 2005), dome and slope instability potential (Scoops3D; Reid et al., 2015) as well as advanced physics-based dynamic models. We will use flow thickness to constrain lava flow forecasts, where both the spatial quality and temporal sampling affect model predictions.
Our proposal responds to the A.45 2.2.1 STV Science component by combining exemplary topography observations from recent radar, lidar, and stereo-photogrammetry observations with physical forecasting models to quantify the product needs for volcano science and applications. Through it we will create the analysis tools during the current decade to support the development of Surface Topography Vegetation (STV) observing capabilities through the next decade.

Our proposal responds to A.45 2.2.1 STV Science component of the NRA. Through the combination of exemplary topography observations from recent radar, lidar, and stereo-photogrammetry observations combined with physical forecasting models we will quantify the product needs and develop the analysis tools during the current decade that will support the development of STV observing capabilities in the next decade.

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Lori Magruder/University of Texas, Austin
Exploring the Quality of Space-Based Laser Altimetry and Imagery Data Fusion for Benthic Studies and Coastal Processes
21-DSI-21-0036

Addressing the Surface Topography and Vegetation (STV) science priorities for filling knowledge, methodology and algorithm gaps using program of record (POR) is a goal of this project. This effort will focus on exploitation of existing resources for uncertainty quantification, and sensitivity analyses with a goal of advancing the current understanding of measurement quality and system performance relative to geophysical and operational information (Decadal Survey Incubation (DSI) topic 2.2.1). More specifically this proposal will look to determining the capability and quality of bathymetry elevation retrievals with respect to environmental and system acquisition influences on space-based laser altimetry for morphological change and benthic habitat characterization.
As stated in the 2017 Decadal Survey (DS), Earth Observation from Space: A transformative capability, satellite based observations allow us to see the extent to which Earth's ever-changing processes influence our lives". This is a true sentiment but definitely realized when the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) launched in 2018 and opened eyes with respect to high-resolution along-track surface elevations at the global scale with a new type of active remote sensing technology. Possibly even more transformative with this mission was the realization of shallow water bathymetry from an altitude of ~500 km above the surface. This capability of ICESat-2 allows for the generation of underwater topography with highly accurate vertical certainty and the opportunity to merge the data with other resources/products to enhance our understanding further, either spatially or temporally.
In response to the 2017 DS, NASA formed an incubation study around the STV targeted observable to identify knowledge gaps, sensor needs, and required measurements deemed critical for understanding impacts associated with climate change on our ecosystems. The STV incubation team's final report highlighted methods and activities to improve science, applications, as well defining the measurement technologies necessary to achieve the science goals. Along with solid earth, cryosphere, vegetation structure, and hydrology, coastal processes are a recognized focus topic in need of better understanding regarding how they react to climate variability and how those changes will subsequently affect societal resources. As such, the motivation behind this proposal is to improve our understanding of critical observations to support coastal process discoveries such as sediment transport (erosion and deposition), and benthic habitat variability all of which requires knowledge of shallow water bathymetry. In fact, one of the STV observables

deemed paramount to understanding coastal processes is maximum water depth. As part of evaluating space-based observations for determination of maximum water depth and benthic characterization is the need for a comprehensive look at how the environment (turbidity, wave structure, sea floor type) and operational aspects (incident angle, time of day, energy level) influence the retrieval quality and fidelity. Further, is the importance of understanding how these data can be effectively combined with other resources to create a more relevant product for bathymetry applications and discoveries.
This proposed effort is focused on answering the specific set of questions associated with coastal dynamics and benthic characterization as an indicator to the Earth's changing climate. The work will support development of a scalable shallow water bathymetry product using combined satellite imagery and altimetry to quantify the changes of coastal environments, monitor coastal resources and create a traceable error budget for the technology's potential to satisfy the STV objectives and plans for future mission concepts, systems and implementation strategies.

Brooke Medley/Goddard Space Flight Center
Addressing the Knowledge Gaps in Ice-Sheet Surface Processes to Inform and Advance the Next Generation STV Mission Concepts
21-DSI-21-0057

When investigating ice-sheet height change at shorter time scales, the signal due to processes such as snow accumulation and its compaction become much more relevant. Thus, the next generation STV mission has the potential to reveal surface mass balance over ice sheets as never before, improving our ability to determine their role in sea-level change. Here, we analyze output from surface process model, forced by atmospheric reanalysis models, to demonstrate the needed measurement thresholds to observe, characterize, and understand ice-sheet height change and the role of surface processes. We will specifically address the following STV Cryosphere gap-filling activities:
- Comprehensive assessment of measurement technologies and algorithms for retrieving snow accumulation and firn compaction over glaciers and ice sheets from airborne and satellite platforms"
- Systematic experiments with existing altimetric datasets (airborne and spaceborne), surface-mass balance, and firn models"
- Identification of potential improvements to surface mass balance and firn models, based on calibrated/ validation experiments with in-situ data"

Pietro Milillo/University of Houston
New Observing Strategies for Beach and Dune Topography and Implications for Coastal Flood Risk

21-DSI-21-0022

The largest cities in the United States, and around the world, lie adjacent to low-lying coastal terrain. It is predicted that in 30 years, flood disaster risk will increase tenfold in these regions, and the recent 2021 IPCC Assessment Report further solidifies the influence of irreversible anthropogenic climate change, thus furthering uncertainty in future conditions. A significant source of uncertainty in coastal flood risk derives from uncertainty in coastal topography and nearshore bathymetry. The overarching goal of this project is to develop new observing strategies (NOS) for measuring the topographic heights and widths of sandy beaches and dunes and reducing uncertainties in coastal flood hazard assessment. To achieve this goal, the project will address two complementary research questions:

(1) What level of horizontal resolution, temporal coverage, and vertical accuracy in beach/dune measurement (horizontal and vertical) can be achieved by combining InSAR, optical and LIDAR methods?
(2) What improvements in coastal flood hazard prediction and sea level rise risk assessment become possible based on the coverage, resolution (spatial and temporal) and accuracy of InSAR/optical/LIDAR derived beach/dune topographic measurements?

To address these questions, we have designed a project with four complementary tasks: (Task 1) We will deploy an acquisition campaign involving TanDEM-X (TDX) InSAR high resolution data, IceSAT-2, sUAS photogrammetry surface elevation models, airborne LIDAR DEMs, and GNSS contemporary surveys of 4 beach/dune test sites in Southern California on a monthly to sub-monthly basis, over a period of three years, to document surface elevation changes and intercompare observational methods; (Task 2) We will test innovative DEM processing algorithms and characterize their accuracy; (Task 3) We will evaluate the accuracy of TDX DEMs relative to the prediction of wave-driven beach overtopping and compound flood hazards from combinations of waves, total water level, precipitation and streamflow, and (Task 4) We will develop a data/model fusion approach to ingest time-dependent, beach/dune DEMs and shoreline positions to estimate the sediment deficits driving coastal erosion and shoreline retreat critical information for adaptation planning. This project responds to STV science and technology goals in the areas of solid Earth, coastal processes and applications. Specifically, we will answer How can large-scale geological hazards be accurately forecast in a socially relevant timeframe? (DS: S-1), How will local sea level change along coastlines around the world in the next decade to century? (DS: S-3) and What processes and interactions determine the rates of landscape change? (DS: S-4). Moreover, we will support achievement of the STV expected outcomes to: Improve understanding of measurement needs, identify which measurements needs can be obtained through suborbital means and which require a space-based component and considerate appropriate split between global observations from space and potentially less expensive and higher resolution airborne measurements.

Adam Milstein/Massachusetts Institute of Technology
AI-Enhanced Infrared Sounding of the Planetary Boundary Layer
21-DSI-21-0034

Improved understanding of thermodynamics within the Planetary Boundary Layer (PBL), including its structure and PBL height (PBLH) over land and water as a function of time of day, is a very high priority for NASA, as recommended by the National Academy of Sciences in the 2017 Decadal Survey for Earth Science and Applications from Space (ESAS 2017"). During the ESAS 2017 process, improved PBL monitoring from space was identified as a high priority across multiple interdisciplinary panels and science and application questions, leading to the current NASA PBL Incubation effort that will invest in future spaceborne PBL mission development. In recent decades, microwave and hyperspectral infrared (HIR) sounding instruments on Aqua, Suomi NPP, and JPSS have significantly improved weather forecasting. However, existing retrievals of lower troposphere temperature (T) and water vapor (q) profiles have limitations in vertical resolution, and often cannot accurately represent key features such as the mixed layer thermodynamic structure and the inversion at the PBL top. Because of the existing limitations in PBL remote sensing from space, there is an urgent need to improve routine, global observations of the PBL and enable advances in scientific understanding and weather and climate prediction. We summarize the key questions to be addressed in this investigation as follows:

- What is the upper limit of HIR vertical sounding capability in the PBL?
- How can both AI and physics be used to constrain retrieval estimates in an explainable way, and improve upon current state of the art retrieval approaches?

We will use a new modular framework to fuse physics constraints (from one or more sensors) with a powerful AI prior model in a way that generalizes traditional optimal estimation techniques familiar to the remote sensing community. A key difference versus previous work is the use of a deep neural network as a generative prior model that exploits temperature and moisture structure over a 3D volume to improve vertical resolution. Such neural network priors, trained on ensembles of real scenes from reanalysis fields, are expected to be more powerful than existing regularizing prior models, representing the joint statistics of the whole 3D scene being reconstructed with high fidelity. In addition, the prior information is incorporated in a way that is explainable to the user, with the physical radiative transfer model-based data fit clearly demarcated from the prior model information as separate modules. This framework, called consensus equilibrium", has been recently introduced in the computational imaging research community, but is new to HIR sounding. We will develop this approach for multiple HIR and microwave sounders (including those of Aqua, NPP, and JPSS). We will produce improved T and q profiles in the lower troposphere, that have the physical (realistic) structure of the PBL mixed-layer and PBL-top inversion. These profiles will then be used to derive PBLH. We will then evaluate the performance versus PBL-focused radiosonde profile data over land and ocean conditions, establishing the performance limit of HIR sounding when prior information is maximized. We will also compare to other PBL data sources, such as GNSS-RO. While the ESAS 2017 outlines numerous high priority scientific questions that will be addressed with improved observations of the PBL, the proposed project will evaluate the scientific utility of the improved retrievals in the context of land-atmosphere (L-A) interactions. This project, by providing improved vertical representation of PBL temperature T, moisture q, and PBLH from satellite remote sensing, will immediately impact and improve the applicability of L-A coupling metrics to the scientific and operational communities, and thus allow for model development to be based on observations of the full 'process-chain' of observations that couple the land surface with the atmosphere, through the PBL.

Myoung-Jong Noh/Ohio State University
High Resolution, Repeat Surface Elevation Models from SmallSats Using Multi-Pair Matching and Data Fusion Approaches to Improve Quality, Efficiency and Error Constraint
21-DSI-21-0021

We propose the development and application of approaches to increase the quality and utility of stereo photogrammetrically-derived Digital Surface Models (DSMs) obtained from constellations of SmallSats. NASA's SVT Incubation Study Team recognized the high potential of commercial SmallSat imagery for surface elevation measurements but identified several critical gaps related to spatiotemporal coverage and DSM quality, including poor stereoscopic geometry, a lack of algorithms able to obtain quality results over varying terrains and surface types and lack of reliable, quantitative metrics of DSM relative accuracy and quality without ground control. We will address these issues by utilizing the frequent, repeat image acquisitions of SmallSat constellations and fusion of SmallSat and high-resolution imagery from conventional satellites.

Utilizing a large archive of PlanetScope SmallSat imagery, acquired by Planet Inc. and distributed through NASA's Commercial SmallSat Data Acquisition Program, we will develop (1) an approach for obtaining optimized DSMs from sets of multiple, overlapping stereo-pairs; (2) a data fusion system for obtaining DSMs from pairs of images collected from satellites with substantially different resolutions and radiometric characteristics; and (3) a methodology for constraining DSM quality based on stereo-geometry. Our work will build upon the open-source, fully automated, HPC-optimized Surface Extraction from TIN-Based Searchspace Minimization (SETSM) software package. SETSM is used to generate continental-scale, high-resolution DSM datasets from commercial satellite imagery as part of the ArcticDEM, REMA and EarthDEM projects.

Our project directly addresses the objectives of this NRA by advancing innovation in the research, development, and demonstration of new measurement technologies in preparation for future integrated observing system architectures" and performing science activities that support maturation of measurement concepts and retrieval algorithms." We will develop new approaches and algorithms that will further mature existing capabilities provided by SETSM. We will use a new, and currently underutilized, dataset

(PlanetScope imagery) to fill key STV knowledge, methodology, and algorithm gaps. Consistent with the stated STV science focus, we will use these and other existing topography datasets to advance understanding of the dependence and limitations of geophysical information quality," specifically that of SmallSat DSMs, on current measurement performance and algorithm maturity." This activity will also exploit existing STV datasets in order to learn the advantages and limitations of relevant existing datasets to better inform technology advancements needed to meet STV science goals." Notably, our objectives to improve DSM coverage and quality, as well as reduce errors and constrain uncertainty, are relevant to all STV science disciplines.

Alek Petty/University of Maryland, College Park
New Sea Ice and Ice Sheet OSSE Frameworks for Determining Ice Topography Science Requirements from a Future STV Mission
21-DSI-21-0063

The polar regions are witnessing some of the fastest climatic changes on Earth. The Greenland and West Antarctic ice sheets are losing mass and this rate of mass loss has been accelerating in recent years. Ice sheet mass loss is expected to be the dominant contributor to global sea level rise in the coming century. Arctic sea ice has been in decline for the last several decades, while Antarctic sea ice has only more recently experienced a sharp decline. Sea ice loss is significantly altering the biogeochemical balance of the polar oceans and is a key factor in the polar amplification of surface warming.

Motivated by these rapid changes, the National Academies 2017-2027 Earth Science Decadal Survey identified 'ice sheet change and its consequences for sea level change' and 'identifying the role of sea ice change in contributing to Arctic amplification' as Most Important and Very Important objectives, while also recommending the incubation of Surface Topography and Vegetation (STV) as a new Targeted Observable, including the measurement of 'ice topography'.

To objectively inform future STV ice topography requirements, our project team will develop new sea ice and ice sheet Observing System Simulation Experiment (OSSE) frameworks. OSSEs have been successfully applied in various flavors within the weather/atmosphere domains for several years, but these approaches are still very much in their infancy within the sea ice and ice sheet domains. Our project will seek to identify the benefits of current (e.g. NASA's ICESat-2) and future ice topography observations most beneficial for constraining ice sheet surface elevation and change and sea ice thickness distribution and change, with a secondary focus of snow depth on sea ice and snow/firn over ice sheets.

Advances in our ability to simulate key processes at the surface and margins of sea ice and land ice, where processes are more complex and change is most rapid, increase confidence that we can achieve the necessary realism in both OSSE frameworks. Satellite altimeters now reliably and routinely generate ice elevation observations that can resolve centimeter-scale ice topographic variability with footprints of meters across entire ocean basins/ice sheets, meaning we can now also plan on the capability to routinely profile, from space, the key features that control the evolution of our sea ice and ice sheets

To establish these two distinct but related OSSE frameworks our project will seek to accomplish the following objectives:
- Integrate model components into the NCAR Data Assimilation Research Testbed.
- Develop necessary OSSE components (nature runs, forward operators, instrument/performance models) across both domains .
- Run, calibrate and validate our OSSE output and generate STV recommendations.

Developing new OSSE frameworks and creating a more objective decision-making process for determining future STV ice topography mission requirements, including a simultaneous impact analysis across both sea ice and ice sheet domains, will be a significant advance. We hope to optimize our work effort through an integrated project team and the coordination of our OSSEs to provide a synthesized cost-benefit assessment of two related but distinct elements of our cryosphere.

All data and tools developed throughout our project will be produced in accordance with established Open Science protocols. Our tools will be well documented and make publicly available to expedite the construction of community-based tools to enable future data assimilation and OSSE activities across cryospheric sciences.

Derek Posselt/Jet Propulsion Laboratory
An OSSE Framework for the NASA PBL Decadal Survey Incubation Activity
21-DSI-21-0017

The trade space of measurements for a future planetary boundary layer mission is large and rapidly expanding. As such, an observing system simulation experiment (OSSE) framework for the PBL must be capable of accurately and efficiently determining which measurement combinations are needed to meet PBL science and applications goals and objectives. In developing a PBL OSSE system, there are a number of challenges that must be addressed.

1. Modern data assimilation systems are not currently capable of assimilating boundary layer measurements at sufficient resolution.
2. Global nature runs do not have sufficient resolution to realistically capture PBL spatial or temporal heterogeneity. Regional (large eddy resolving) simulations can capture PBL processes, but are not global in scale.
3. Exploring trades among the diverse set of PBL measurements requires a collection of instrument simulators of many different types.
4. Effective use of multiple measurement types requires techniques to combine information from observations with very different spatial and temporal resolution.

We will design a system that meets these challenges and thoroughly and efficiently explores the instrument trade space for PBL science and applications. Because assimilation of PBL measurements will necessarily continue to be a research topic for the next decade, and because of the diverse set of measurements that are available, our PBL OSSE system will focus on quantifying the relative information in various measurement and orbit combinations. This will result in 1) immediate actionable instrument-level trades for the PBL formulation effort, and 2) a longer-term and comprehensive assessment of measurement combinations and constellation configurations to inform PBL mission design.

We will leverage capability that has been developed at the Jet Propulsion Laboratory (JPL), NASA Langley Research Center (LaRC), and at the NASA Goddard Global Modeling and Assimilation Office (GMAO). We will use the Global Earth Observing System (GEOS) nature run (G5NR) as context, as the two-year integration is expected to contain a large range of large scale and relatively coarse resolution dynamic and thermodynamic states. To obtain the spatial and temporal resolution needed for detailed instrument simulations, we will employ a library of large eddy simulations produced at JPL for a range of different PBL environments (marine, continental, stratocumulus topped, convective, etc). Simulation of measurements will be accomplished using state of the art forward models developed at NASA LaRC for the differential absorption lidar, and at JPL for differential absorption radar, thermodynamic sounding, and GPS radio occultation. The NASA ESTO AIST-funded parallel OSSE (ParOSSE) toolkit will be used to rapidly assess the measurement trade space for combinations of various instruments and to track and tag experiments. An orbit simulator also developed under ESTO AIST funding (the Tradespace Analysis Toolkit for Constellations; TAT-C) will be used to assess the effectiveness of various orbit and swath configurations for PBL science and applications objectives.

The result will be an OSSE system that will be capable of rapidly and thoroughly evaluating various measurement and orbit combinations for PBL science and applications. It utilizes tools that have already been developed and brings them together under a unified umbrella. It leverages both comprehensive global and fine scale regional information, and is easily extensible to new nature runs, new LES experiments, and new measurement types. This system can be used to provide guidance to NASA in determining an optimal mission concept and architecture to address PBL science in the next decade.

Patrick Rennich/Aloft Sensing, Inc.
Embedded PNT Module for Distributed Radar Sensing
21-DSI-21-0079

Techniques for collecting interferometric synthetic aperture radar (SAR) data over multiple simulta-neous baselines, such as polarimetric interferometric and tomographic

SAR (PolInSAR and TomoSAR), are emerging as key enablers for new insights into Surface Topography and Vegetation (STV) science. To fully realize the accuracy and resolution benefits of these distributed interferomet-ric techniques, however, the precise relative positioning and timing of the distributed sensing plat-forms must be known to a small fraction of a wavelength and the equivalent distance in time. Patent-pending algorithms developed by Aloft Sensing, Inc. (Aloft) have demonstrated the necessary lev-els of precision and accuracy both theoretically and with representative field data to achieve the full potential of multi-baseline distributed interferometric collections.

The Aloft team proposes to develop, implement, and validate a hardware module that efficiently deploys these algorithms for real-time position, navigation, and timing (PNT) onboard radar sensing platforms. Suitable for both satellite constellations and suborbital platforms, this self-contained mod-ule can retrofit existing radars or be tightly integrated into new designs and observing systems.
Objectives and Benefits: Aloft will develop, implement, and demonstrate a hardware module that captures and digitally processes radar pulses to establish the precise relative positioning and timing of a sensor within a distributed sensing architecture such that coherent image alignment for interferometrics can readily occur and high-quality products can be achieved. Embedded software provides the PNT updates in real-time, supporting onboard data processing needs and minimizing the amount of data to be shared between nodes.

Outfitting each platform with this PNT module facilitates the accurate and timely construction of mul-ti-baseline interferometric products. This module is best suited for sensors with multiple receive channels and systems with inter-platform communication links, but it is also applicable to single channel sensors operated as a distributed system without inter-platform communications. The end results are distributed interferometric products with accuracy and resolutions that are improved by 10 to 100× beyond the current state of the art and facilitates near real-time product generation. This level of advancement enables new science in multiple STV areas.
Outline and Methodology: The first year conducts a mission requirements and concept of op-erations study, establishes the module hardware architecture, orders long-lead components, maps the existing floating-point algorithms to the hardware architecture, and implements the embedded software. The second year establishes a detailed layout and design of the hardware board, fabri-cates units for testing, and ends with a lab-based test vector demonstration of the full embedded module. The third year validates the real-time PNT module performance and capabilities within an existing radar testbed, first in the laboratory and then with outdoor tests and demonstrations.

Period of Performance: A 33-month effort: 1 April 2022 to 31 December 2024.

Entry and Exit TRL: (Entry: TRL2/3, Exit: TRL5/5) With internal funding, the concept for the PNT system module has been established and key pieces of the Matlab-based algorithms have been demonstrated with field data (System: TRL2, Algorithms: TRL3). The first year establishes the mod-ule's detailed hardware design and validates the algorithms as mapped onto that hardware (Sys-tem: TRL3, Algorithms: TRL 4). The second year fabricates and tests the hardware and conducts an end-to-end benchtop test of the full hardware module with embedded firmware/software (System: TRL4). The third and final year demonstrates real-time operation of the PNT module within a representative radar system, in both a laboratory setting as well as in an outdoor environment (System: TRL5, Algorithms: TRL5).

Sassan Saatchi/Jet Propulsion Laboratory
Multi-Sensor Multi-Platform Surface Topography and Vegetation Structure Data Fusion Information System (STV-FIS)
21-DSI-21-0066

We propose to develop a multi-sensor, multi-platform surface topography and vegetation structure (STV) data fusion information system (STV-FIS) to characterize future STV performance. Our STV-FIS will address all four major gaps and gap-filling activities identified in the STV incubation study white paper (STVWP, p. vii): 1) Knowledge Gaps by providing a large number of simulated data products, 2) Methodology Gaps by developing and implementing a multi-sensor data fusion information system, and 3) Algorithm Gaps by integrating physically based models with AI for STV change detection, and 4) Measurement Gaps by developing trade study for simulating multi-sensor and multi-platform architecture and smart-tasking. Our goal is to leverage existing models and data in active sensing of STV geophysical parameters to build a multi-sensor, multi-platform STV Data Fusion Information System (STV-FIS) to address the STV identified gaps by focusing on the following objectives:
Obj-1. Develop a multi-sensor (Radar and Lidar) fusion formulation and testing platform based on a dedicated EM model of vegetation 3D structure and surface condition (topography, dry, wet, snow, etc.).
Obj-2. Develop Artificial Intelligence (AI) model-data analytics for sensitivity analysis, STV parameter retrieval, change detection, and uncertainty assessment.
Obj-3. Simulate a dedicated data fusion observing system for multi-sensor and multi-platform trade study, and on-board processing and smart-tasking.
Obj-4. Integrate model and data fusion within a visualization system and on-line analytical toolbox for enabling simulations of STV observations, AI algorithms, and implementation future OSSEs.
The proposed STV-FIS include a user-friendly platform along with visualization and algorithmic tool boxes to meet the needs of all STV disciplines for data analysis, trade studies and OSSEs. STV-FIS components will start at average TRL of 2 and exit at the average TRL of 5.

David Shean/University of Washington, Seattle
Advanced Information Systems to Fill STV Gaps: Next-Generation Stereo+Lidar Fusion and Sensor Technology

21-DSI-21-0008

Instrument fusion is the prerequisite to data fusion for the high-resolution global Surface Topography and Vegetation (STV) targeted observable data collected by a combination of single- or multi-platform radar, lidar, and stereo instruments must be precisely aligned with known uncertainty to enable essential downstream fusion and scientific analysis. This is one of many critical measurement gaps identified by the Decadal Survey Incubator (DSI) program for the STV TO that will require new, innovative technology. Other priority gaps include 1) insufficient multi-sensor data fusion methods and algorithms, 2) insufficient measurement geolocation and vertical accuracy, 3) stereo processing uncertainty and shortcomings for vegetation, and 4) poorly defined requirements for key stereo acquisition parameters.

This crossover proposal focuses on two priority technologies identified by the DSI to reduce these STV measurement gaps: Information systems (including improved multi-sensor data fusion methods and algorithms)," and Subsystems/components to significantly improve spaceborne high-resolution stereo photogrammetry over the current state-of-the-art." We assembled an experienced team from academia, government, and industry to address these priority gaps. Specifically, we will:

1) Develop novel information systems and on-board algorithms that can deliver the precise pointing knowledge needed for next-generation lidar and TDI linescan image sensors. These subsystems will solve the notorious jitter" problem responsible for large residual geolocation uncertainty in commercial stereo images. We will co-develop these information systems through a long-standing partnership with Planet.
2) Develop information systems that use cutting-edge, multi-sensor deep learning fusion techniques to improve the horizontal resolution, vertical accuracy/precision, and quality of stereo+lidar datasets for priority STV targets (vegetation, ice/snow).
3) Develop stereo photogrammetry information systems with robust joint optimization routines, rigorous uncertainty metrics, and stereo+lidar fusion alignment to support next-generation stereo imaging rigs and constellations
4) Leverage state-of-the-art radiative transfer model simulations (DART) and existing/new on-orbit and airborne datasets to support development activities and evaluate key stereo acquisition parameters, which will complement STV OSSE efforts to define STV instrument requirements.

We will primarily focus on fusion of lidar and stereo photogrammetry to improve lower-level elevation data products (e.g., point clouds, gridded raster DSM/DTM), as these topographic data products are fundamental for many downstream applications and science fusion" approaches involving high-level products from other measurement approaches (e.g., SAR). These innovative algorithms will guide development of a next-generation, cloud-based processing framework that will efficiently generate enhanced, high-quality data products for STV and commercial satellite imaging constellations in the coming decades.

Matthew Siegfried/Colorado School of Mines
Quantifying Bias and Uncertainty Sources between Laser and Radar Retrievals of Surface Topography Over Cryospheric Targets
21-DSI-21-0056

Motivation: Accurate quantification of the primary observables identified by the Surface Topography and Vegetation (STV) working group bare surface land topography, ice topography, vegetation structure, shallow water bathymetry, and snow depth requires geodetic measurements with sub-meter vertical resolution and sub-weekly temporal repeat-sampling. A multi-sensor fusion approach combining lidar, radar, and stereophotogrammetry from both orbital and suborbital platforms will likely be necessary to achieve these resolution requirements. However, a thorough investigation of the biases and uncertainties inherent to each of these geodetic measurements, as well as how these biases and uncertainties might compound in a multi-sensor fusion approach, is needed before any such multi-sensor framework can be developed and optimized.

Proposed Work: We propose to investigate the sources of measurement bias and uncertainty in orbital laser altimetry, radar altimetry, and interferometric synthetic aperture radar (InSAR) measurements over ice sheet surfaces and periglacial land surfaces. These two surface types are subject to the time- and space-varying surface dielectric properties of snow, ice, and surface water, and subjected to seasonal and interannual geomorphic processes that can reshape surface topography (such as sub- or supra-glacial lake drainage at ice sheet boundaries and permafrost thaw and thermokarst initiation in periglacial regions), all of which complicate the error inherent in and interpretation of surface height measurements. Our proposed work will consist of three cross-cutting objectives:

1. Characterize and reduce sources of uncertainty and biases in laser altimetry, radar altimetry, and InSAR measurements over ice sheet surfaces and periglacial land surfaces.
2. Quantify the effect of these uncertainties on vertical and rate of change accuracies for both cryospheric and solid-earth/hydrologic targets.
3. Develop and test novel multi-sensor data fusion methods and algorithms that leverage complementary geodetic measurements for improved topographic products and temporal-repeat measurements.

We will achieve our objectives by using existing STV datasets collected by NASA and ESA missions, such as ICESat-2, UAVSAR, Operation IceBridge, ABoVE, Sentinel-1, -3, and -6, and CryoSat-2.

Relevance: Our proposed investigation of measurement biases and uncertainties in single and multi-sensor geodetic measurements directly responds to Section 2.2.1.1 of the STV Solicitation. We will 'exploit existing STV datasets [to] conduct uncertainty quantification, sensitivity analyses, and other assessments to advance understanding of the dependence and limitations of geophysical information quality on current measurement performance and algorithm maturity', with the further goals of 'help[ing]

[to] fill key STV knowledge, methodology, and algorithm gaps using POR and other existing data', and 'inform[ing] an architecture of platforms and sensors that will support the breadth of geophysical, ecological, cryospheric, and hydrological science objectives outlined in the STV STR.' Finally, we are an 'interdisciplinary team [seeking to] address two or more of the STV science disciplines in an integrated fashion.'

Marc Simard/Jet Propulsion Laboratory
STV for Coastal Wetlands
21-DSI-21-0067

JPL, NASA GSFC and the US Fish and Wildlife Service propose science activities designed to advance and accelerate the readiness of the Surface Topography and Vegetation (STV) Targeted Observable (TO).
We propose to address the knowledge and data gaps identified in the STV Incubation Study Report focusing on a particularly challenging but vital environment: coastal wetlands. Coastal wetlands are spatially and temporally complex systems that embody multiple disciplines of the Report: vegetation structure, hydrology, solid Earth (topography) and coastal processes (shallow water bathymetry). Coastal wetlands, along with the socioeconomic services they provide, are threatened by the impacts of climate change (e.g. storm surge and sea level rise) and human activity (e.g. water diversion projects, sediment starvation, pollution). STV mission data in these regions will support multidisciplinary scientific breakthroughs with direct societal benefits.
Coastal wetlands are shallow water environments characterized by herbaceous (marsh) and/or woody (swamp) wetland vegetation that are often intersected with estuaries, tidal channels and channel networks, lagoons and lakes. Micro-topography (including shallow bathymetry) is a major control that determines the hydrology and spatial patterns of vegetation. Flood extent, nutrient loads, hydroperiod and salinity gradients vary with elevational gradients, and with changes in river discharge and tides. In these environments, the STV-TO should resolve 3 categories of vertical layers: micro-topography (bathymetry and terrain elevation), water surface elevation and vegetation vertical profile (including height).
Our approach begins with surveying the research and applications communities about data gaps and needs to confirm and refine wetland-related requirements of the STV Incubation Study Report. Then we will evaluate existing airborne and spaceborne data as well as simulated spaceborne data with respect to refined community requirements. The existing spaceborne data (GEDI, ICESAT-2, TanDEM-X, NASADEM, ALOS/PALSAR-2, Sentinel-1a/b, TerraSAR-X) will be used to evaluate current data capabilities and identify data gaps. We will exploit existing airborne datasets collected during the AFRISAR and Delta-X campaigns. This data set (UAVSAR, LVIS, discrete green and NIR Lidar, AirSWOT), which we deem to be near-ideal, will be used to simulate upcoming NISAR and SWOT data. They will be subsampled and degraded to simulate a range of potential spaceborne observation configurations (e.g. spatial and temporal resolutions, noise level, technology) and data fusion approaches.

Within these campaign sites, we will also compare the airborne with spaceborne data to assess current spaceborne measurement capabilities. The proposed airborne data sets cover a wide range of wetland conditions (e.g. phenological stage, swamps vs marshes, etc.), geophysical (e.g. lakes, riverine, lagoons, estuaries and deltas, width of channels and islands, etc.) and environmental settings (e.g. discharge, tidal range, precipitation patterns, temperature). However, time permitting, we will explore the potential of current spaceborne data in other sites to increase the representativeness of our two sites.
Our deliverables include refinement of STV Study Report's science questions and geophysical measurement requirements specific to coastal wetlands, recognizing the wetland theme may impact requirements of multiple STV disciplines. In addition, we will deliver quantitative evaluations of the capabilities of a wide range of current and future sensors to provide needed measurements of ground micro-topography and shallow bathymetry, water surface elevation, water surface slope and vegetation vertical structure, as well as corresponding elevation changes.

Benjamin Smith/University of Washington, Seattle
Data Fusion for Mass-Change Measurements Over Complex Ice Surfaces
21-DSI-21-0013

This proposal is aimed at measuring ice-sheet surface topography and mass change in critical areas of the Antarctic and Greenland ice sheets, with the goal of developing records of change that are relevant for estimating the rate ice-sheet mass loss, for understanding changes in glacier dynamics, and developing estimates of short-wavelength ice-sheet features that we will use to understanding the role of crevasses and surface channels in ice-sheet hydrology, to understand material properties of the near-surface ice, and to predict how potential STV mission scenarios will perform in recovering ice-sheet mass change in different parts of the ice sheets. We choose six focus areas for this study, in part because common techniques for ice-sheet change measurement have difficulty achieving consistent results in these areas due to the fast ice motion and large surface roughness caused by crevasses, rifts, and surface melt features, and in part because of their importance as sites of fast ice-dynamic change. Because surface features move between measurements, even sensors with high intrinsic precision can produce badly scattered height-change measurements in these areas. As part of this analysis, we will develop techniques to account for the motion of surface features to create mass-change time series, to understand the evolution of surface features, and to estimate the contribution of small-scale surface features evolution to mass change and to glacier dynamics. These techniques take into account the distinction between surface-height changes due to thinning of the entire ice column and surface-changes due to surface feature advection, and should produce separate records of the ice-column thickness change, the advecting fields, and rates of change in the advecting fields. We will develop metrics for surface topography that describe the features whose motion produces the largest scatter in altimetry time series, and will apply these metrics to data from around Greenland and Antarctica to help evaluate potential measurement strategies for the Decadal Survey Surface Topography and Vegetation mission. As part of this work we will update existing sets of stereophotogrammetric data for our study areas, and will develop records of surface metrics that describe small-scale features of the ice sheets. These records will be shared through the National Snow and Ice Data center, as well as smaller datasets that will be shared through a set of publications in the third year of the project.

Kay Suselj/Jet Propulsion Laboratory
A Novel Data Assimilation Tool for Optimizing PBL Observing System Design in Support of Parameterization Development
21-DSI-21-0016

In the light of the latest Earth Science Decadal Survey (DS) recommendations to improve observations, understanding and parameterization of the atmospheric planetary boundary layer (PBL) processes, we will design a novel data assimilation system that will help refine DS science requirements for the design of a future PBL-targeted observing system, and prepare science community to jumpstart utilizing the new observations for PBL parameterization improvements.

To refine observational requirements in an objective and scientifically sound manner, we will first evaluate the skill of the current program of record observations to constrain PBL parameterizations via assimilation of simulated observations. Evaluating the added value of observations from different scenarios of possible future PBL-targeted observing system will help us infer an optimal observing system design for parameterization development. For the robustness of observing system requirements, the data assimilation system will be applied to two parameterizations, one from the operational PBL parameterization in the NASA GEOS model, and the other one representing a future unified parameterization.

To jumpstart utilizing future PBL observations, the new data assimilation system will assimilate actual PBL-relevant observations in the operational NASA GEOS model to provide a global observational constraint for PBL parameterization and to help with a process-based parameterization improvement. We will demonstrate the utility of the new system by assimilating current PBL observations, but the key goal is to design a data assimilation system that will revolutionize parameterization development by utilizing new PBL-targeted observations.

Joao Teixeira/Jet Propulsion Laboratory
Observing the Interactions between PBL Thermodynamic Vertical Structure and Horizontal Variability with an Optimal Combination of Instruments: The Merged Infrared + Radio Occultation (IR+RO) Approach

21-DSI-21-0059

Some of the key planetary boundary layer (PBL) science questions discussed in the NASA PBL Study Team Report are related to critical interactions between the PBL thermodynamic vertical structure and horizontal variability. To properly address these questions, a new PBL satellite mission would require both high vertical and high horizontal resolutions for temperature and water vapor profiles. Unfortunately, there is no single instrument that from a space-based perspective will be able to provide the required high vertical and horizontal resolutions.

A strategy to overcome this issue is to take advantage of the optimal combination of instruments with different characteristics. In this proposal, we address the issue of merging information provided by: (i) instruments with (current and/or potential) high vertical resolution (approximately 100-200 m) but poor horizontal resolution and horizontal sampling (e.g., radio occultation RO, differential absorption lidar DIAL, and differential absorption radar DAR), with (ii) instruments with potential high horizontal resolution (approximately 1 km2) and good horizontal sampling but poor vertical resolution such as hyperspectral infrared (IR) instruments.

In particular, we will take advantage of the positive characteristics of these different types of measurement technologies (i.e., high vertical and horizontal resolution, and high horizontal sampling) by introducing a fairly straightforward methodology in which we utilize the high vertical resolution profiles of water vapor (and/or temperature) (e.g., from GNSS-RO) as a priori for an IR retrieval.

We will evaluate this approach using: (i) synthetic data obtained from a basic PBL observing system simulation experiment (OSSE) framework that includes large-eddy simulation (LES) models, forward radiative transfer models and retrievals, for a variety of key PBL physical regimes; and (ii) data from the current program of record (POR), namely global navigation satellite system (GNSS)-RO retrievals and single footprint IR retrievals from the Atmospheric Infrared Sounder (AIRS).

We will use these combined datasets, that take advantage of both high horizontal and vertical resolution, to address key PBL science questions regarding the interactions between the PBL thermodynamic vertical structure and horizontal variability.

Qing Yue/Jet Propulsion Laboratory
Regime-Based Assessment on the Capability, Limits, and Gaps of the Space-Borne Hyperspectral Infrared Sounders for Resolving PBL Thermodynamic Structures
21-DSI-21-0004

We propose to use high-quality in-situ global radiosonde observations to quantitatively assess the capability, limits, and gaps of the current space-borne hyperspectral infrared (IR) sounders to resolve planetary boundary layer (PBL) thermodynamic vertical structures and PBL height in a variety of PBL regimes. This study is motivated by the importance of exploiting and utilizing the content in the key components of Program of Record (POR) Observations for PBL. It directly responds to the research themes of 2.1.1.1 in the NOFO. As pointed out by the NASA PBL Incubation Study Team Report (Teixeira et al. 2021, hereafter PBL2021): the ability to leverage research and operational satellite observations to extend the POR until a new and improved PBL observing system is realized is critical.

The space-borne hyperspectral IR sounders provide global vertical profiling of atmospheric temperature (T) and water vapor (Q), with enhanced capability by accompanying microwave sounders for profiles below the cloud. The global coverage, long-term continuity, and potential in the retrieval algorithm developments make the IR sounders an important POR element for PBL science. Over the years, the operational IR sounder retrieval algorithms have been developed without necessarily prioritizing the vertical resolution and accuracy in PBL, although studies have hinted at underutilized information existed in regimes with clear or partially cloudy conditions, subtropical marine boundary layer, and the characterization of lower troposphere large-scale environment in deep convective events. Quantitative evaluations on how current operational retrieval algorithms utilize spectral information and a priori constraint and their dependence on PBL regimes are critical to assess the instrument capability in the sounding of PBL thermodynamic structure, which is key for the PBL-targeted optimization of sounder retrieval algorithms.

Motivated by these considerations, we propose three primary goals in this effort:
"	Goal-1: Classify global PBL into regimes by distinguishing various PBL thermodynamic structures obtained from high quality global in-situ observations and large-scale circulation conditions from reanalysis, by applying deep learning models.
"	Goal-2: Quantify the instrument information content and sensitivity of the major modern hyperspectral IR sounders in PBL T and Q profiles and PBL height to resolve critical structures and separate various PBL regimes, and evaluate the performance of NASA operational IR sounder retrieval algorithms in various PBL regimes.
"	Goal-3: Investigate the improvements that can be made to the current IR sounder retrieval algorithms for better sounding of PBL thermodynamic vertical structure and PBL height.
By reaching these goals, our study will quantitatively answer the following questions:
"	How well do the current space-borne hyperspectral IR sounders resolve global PBL thermodynamic structures and PBL height in the varying PBL regimes?
"	What improvements could be made to the operational NASA IR sounder retrieval algorithms to provide better PBL T and Q profiles?

We will focus on multiple major modern operational IR sounders, including AIRS, CrIS, and IASI instruments. The proposed regime-based instrument information content analysis, and PBL-centered evaluation and improvement on operational IR sounder retrieval algorithms will provide new tools to obtain better observations of PBL T and Q profiles and of PBL height from the existing IR sounder POR.

Our analyses and the framework established here will help to quantify how much valuable information can be further obtained from operational sounder measurements to extend POR for PBL science. Our work will also provide a thorough characterization for gaps that could not be addressed by the existing observation system and need to be the focus of future PBL technique developments on sounding of PBL thermodynamic vertical structures.

Yanqiu Zhu/Goddard Space Flight Center
Exploring Strategies and Developing PBL Data Assimilation Including PBL Height from Multiple Observing Systems in the Global GEOS System
21-DSI-21-0042

Objectives: We propose to develop Planetary Boundary Layer (PBL) data assimilation capabilities, focusing on PBL height (PBLH), from multiple observing systems in the global Goddard Earth Observing System (GEOS) data assimilation system to improve the representation of PBL thermodynamic structure. We will explore optimal global data synergy strategies for PBLH data, pinpoint scenarios and regions where PBLH data of different observing systems are most suitable and identify data gaps in the existing Program of Record (POR). We will also aim to improve the characterization of the PBL by exploring strategies of assimilating surface-sensitive radiances and Global Navigation Satellite System Radio Occultation (GNSS-RO) data together with the PBLH data in the GEOS system, and by developing methods to assess and improve retention of information from PBL observations.

Motivation: The accuracy of PBLH simulation is a key issue in many applications including forecasting near-surface meteorology and air quality, however, it is a very challenging problem due to the lack of not only comprehensive, global PBL observations but also a strategy and infrastructure to utilize PBLH data from a variety of sensors. To prepare for integrated PBL observing systems in the coming decade, we propose to explore and develop novel ways to utilize PBL observations focusing on PBLH data from multiple observing systems into the GEOS system.

Technical Approach: In this proposal, estimates of PBLH suitable for assimilation will be derived from GNSS-RO refractivity, space-based lidars, radiosonde, radar wind profilers and Micro Pulse Lidar Network (MPLNET) backscatter, and corresponding model-based PBLH definitions will be derived based on a deep understanding of the retrieval algorithm for each observing system in order to make consistent comparisons between the observed and simulated PBLH.

We propose to explore optimal global data synergy strategies for the assimilation of PBLH data from multiple observing systems. The control variable vector will be augmented with the PBLH variables, thereby allowing the assimilated PBLH data to impact not only the PBLH analysis but also temperature and moisture analyses through ensemble background error covariance. We will also explore the possibility of an innovative approach to assimilating GNSS-RO refractivity gradient in the lower troposphere, and investigate interactions and joint impacts of using radiances, GNSS-RO and PBLH data on temperature, moisture and PBLH in the GEOS system. The impact of these interactions will be assessed using sondes, reanalyses and land-atmosphere coupling metrics.

We propose to develop methods to assess and improve the retention of PBL observation information, assessing model forecast response to assimilation tendencies, and developing methods to reduce compensation by model parameterizations and to improve consistency of PBL structure.

Relevance: This PBL Science proposal will develop PBL data assimilation techniques and exploit POR datasets, as specifically requested in the A.45 Decadal Survey Incubation (DSI) solicitation. This proposal also addresses methods to determine how information content of PBL observations will be retained in data assimilation systems" as requested by the call. The infrastructure developed in this proposal will remain relevant in the coming decade, and indeed is a critical capability to evaluate the impact and ultimately make use of future PBL observing systems including the array of PBLH information that will be available going into the next decade.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2021
NNH21ZDA001N -AIST
A.46 Advanced Information Systems Technology
Updated 05/02/22

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the Advanced Information Systems Technology Program (AIST-21) in support of the Earth Science Division (ESD). The AIST-21 awards will provide novel information systems and computer science technologies to reduce the risk, cost and development time of NASA space- and ground-based information systems, to significantly increase the accessibility and utility of science data, and to enable advanced observation measurements and Earth Science information capabilities.

ESD's Earth Science Technology Office (ESTO) evaluated 65 proposals and will award a total of 28 proposals with a 2-year period of performance. The total amount of all the awards is $31M.

NASA's Advanced Information Systems Technology (AIST) Program identifies, develops, and supports adoption of software and information systems, as well as novel computer science technology expected to be needed by the Earth Science Division in the next 5 to 10 years. Currently, the AIST Program is organized around three primary thrusts, the New Observing Strategies (NOS), the Analytic Collaborative Frameworks (ACF) and the Earth System Digital Twins (ESDT) . Proposals were solicited in either one of these three thrusts or in several very advanced and promising software technology areas and were expected to explicitly show how the resulting technology would be infused into at least one of ESD's science domains. The AIST Program anticipates the technologies in these proposals will mature at least one Technology Readiness Level with an eventual goal to demonstrate their value to the relevant science communities.

Thomas Allen/Old Dominion University
Pixels for Public Health: Analytic Collaborative Framework to Enhance Coastal Resiliency of Vulnerable Populations in Hampton Roads, Virginia
21-AIST21_2-0031

Increasing coastal flooding owing to sea level rise and climate-change drivers of extreme precipitation combine to threaten vulnerable communities, posing imminent as well as evolving dynamic threats given sea-level rise and climate changes. A diversity of social, economic and cultural vulnerabilities, and coping capacities exist across coastal communities, yet decision support systems for response and planning alike are disparate and siloed. Vulnerable urban communities contend with the legacy of racial segregation and discrimination, with manifest disparities leading to unmet health related social needs (HRSNs) such as access to basic resources and health care to treat higher hazard exposures. Coastal cities such as Norfolk, VA, exhibit increased tidal, rainfall, and storm surge flooding owing to sea level and climate changes exacerbated by subsidence. Cities lack high-resolution compound flood forecasting and have disparity in exposure and inequitable outcomes. To address these hazards and proactively mitigate future vulnerability, this project proposes an innovative analytic collaborative framework (ACF) and a Digital Twin approach. We seek to more fully utilize Earth observations and computing to provide improved predictive decision support tools. We propose to design and demonstrate to an operational state a system linking an Earth Observation (EO) data source (Virginia Open Data Cube), a socio-spatial-health information Digital Neighborhood" (DN) (Hampton Roads Biomedical Research Consortium), hydrodynamic models, and in situ flood sensor network. This Digital Twin approach will connect observational and physical environmental domains with human vulnerability. Although individual technologies are fairly mature, they remain siloed and uneven, with limited interoperability, and challenging to operationalize and innovate predictive models or ask what-if scenarios. EO data are leveraged with the Virginia Data Cube using Landsat, Sentinel, MODIS (and forthcoming NISAR) missions to improve hydrodynamic model prediction of flood events by calibration from satellite, autonomous unmanned systems, and linking to smart community IoT flood sensors. This project increases technology-readiness levels system of systems and emphasizes the catalyst role of geospatial integration of flood modeling, predictive analytics, and place-based community vulnerability. Dynamic uncertainties in sea level and flood processes are also analyzed to better plan for worsening future threats. Climate models are used to reconstruct historic flood attribution and estimate future probabilities of flooding, differentiating tidal, surge, extreme rainfall, and compound flood events. A GeoHub is developed to implement the framework and lay a foundation for adoption by flood forecasters, planners, health practitioners and emergency managers, reflecting growing recognition of the need for convergence of modeling and stakeholder engagement and participation (Baustian et al. 2020; Hemmerling et al. 2020.) The hub provides a resource of open science data, models and algorithms for fellow scientists and practitioners. We extend this portal to build stakeholder adoption in a proposed third year drawing end-users to learn and train in a functional exercise simulation. The hub serves as a resource for forecasters, emergency managers, and hazard mitigation planners that integrates diverse vetted data, geospatial tools, and predictive spatial analytics of flood exposure with improved granularity for human health. The resulting technology will demonstrate new analytical and collaborative approaches for modeling, IoT sensor, and EO data integration, synergy between physical earth science and social science Digital Twins, and practical tools for timely and equitable flood response and planning.

Rajat Bindlish/Goddard Space Flight Center
Digital Twin Infrastructure Model for Agricultural Applications
21-AIST21_2-0056

Fully coupled Earth system models are fundamental to timely and accurate weather and climate change information. These process-based estimates are then used as critical inputs in a variety of end-use earth system environments. For example, agricultural models require inputs of precipitation, temperature and moisture conditions along with historical data as key weather parameters to develop estimates of field operations schedules, from seeding to harvesting, with fertilizer and herbicide treatments in-between. Unexpected extreme weather and climate change has a major socioeconomic impact on agriculture and food security. Though important, integration of such end-use oriented and socio-economic models are currently not adequately captured in Earth system modeling efforts and need to be part of the vision for 'Digital Twin'. Here we propose the development of such a prototype by integrating land/hydrology process models, agricultural system models, and remote sensing information.

The aim of this project is to develop an agriculture productivity modeling system over Continental United States as an example of incorporating representations of infrastructure oriented process, so that our understanding, prediction, and mitigation/response to Earth system process variability can be characterized. Crop growth, yield, and agricultural production information is critical for commodity market, food security, economic stability, and government policy formulation. The ability to model agriculture is important for NASA Earth Sciences Program towards its goals for providing timely and relevant information for science decisions". The current USDA National Agricultural Statistics Service (NASS) crop yield is mainly based on agricultural survey which relies on a limited number of samples though linear regression models based on remote sensed NDVI and NASS historical yield records are also used as complementary. Further improvement of crop yield estimation and better crop progress monitoring are needed.

This proposal will target Advanced and Emerging Technology (AET) by developing a modeling framework for Agricultural Decision Support System (ADSS). The specific goals of the proposal are to (1) establish a digital twin framework that enables the NASA remote sensing data products and land surface model products to be directly coupled with or assimilated into the crop growth model; (2) leverage the information from high-resolution remote sensing inputs (precipitation, temperature, solar radiation, soil moisture, snow water equivalent, ground water, leaf area index) through the NASA Land Information System (LIS) to estimate land surface variables (water and energy fluxes) at daily time scales; (3) implement crop growth models (APEX, RZWQM2 and DSSAT) to estimate crop growth stages, biomass, and crop yield under forecasted weather and projected climate conditions; (4) implement Bayesian Neural Network (BNN) model to predict final county level crop yield by using NASS historical yield reports, yield, biomass, and phenology outputs from APEX/ DSSAT model, and other variables from LIS; (5) develop tools to conduct 'what if' investigations to provide agricultural guidance; and (6) develop capability for disseminating non-confidential crop progress data, biomass and crop yield maps using an operational web application. The proposed environment will be developed in an interoperable manner to allow for future interactions with other ESDT efforts.

William Blackwell/MIT Lincoln Laboratory
Sensor-in-the-Loop Testbed to Enable Versatile/Intelligent/Dynamic Earth Observation (VIDEO)
21-AIST21_2-0044

There has been significant recent interest in sensor systems that are reconfigurable, i.e. where one or more of the spectral, spatial, radiometric, and geometric (i.e. viewing angle) properties of the sensor can be changed dynamically. However, no laboratory-based test resources exist to evaluate and optimize end-to-end performance in a realistic fashion. We develop in this proposed Advanced and Emerging Technology (AET) program a methodology and test approach to provide the capability for the scene measured by the sensor (or other sensors that are acting collaboratively) to inform how the sensor is configured in real time during the scene measurement. This innovative New Observing Strategy (NOS) has the capability to dramatically improve the resolution of the retrieved atmospheric fields in regions in which that improvement is most beneficial while conserving resources in regions where the atmospheric fields are relatively homogeneous and therefore free of significant high spatial frequency content. The use case for this proposal is a highly versatile scanning microwave atmospheric temperature profiling radiometer, where ALL of the sensor response functions (spectral, spatial, radiometric, and geometric) are dynamically reconfigurable.

The technology to be developed and evaluated as part of this program has two components: (1) a Radiometric Scene Generator and its associated control software, and (2) intelligent processing and configuration software that would run on the sensor itself to detect and react to changes in the observed scene by dynamically optimizing the sensor response functions. This approach would significantly improve upon current state-of-the-art simulation-only approaches for this evaluation by placing an actual sensor in the observing loop, where the effects of sensor transfer function errors, calibration uncertainty, and processing algorithm imperfections are fully present in the end-to-end system evaluation and would be highly representative of on-orbit performance.

A key aspect of this program to enable development, test, and evaluation of Versatile, Intelligent, and Dynamic Earth Observation (VIDEO) is the recent emergence of metamaterials for use in high-performance blackbody radiometric targets. These materials are very thin (~200 microns) and lightweight (tens of grams), allowing them to be easily scaled up to realize very large targets (> 1 m^2) to subtend an entire sensor field of regard during laboratory measurements. Furthermore, the thin planar structure of the metamaterials provides a relatively small thermal mass, thereby permitting the projection of thermal features with very high spatial frequency content into the sensor field of view at the subpixel level. We propose to adapt the metamaterials developed for the Miniaturized Microwave Absolute Calibration (MiniMAC) ACT-20 project (S. Reising, PI) for use here to produce a 50 cm x 75 cm (20" x 30") Radiometric Scene Generator (RSG) operating near 54 GHz with very large thermal contrast at the subpixel level for a typical spaceborne microwave radiometer full-width-at-half-maximum (FWHM) beamwidth in the range of 1-3 degrees.

The RSG will be used to project spatial features into the radiometer field of regard that can be detected and acted upon by the intelligent processing algorithms. The intelligent processing algorithm will use feature detection and machine learning techniques to recognize regions of interest in the atmospheric scene and cause the sensor to react to the scene characteristics by changing the sensor response function.

The project is led by MIT Lincoln Laboratory, who will provide the VIDEO software toolkit and execute the sensor-in-the-loop tests in collaboration with Colorado State U., who will provide the Radiometric Scene Generator. Entry TRL is 3 and exit TRL is projected to reach 5 after Year 2.

Yehuda Bock/Scripps Institution of Oceanography, UCSD
Detection of Artifacts and Transients in Earth Science Observing Systems with Machine Learning
21-AIST21_2-0093

Our proposal is responsive to AIST objective O2 under the Analytic Collaborative Frameworks (ACF) thrust area, addressing challenges in assimilating, manipulating and visualizing data associated with geodetic observing systems (GNSS and InSAR). We seek to create open-source software to provide a rich, interactive environment where machine learning (ML) models are used as collaborator to direct the attention of the human analyst to non-physical artifacts and real transient events that require interpretation. The proposed system will be realized through two coupled sub-systems: a novel back-end" ML software called the Transient and Artifact Continuous Learning System (TACLS), and a significant upgrade to our front end" interactive MGViz user environment, originally designed to view displacement time series and their underlying metadata, to now interact and display layers of spatiotemporal information.
Our uniqueness is our archive of thousands of artifacts and transients, and acquired expertise in creating calibrated and validated Earth Science Data Records (ESDRs) from thousands of GNSS stations and 30 years of data; these will be used to train the ML algorithms. ESDRs include crustal deformation and strain rate fields, which reflect steady-state and transient motions due to postseismic processes, episodic tremor and slip - ETS, volcanic inflation, and mostly vertical motions due to other natural (tectonic, geomorphic) and anthropogenic processes (sea level rise, subsidence due to water extraction), and atmospheric precipitable water as a harbinger of extreme weather events. Our interactive environment will also be designed for displacement fields of higher precision and spatial resolution produced through GNSS/InSAR integration.
A primary bottleneck to the extraction of scientific insight from geodetic data is the challenge to separate non-physical artifacts and secular trends from scientifically relevant transients, which often requires costly and intensive manual intervention to achieve the most robust and accurate results. This process is often performed redundantly, inefficiently and inconsistently by groups of students and individual researchers, focused on a particular science problem. An example of a transient is slow slip deformation, which plays a crucial role in advancing our understanding of earthquake dynamics and hazards, indicating possible change of stress on the fault interface, triggered earthquake swarms or seismicity and release of accumulated elastic strain. Increasing evidence suggests that slow slip often precedes and possibly leads to the large earthquakes. As another example, GPS-based integrated water vapor estimates enable improved forecasting skill for extreme weather events, improved understanding of long-term water vapor trends, probable maximum precipitation, and retrospective analysis of weather events and watch/warning situational awareness involving extremes in precipitable water.

We will demonstrate the MGViz/TACLS system by two representative science test cases. The first will address transient tectonic signals and associated hazards in the subduction zones of the Pacific Rim with the participation of the NOAA/NWS Pacific Tsunami Warning Center (PTWC) in Hawaii. The second will track variations in atmospheric water vapor as precursors to weather events such as monsoons and atmospheric rivers to forecast flash flooding, with the participation of the National Weather Service's (NWS) Weather forecasting Offices (WFOs) in southern California. We propose a third year to our project that will transfer the MGViz/TACLS system to PTWC and the WFOs. All software developed under this proposal will be deposited under the existing, publicly accessible MGViz repository. This software will be freely available to anyone to use with no restrictions other than those stipulated in the license. Our entry level is TRL 4 with an output level of TRL 6 at the end of year 2 and TRL 7 at the end of year 3.

James Carr/Carr Astronautics Corporation
Edge Intelligence for Hyperspectral Applications in Earth Science for New Observing Systems
21-AIST21_2-0043

We use the SpaceCube processor and the TRL-5 SpaceCube Low-power Edge Artificial Intelligence Resilient Node (SC-LEARN) coprocessor [1] powered by Google Coral Edge Tensor Processing Units (TPUs) to implement two AI science use cases in hyperspectral remote sensing. The first (daytime) application uses learned spectral signatures of clear-sky scenes to retrieve surface reflectance and therefore increase the efficiency of collecting land observations on our ~68% cloudy planet [2], which benefits Surface Biology and Geology (SBG) decadal survey objectives. The second (nighttime) application classifies artificial light sources after training against a catalog of lighting types. SC-LEARN was developed at GSFC for AI applications such as neural networks and is packaged in a small, low-power 1U CubeSat form factor. SC-LEARN will fly on STP-H9/SCENIC to the ISS with a Headwall Photonics HyperspecMV [3] hyperspectral imager. SCENIC is not dedicated to fixed objectives, rather investigators may reprogram SCENIC for experiments and demonstrations. In Year-1, we develop and test our science applications in a testbed environment on development boards and with actual SpaceCube hardware. We use SCENIC in Year-2 as an early flight opportunity to test and demonstrate our science application cases. We also take advantage of hyperspectral datasets from the TEMPO observatory, which will be available in Year-2, for use in further demonstrations in the testbed. Two flight builds for SCENIC are foreseen to allow us to take advantage of flight experience to refine the applications. Our targeted outcome is two fully developed science cases implemented on the innovative SC-LEARN AI platform and tested in space, with lessons learned, best practices, and an AI framework code to share. The framework code serves as a template for prototyping hyperspectral science applications for SC-LEARN that will enable others to prepare their applications more efficiently for porting onto SC-LEARN or similar hardware. By working two science cases, we assure that it is not overly specific towards a single target application. We aim to build a community of practice for AI developers in the Earth Science community. In doing so, we advance NOS objectives by advancing state-of-the-art technology to enable systems where data volume or latency considerations require Edge Intelligence.

Our industry-government team is led by PI Dr. James Carr. He is PI of the successful StereoBit AIST-18 project. It is a Structure from Motion (SfM) application on SpaceCube that tracks motions of clouds in 3D [4]. Government partners are Dr. Christopher Wilson, Associate Branch Head of the Science Data Processing branch (Code 587), and Dr. Joanna Joiner, a NASA Earth Scientist. Dr. Wilson is the payload lead for STP-H9/SCENIC and has an established working relationship with Dr. Carr from StereoBit. Drs. Carr and Joiner belong to the TEMPO Science Team. Dr. Joiner is the author of the first science case, which has been demonstrated on conventional ground computers with data from the Hyperspectral Imager for the Coastal Oceans (HICO) instrument on ISS [5, 6]. Dr. Carr has proposed the second science case as a green paper" activity for TEMPO [7] to take advantage of otherwise unutilized nighttime hours. Classification of nightlights has implications for the quality of the dark night sky on Earth, ecology, and human health. Dr. Virginia Kalb, Black Marble PI, is a Collaborator. Justin Goodwill (GSFC) is part of our team and the lead AI-application hardware/software developer for SC-LEARN on SCENIC.

[1] https://digitalcommons.usu.edu/smallsat/2021/all2021/185/
[2] https://doi.org/10.1175/BAMS-D-12-00117.1
[3] https://cdn2.hubspot.net/hubfs/145999/June%202018%20Collateral/HyperspecMV0118.pdf
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Meghan Chandarana/Ames Research Center
Intelligent Long Endurance Observing System
21-AIST21_2-0098

Existing satellites provide coarse-grained (~ 10 km^2/pixel) data on surface features and column gas concentrations of climate-relevant trace gases. While these data can be supplemented by fine-pointing satellites and aircraft, the spatial and temporal resolution available is not sufficient to observe stochastic, ephemeral events that take place between observations. Emerging HALE UAS can operate for months at a time and loiter over targets to provide continuous daylight geostationary-like observations but must be integrated with existing satellites. We propose the development of the Intelligent Long Endurance Observing System (ILEOS), a science activity planning system. This Advanced and Emerging Technology (AET) proposal directly responds to Solicitation Objective O1: Enable new observation measurements and new observing systems design and operations through intelligent, timely, dynamic, and coordinated distributed sensing. ILEOS will help scientists build plans to improve spatio-temporal resolution of climate-relevant gases by fusing coarse-grained sensor data from satellites and other sources (e.g., terrain, wind forecasts), and plan HALE UAS flights to obtain finer-grain (high spatio-temporal) data. ILEOS will also enable observations for longer periods and of environments not accessible through in-situ observations and field campaigns.

ILEOS consists of 3 components: the Target Generation Pipeline (Targeter), the Science Observation Planner (Planner), and Scientists' User Interface (Reporter). The Targeter identifies candidate target scenes for HALE UAS-mounted instrument observations. The Targeter leverages Science SME domain knowledge to fuse available coarse-grained data from satellites and other sources into pixel value maps, used to generate scenes and scene values. The Planner will use automated planning and scheduling technology to automatically generate a flight plan to observe the best identified target scenes while enforcing all operating constraints for a HALE UAS. The Reporter provides the user interface for science mission planners to visualize pixels, scenes, flight plans, and other data such as clouds and winds. The Reporter will allow mission planners to request explanations detailing pixels, scenes, and the underlying constraints and assumptions used to schedule measurements over scenes and generate a flight plan. The Reporter also allows scientists to modify constraints as necessary to adjust science objectives.

Diverse science use cases will be developed based on characterizing NO2 and CH4 emissions in different parts of the world (e.g., permafrost thaw methane in the Arctic, high-altitude lightning-induced NOx (=NO+NO2)), and anthropogenic sources such as cities and oil platforms in the Gulf of Mexico) that benefit from sustained observations by emerging HALE UAS technologies. The first 2 years of the effort development will be performed in parallel 'spirals'. The first spiral will concentrate on first science domain; the second domain effort will benefit from lessons learned from the first domain. In the 3rd year we will infuse ILEOS into NASA's heritage Mission Tool Suite (MTS) application, used by the Airborne Sciences Program (ASP), and with NASA's ETM project.

The project will advance the state of the art by:
- Developing a Target Generation Pipeline controllable by scientists to generate observation objectives for HALE UAS mounted instruments.
- Developing a Science Observation Scheduler controllable by scientists to generate flight plans for HALE UAS.
- Demonstrating the Scientists User Interface capability to task fleets of HALE UAS.
- Enabling a NOS employing a combination of existing satellites and instruments combined with new HALE UAS-borne instruments to complement coarse-grained climate-relevant data with targeted high spatio-temporal coverage.

The proposal team leverages technologists, human factors experts, science subject matter experts and instrument designers.

Arlindo da Silva/Goddard Space Flight Center
An Analytic Collaborative Framework for the Earth System Observatory (ESO) Designated Observables
21-AIST21_2-0107

MOTIVATION: NASA's Earth System Observatory ground breaking observations will provide critical measurements to address societal relevant problems in climate change, natural hazard mitigation, fighting forest fires, and improving real-time agricultural processes. Central to the ESO vision is the notion of Open-Source Science (OSS), a collaborative culture enabled by technology that promotes the open sharing of data, information, and knowledge aiming to facilitate and accelerate scientific understanding, and the agile development of applications for the benefit of society. The larger vision of an Earth System Digital Twin (ESDT) set forth in the AIST solicitation is the linchpin for the implementation of OSS at NASA. It calls for integrated Earth science frameworks that mirror the earth by a proxy digital construct that includes high resolution earth system models and data assimilation systems along with integrated set of analytic tools to enable the next generation of science discoveries and evidence-based decision making. Among the many applications of these frameworks is the design of future observing systems, from selection of space mission architectures, to the exploration of science and societal applications, well before launch. Thus, realistic simulations of the future measurements become a necessity if a mature OSS environment is to become available early in the lifetime of the mission, this way maximizing the impact and societal benefits of NASA observations.

OBJECTIVES: Our ultimate vision is to develop an Analytic Collaborative Framework for ESO missions, based on realistic, science-based observing system simulations and the Program of Record (PoR). Tying it all together is a cloud based cyberinfrastructure that will enable each uniquely designed satellite in the Earth System Observatory to work in tandem to create a 3D, holistic view of Earth. In this proposal, we lay the technological ground work for enabling such a vision.

TECHNICAL APPROACH: Our approach consists on the 3 main interconnected building blocks:

1) Cloud-optimized representative datasets for ESO missions and the PoR to serve as basis for developing and prototyping an Analytic Collaborative Framework.
2) An Algorithm Workbench for enabling experimentation and exploration of synergistic algorithms not only for instruments within a mission, but also including the PoR and other ESO missions.
3) A series of concrete Open-Source Science demonstrations including use cases that span science discovery and end-user applications with direct societal impact.

While our ultimate goal is include all of the main missions comprising the Earth System Observatory, in our initial 2 years we will focus on AOS and SBG, two missions for which specific synergisms have been identified in a recent workshop.

RELEVANCE: The proposed effort directly addresses the AIST solicitation by developing a cloud-based Analytic Collaborative Framework for the ESO missions. In doing so it enables investigative technologies to facilitate "what-if" investigations inherent to ESDT systems. Our framework will enable global cloud-resolving OSSEs that significantly contributes to the exploration of synergistic new algorithms, enables trade studies during mission development, and provides a transparent mechanism for early engagement of the applications and scientific communities at large. In addition, such capabilities make a direct contribution to NASA's emerging Open-Source Science Initiative.

Yulia Gel/University of Texas at Dallas
Innovative Geometric Deep Learning Models for Onboard Detection of Anomalous Events
21-AIST21_2-0059

Artificial intelligence (AI) tools based on deep learning (DL) which are proven to be highly successful in many domains from biomedical imaging to natural language processing, are still rarely applied not only for onboard learning of Earth Science processes but for Earth Science data analysis in general. One of the key obstructing challenges here is limited capability of the current modeling tools to efficiently integrate time-dimension into the learning process and to accurately describe multi-scale spatio-temporal variability which is ubiquitous in most Earth Science phenomena. As a result, such DL architectures often cannot reliably, accurately and on time learn many salient time-conditioned characteristics of complex interdependent Earth Science systems, resulting in outdated decisions and requiring frequent model updates.

To address these challenges, we propose to fuse two emerging directions in time-aware machine learning, namely, geometric deep learnining (GDL) and topological data analysis (TDA). In particular, GDL offers a systematic framework for learning non-Euclidean objects with a distinct local spatial structure such as exhibited, for instance, by the smoke plumes. As a result, GDL allows us for more flexible modeling of complex interactions among entities in a broad range of Earth Science data structures, including multivariate time series and dynamic networks. In turn, TDA yields us complementary information on the time-conditioned underlying intrinsic Earth Science system organization at multiple scales.

The ultimate goal of the project is to develop efficient, systematic, and reliable learning mechanisms for the onboard exploration by explicitly integrating both space and time dimensions into the knowledge representation at multiple spectral and spatial resolutions. Using radiance data from NASA's GeoNEX project [Nemani et al. 2020] and High-End Computing (HEC) systems, we will address the following interlinked tasks:

T1. Develop time-aware DL architectures with shape signatures from multiple spectral bands for semi-supervised onboard learning of multi-resolution smoke observations.

T2. Detect smoke plumes and other anomalies in multi-resolution observations with time-aware DL with a fully trainable and end-to-end multipersistence module.

T3. Investigate the uncertainty in topological detection of smoke plumes.

T4. Improve the efficiency of GDL for onboard applications.

In addition to developing the novel early-stage technology, topological and geometric DL methods for onboard exploration, we will disseminate all new topological and geometric DL tools in the form of publicly available Python packages. We will maintain all software in a public GitHub repository and use GitHub's built-in issue JIRA system for tracking issues and collaborative software management.

Colin Gleason/University of Massachusetts Amherst
A Hosted Analytic Collaborative Framework for Global River Water Quantity and Quality From SWOT, Landsat, and Sentinel-2
21-AIST21_2-0037

NASA's soon to be launched SWOT mission promises a sea change for terrestrial hydrology. Principally, SWOT's reservoir/lake volume change observations and SWOT's derived river discharge product are each unprecedented in terms of their resolution, scale, and frequency. This water quantity information is among the primary reasons for SWOT's development and launch. SWOT water quantity algorithms and products are well documented in the literature, and a robust plan is in place to produce these products globally.

Rivers are also more than just water quantity: the quality of river water is essential knowledge for ecosystems and society. There are currently no plans to assess river water quality from SWOT data. However, optical image analysis has a long history in hydrology and can detect river water quality, especially information regarding river sediment concentrations and algal blooms. However, hydrology faces a knowledge gap: computer vision has advanced separately from image analysis as practiced by hydrologists, and computer vision capabilities as practiced in computer science are far more accurate, efficient, and robust for extracting information from imagery than are traditional hydrologic measurement techniques. Many important hydrologic image-based tasks such as water surface classification, river and lake dimensional measurements, and water quality quantification (e.g. sediment and algae) could potentially benefit from improvements as practiced in computer vision.

The launch of SWOT therefore presents a tremendous opportunity to combine SWOT and optical data in a single Analytic Collaborative Framework (ACF) to simultaneously co-predict river water quantity and quality at a scale that is not currently possible. This advance is non-trivial: multiplying the mass flux of water (estimated via SWOT) by its constituent concentrations (estimated via optical data) provides a constituent mass loading (e.g. sediment, algae) in the world's river systems and therefore a direct benefit to society and ecosystems.

This project seeks to integrate data from the soon-to-be launched SWOT mission with traditional optical imagery into a common platform to address previously intractable scientific and science-informed application questions" as solicited for an ACF. Specifically, we will build on an existing ACF already in development as part of the SWOT Science Team named 'Confluence.' Confluence currently seamlessly integrates with SWOT data (as solicited) but has a very narrow scope and mission: to analyze SWOT data and deliver the parameters needed for the SWOT river discharge product to NASA's JPL. In addition, Confluence is only available to its developers and not the broader community. Confluence also does not currently integrate optical data into its analysis framework and has no ability to predict water quality.

We argue that the ability to co-predict river discharge and river water quality is currently intractable, and that our proposed ACF will make it tractable. The outputs of our ACF will be 1) a unique seamless data environment for SWOT and optical data, 2) an extended library of algorithms for water quantity, 3) a novel library of computer vision algorithms for water quality, and 4) an automated computational environment to produce river water quantity and quality products, globally. As an AET, we plan to transition our ACF to PO.DAAC in year 3, allowing our ACF and its outputs to reside 'alongside' the SWOT mission products (PO.DAAC is the designated NASA archive for SWOT) for ease of discovery and use by the hydrology community. Our proposed ACF should dramatically and uniquely advance our understanding of the world's river water quality and quantity, informing the management, use, and study of rivers as it is transitioned to PO.DAAC for year 3 and beyond.

Alison Gray/University of Washington
DTAS: A Prototype Digital Twin of Air-Sea Interactions
21-AIST21_2-0091

Boundary layer interactions between oceanic and atmospheric surfaces are essential for predicting long-term climatic changes and the increasing occurrence of extreme weather events. These exchanges are critical indicators of climatic changes, especially regarding floods, droughts, storms, and hurricanes, and are increasingly studied to better understand extreme weather events. However, they are also a significant source of uncertainty in climate models as they are notoriously hard to directly observe and often involve expensive instrumentation, which introduces scaling difficulties. Traditionally, modelers have used various kinds of numerical physics-based parameterizations to understand these linkages. While these are helpful, their computational and memory needs make it inefficient to incorporate advanced parameterizations into larger climate models or run uncertainty quantification analyses. Moreover, these models tend to be one-directional, as they are generally initialized with a boundary layer condition to assess the outcome.

In this research project, we propose to develop a hybrid physics-informed artificial intelligence model that ingests several existing flux estimates and observational data products to train against flux estimates computed from measurements collected by Saildrones, state-of-the-art autonomous platforms for simultaneous ocean-atmosphere observation. Hybrid models have been increasingly used in several domains as they can remarkably decrease the computational effort and data requirements. While data-driven models can handle high-dimensional complex systems and provide rapid inference, they are often considered ``black box" models with poor interpretability, and they typically do not extrapolate well beyond the training data. Our novel hybrid approach of combining physics-based models with neural networks will overcome these deficiencies. It will provide rapid scalability and fast inference of data-driven models and has the advantages of traditional numerical physics-based models regarding data efficiency, interpretability, and generalizability.

We will use the hybrid model for two primary purposes: (1) to ascertain the spatiotemporal uncertainty of existing flux measurements compared to those computed from Saildrone observations; and (2) to find the possible combinations of near-real-time data of existing flux products (satellite-based and reanalysis) and observational data of oceanic and atmospheric variables (remotely-sensed and in situ)) to obtain the best estimates for a given spatiotemporal slice. The near-real-time aspect of the hybrid model enables the development of a ``Digital Twin" of the boundary layer air-sea interactions. We will complete the framework with a front-end visual analysis system, which lets the user perform several actions: 1) identify the possibility space of future predictions based on a set of parameter choices (``what-if" investigations); 2) identify the parameter sweep of initial conditions for a given future prediction; and 3) perform sensitivity analysis of parameters for different scenarios. The model developed in this research investigation will focus on the Gulf Stream region. However, this is the first step towards building a Digital Twin for the Planetary Boundary Layer, which would be game-changing for scientists and decision-makers looking to advance our understanding of weather and climatic changes, to better forecast extreme weather events such as floods, hurricanes, and marine heatwaves, and to manage better and mitigate changes to ocean ecosystems.

Thomas Grubb/Goddard Space Flight Center
GEOS Visualization and Lagrangian Dynamics Immersive eXtended Reality Tool (VALIXR) for Scientific Discovery
21-AIST21_2-0052

Traditionally, scientists view and analyze the results of calculated or measured observables with static 1-dimensional (1-D), 2-D or 3-D plots. It is difficult to identify, track and understand the evolution of key features in this framework due to poor viewing angles and the nature of flat computer screens. In addition, numerical models, such as the

NASA Goddard Earth Observing System (GEOS) climate/weather model, are almost exclusively formulated and analyzed on Eulerian grids with fixed grid points in space and time. However, Earth Science phenomena such as convective clouds, hurricanes and wildfire smoke plumes move with the 3-D flow field in a Lagrangian reference frame, and it is often difficult and unnatural to understand these phenomena with data on Eulerian grids.

We propose to develop a scientific exploration and analysis mixed augmented and virtual reality tool with integrated Lagrangian Dynamics (LD) to help scientists identify, track, and understand the evolution of Earth Science phenomena in the NASA GEOS model.

VALIXR will:

- Enhance GEOS to calculate Lagrangian trajectories of Earth Science phenomena and output budget terms (e.g., momentum) and parcel attributes (e.g., temperature) that describe their dynamics
- Enhance the NASA open source eXtended Reality (XR, i.e., AR and VR) tool, the Mixed Reality Exploration Toolkit (MRET) developed by the PI, to visualize and animate GEOS fields as well as initialize and track LD features (i.e., parcel trajectories)

This project has wide applicability to the Earth Sciences, from analysis of smoke plumes moving around the globe, to organized convection in hurricanes, to eddies associated with the polar vortex, and more. VALIXR will provide Earth scientists:

- Enhanced scientific discovery of key phenomena in the Earth system through the combination of advanced visualization and quantitative LD with NASA models and data
- An immersive, interactive, and animated visualization of GEOS fields and particle trajectories to allow scientists to intuitively initialize LD for subsequent GEOS model runs
- Intuitive initialization, manipulation and interaction with GEOS data and trajectory paths through the use of XR

Leveraging the NASA open source MRET tool and integrating it with a generalized open-source point cloud system has huge applicability to any Earth Science domain. MRET provides an open-source foundation for collaborative XR with dispersed groups working together in a common 3D space that can combine DEM terrains, 3D engineering models and point clouds, including LIDAR data. This will enable the following benefits:

- Visualizing enormous scientific point clouds as one dataset. Current XR tools for visualizing point clouds are deficient. Problems include losing precision; requiring all points to fit on the GPU; poor visual quality for data from multiple sources; and requiring commercial licenses.
- Enabling collaboration. Remote collaboration is a powerful benefit of XR, allowing geographically separated scientists to work together and is particularly relevant given the emphasis on teleworking.
- Improving Analysis. XR enables improved ways of looking at science data. For example, using another tool by the PI, astrophysicists examined eight nearby young moving star groups and found seven new likely disk-hosting members. None of these objects had been identified via clustering algorithms or other tools in the literature.
- Improving Interaction. Not only does XR provide superior visualizations, but interaction is more intuitive. For example, if scientists need to specify a point in 3D space, traditionally this required specifying a point in three 2D coordinate systems (XY,

XZ, and YZ) which is cumbersome. Specifying a location in a 3D environment is much easier as you just point at the location.
This proposal will address the development of an Earth System Digital Twin that provides both a scientific discovery tool and a model analysis and improvement tool.

Alexandre Guillaume/Jet Propulsion Laboratory
Stochastic Parameterization of an Atmospheric Model Assisted by Quantum Annealing
21-AIST21_2-0005

Despite the continuing increase of computing power, the multiscale nature of geophysical fluid dynamics implies that many important physical processes cannot be resolved by traditional atmospheric models. Historically, these unresolved processes have been represented by semi-empirical models, known as parameterizations. Stochastic parameterization is a method that is used to represent subgrid-scale variability. One of the reasons stochastic parameterization is necessary is to compensate for computing limitations. Independently, quantum annealing (QA) has emerged as a quantum computing technique and is now commercially available. This technique is particularly adapted to optimize or solve machine learning problems defined with binary variables on a regular grid.
Our goal is to create a quantum computing framework to characterize a stochastic parameterization of the boundary layer clouds constrained by remote sensing data. Using the formal similarity of both, the stochastic parameterization and the quantum hardware, to a regular lattice known as the Ising model, we can take advantage of the quantum computing efficiency.
First, we will implement a Restricted Boltzmann Machine (RBM) using a quantum annealer to learn the horizontal distribution of clouds as measured by Moderate Resolution Imaging Spectroradiometer (MODIS). Secondly, we will use this Machine Learning method to determine the parameters of a stochastic parameterization of the stratocumulus cloud area fraction (CAF) when it is coupled to the dynamics of large scale moisture. We will use the stochastic parameterization developed by Khouider B.and Bihlo, A. in 2019 to model the boundary layer Clouds and stratocumulus phase transition regimes.
The main outcome of the proposed work will be the delivery of a quantum computing framework that will improve upon the current state of the art of the conventional computing framework and will enable the full characterization an atmospheric stochastic parameterization using remote sensing data. Until now, it has been too computationally expensive to retrieve dynamically the parameters of the local lattice describing the CAF of stratocumulus when it is coupled to the large-scale moisture evolution. The innovation here is to use the quantum annealer to sample from the Gibbs distribution more efficiently than a conventional Markov Chain Monte-Carlo (MCMC) would. Numerical experiments have shown that quantum sampling-based training approach achieves comparable or better accuracy with significantly fewer iterations of generative training than conventional training. We emphasize that the current effort is a rare example of a

problem that can be a solved with current quantum technology. This should be contrasted with most real life optimization problems that are usually too big to be solved on a quantum annealer. Current quantum annealer chips, e.g. D-Wave's, already has a number of quantum bits that is commensurate with the number of lattice cells in the current formulation of the cloud stochastic model.

Ziad Haddad/Jet Propulsion Laboratory
Thematic Observation Search, Segmentation, Collation and Analysis (TOS2CA) System
21-AIST21_2-0015

Over the years, AIST has supported the development of a large and diverse set of science software resources   technical algorithms, data ingestion and processing modules, visualization capabilities, cloud computing, immersive environments   for the analysis and representation of science data and scientific results for different instruments, missions and applications. These capabilities were mostly tailored for a particular mission or even a particular set of users such as mission personnel, science teams or singular researchers. This proposal is to remedy the fact that we still do not have a practical framework for inter- nor intra- coordination and collaboration to promote and reuse these developed and refined resources, particularly to search for, collate, analyze and visualize data relevant to the Earth System Observatory (EOS) investigations.

The best analyses of a phenomenon typically require identifying scenarios of specific interest in the observations, often in nearly-coincident nearly-simultaneous data from different observing systems. For NASA's current Program of Record (PoR) and incipient EOS, the need for this ability to identify, collate and analyze data from different sources including different missions   that are relevant to a single user-specified scientific process or phenomenon is all the more pressing.

TOS2CA is a user-driven, data-centric system that can identify, collate, statistically characterize and serve Earth system data relevant to a given phenomenon relevant to EOS. Designed as a multi-discipline analytic collaborative framework (ACF), TOS2CA will not only facilitate the collation and analysis of data from disparate sources, it will also make it possible for scientists to establish science-traceability requirements, quantify detection thresholds, define uncertainty requirements and establish data sufficiency to formulate truly innovative missions. To do this, TOS2CA will allow one to characterize the joint distribution of several variables, and quantify and visualize how well that joint distribution would be sampled from different orbits over different durations.

As an ACF, the components of TOS2CA will include: 1) a user-driven thematic data collector; 2) a statistical analyzer; and 3) a user-friendly visualization and data exploration toolkit. One of the first objectives of TOS2CA is to develop a means for efficiently identifying, managing and utilizing relevant PoR datasets   typically massive, heterogenous and with varied access mechanisms   for analysis. TOS2CA will streamline and encapsulate the ingestion of these data in support of Earth System Observatory analyses, maintaining data fidelity, provenance and repeatability of the data collation, and providing a realistic quantitative evaluation of results.. The data collation will be developed by adapting software already developed for the joint NASA-ESA Multi-mission Analysis Platform Project" collaboration for the eco-systems community.

The first component of TOS2CA is a data curation service with an ontological approach to identify data relevant to a user-defined phenomenon, and an information extraction and collation module made very efficient by systematic use of metadata records stored in NASA's Common Metadata Repository (CMR). The efficiency of this data curation approach is driven by the definition of the specific Earth Science phenomenon. A vocabulary that will be defined by subject matter experts from GCMD keywords, will allow users to formulate a phenomenon so that it is mathematically supported on a bounded topological subset of space-time. The connected components of this subspace will then allow TOS2CA to break the curation service down chronologically, and thereby drastically reduce the number of potentially relevant data granules that need to be interrogated for each connected component.

Milton Halem/University of Maryland, Baltimore County
Towards a NU-WRF Based Mega Wildfire Digital Twin: Smoke Transport Impact Scenarios on Air Quality, Cardiopulmonary Disease and Regional Deforestation
21-AIST21_2-0045

Recent persistent droughts and extreme heatwave events over the Western states of the US and Canada are creating highly favorable conditions for mega wildfires that are generating broad regions of deforestation. Smoke from these Western wildfires, which depend on their atmospheric states, their intensity, and the vegetation fueling them, can be observed in distant cities and towns over the Eastern US, significantly affecting the air quality of these communities and leading to adverse human health effects, such as increased Covid-19 morbidity cases owing to the smoke as well as respiratory and smoke-related heart disease. Such mega wildfire conditions are expected to continue occurring globally with increasing frequency and intensity over forested regions as reported by the IPCC AR6.

Our goal is to develop and implement a Regional Wildfire Digital Twin (WDT) model with a sub-km resolution to enable the conduct of mega wildfire smoke impact scenarios at various spatial scales and arbitrary locations over N. America. WDT will provide a valuable planning tool to implement parameter impact scenarios by season, location, intensity, and atmospheric state. We will augment the NASA Unified WRF (NUWRF) model with an interactive locality fueled SFIRE parameterization (SFIRE) coupled to GOCART, CHEM and the HRRR4 physics. We will implement a data-driven, near time continuous, data assimilation scheme for ingesting and assimilating mixed boundary layer heights, cloud heights, and precipitation from a streaming sensor web of radars, ceilometers and satellite lidar observational systems into a nested regional WDT model.

We will accelerate the NUWRF model performance to enable high resolution by emulating the microphysics and GOCART parameterizations with a deep dense machine learning progressive neural net architecture that can track the penetration of wildfire smoke into the planetary boundary layer. The SFIRE model will be a unique contribution to NUWRF, fully enabling the interaction of smoke aerosols with observed clouds, the microphysics precipitation, convection and the GOCART Chem, currently unavailable in other fire forecasting models.

This proposal builds upon the AI expertise of CO-Is gained from a prior AIST incubation grant to explore the potential impact of machine learning technologies to infer boundary layer heights from Lidar aerosol backscatter. We have successfully implemented a sensor web to simultaneously stream, process and assimilate ceilometer data from Bristol, PA, Catonsville, MD and Blacksburg, VA in real-time data into the WRF model. In addition, our CO-Is from U/CO at Denver, SJSU and Howard university are the developers and analysts of the SFIRE data products and will implement the SFIRE system into NUWRF as a fully interactive physics package.

This proposal is in keeping with the Science and Applications priorities of the Decadal Strategy for Earth Observations from Space 2018, which considers it most important to Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts at minutes to sub-seasonal time scales". Further, it supports the NASA diversity goals by engaging students at Howard U, an HBCU and three MSI schools, SJSU, U/C at Denver and UMBC. Thus, if awarded, we expect to transform NUWRF into a wildfire digital twin model from a current TRL 3/4 to achieve a TRL 6/7 by the end of Year 2. We are proposing for Year 3, the testing of an extension of the scenario implementations of WDT to global located forested regions, allowing one-way feedback interactions between the GFS and Geos global models and the NUWRF based WDT, thereby laying the groundwork towards a fully global interactive digital twin model for operational analytics. We further expect to test the implementation of the SFIRE and Data Assimilation System in the EPA operational Community Model for Air Quality.

Matthias Katzfuss/Texas A&M University
A Scalable Probabilistic Emulation and Uncertainty Quantification Tool for Earth-System Models
21-AIST21_2-0082

We propose to develop a new, fully automated toolbox for uncertainty quantification in Earth-system models, to provide insight into the largest and most critical information gaps in Earth Sciences and to identify where potential future observations would be most valuable. We will achieve this goal by building a probabilistic emulator that is able to learn the non-Gaussian distribution of spatio-temporal fields from a small number of nature runs from Earth-system models, allowing users to, for example, discover and examine nonlinear dependence structures. In a significant step toward an Earth system digital twin (ESDT), the learned distribution can be a function of covariates (e.g., emissions scenarios), which allows interpolation between observed covariate values and running extensive what-if scenarios. Our proposed software tool is a crucial component in societal decision-making and in numerous NASA applications and missions, including studying climate projections, efficient observing system simulation experiments (OSSEs), uncertainty-quantification efforts for existing missions, and "what-if" investigations for potential future observing systems.

The project will consist of three broad goals. As the first goal, the team will develop statistical methodology for efficient estimation of and simulation from the probability distribution of multiple geophysical fields of interest. The approach, based on Bayesian transport maps, learns the spatio-temporal and multivariate dependence structure from a small- to moderate-sized ensemble of runs from an Earth-system model. The second goal is to implement the methodology in a user-friendly open-source software-package with documented examples. The third goal is to demonstrate use of the toolbox in assessing the probability distribution of important hydrological variables, as represented in Earth system models.

In order to characterize the uncertainty in spatio-temporal dependence that besets so many variables in the Earth sciences, we will specifically examine precipitation, snow water equivalent, and runoff in CMIP6 simulations to demonstrate how powerful a tool like this can be for the future NASA applications. Our technology provides flexibility to identify impactful characteristics of the water cycle under current conditions and its response to climate change, including nonlinear changes in time and under multiple emission scenarios. Further, the investigation will provide insight into hydrological processes and associated scales that are particularly uncertain, providing motivation for future observing needs for terrestrial hydrology, including upcoming missions like Surface Water and Ocean Topography (SWOT) and the mass change (MC) designated observable.

The proposed project addresses the advanced and emerging technology (AET) topic area in the AIST-21 solicitation. It will provide technologies and tools for use in ESDT. Specifically, the project will "enable running large permutations of what-if scenarios using large amounts of data and high-resolution and high-fidelity models" and comprises "statistical methodologies that optimize the computational efficiency of such what-if investigations."

Christoph Keller/Goddard Space Flight Center
Development of a Next-Generation Ensemble Prediction System for Atmospheric Composition
21-AIST21_2-0024

We propose to develop a next-generation modeling framework for the real-time simulation of reactive gases and aerosols in the atmosphere. The core innovations of this project are (a) the deployment of computationally efficient parameterizations of atmospheric chemistry and transport and (b) the development of generative models based on machine learning (ML) to predict model uncertainties. Combined, these innovations will enable improved and novel applications related to atmospheric composition, including probabilistic air quality forecasts at increased horizontal resolution, advanced use of satellite observations using ensemble-based data assimilation techniques, and scenario simulations for real-time event analysis. The proposed simulation capability will be developed and tested within the NASA GEOS Earth System Model (ESM), and its utility will first be demonstrated in the GEOS Composition Forecast system (GEOS-CF). In a second step, we propose to transfer the technology to NOAA's air quality forecasting (AQF) system. This project will greatly advance NASA's capability to monitor, simulate, and understand reactive trace gases and aerosols in the atmosphere. It directly supports NASA's TEMPO mission scheduled to launch in November 2022 and other upcoming NASA missions including PACE and MAIA. It alleviates a major limitation of existing ESMs, namely the prohibitive computational cost of full chemistry models. We address this issue by implementing simplified parameterizations for the slowest model components, the simulation of atmospheric chemistry and the advection of chemical species. We further propose the use of conditional generative adversarial networks (cGAN) ML algorithms for the estimation of probability distributions to enable ensemble-based applications.

A key aspect of the proposed system is that the original numerical model and the accelerated models can be used in tandem. This way, the full physics model can be deployed for the main analysis stream, and the accelerated system is used to improve overall analytic and predictive power during forecast and data assimilation. This minimizes the impact of compounding errors that can arise from the use of ML models alone.

The project comprises two science tasks: Task 1 is to implement simplified parameterizations for atmospheric chemistry and tracer transport. This task builds on extensive previous work by the proposal team. For instance, PI Keller has developed a ML emulator for atmospheric chemistry based on gradient boosted regression trees, but this algorithm has not yet been tested for high-resolution applications such as GEOS-CF. Here we propose to do so, along with the development of an accelerated tracer transport capability based on optimizing the number of advected tracers and time stepping. Computation of atmospheric chemistry and transport consume more than 80% of the total compute time of full chemistry simulations, and we project that the accelerated system will deliver a 3-5 fold model speed-up. The second task is to develop an efficient methodology for generating probabilistic estimates of atmospheric composition. This task leverages the fact that cGANs offer a natural way to estimate probability distributions from a limited set of samples. The accelerated model developed in Task 1 will make it feasible to produce such samples, and we will combine that model sampling capability with the density estimation power of cGANs to dynamically estimate model uncertainties. Combined, Tasks 1 and 2 will offer an ensemble-style modeling framework for reactive trace gas and aerosol simulations that is applicable to a wide array of systems and applications. We will demonstrate these capabilities by integrating the framework into the NASA GEOS-CF system, and transfer the technology to NOAA's air quality forecasting system in Task 3. Thus, the proposed project will greatly advance the composition modeling, prediction, and monitoring capabilities of NASA and NOAA.

Huikyo Lee/Jet Propulsion Laboratory
Open Climate Workbench to Support Efficient and Innovative Analysis of NASA's High-Resolution Observations and Modeling Datasets
21-AIST21_2-0020

We propose to develop an Analytic Collaborative Framework (ACF) that can power the processing flow of large and complex Earth science datasets and advance the scientific analysis of those datasets. In the proposed ACF development, we aim to address one of the current, fundamental challenges faced by the climate science community: bringing together vast amounts of both model and satellite observation data at different spatial and temporal resolutions in a high-performance, service-based cyberinfrastructure that can support scalable Earth science analytics.

The Regional Climate Model Evaluation System (RCMES) developed by the Jet Propulsion Laboratory in association with the University of California, Los Angeles has undertaken systematic evaluation of climate models for many years with NASA's ongoing investments to advance infrastructure for the U.S. National Climate Assessment (NCA). RCMES is powered by the Open Climate Workbench (OCW; with a current public version of v1.3), an open-source Python library, that handles many of the common evaluation tasks for Earth science data such as rebinning, metrics computation, and visualization. Over the next three years, we propose to significantly advance the use and analysis of large and complex Earth science datasets by improving and extending the capabilities of OCW to version 2.0, and OCW v2.0 will be the ACF.
The primary goal of developing OCW v2.0 is to improve and extend the capabilities of OCW for characterizing, compressing, analyzing, and visualizing observational and model datasets with high spatial and temporal resolutions. As an open-source ACF for climate scientists, OCW v2.0 will run on AWS Cloud with special emphasis on developing two use cases: air quality impacts due to wildfires and elevation-dependent warming. Our four specific objectives are to:
O1. Migrate the RCMES database (RCMED) to AWS and provide observational datasets for the upcoming fifth NCA
O2. Optimize the scientific workflows for common operations, applying data compression techniques and autonomic runtime system
O3. Integrate cross-disciplinary algorithms for analyzing spatial patterns
O4. Provide a comprehensive web service and supporting documentation for end-users

The primary outcome of our proposed work will be a powerful ACF with enhanced capabilities for utilizing state-of-art observations and novel methodologies to perform comprehensive evaluation of climate models. By infusing recent advances in data management and processing technology, OCW v2.0 will be able to optimize scientific workflows when users analyze high-resolution datasets from RCMED, CMIP6 S3, and NASA's Distributed Active Archive Centers (DAACs). All of the OCW v2.0's capabilities will be made available from both command-line scripts and Jupyter Lab notebooks, which capture the end-to-end analysis workflow from collaborating climate scientists for reuse and modification.

The proposed ACF development will meet one of the three AIST program's main objectives by "fully utilizing the large amount of diverse observations using advanced analytic tools, visualizations, and computing environments." Our data compression and runtime system will "address the Big Data challenge associated with observing systems and facilitate access to large amounts of disparate datasets" by compressing the datasets while assessing the trade-offs between lowering spatial resolution and accuracy. In addition, the ACF will "make unique topological data analysis (TDA) tools accessible and useful to the climate science community." By testing two use cases with our ACF, we will enable our long-term vision of "moving from custom-built ACF systems to reusable frameworks" for supporting various research activities in climate science, and broadening NASA's footprint in earth-science analytics in a way that increases the utility of current data products and cultivates demand for future ones.

Seungwon Lee/Jet Propulsion Laboratory
Ecological Projection Analytic Collaborative Framework (EcoPro)
21-AIST21_2-0032

In this time of global heating and rapid climate change, Earth's ecosystems are under great stress for their survival and Earth's biodiversity is being rapidly reduced and widely redistributed. Despite the importance of biodiversity for humanity and the imminent nature of the threat, efforts to project these losses over the coming decades remain crude, especially contrasted with other processes of global importance such as relative sea level rise. As a discipline, ecological projection is still in its early stages, and will become increasingly important as stress drivers increase and losses mount. A systematic framework, that includes advanced data science tools that are vetted and refined iteratively during application to multiple use cases, will accelerate progress.

Following the 2017 Earth Science Decadal Survey, NASA has made biodiversity a priority. This is reflected in ongoing and upcoming missions, e.g., ECOSTRESS, UAVSAR, NISAR, PACE, and SBG. In the next few years, these biodiversity remote sensing missions will create, improve, and lengthen high-resolution records of changing environmental variables and indicators for ecological systems. This provides a unique and well-timed opportunity to advance ecological projection on multi-decadal timescales, as well as ecological forecasting on shorter timescales.

We propose to build Ecological Projection Analytic Collaborative Framework (EcoPro) to support multidisciplinary teams to conduct ecological projection studies, collaborations, applications, and new observation strategy developments. EcoPro will contain (1) an analytic toolkit to perform the multidisciplinary analyses, (2) a data gateway to organize, store, and access key input and output datasets, and (3) a web portal to publish and visualize the results of the studies and to provide a virtual collaborative work space.

The project aims to achieve the following three outcomes by building and applying EcoPro to the ecological projection and forecasting.

Outcome 1: Perform scientific studies to demonstrate the scientific use of EcoPro. Giant sequoias forests, giant kelp forests, and coral reefs will be used as case studies. They are important local ecosystems threatened by climate change. The case studies will demonstrate the sufficiency of EcoPro Analytic Toolkit for ecological projection studies.

Outcome 2: Generate application-usable datasets and visualize them to demonstrate the application use of EcoPro. Climate stressor variables and habitability and mortality indicators of our three case-study ecosystems will be generated and visualized for the use by the application community (e.g., conservation managers from the California Department of Fish and Wildlife, the California Ocean Protection Council, the National Park Service, the US Forest Service, NOAA Coral Reef Conservation Program, the Great Barrier Reef Marine Park Authority). This will demonstrate the sufficiency of EcoPro Web Portal for sharing and visualizing the ecological projection datasets with the application community. In particular, we plan to transition and infuse EcoPro to the SBG Application Working Group in the optional third year.

Outcome 3: Conduct experimental studies to demonstrate the New Observing Strategies (NOS) use of EcoPro. We will experiment with different resolutions of predictor observations to quantify the adequacy of the observation datasets used in generating and validating ecological projection datasets. This will lead to new observation requests to existing observing systems or new observation requirements for future mission formulations. In the optional third year, we plan to transition and infuse EcoPro to the SBG Science Team to support assessment of data sufficiency of SBG products and formulation of complementary missions.

Carl Legleiter/U.S. Geological Survey
An Intelligent Systems Approach to Measuring Surface Flow Velocities in River Channels
21-AIST21_2-0049

The goal of this project is to develop a New Observing Strategy (NOS) for measuring streamflow from a UAS using an intelligent system. This framework will satisfy the AIST program objectives of enabling new measurements through intelligent, timely, and dynamic distributed sensing; facilitating agile science investigations that utilize diverse observations using advanced analytic tools and computing environments; and supporting applications that inform decisions and guide actions for societal benefit. More specifically, by focusing on hydrologic data collection, this project is consistent with NASA's vision for NOS: optimize measurement campaigns by using diverse observing and modeling capabilities to provide complete representations of a critical Earth Science phenomenon - floods.

The USGS operates an extensive monitoring network but maintaining streamgages is expensive and places personnel at risk. This project will build upon a UAS-based payload for measuring surface flow velocities in rivers, developed jointly by the USGS and NASA, to improve the efficiency and safety of data collection. The sensor package consists of thermal and visible cameras, a laser range finder, and an embedded computer, all integrated within a common software middleware. At present, these instruments provide situational awareness for the operator on the ground by transmitting a reduced frame rate image stream. Our current concept of operations involves landing the UAS, downloading the images, and performing Particle Image Velocimetry (PIV). This analysis includes image pre-processing, stabilization, geo-referencing, and an ensemble correlation algorithm that tracks the displacement of water surface features. For this project, the workflow will be adapted for real-time implementation onboard the platform. Developing this NOS is timely because the impacts of climate change on rivers create a compelling need for reliable hydrologic information not only through regular monitoring but also in response to hazardous events. Our intelligent system will be designed to address both of these scenarios. First, we will facilitate quality control during routine streamgaging operations by quantifying uncertainty. For example, the UAS could be directed to hover at a fixed location above the channel and acquire images until a threshold that accounts for natural variability and measurement error is reached; only after this criterion is satisfied would the platform advance to the next station. We refer to this mode of operations as stationing autonomy. Second, during hazardous flood conditions identified via communication with other sensors, the focus of the intelligent system would shift to autonomous route-finding. To enable dynamic data collection, heavy precipitation or abrupt rises in water level within a basin would trigger deployment of a UAS to measure streamflow during a flood. Onboard PIV will provide the intelligent system with real-time velocity information to direct the UAS to focus on high velocity zones, areas likely to scour, and threatened infrastructure. This information could be transmitted wirelessly and used to inform disaster response. By developing these capabilities, we will introduce a NOS that significantly enhances both hydrologic monitoring and response to extreme events.

Our intelligent systems framework will be implemented in three phases. Initially, simulations will be used to develop methods of characterizing uncertainty and selecting optimal routes. These simulations will be based on field data sets from a range of river environments and created within a real-time robotics simulator. In the second stage, the algorithms will be applied to data recorded during previous UAS flights. The third phase will apply the intelligent system to live data during a flight, with the sensor payload being used for verification. This progression will transition the NOS from an initial TRL of 4 to 6 by the conclusion of the two-year effort.

Tanu Malik/DePaul University

Reproducible Containers for Advancing Process-Oriented Collaborative Analytics

21-AIST21_2-0095

For science to reliably support new discoveries, its results must be reproducible. This has proved to be a severe challenge. Lack of reproducibility significantly impacts collaborative analytics, which are essential to rapidly advance process-oriented model diagnostics (PMD). As scientists move from performance-oriented metrics toward process-oriented metrics of models, routine tasks require diagnostics on analytic pipelines. These diagnostics help to understand biases, identify errors, and assess processes within the modeling and analysis framework that lead to a metric.

To conduct diagnostics, scientists refer to the same pipeline". Referring to the same software and data, however, becomes contentious---scientists iteratively tune and train pipelines with parameters, changing model and analysis settings. Often reproducibility in terms of sharing a common analytics pipeline, and methodically comparing against different datasets cannot be achieved. While tracking logs, provenance, and sufficient statistics are used, these methods remain disjoint from analysis files and only provide post hoc reproducibility. We believe a critical impediment to conducting reproducible science is the lack of software and data packaging methods which methodically encapsulate content and record associated lineage. Without such methods, deciding a common reference pipeline and scaling-up collaborative analytics, particularly in operational settings, becomes a challenge.

Container technology, such as Docker, Singularity, provides content encapsulation and improves software portability and is being used for conducting reproducible science. Containers are useful for well-established and documented analysis pipelines, but, in our experience, the technology has a steep learning curve and significant overhead of use, especially for iterative, diagnostic methods.

This proposal aims to establish reproducible scientific containers that are easy-to-use and are lightweight. Reproducible containers will transparently encapsulate complex, data-intensive, process-oriented model analytics, will be easy and efficient to share between collaborators, and will enable reproducibility in heterogeneous environments. Reproducible containers, developed by the PI so-far, rely on reference executions of an application to automatically containerize all necessary and sufficient dependencies associated with the application. They record application provenance and enable repeatability in different environments. Such containers have met with considerable success, demonstrating a lightweight alternative to regular containers for computational experiments conducted by individual geoscientists in the domains of Solid Earth, Hydrology, and Space Science. However, in their current form, containers, reproducible or otherwise (such as Docker), are not data-savvy---they are oblivious to spatio-temporal semantics of data and either include all data used by an application or exclude it entirely. When all data is included, containers become bloated; alternatively when excluded, they cause network contention at the virtual file system.

The target outcome of this project is to develop reproducible containers that are data-savvy---that is to retain their original properties of automatic containerization, provenance tracking, and repeatability guarantees, but provide ease of operation with spatio-temporal scientific data, and are efficient to share and repeat even when an application uses a large amount of data. This outcome will be achieved by (i) developing an I/O-efficient data observation layer within the container, and (ii) including spatio-temporal data harmonization methods when containers encapsulate heterogeneous datasets (ii) applying data-savvy, reproducible containers to process-oriented precipitation feature (PF) diagnostics, and (iv) finally assessing how diagnostics improve with the use of data-savvy, provenance-tracking reproducible container.

Craig Pelissier/Goddard Space Flight Center
Terrestrial Environmental Rapid-Replicating Assimilation Hydrometeorology (TERRAHydro) System: A Machine-Learning Coupled Water, Energy, and Vegetation Terrestrial Earth System Digital Twin
21-AIST21_2-0003

The Earth's environment is changing rapidly, resulting in more extreme weather and increased risk from weather and climate related phenomena. Land Surface Models (LSMs) are a critical component of climate and weather forecasting models, and are integral tools for regional drought monitoring, agricultural monitoring and prediction, famine early warning systems, and flood forecasting, among other things. A vital part of NASA's Earth Science mission includes supporting terrestrial models (LSMs) that can leverage available Earth observation data (EOD) to provide accurate and timely information about the terrestrial water, energy, and carbon cycles. The increase in adverse weather conditions makes near real-time and short-term capabilities increasingly critical for early response systems and mitigation.

In the past 5 years, Machine Learning (ML) has emerged as one of the most powerful ways to extract information from large and diverse sets of terrestrial observation data (see references in the Open Source Software Licensing section). Our group and others in the hydrological community have successfully developed models of most of the key states (streamflow, soil moisture, latent and sensible heat, and vegetation) and fluxes that are significantly more accurate than the traditional process-based models (PBMs) currently deployed by NASA. Importantly, they run several orders of magnitude faster than traditional PBMs. This arises from a simpler numerical structure and from the ability to efficiently use hardware accelerators (GPUs, TPUs). Their rapid-adaptation and increased throughput can provide unprecedented near real-time and short-term forecasting capabilities that far exceed the current PBM approaches in use today. Although ML models do not currently provide a process-based scientific explainability, and there remains skepticism about long-term forecasting in the presence of non-stationarity (changing climate), their accuracy and ability to enhance the current near real-time and short-term capabilities is undeniable.

The current NASA LSM software infrastructures (SI), (e.g., the NASA Land Information System; [1]) are not designed in ways that allow them to fully leverage ML technologies due to several differences such as: native programming languages, software stacks, numerical algorithms, methodologies, space-time structures, and High-Performance Computing (HPC) capabilities. The effort to merge these technologies into a unified SI, if feasible, would be significant and likely result in something brittle, not easily-extensible, hard to maintain, and impractical. We propose to develop a terrestrial Earth System Digital Twin (TESDT) that is designed from the ground-up to couple state-of-the-art ML with NASA (and other) EOD. This TESDT will combine the best ML hydrology models with capabilities for uncertainty quantification and data assimilation to provide a comprehensive TESDT. The software infrastructure will be developed in Python and specifically designed to provide a flexible, extensible, modern, and powerful framework that will be a prototype AI/ML based TESDT. It will be able to perform classically expensive tasks like ensemble and probabilistic forecasting, sensitivity analyses, and counterfactual what if" experiments that will provide critical hydrometeorological information to aid in decision and policy making.

We will build the SI to integrate and couple the land surface components including data management, training, testing, and validation capabilities. Different coupling approaches will be deployed, researched, and tested, as well as, an ML specific data assimilation framework. In the optional year, relevant hydrometeorological events, e.g., the 2006-2010 Syrian drought and current changes to water storage in the Himalayan mountains, will be used to demonstrate and validate the performance of the aforementioned capabilities to real world applications.

Saurabh Prasad/University of Houston
Knowledge Transfer for Robust GeoAI Across Space, Sensors and Time via Active Deep Learning
21-AIST21_2-0051

Recent advances in optical sensing technology (e.g., miniaturization and low-cost architectures for spectral imaging in the visible, near and short-wave infrared regimes) and sensing platforms from which such imagers can be deployed (e.g. handheld devices, unmanned aerial vehicles) have the potential to enable ubiquitous passive and active optical data on demand to support sensing of our environment for earth science. One can think of the current sensing environment as a vast sensor-web of multi-scale diverse spatio-temporal data that can inform various aspects of earth science. Although this increase in the quality and quantity of diverse multi-modal data can potentially facilitate improved understanding of fundamental scientific questions, there is a critical need for an analysis framework that harmonizes information across varying spatial-scales, time-points and sensors. Although there have been numerous advances in Machine Learning models that have evolved to exploit the rich information provided by multi-channel optical imagery and other high dimensional geospatial data, key challenges remain for effective utilization in an operational environment. Specifically, there is a pressing need to have an algorithm base capable of harmonizing sensor-web data under practical imaging scenarios for robust remotely sensed image analysis.

In this project, we propose to address these challenges by developing a machine learning algorithmic framework and an associated open source toolkit for robust analysis of multi-sensor remotely sensed data that advances emerging and promising ideas in deep learning, multi-modal knowledge transfer between sensors, space and time, and provides capability for semi-supervised and active learning. Our model would seek to harmonize data from heterogenous sources, enabling seamless learning in a disparate ensemble of multi-sensor, multi-temporal data. Our proposed architecture will be comprised of a generative adversarial learning-based knowledge transfer framework that will use optics inspired and sensor-node specific neural networks, multi-branch feed forward networks to transfer model knowledge from one or more source sensor nodes to one or more target sensor nodes, and semi-supervised knowledge transfer. This game-changing model transfer and cross-sensor super-resolution/sharpening capability will enable end-users to leverage training libraries that provide disparate or complementary information (for example, imparting robustness to spatio-temporal non-stationarities and enabling learning from training libraries from different geographical regions, sensors, times and sun-sensor-object geometries). We will develop and validate active deep learning capability within our knowledge transfer framework that will seek to strategically facilitate additional labeling in the source and/or target sensor-nodes for further improving performance. A functional prototype of our framework will be implemented on a commercial cloud for dissemination and access to stake-holders and the broader research community. Our algorithms will be developed with a specific earth science application focus   earth observation based agricultural sensing. However, the tools developed in this project will be readily applicable to other domains, and will have far reaching benefits to NASA earth science   including ecological impacts of climate change, forestry, wetlands, etc., using a wide array of spaceborne data sources such as: (1) multispectral imaging systems (e.g. Landsat, Sentinel), (2) imaging spectroscopy (e.g. DESIS and the future HyspIRI and CHIME missions), (3) SAR (Sentinel, (future) NISAR),   and a rich archive of NASA, ESA and commercial satellite imagery, as well as airborne platforms (e.g. AVIRIS-NG, G-LiHT, commercial). The proposed capability will also be important in successful analysis of data acquired by constellations of satellites, for which seamless learning is a key objective.

Stephanie Schollaert Uz/Goddard Space Flight Center
Integration of Observations and Models into Machine Learning for Coastal Water Quality
21-AIST21_2-0067

Coastal areas are impacted by population growth, development, aging infrastructure, and extreme weather events causing greater runoff from land. Monitoring water quality is an urgent societal need. A growing fleet of satellites at multiple resolutions provide the ability to monitor large coastal areas using big data analytics and machine learning. Within our AIST18 project, we started working closely with state agencies who manage water resources around the Chesapeake Bay. We propose to build upon these activities to

improve the integration of assets to monitor water quality and ecosystem properties and how they change over time and space. Initially we are taking advantage of technologies and data collected in and around the Chesapeake Bay, with a plan to expand to other watersheds.
As the largest estuary in North America, the Chesapeake Bay receives runoff from approximately 100,000 tributaries, carrying sediment, fertilizer, and pollutants from farms, developed communities, urban areas, and forests. These constituents degrade water quality and contribute to its optical complexity. Resource managers tasked with enforcing pollution reduction goals for these point and non-point sources are also challenged by shrinking budgets with which to monitor multiple aspects of the ecosystems while the use of the Bay for recreation, fishing, and aquaculture is increasing. Of particular concern are the increasing number of harmful algal blooms (HABs) and septic tank leaks due to aging infrastructure and rising sea level [Wolny et al., 2020; Mitchell et al., 2021]. State agencies already work closely with NOAA and EPA and are looking to NASA to apply advanced technologies to further improve their natural resource management.
Our AIST18 project demonstrated promising results with multispectral optical, medium spatial resolution satellite data trained using geophysical model variables within a machine learning (ML) architecture by extracting multi-source feature maps. The nearshore environment demands finer spatial resolution than government assets alone can provide, thus we plan to build on this work by utilizing higher spatial resolution data from commercial satellites. Following our demonstration of feasibility using medium resolution satellite imagery from one sensor, we will now derive feature maps from many sensors of varying spatial, spectral, and temporal resolution. These can be effectively merged regardless of initial source resolution at progressively higher (hierarchical) contextual levels by fusing at multiple layers within the ML model. Heterogeneous feature maps can be adaptively scored and weighted, which influences their significance in the resulting predictions. We plan to analyze higher spectral information from in situ inherent optical property observations to determine the minimum set of requirements for remote sensing of water quality, e.g. water clarity, phytoplankton blooms, and the detection of pollutants. In situ observations will facilitate ML training using higher spectral and spatial resolution imagery from commercial satellites at the coast. We are also collaborating with community experts to evaluate the utility of hyperspectral remote sensing for detecting aquatic features not discernable through multispectral imaging, such as phytoplankton community structure and the likelihood of harmful blooms. In situ observations will facilitate ML training using hyperspectral and higher spatial resolution imagery from commercial satellites at the coastal margins and land-water interface. Finally, we aim to eventually integrate upstream assets of land cover classification, elevation, vertical land motion, and hydrology as inputs to the ML architecture, leveraging other projects that characterize the watershed and runoff of sediments and nutrients to coastal water bodies. Adapting our process to an open science framework will facilitate future integration of these data beyond the aquatic community.

Daniel Selva/Texas A&M University

3D-CHESS: Decentralized, Distributed, Dynamic and Context-Aware Heterogeneous Sensor Systems
21-AIST21_2-0089

The overarching goal of the 3D-CHESS Early-Stage Technology proposal is to demonstrate proof of concept (TRL 3) for a context-aware Earth observing sensor web consisting of a set of nodes with a knowledge base, heterogeneous sensors, edge computing, and autonomous decision-making capabilities. Context awareness is defined as the ability for the nodes to gather, exchange, and leverage contextual information (e.g., state of the Earth system, state and capabilities of itself and of other nodes in the network, and how those relate to the dynamic mission objectives) to improve decision making and planning. We will demonstrate the technology and characterize its performance and main trade-offs in a multi-sensor in-land hydrologic and ecologic monitoring system performing four inter-dependent missions: studying non-perennial rivers and extreme water storage fluctuations in reservoirs, and detecting and tracking ice jams and algal blooms.

The Concept of Operations is as follows. Nodes in the sensor web can be ground, air or space. Nodes may be manually operated or fully autonomous. Any node can send a request for a mission to the sensor web (e.g., measuring geophysical parameter p at point x and time t+/-dT with a certain resolution dx and accuracy dp). Upon reception of a mission request, each node uses a knowledge base to decide if given its own state and capabilities it can perform part or all of the proposed mission. If so, it enters a planning phase in which based on its own goals and utility function it decides whether and how much to bid for the proposed mission. A market-based decentralized task allocation algorithm is used to coordinate assignments across nodes.

To establish proof of concept for a sensor web that works as described in the previous paragraph, we will develop a multi-agent simulation tool by integrating existing tools developed by the team and apply it to a relevancy scenario focusing on global inland hydrologic science and applications. A continuous monitoring system will be simulated that will provide global, continuous measurements of water levels, inundation, and water quality for rivers and lakes using a variety of sensors and platforms. The system will start with a default scientific mission objective to study extreme water storage fluctuations in reservoirs and wetting and drying processes in non-perennial rivers (science-driven). In addition, two applications-driven missions of opportunity will be modeled and considered: ice jams and corresponding upstream flood events, and harmful algal blooms in lakes.

We recognize that 3D-CHESS represents an aggressive" vision that departs significantly from the state of practice. Therefore, in addition to comparing the value of an implementation of the full 3D-CHESS vision against the status quo (Goal 1), we will also systematically study transition" architectures that lie somewhere in between the full 3D-CHESS concept and the status quo (Goal 2). For example, in these transition architectures, new task requests may come only from human operators, or planning may be manually done by operators for some nodes while being fully autonomous for others although still allowing for humans to update the nodes' utility functions and intervene in case of contingency.

The proposed work has direct relevance to the O1 objective of the AIST program solicitation as it develops new technologies that enable unprecedented degrees of autonomy, decentralization, and coordination to achieve new science capabilities and improved observation performance while reducing development and operational costs. The combination of the knowledge-based technologies and decentralized planning technologies integrated within a multi-agent system framework enables the EOS to respond to scientific and societal events of interest faster and more effectively.

Jouni Susiluoto/Jet Propulsion Laboratory
Kernel Flows: Emulating Complex Models for Massive Data Sets
21-AIST21_2-0012

Inference about atmospheric and surface phenomena from remote sensing data often requires computationally expensive empirical or physical models, and always requires uncertainty quantification (UQ). Running these models to predict or retrieve geophysical quantities for very large data sets is prohibitive, and Monte Carlo experiments for UQ, which involve rerunning these models many times, are out of the question except possibly for small case studies. These problems can be overcome with emulators: machine learning models that ``emulate'' physical models. Emulators are trained on carefully selected examples of inputs and outputs generated either by pairs of inputs and outputs acquired directly from observations, or by a physical model under specific conditions that are representative of the problem space. Then, the emulator is applied to new inputs, and produces estimates of corresponding outputs, ideally with uncertainties due to the emulation itself. The latter are crucial for interpreting emulator output, and must be included in the total uncertainty ascertained from Monte Carlo-based UQ experiments.

We propose a general-purpose, versatile emulation tool that (1) provides fast, accurate emulation with little tuning, (2) scales up to very large training sets, (3) provides uncertainties associated with outputs, and (4) is open source. This tool set will facilitate large-scale implementation of forward modeling and retrievals, and of UQ at production scales. We choose two science application areas to showcase these capabilities: (A) nowcasting the evolution of convective storms; an example of empirical modeling, and (B) radiative transfer for Earth remote sensing; an example of physical modeling.

Our methodology is based on Gaussian Processes and cross-validation. These are combined in an algorithm called Kernel Flows, hereafter KF (Owhadi and Yoo, 2019). KF has been used in a variety of settings with excellent results, including climate model emulation (Hamzi, Maulik, and Owhadi, 2021). Preliminary results applying KF to radiative transfer problems for OCO-2, MLS, and imaging spectroscopy show that KF is well-suited to high-dimensional emulation required in the types of problem represented by our applications. Our method is general enough to apply to a wide range of analysis and prediction problems, and will enable agile science investigations as called for in Objective O2 of the Notice of Funding Opportunity. Software interfaces will be lightweight, simple, and general, to enable easy integration with different data sources.

The two science applications involve running models on very large data sets, the need to do it faster than is currently possible, and to quantify uncertainties that result from the emulation process. In the nowcasting example, the model to be emulated is the relationship between vertical structure of storm clouds and convective storm formation. In the other application, it is a radiative transfer model. The Gaussian Process underlying our method is based on a rigorous probabilistic model that can be used to generate Monte Carlo replicates of the predicted fields. This enables forward UQ experiments to derive uncertainties on predicted quantities, including emulator uncertainty.

Carrie Vuyovich/Goddard Space Flight Center
A New Snow Observing Strategy in Support of Hydrological Science and Applications
21-AIST21_2-0055

Snow is a seasonally evolving process that results in a reflective, insulating cover over the Earth's land mass each year, provides water supply to one in four people globally (over 2 billion people) and supports numerous ecosystems. Snow also contributes to short-term and long-term disasters. It is a critical storage component of the global water cycle, yet we currently do not have global snow observations that provide data needed to understand its role in hydrological regimes and respond to snow-related events. While numerous existing or expected satellite sensors are sensitive to snow and provide information on different snow properties, none provide global snow water equivalent (SWE) data, the essential information to address hydrologic science questions, at the frequency, resolution and accuracy needed. A new observing strategy for snow that incorporates existing and expected observations, models, and a future snow satellite mission is required.

While snow contributes water resources to a large portion of the Earth's terrestrial area, its coverage and role evolves throughout the season, affecting different regions, elevations and latitudes at different times of the year. For instance, in North America, peak SWE, peak SWE uncertainty and melt onset shift from lower latitudes and elevations early in the year (Jan   Apr) to northern latitudes and elevations later (May June), indicating that data needs may also shift throughout the year. Seasonal snow is a perfect candidate for an optimized observational strategy that leverages existing sensors and focuses future mission concepts on monitoring the most critical areas to provide cost-effective and robust information.

The National Academy of Science identified snow water equivalent or snow depth as a critical observation in the 2017-2027 Decadal Survey and recommended it as a measurement priority in the Earth System Explorer (ESE) class missions. An ESE announcement of opportunity is expected within the next year (NASA Earth Science Division's Earth System Observatory Community Forum, 30 June 2021. Webinar), which could provide an opportunity to launch a SWE-focused mission. An optimized observing strategy for snow will be integral to the mission design to target the most critical data needs.

This proposal will develop a new Snow Observing System (SOS) to estimate SWE and snow melt throughout the season, targeting observations (e.g. peak SWE and the onset of melt) with the greatest impact to hydrological metrics as they occur in different regions. We will develop an approach that evaluates observations from existing missions that have previously not been combined in an optimized way; create a hypothetical experiment to determine an optimal observing strategy focused on specific hydrological events; assess the value of new potential sensors, such as from commercial SmallSats to fill observing gaps and provide higher frequency observations during critical time periods. We will also evaluate the potential for focusing higher density observations in regions where concerns for flood, drought or wildfires will benefit from early warning. These dynamic observations could help rally ground, UAS or airborne observations in regions showing snow volumes outside the normal range or experiencing unexpected snowpack conditions.

The expected outcome is a demonstrated plan for a new observing system that responds to the dynamic nature of seasonal terrestrial snow and focuses on regions of interest in a timely manner. This strategy will allow high-resolution observations in critical areas for improving science and application understanding, reduce the potential cost of a global snow-observing satellite mission by not observing non-snow-covered areas, and take advantage of new commercial small-sat assets which are advancing rapidly and becoming increasingly available at the frequencies of interest.

Brian Wilson/Jet Propulsion Laboratory
Adaptable Self-Supervised Learning for Earth Imagery: Classification, Segmentation, Phenomena Detection
21-AIST21_2-0025

** This proposal has been renamed to: SLICE: Semi-supervised Learning from Images of a Changing Earth" **

The field of computer vision (CV) is advancing rapidly, enabling significant accuracy improvements for image classification, segmentation, object detection problems. In particular, multiple self- and semi-supervised learning approaches have been published in recent years:

" SimCLR (v2) from Google (A Simple Framework for Contrastive Learning of Visual Representations),

". FLASH from University of Pennsylvania and Georgia Tech (Fast Learning via Auxiliary signals, Structured knowledge, and Human expertise)
". DINO / PAWS from Facebook (Self-Supervised Vision Transformers with DINO / Predicting View-Assignments with Support Samples),
". EsViT from Microsoft (Efficient Self-supervised Vision Transformers for Representation Learning).

We propose to investigate and characterize the efficacy of multiple SSL techniques for representative image problems on Earth imagery, and then select the best for further infusion into mission and science workflows. The challenge for assessing climate change is to build a flexible Cloud-based system, with additional GPU training on supercomputers, that can apply cutting-edge computer vision techniques at scale on years of satellite-based Earth and ocean imagery.

Therefore, we propose to build a Cloud and supercomputing-based platform for cutting-edge computer vision at scale. The three top-level goals of the SLICE system, Semi-supervised Learning from Images of a Changing Earth" are:

1. Establish the SLICE framework and platform for applying scalable semi-supervised computer vision models to Earth imagery, running in AWS Cloud and supercomputing environments, that can be easily adopted as a reusable platform by NASA data centers, mission science teams and NASA PIs.

2. Investigate and characterize the accuracy of multiple SSL models (i.e. SimCLRv2, DINO, EsViT) on a variety of relevant remote sensing tasks with minimum labels (here ocean phenomena).

3. Build and publish self- and semi-supervised learning models with a focus on the upper ocean small-scale processes in anticipation of several on-going and upcoming NASA missions (i.e. SWOT, WaCM, and PACE). Ocean eddy properties and derived heat flux will be modeled and predicted from SST, SSH, and SAR data.

The proposed work is directly traceable to AIST Objective O2 by developing a task-agnostic deep learning framework that facilitates large-scale image analytics on disparate, multi-domain datasets. The development of a framework and platform to train SOTA deep learning models with limited labels is responsive to the Analytic Collaborative Frameworks (ACF) thrust of the AIST element because such models can be used as individual, high-performing building blocks of a unified ACF, or for that matter surrogate models in an ESDT.

The SLICE platform will provide correct example ML workflows, parallel image tile preparation, best of breed data augmentation and training frameworks that do distributed training on multiple GPU's, and publish multiple tuned SOTA SSL and vision transformer models for reuse. The pretrained SSL models will give scientists a headstart in that they can be immediately applied and finetuned on the target problem, with less training time required. By providing models pretrained on physics model outputs (not ImageNet), the starting model weights can be physics informed" for the geophysical system being studied. Since all of the algorithms will be pluggable", they can be replaced with modified data preprocessing & augmentation, or the latest cutting-edge DL approach and network architecture. The CV field applied to Earth imagery is growing rapidly and is overdue for a standard platform that can evolve rapidly, so that the science applications stay on the cutting edge of ML. SLICE is a first step at standardization and spreading SOTA semi-supervised learning approaches to CV in all science areas.

Yiqun Xie/University of Maryland
Coupled Statistics-Physics Guided Learning to Harness Heterogeneous Earth Data at Large Scales
21-AIST21_2-0068

Despite recent advances of machine learning (ML) in computer vision and machine translation, creating learning techniques that are spatially-generalizable and physics-conforming remains an understudied and challenging task in Earth Science (ES). In particular, direct applications of typical ML models often fall short due to two major challenges posed by ES data. First, a fundamental property of spatial data is spatial heterogeneity, which means the functional relationships between target variables (e.g., land cover changes, water temperature and streamflow) and Earth observations tend to be non-stationary over space. The footprints of such heterogeneous data generation functions are often unknown, adding an extra layer of complication. Second, annotated data available in ES applications are often limited or highly localized due to the substantial human labor and material cost for data collection. As a result, pure data-driven attempts which are often carried out without consideration of underlying physics are known to be susceptible in learning spurious patterns that overfit limited training data and cannot generalize to large and diverse regions.

We aim to explore new model-agnostic learning frameworks to explicitly incorporate spatial heterogeneity awareness and physical knowledge to tackle these challenges in ES. First, to harness spatial heterogeneity, we will explore a statistically-guided framework to automatically capture spatial footprints of data generated by different functions (e.g., target predictions as functions of spectral bands) and transform an user-selected deep network architecture into a heterogeneity-aware version. We will also investigate more effective spatial knowledge sharing models using the spatial-heterogeneity-aware architecture. Second, to further improve the interpretability and generalizability for data-sparse regions, we will explore new physics-guided ML architectures to incorporate domain knowledge, e.g., water temperature dynamics driven by the heat transfer process and other general physical processes embedded in physics-based models. To address the biased parameterizations of physics-based models, we will also investigate new learning strategies to effectively extract general physical relations from multiple physics-based models. Finally, we will explore synergistic integration of the statistically and physically guided frameworks to create a more holistic solution to address various challenging ES application scenarios. Results will be evaluated using important ES tasks, including land cover and land use change (LCLUC) mapping and surface water monitoring, with support from chief scientists of NASA LCLUC and USGS water monitoring programs.

To improve the confidence in the success of the new technology, our preliminary exploration has created prototypes of the frameworks to perform statistically-guided spatial transformation for data with spatial heterogeneity, and physics-guided learning for scenarios with limited data. Preliminary case studies using ES data have demonstrated feasibility and the potential of the new frameworks: (1) for land cover mapping, our prototype of spatial transformation improved the F1-score by 10-20% over existing deep learning baselines; and (2) for water temperature and streamflow prediction, the preliminary physics-guided learning model demonstrated improvements over both existing process-based models used by USGS and ML models over large-scale river basins and lakes, and the model has been included in USGS's water prediction workplan. The proposal team includes experts from both computer science and ES. Targeted deliverables of this project include the new technology as well as its open-source implementation, and related ES benchmark datasets used for validation.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences -2021
NNH21ZDA001N-SARI
A.47 NASA Land-Cover/Land-Use Change-SARI Synthesis

This synopsis is for the Land-Cover and Land-Use Change (LCLUC) part of the NASA Research Announcement (NRA) ROSES-2021 NNH21ZDA001N-SARI. This NRA offered opportunities for conducting synthesis of research over South/Southeast Asia with multi-source remote sensing technologies to improve understanding of human interaction with the environment, and thus provide a scientific foundation for understanding the sustainability, vulnerability and resilience of land-cover and land-use systems. NASA LCLUC research contributes toward the goals of the U.S. Global Climate Research Program (USGCRP) by providing critical scientific information about LCLUC-climate interactions and the consequences of land-cover and land-use change on environmental goods and services, the carbon and water cycles and the management of natural resources. NASA received 10 proposals and selected 1 proposal for a total funding of $2.1 Million for three years. More details are available at: http://nspires.nasaprs.com.

David Skole/Michigan State University
South Asian Smallholder Forests and Other Tree-Based Systems: Synthesizing LCLUC Data and Approaches to Foster a Natural Climate Solution that Improves Livelihoods
21-SARI-21-0005

This proposed SARI synthesis project for South Asia is focused on understanding LCLUC patterns and processes related to agricultural landscapes of smallholder tree-based systems and their potential as natural climate solutions. The synthesis shall provide an observation-based evaluation of the degree to which these landscapes are increasing in terms of cover and biomass, and then evaluate what conditions lead to increases in tree and forest cover in South Asia, and under what conditions do improvements in tree and forest cover contribute to improving rural livelihoods. The objective of the proposed SARI South Asia Synthesis Consortium (SARI-SAS) is twofold: 1) synthesize current and recent NASA research on LCLUC to contribute to a fundamental understanding of their patterns and drivers and 2) translate fundamental science into evidence-based contributions to important climate mitigation and adaptation policy for the region.

The team proposing this synthesis effort is comprised of all the current SARI projects in South Asia, 6 university teams with 12 regional counterparts and collaborators. The SARI-SAS Consortium will synthesize existing research to assess the current state and trends of land-use change in the SARI region and identify important emerging trends and themes relevant to global change science and climate change policy. This shall advance our understanding of the processes, drivers and impacts on carbon emissions and removals, with the ultimate goal of developing new understanding of the landscape-level drivers of biotic emissions and removals. To do this in a tractable and focused way that illuminates new and emerging issues, the SARI-SAS Consortium shall evaluate the importance of tree-based systems in non-forest landscapes outside the well-understood forest estate, with a focus on atmospheric emissions and removals of carbon and the processes that drive or mediate increasing woody cover and biomass at the landscape scale.

The project deploys a synthesis framework around the concept of Sustainable Landscapes (SL), which is an emerging framework that combines evidence from empirical and process-based scientific research with policy and development oriented models that integrates biophysical and socio-economic analysis. The SL framework is adept at translational work that links evidence from empirical analysis to successful policy interventions; a central focal point being linking LCLUC observations to their social and economic drivers to support climate change mitigation and adaptation.

The strategic flow of synthesis begins with assessments of the observational data from remote sensing. We synthesize all reporting on tree cover change, with an emphasis on where we see increases in trees outside of forest (TOF). We assess trends based on both medium resolution data analysis as well as very high resolution data analyses of individual trees. We extend beyond cover analysis to explicitly assess biomass and carbon increases. Next, we examine questions related to process and drivers of observed change. First, we review the relationship between TOF and a range of social and economic indicators. The proposed framework here benefits from the LCLUC work that integrates satellite remote sensing data with downscaled socioeconomic indicators to generate a broad view of causes of tree cover change. The second line of inquiry reviews what we can synthesize from LCLUC projects specifically related to income and livelihood drivers. The third line of inquiry seeks to understand how farmers internalize values of ecosystem services. The fourth line of inquiry seeks to understand how governance, farm-scale decision-making and policy influences tree cover. Lastly, we shall develop a knowledge base that informs more effective policies on natural climate solutions and interventions for climate change mitigation and adaptation in the AFOLU sector.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences (ROSES) – 2021
NNH21ZDA001N-SEA
A.48 Earth Science Applications Socioeconomic Assessments

The Earth Sciences Applied Sciences ROSES-2021 Research Announcement NNH21ZDA001N-SEA sought to expand research, methodologies, tools, and capacity for assessments of the socioeconomic value from Earth science information for applications, including decision- and policy-support issues and operational contexts. The NASA Earth Science Division is organizing this element with co-sponsorship from NOAA and in collaboration from USGS. This activity encompasses 1) socioeconomic assessments that advance assessment techniques on the value of Earth science information, and 2) community and capacity development that fosters a thriving, cross-disciplinary community of Earth scientists, engineers, and economists and other social scientists, with critical considerations lent to diversity and inclusion.

NASA received 10 proposals and selected one for a total funding of $8.5 Million over five years. More details are available at: http://nspires.nasaprs.com

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Rebecca Chaplin-Kramer/University of Minnesota
Socioeconomic Assessments: Enhancing and Measuring the Value of Earth Observations for Informing Decisions
21-SEA21-0010

Earth Observations (EO) offer unique data and science opportunities to improve decisions at local to global scales. Realizing these opportunities will require better translation of EO into metrics of value to society and closer collaboration with end users of such information. This project integrates two fields with untapped synergies: the decades of study using EO to assess the environment at global extents and the rich literature that has more recently emerged on human-environment connections, typically at more local scales. In integrating these fields, we will make EO more relevant to a wider array of decisions and help scale up modeling and mapping of human-environment connections for broader application.
We expect the value of EO will increase by linking it more tightly to socioeconomic endpoints that resonate with decision-makers and stakeholders. We will measure the value of information in two different ways: 1) the cost savings for monitoring by EO rather than field-based information collection, and 2) the socio-economic benefit from improving a decision, whether in terms of modeled or actual outcomes. We propose a program of activities that enhances the value of EO by linking more tightly with socioeconomic indicators, and measures the value of improved information of these different EO-derived indicators across a variety of geographies and decision contexts. Our proposal brings together a diverse and highly qualified team from 6 collaborating institutions and practitioners representing 15 important government, NGO, private sector,

and multilateral organizations, to build a system for the integration of EO and socioeconomic information in order to achieve the following objectives:
1) Advance socioeconomic assessment techniques and methods, including both developing socioeconomic metrics from EO and evaluating the socioeconomic benefit of such information.
2) Conduct case studies to expand the knowledge base applying methods developed in (1) across multiple themes, sectors and decision contexts, in collaboration with decision-makers.
3) Characterize complexities that arise from converting inputs from multiple EO systems into
actionable information for decisions, and identify ways to address them.
4) Build a transdisciplinary network of academics, educators, practitioners, and decisionmakers
to advocate for and advise on socioeconomic assessments using EO information.
5) Design and implement capacity-building, including open-source software development,
training and education programs to promote the uptake of techniques developed in (1) and (3).
6) Strengthen collaborations between earth scientists and social scientists participating in the
network formed in (4) through the innovations and applications developed in (1) and (2).
7) Develop communication strategies and campaigns for translating the socioeconomic value
and benefits of Earth science information in decision contexts.
We propose six candidate research topics that could form the basis of cross-institutional interdisciplinary and transdisciplinary collaborations. All six have strong dimensions of Environmental Justice, and span many of NASA's other Applied Sciences Themes (climate, water, agriculture, health, biodiversity; Table 1). Candidate research topics use EO to improve: 1) mapping of structural poverty for equitable sustainable development planning; 2) predictions of vulnerability, adaptation,
and nature-based solutions for climate hazards; 3) quantification of the social cost of water pollution to improve targeting of agricultural interventions; 4) assessment of biocultural values in conservation and rural livelihoods; 5) understanding of equity in access to urban greenspace and impacts on human health; and 6) multi-use planning for sustainable and equitable use of ocean resources.

Rhiannan Price/Devglobal Partners LLC
Mission: Green Zone - Earth Observation for Humanitarian Action
21-SEA21-0001

Mission: Green Zone will convene brilliant scientific minds and empathetic leaders on the frontlines of crises to advance our shared understanding of the socioeconomic value of Earth science and communicate its impact far and wide. Everyone is affected by increasingly complex global crises—whether the climate crisis, pandemic, disasters, conflicts, or food insecurity affecting communities around the world. With real-time dialogue on the benefits of Earth science in addressing current and future crises, Mission: Green Zone will capture the attention of key constituencies and make collaborative assessments of the socioeconomic benefits of Earth science a fundamental and routine component of research.

Hallmarks of Mission: Green Zone include: (a) a human-centered design (HCD) approach to improve program impact and sustainability; (b) a focus on inclusion and equity; (c) lifting up researchers from historically disadvantaged communities and from our beneficiary communities; (d) developing early career researchers and students; and (e) a bidirectional communications campaign to enable community dialogue.

To build the evidence base of the benefits of Earth science around key questions, Mission: Green Zone will showcase the known benefits and untapped potential of Earth science in the words and voices of the communities affected—the smallholder farmer deciding when to harvest, the city planner zoning for flooding, the policymaker working to address health inequities. NASA scientists recently connected health outcomes to satellite and ground-based data on air pollution to establish a clear linkage to 10.2 million premature deaths due to fossil fuel pollution, many of which are children.12 How could this impact policy decisions around shifting to clean energy, for example? Do community leaders know that Earth science can help address pollution and equitably improve lives? Our approach aligns research to priority decisions and contexts that will have the greatest reach and impact. Our approach also makes assessment methods, such as the air pollution study accessible to more scientists. These studies combined two decades of satellite observations across 13,000 urban areas with health data on risk factors, disease, and death in 204 countries. Such complex analysis requires expertise in remote sensing, geospatial analysis, and spatial epidemiology, alongside significant data and infrastructure resources.

By design, questions of value and benefits require diverse expertise and partnerships to answer. This program convenes experts from historically siloed disciplines to collaborate using novel methods to better assess the socioeconomic benefits of Earth science. Researchers also need better tools to integrate disparate sources of data (i.e., earth observation, survey data, population density), methods to account for a lack of ground-truth (i.e., citizen science, Google Earth), and methods to account for gaps in socioeconomic data (i.e., no data in low-and-middle-income countries, lack of gender disaggregation), among other data challenges. Mission: Green Zone will provide prototypes and toolkits, alongside publications on new methods and techniques, to address the researchers' main data workflow frustrations. By streamlining data processes, our contributions will incentivize more socioeconomic benefit studies and allow researchers to focus their time on more complex analyses.

This ambitious undertaking encompasses NASA's priorities, including wildfires and disasters, health, water, ecologies and biodiversity, agriculture, and environmental justice. More specifically to the solicitation's objectives, Mission: Green Zone will foster a thriving, cross-disciplinary community of Earth scientists, engineers, economists, and social scientists collaborating with user communities to illustrate the value of Earth science across multiple scales and crises—from flooded coastal cities to indigenous peoples to smallholder farms.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-EEJ
A. 49 Earth Science Applications: Equity and Environmental Justice

This synopsis is for the Earth Science Applications: Equity and Environmental Justice NASA Research Announcement (NRA) ROSES-2021 NNH21ZDA001N-EEJ. This NRA offered opportunities for research to advance progress on equity and environmental justice (EEJ) domestically through the application of Earth science, geospatial, and socioeconomic information. NASA's Applied Sciences Program promotes efforts to discover and demonstrate innovative, practical, and beneficial uses of Earth science information to help inform organizations' decisions and resulting actions. These projects address EEJ issues that can benefit from the insights offered by NASA Earth science information and include three elements: 1) landscape analyses to understand the broader EEJ community context to inform actionable next steps, 2) Community based feasibility projects that apply Earth science information to demonstrate the feasibility of the approach with suggested expansion opportunities, and 3) Data integration projects that combine Earth science information and socioeconomic information into interoperable Geographic Information Systems (GIS)-enabled tools to serve community decisions and actions. NASA received 72 proposals and selected 39 proposals for a total funding of $6.9 Million for up to three years. More details are available at: http://nspires.nasaprs.com.

Selected proposals by element:

Landscape Analyses:	Feasibility Studies:	Data Integration Projects:
21-EEJ21-0002 / Everett	21-EEJ21-0010 / Carrion	21-EEJ21-0057 / Bixler
21-EEJ21-0058 / Fernandez	21-EEJ21-0044 / Cheng	21-EEJ21-0067 / Comer
21-EEJ21-0043 / Flynn	21-EEJ21-0060 / Grimm	21-EEJ21-0054 / Douglas
21-EEJ21-0025 / Marcotullio	21-EEJ21-0049 / Hang	21-EEJ21-0003 / Dronova
21-EEJ21-0007 / Meenar	21-EEJ21-0053 / Hultquist	21-EEJ21-0037 / Jennings
21-EEJ21-0020 / Morrow	21-EEJ21-0064 / Ibsen	21-EEJ21-0028 / Kerner
21-EEJ21-0001 / Mothes	21-EEJ21-0017 / Masteller	21-EEJ21-0070 / Liu
21-EEJ21-0045 / Rice Boayue	21-EEJ21-0024 / Miller	21-EEJ21-0055 / Marlier
21-EEJ21-0066 / Wilkins	21-EEJ21-0011 / Mueller	21-EEJ21-0015 / Nalley
21-EEJ21-0014 / Wolf	21-EEJ21-0041 / Pricope	21-EEJ21-0016 / Pourpeikari Heris
	21-EEJ21-0050 / Silva	21-EEJ21-0061 / Raysoni
	21-EEJ21-0048 / Smith	21-EEJ21-0038 / Seto
	21-EEJ21-0005 / Zhang	21-EEJ21-0006 / Sharma
		21-EEJ21-0012 / Stuhlmacher

		21-EEJ21-0019 / Tessum
		21-EEJ21-0029 / Wood

Patrick Bixler/University of Texas, Austin
ATX CA3TCH UP: Climate Atlas for Accountability and Advocacy Strategies Through Co-Production with Historically Underserved Community Partners in Austin, TX
21-EEJ21-0057

Austin, TX (ATX) wants to strategically address equity and environmental justice (EEJ) through climate resiliency and infrastructure investment options. This strategic path has challenges. One important being, prioritizing the neighborhoods where investments are made relative to the hotspots of environmental stresses they experience. Community groups such as Go Austin/Vamos Austin (GAVA) have compiled information and experiences that show the disproportionate environmental extremes the historically underserved neighborhoods face and the additional costs they incur due to growing insurance and tax rates. Yet, for community groups to advance the arguments and create effective pressure points they need better environmental data. This project postulates that combination of local community experiences and independent geospatial data from academic teams provides an effective means for the City to undertake EJ decisions. Accordingly, this integrated team from GAVA, City, and University of Texas at Austin (UT), seeks to integrate satellite data products in advancing equity and environmental justice. GAVA and the City has been using the UT's Austin Area Sustainability Indicators data portal as a decision tool (A2SI, austinindicators.org, led by PI Bixler) for helping project priorities and planning related to climate-hazard vulnerability, human health, and community resilience. The team is actively engaged and has undertaken recent studies related to heat, air quality, flooding, health, disaster preparedness, and survey-based data briefs in specific zip-codes that GAVA serves. These studies have resulted in different data products to cross the boundary between community organizations, the university and the City decisions spheres and advance equity-based and resilience-related outcomes. However, satellite datasets are not currently integrated into the A2SI, GAVAs, or the City's climate resilience or EEJ assessments. This gap will be bridged in this project. Integration of satellite data, socioeconomic data, survey data, and qualitative data can raise community voices and inform planning and decision making. The team successfully completed a NASA DEVELOP project to use satellite data for heat, and it has been well received by the community and stakeholders. Building off this, the team will use satellite data, and downscaling tools for integrating city and neighborhood scale satellite products withinA2SI. Focus will be for landcover change, temperature, rainfall, particulate matter, soil moisture and environmental data from MODIS, Landsat, IMERG, NASA LIS, and as needed CyGNSS, SMOS/SMAP, VIIRS, and GOES-R. Concurrently, the team is preparing A2SI's biennial community survey data collection. With the active involvement of GAVA, the City, and the seed investments from UT and other partners in place, a robust sustenance and transition plan is possible. The team has experience in every aspect of the proposed work. It has prior success in working together, has a well-defined coordination plan for City Office of Sustainability to be the stakeholder integrator, and different academic researchers working with the team on different aspects of the project. These activities will be conducted by an already-established formal interlocal agreement signed by UT, the City, and GAVA. The project team has partnered with industry partners such as Microsoft Research in the pilot deployment of environmental sensors, and the team is actively working with a network of local community organizations. The enduring outcome of the project will be a workflow and decision portal for climate adaptation planning that integrates satellite observations, socioeconomic census data, community survey, and community (qualitative) voices that can guide a cycle of reflexive co-production– recognize, reflect, and response –to advance climate justice in vulnerable communities that have a history social, economic, and environmental injustice in ATX.

Daniel Carrion/Yale University
Identifying Temperature Disparities, Energy Insecurity, and Social Vulnerability for Energy Justice in New York State
21-EEJ21-0010

The severity and frequency of extreme heat is increasing in the United States, which is yielding profound health and economic costs on the American people. Unfortunately, there is evidence of temperature disparities, where people of color and poor people are experiencing the warmest of those extreme temperatures. Simultaneously, evidence shows that these groups are also more likely to experience energy insecurity, whereby they are unable to meet their household energy needs. Taken together, the groups who experience the warmest temperatures are the least able to protect themselves from those conditions. Yale University and the Green and Healthy Homes Initiative have partnered to conduct a feasibility study to create the Temperature and Energy Justice Mapping (TEJM) tool for New York State. This tool is designed to identify 1) localized areas of temperature disparities, 2) areas exhibiting characteristics of energy insecurity, and 3) areas of high social vulnerability. To accomplish this, the team will construct two measures of summertime temperature exposure: heat index cooling degree days (derived from the NASA-supported Daymet product) and land surface temperature cooling degree days (derived from MODIS and LandSat land surface temperature). We will use sophisticated population allocation methods to population-weight temperature metrics using Census data and the Gridded Population of the World from NASA’s socioeconomic datasets. Energy insecurity analyses will ingest data from the newly-established Utility Energy Registry, a Department of Energy-supported initiative to make electricity utilization data openly available. The goal is to leverage Earth science data to provide a tool to help target energy efficiency and weatherization dollars to those who would most benefit. After constructing the TEJM tool, we will conduct a series of focus groups with the four site leaders for the Green and Healthy Homes New York State regional offices. We will also invite other energy efficiency stakeholders in New York State. These focus groups will allow us to collect critical qualitative data to help us improve the tool and identify strengths and barriers to its broader utility and feasibility. By the end of the project period, we will determine the feasibility of the tool and document it in a final report that will be made publicly available. While this feasibility study is directed at New York State, all inputs were chosen because of their regional or national scope, which will lend towards extensibility and scalability of the TEJM tool to other time periods and regions. The tool will be broadly available using ArcGIS online, and all programmatic code and data outputs will be posted to public repositories. The team will use completely open-source code and datasets, with specific programming tools designed to enhance reproducibility. We will conduct reproducibility checks across platforms to maximize end-user reproducibility of our codebase. Ultimately, we aim to develop a tool that will complement preexisting NASA initiatives like NASA POWER, while supporting broader federal efforts towards climate adaptation and justice. The TEJM tool will fill a critical gap at the nexus of environmental, climate, and energy justice for socially-vulnerable populations nationwide.

Wenwen Cheng/University of Oklahoma, Norman
A Spatial Decision Support System for Identifying Heat Vulnerability Based on a Comprehensive Energy Budget Model and Multi-Criteria Decision Analysis in Oklahoma City, OK
21-EEJ21-0044

Overview
Climate change is causing extreme heat in American cities. Previous heat exposure assessments and predictions failed to reveal the energy exchange between the human body and the environment due to the focus only on meteorological-based metrics, leading to an incomplete understanding of the impacts of heat exposure on the human body. Existing heat vulnerability assessments are from a top-down policy perspective, neglecting the viewpoints of different stakeholders, especially vulnerable populations. The City of Oklahoma City (OKC), OK has recently focused on urban heat mitigation by a series of sustainable plans and actions due to the increasing frequency and intensity of extreme heat events. There is an urgent need in OKC to gain a comprehensive picture of the urban areas and populations vulnerable to heat, as well as preferences and recommended decisions from different stakeholders, to conduct sustainable and equitable planning. The objective of this proposal is to develop an innovative Heat Exposure Index (HEI) based on NASA data and a human-environmental energy budget model; a Heat Vulnerability Index (HVI) by integrating multi-dimensions of heat vulnerable indicators, as well as a spatial decision support system to promote heat-related policymaking processes among different stakeholders, especially vulnerable populations. Upon completion of this project, we will provide three products for OKC: 1) a weekly prediction on HEI; 2) a Web-GIS HVI, and 3) an interactive and collaborative decision support system for leveraging inputs from different stakeholders in vulnerable communities.

Intellectual Merit: This HEI will be the first prediction index demonstrating human-environmental energy exchange including climatic, human physical, and physiological parameters from the perspective of bio-meteorology. Besides, the proposed HEI can be modified based on the physical and physiological characteristics of the vulnerable groups (e.g. elders and children, etc.). With the support of the NASA Unified-Weather Research and Forecasting model (NU-WRF), the HEI can be weekly updated for heat exposure predictions. The HVI will be composed of population sensitivity and adaptive capacity to heat, along with HEI. Embedded into a collaborative decision-making interface, community-driven HVI through a multi-criteria decision-making process will be developed among policymakers and vulnerable groups, to facilitate equitable and inclusive urban planning and policymaking.

Broader Impacts: Identifying the populations and locations at high risk of heat vulnerability is essential for urban planning and policy-making and health interventions. The HVI and the weekly- updated HEI will help local planners and designers determine where actions are most urgently needed within the city or neighborhoods, as well as what kind of interventions are required for heat events. Community workshops organized in heat-vulnerable communities based on the collaborative decision-making support system can promote meaningful conversations among stakeholders to identify problems and balance possible solutions in terms of heat mitigation. Moreover, the process of achieving our project goals through community workshops has great potential as a service-learning opportunity for students in the Division of Landscape Architecture at the University of Oklahoma. A final heat mitigation planning and design document developed through student-community workshops, research webinars, and various community engagement activities can guide an action path forward for OKC.

Dawn Comer/City of Los Angeles
Predictive Environmental Analytics and Community Engagement for Equity and Environmental Justice (PEACE for EEJ)
21-EEJ21-0067

Every 5 seconds, someone dies from the effects of air pollution; in fact, it is responsible for the early deaths of 7 million people every year and 107.2 million disability-adjusted-life-years globally. According to the American Lung Association and NIH National Institute of Environmental Health Science, poor families and people of color often face higher exposure to air pollutants and experience greater health impacts. Our recent study on the people of California demonstrates that minority and low-income communities tend to be exposed to higher levels of air pollution and are hit hardest by the adverse health consequences of air pollution.

The integration of socioeconomic data with ground-based data, satellite data and other Earth observations, along with advanced data analytics and machine learning methods can significantly improve our understanding of air pollution, enable us to predict air pollution and its health effects, and enhance our capabilities to support the most vulnerable people, including minority and low-income communities that tend to be exposed to higher levels of air pollution and its health consequences.

In this proposal, we propose to create a Predictive Environmental Analytics and Community Engagement system for Equity and Environmental Justice (PEACE for EEJ) to increase the accessibility and use of Earth observations and socioeconomic data for understanding air quality and integrate it into governmental and health organizations' decision making processes to support equity and environmental justice. We propose the development of advanced data analytics algorithms, machine learning (ML)-based models, and user interfaces (UIs) that link Socioeconomic data with ground-based in-situ and space-based Earth observations to (a) identify, discover, and classify patterns in urban air quality, (b) enable the forecast of air pollution events for air quality management and decision making, (c) understand and predict the impact of air pollution on people's health, (d) identify and support the neighborhoods and communities that face higher exposure to air pollutants and experience greater health impacts, and (e) provide information about air pollution predictions and future health effects/risks through a mobile application and a web dashboard.

This project is a collaboration between the City of Los Angeles (the Co-I of the project is the Deputy Mayor at the City of Los Angeles), California State University Los Angeles (a public comprehensive university and a Hispanic-Serving Institution that is ranked number one in the nation for the upward mobility of the students), and OpenAQ (a non-profit organization that supports open source air quality data). The proposal team is highly diverse, the leaders are 75% women, and team members and the City of Los Angeles have a long, public committed to diversity and inclusion in STEM careers and education.

Jason Douglas/Chapman University
Communities for a Better Environment: Triangulating NASA Data and Participatory GIS with Local Organizing to Advance Environmental Justice in Los Angeles
21-EEJ21-0054

In partnership with Communities for a Better Environment, a community-based organization leading the advancement of zero-emission technologies and green infrastructure in environmental justice communities, the proposed 2-year Data Integration Project seeks to examine urban heat island- and air pollution-related inequities and identify ecosystem service-based solutions for advancing equity and environmental justice (EEJ) in Southeast Los Angeles (SELA), California. SELA is a large, underserved, environmental justice community of color that bears an uneven burden of urban heat islands and mobile and stationary sources of air pollution. Further, inequitable access to ecosystem services (e.g., health benefits derived from natural environments) that mitigate heat island and air pollution impacts (e.g., public parks, open space, treetop canopy) may exacerbate poor health outcomes in SELA. Accordingly, our participatory research will examine the public health impacts of (1) localized urban heat islands and air pollutants, and (2) access to urban public parks, open spaces, and treetop canopy (i.e., greenspace) associated with ecosystem services that may serve to mitigate urban heat island- and air pollution- related health impacts. Aligning with NASA Earth Science

Applications: Equity and Environmental Justice priorities, our project will be guided by the following aims:

A. Quantify the spatial distribution of urban heat islands, air pollutants (e.g., NOx, PM2.5), greenspace, and community health in SELA. We will use satellite remote sensing from ECOSTRESS, OMI, Landsat, and Sentinel-2, and participatory geographic information systems (PGIS) analysis to capture, quantify, and examine environmental, health, and socioeconomic data.
B. Identify the primary locations of community exposure to urban heat islands, air pollutants, and greenspace in SELA. We will utilize our team's innovative participatory mapping methodology (Douglas et al., 2020) to ground-truth resident exposure to UHIs (e.g., high roadway and housing density areas) and air pollution (e.g., high traffic density areas, heavy industry) hotspots, access to greenspace (e.g., public parks), and associated health disparities (e.g., asthma, cancer).
C. Develop a GIS-enabled decision-making tool to disseminate air pollutant and urban heat island exposure information, and advance greenspace access and community health. We will develop an open-access, layperson accessible, web-based, GIS-enabled decision-making dashboard that visualizes Los Angeles County-level data (e.g., socioeconomic and health data, UHI and air pollution hotspots, greenspace access) and findings from aims 1 and 2.

Completing these aims will provide: (1) critical information and data for CBE, community residents, and policymakers to inform and develop health promoting policies and direct life-saving resources; and (2) the necessary data and methods needed to inform and support our long-term goal of examining air pollutant and heat island impacts and greenspace-based mitigation strategies in environmental justice communities across Los Angeles, California, and broader U.S. and global communities.

Iryna Dronova/University of California, Berkeley
Where the Grass Grows Greener:
The Impacts of Urban Greening on Housing Prices and Neighborhood Stability
21-EEJ21-0003

The onset of climate change has increased awareness of the importance of green space in cities, which mitigate heat extremes, absorb flood waters, act as fire breaks, support urban agriculture, and provide much needed recreational space for residents. Yet, a rich literature has established not only the economic benefits of such green space, but its potential for green gentrification," as new investments in urban greenery increase property values and rents, thereby displacing residents. Moreover, cities often support the redevelopment of informal open space, heavily utilized by locals for community gardens, urban pathways, and sports fields, since it is considered vacant or underutilized land. Thus greening trends place vulnerable urban residents in double jeopardy: first, they risk losing access to existing open spaces, and second, they may not be able to stay in their communities. Yet, the relative importance of various drivers of displacement variability as well as specific contribution of green space remains insufficiently understood at regional scales relevant to development planning and climate adaptation.

We propose to examine the relationship of green space, both formal and informal, in the San Francisco Bay Area, California, USA to property prices and rents, household mobility, and the redevelopment pipeline in order to determine first the impacts of proximity to such space on community stability, and second the potential that such space will be eliminated. We will conduct the research using publicly available remote sensing imagery emphasizing NASA satellite products and census data coupled with proprietary (Infogroup and Infutor) data on household mobility. This proprietary data is available at a parcel level, which allows us to use remote sensing to identify informal green spaces in the immediate vicinity of housing units. Using the 9-county Bay Area as our case allows us to examine a variety of contexts, including core urban areas undergoing high-intensity redevelopment, and peripheral urban areas seeing the conversion of open space and farmland in the wildland urban interface.

The final outcome of this study will be a data integration product in the form of a web-based interactive map, which will allow residents to examine the location of greenery in relation to housing market dynamics and current and planned development.

Kibri Everett/Research Triangle Institute
Landscape Analysis of African American Farmers in North Carolina and Approaches for Applying NASA's Data to Help Prevent Their Extinction
21-EEJ21-0002

NASA gathers satellite data that can be used to monitor crop health, develops remote sensing technologies that track fluctuations in drought, and creates tools that can be used to ameliorate food insecurity. These tools have undoubtedly benefited the agriculture industry in NC, which has a history of being one of the nation’s top agricultural-producing states. It currently ranks in the top five for commodities, including sweet potatoes, tobacco, and pig production. African American farmers in NC also have a history of playing a significant role in the state’s agricultural industry. They’ve also been at the forefront of racial injustice. In 1997, an African American tenant farmer from NC, Timothy Pigford, filed a class-action lawsuit against the U.S. Department of Agriculture seeking restitution for the Department’s discrimination.7 The case was decided in the farmers’ favor, making it the largest civil rights settlement in U.S. history. Nevertheless, the fight for reparations by African American farmers continues today, as financial resources earmarked in 2021 have been halted by lawsuits.

Not only are African American farmers facing hardships resulting from structural racism, they also are fighting the deleterious effects being caused by climate change, which is leading to increased droughts, crop loss, and other disruptions to their farming practices. The hardships caused by structural racism, particularly those that have made it difficult for African American farmers to receive loans, have a trickle-down effect. When financial resources are limited, farmers are unable to invest in the equipment, tools, and technology that can enhance their operations and can make it difficult to carry out the improvements needed to assist with the adaptations required for operating in a changing climate.

African American farmers in NC use drone technology for crop planning and to inform decisions about irrigation, fertilizer application, and pest control.2 The degree to which they currently use, or have the ability to use, the products NASA has developed to support agriculture is unknown. A Landscape Analysis of African American farmers in NC is needed to identify barriers in place that prevent farmers, who largely live in rural, poverty-persistent areas, from accessing and understanding NASA's Earth science information. The information gleaned from this analysis can serve as a lifeline for sustaining this underserved community, which is on the brink of extinction.

To identify issues faced by African American farmers, we have convened a team of Earth and social scientists who will partner with four community organizations that work directly with African American farmers. Our partners' expertise and connections to the African American farming community will be used to guide every stage of the Landscape Analysis. The Analysis will begin with a literature review and environmental scan to identify environmental issues and burdens faced by farmers. We will then conduct in-person and virtual listening sessions with African American farmers to ascertain the degree to which they are aware of and can use NASA's technology in support of addressing the environmental challenges they face. Surveys will be developed to capture information that can be used to provide the ASP details about the African American farming population's ability to use NASA's Earth science information.

The output from this literature review, environmental scan, listening sessions, and surveys will be beneficial in determining the next steps necessary to provide technical assistance and to get African American farmers engaged and onboard with using NASA's data to optimize their current farming operations. The resources and support provided by NASA's ASP will aid in sustaining this community. Approaches used and information gleaned from this Analysis can help inform next steps for the ASP and be applied to all farmers across the country.

Jeanne Fernandez/Stockholm Environment Institute U.S.
Can Remote Data Connect Us to the Land? A Landscape Analysis for Braiding Satellite-Based Information and Indigenous Knowledge in California
21-EEJ21-0058

The proposed landscape analysis is a scoping project to identify interest in- and potential barriers to the use of Earth Science information in understanding wildfire risks but also benefits, forest cover loss, drought, and other indicators related to water and land resources, in Indigenous communities in California. It aims to provide a picture of the current access and use of remote-sensing-based information and derived tools for tribal lands and to understand if and how spatial-temporal mapping can support decision-making on land and water management in tribal communities, combined with traditional approaches.

Through qualitative and semi-quantitative methods identified with community members in tribes across California, in particular Tribes in the Klamath River Basin, in Northern California, the project will explore the potential for combining traditional knowledge and NASA satellite imagery and data products to develop tools, in future projects, that are adapted to the needs and values of the communities. A number of research questions will guide this investigation of the current landscape, more specifically of the ways communities interact with their environment, and how their tools and principles could, in conjunction with Earth Science information support the development of innovative land and water resources conservation approaches. The questions will address trends, opportunities and gaps in the field of remote sensing water and land management in tribal communities. How can remote sensing and spatial data serve environmental justice in the context of land and water resources management? What are the current uses or barriers to using spatial data in Tribal communities in California? Do the communities feel included in the projects that apply spatial data and GIS-based tools for forest and water resources management?

By identifying opportunities for future developments of innovative tools that are adapted to local needs and values, the project findings can lead to informed action and support environmental justice.

Stephen Flynn/Northeastern University
Leveraging Earth Observation Data to Support Environmental Justice: A Puerto Rico Coastal Community Case Study
21-EEJ21-0043

The Global Resilience Institute at Northeastern University is partnering with the Puerto Rico Science, Technology, and Research Trust (PRST) to collaborate with a community in Puerto Rico, ??Comunidad Las Margaritas in the town of Salinas, to conduct a landscape analysis of how NASA Earth observation (EO) data can aid communities in addressing their environmental justice (EJ) challenges. We seek to investigate what the community feels are its most pressing EJ concerns, and use this information to co-develop “Environmental Justice Scenarios.” This participatory approach will inform actionable steps that both the community and NASA can take to leverage NASA EO data to address environmental justice concerns and to articulate the process through which communities would like to be engaged.

The island of Puerto Rico has a multitude of environmental justice issues that merit immediate attention. Based on the Environmental Justice Advisory Council’s definition of “EJ Communities” as “geographic locations with significant representation of persons of color, low-income persons, indigenous persons or members of Tribal nations, where such persons experience, or are at risk of experiencing, higher or more adverse human health or environmental outcomes," the entire island of Puerto Rico represents a community that is vulnerable to environmental injustice (NASA, 2022). Its historic economic dependence on the United States, high poverty levels, and increasing susceptibility to dangerous effects of climate change have even led some scholars to refer to Puerto Rico's main island as an "Environmental Justice Island" (Brown et al., 2018). There also exists critical inequities within the island itself. Environmental justice index studies have shown that many communities on the southern coast have particularly high vulnerability to environmental injustice (Sotolongo et al., 2021), which includes the coastal municipality of Salinas. Many climate change challenges are more pronounced in island communities, therefore, they make critical case studies for understanding inequity in their impacts (USGCRP, 2018). The integration of Earth observation data on land, oceans, and atmosphere with socioeconomic data on poverty levels, race/ethnicity, political structures, health, etc. can be instrumental in identifying environmental injustice across communities and developing equitable solutions.

It has been well established that handing a community a pre-built tool or solution without engaging its members in its development (a top-down approach) is ineffective. Communities need to be engaged from the beginning using a bottom-up approach. However, when it comes to building resilience in the face of climate change, communities may be limited in their ability to enact lasting change for a variety of reasons - lack of capacity being the most notable. Therefore, it is important to collaborate with communities in order to assess how to best engage and use valuable Earth observation data to create solutions for the self-identified environmental justice concerns of island communities.

Kerry Grimm/Northern Arizona University
Assessing Accessibility, Inequities, and Barriers Using NASA and Other Wildfire Communication Tools in Environmental Justice Communities
21-EEJ21-0060

Important to community wildfire preparedness is ensuring that the correct information about ecological conditions, mitigation approaches, and fire safety and evacuation plans are communicated to as many people as possible in directly and indirectly affected communities. The accessibility and accuracy of information, including NASA's Fire Information for Resource Management System (FIRMS) and the interagency Inciweb, shared through both formal (Emergency Alert) and informal pathways (e.g., social media) is not well quantified, especially for non-English speaking and other Environmental Justice or underserved communities. Environmental justice, or injustice, has been applied to many socio-ecological issues, but inequities among different groups of people (e.g., race, ethnicity, socio-economic classes) are less explored in fire-impacted communities. These groups may have limited capacities to access accurate information involving wildfire risk, mitigation strategies, or evacuation preparedness. To help inform and expand equitable access of NASA and other wildfire tools, we propose a community feasibility study to examine how diverse groups in northern Arizona's fire-impacted communities access wildfire information, as well as the types of information used and their methods accessing this information. To collect data, we will survey residents, interview key stakeholders and those involved with wildfire management or communication, and take ecological measurements. We are working with existing community partners from Environmental Justice and underserved communities (e.g., Latino/a, Indigenous), and plan to include additionally community partners who are interested.

Our study area includes Flagstaff and surrounding areas near recent fires (Slide, Rafael, Museum), as well as areas further away but still affected by the fires (e.g., smoke). We will evaluate when and which NASA fire products are used for community decision-making, as well as their use by officials in fire communication and management. We will also investigate why and where these products are not used and identify ways to improve their accessibility. Furthermore, we plan to integrate social and ecological approaches by measuring both ecological variables (e.g., tree density on private property and neighborhoods, proximity of structures to vegetation) and conducting surveys to understand fire awareness, level of concern, approaches used to mitigate fires, and types of information accessed. Understanding the relationship between ecological measures and perceptions of fire risk and awareness can inform NASA and other agencies about additional information they could include to increase resident fire knowledge. In particular, we will compare differences between user groups such as ethnicity (e.g., Latino/a, Diné, Caucasian), language (e.g., Spanish, Diné, English), socio-economics (e.g., income level, home ownership type), and landowner jurisdictions (e.g., neighborhood HOA) to determine if significant differences exist between groups, what causes these differences (e.g., lack of funding, lack of communications, lack of trust), and ways to address weaknesses (e.g., identify trusted sources and ways to leverage these sources). We will also identify preferred methods of communications among different user groups and share this information with interested stakeholders and NASA to improve their information accessibility and use. We will share ecological and safety (e.g., evacuation planning suggestions) information through different outreach methods and determine effective ways (informed by survey responses about preferred communication and trusted sources) among different users to increase information reach, knowledge and awareness, and concern of fire risk, as well as ways to increase community resilience to future fires. We anticipate community resilience can be increased by identifying inequities and ways to mitigate impacts resulting from these inequities.

Yun Hang/Emory University
Using NASA Earth Observations to Support Environmental Justice Communities in Atlanta, Georgia
21-EEJ21-0049

Low-income and minority communities have been facing a much higher health risk resulting from disproportionately distributed environmental exposure and increased vulnerability to climate change. In Atlanta, Georgia, many communities face serious environmental justice (EJ) issues such as having higher levels of exposure to extreme heat, air pollution, and the lack of green space. Race has been reported as a strong determinant of exposure to ambient air pollution and extreme heat that are established risk factors for adverse health outcomes including cancer, heat stroke, cardiovascular and respiratory diseases, and premature death. Exposure assessment is often the first step to promote public health facing those environmental exposures. Historically, public health agencies have relied on ground monitors and weather stations to estimate population-level exposures. However, the lack of ground monitoring sites in EJ communities presents a challenge for decision-makers to assess the health burdens of associated exposures. Satellite observations can effectively extend ground monitoring networks to produce full-coverage exposure estimates that provide required information to advance progress in EJ.

We propose to assess the feasibilities of using NASA Earth Observations to support science education and decision-making in Metro Atlanta's EJ communities. In close collaboration with our local partners and stakeholders, we aim to perform the following tasks:

1. Assess major environmental risk factors faced by EJ and underserved communities with satellite data, ground measurements, and machine learning techniques;
2. Enhance community stakeholders' knowledge on health effects of environmental exposures and build their awareness of NASA Earth Observations;
3. Support local community decision-making toward achieving EJ with the help of high resolution data products and education materials.

A multi-organizational, multi-disciplinary, and multi-sectoral team of investigators will participate in this study. Dr. Yun Hang (PI) studies the intersection of atmospheric science and public health with remote sensing techniques and machine learning algorithms. She has been funded by NASA and NIH to apply satellite data in air quality modeling and assess the health impact of climate change exposures. Dr. Yang Liu has led and participated in numerous projects funded by NASA, EPA, and NIH to develop satellite-driven exposure models to evaluate the health impact of regional and local air pollution. Dr. Howard Chang is a statistician with extensive experience in developing statistical methods to optimize exposure assessment of air pollution and extreme heat in Atlanta. Dr. Christine Ekenga is an environmental epidemiologist studying health disparities with community-engaged approaches. Mr. Garry Harris is an Atlanta EJ community leader dedicated to advancing the resilience of under-resourced communities and neighborhoods. He has contributed to twelve EJ organizations and their associated programs including EPA's EJ Academy. Dr. Melanie Pearson is a community engagement expert who has brought Atlanta's environmental stakeholders together to expand the multi-directional dialogue around EJ issues. Dr. Guanyu Huang is the PI of NOAA-funded Atlanta Heat Watch Campaign, studying EJ at Spelman College, a historically black college in Atlanta. Dr. Amy Sharma is a local science communicator working to build a bridge between scientists and the public to advocate for the use of science in actions. Together collaborate with multiple community stakeholders, we anticipate advancing progress in Atlanta's EJ and support future decision-making.

Carolynne Hultquist/Columbia University
Pairing Earth Observations and Socioeconomic Data to Enable Student-Led Hazard Monitoring for Environmental Justice in New York
21-EEJ21-0053

Environmental justice communities (EJC) in the United States are at risk of experiencing higher or more adverse human health or environmental outcomes. Among EJC, schools can be both a pathway for elevated exposure and a pathway to reduce harm. Functioning heating, ventilation, and air conditioning systems (HVAC) may reduce exposure to hazardous temperatures and air quality while students are in school and present the possibility for schools to be refugees for vulnerable populations in EJC. However, little is known about which public schools can enhance or mitigate exposure among the EJC because environmental hazards have not been comprehensively mapped to public schools across the US. In fact, it is unclear if satellite-borne earth observation (EO) climate and meteorological data widely used for monitoring and forecasting environmental hazards are sufficiently fine-grained to capture environmental hazards in and around public schools.

To fill this knowledge gap, we propose to explore the feasibility of combining citizen science in situ data collection with space-borne EO products to monitor two environmental hazards – hazardous air quality and temperature – in and around public schools serving EJC in New York State (NYS). We will first map daily hazardous air quality and temperature for school districts in NYS from 2000 - 2016, as well as identify annual and seasonal changes. This EO-derived environmental data will be integrated with socioeconomic variables available from the National Center for Education Statistics (NSES) through the American Community Survey (ACS) Education Tabulations on demographics and economic statistics on students attending each school. This will allow stakeholders to identify which EJC-serving NYS public schools, and their surrounding communities, face the greatest burden of exposure to these twin hazards, and which public schools can be best leveraged to reduce harm. While our initial focus is NYS, the underlying datasets can be scaled to produce EO-derived national-level exposure data for each public school in the US.

Next, we will pilot community-based citizen science to compare in situ air quality and temperature monitoring with the EO-derived air quality and temperature data we develop. To this end, we will partner with public high school teachers and students in New York City. Students will be trained to install and use air quality and temperature monitors that collect indoor and outdoor data in real time, as well mobile sensors to measure air quality and temperature in their neighborhoods. Students will be introduced to the fundamentals of EO data collection and analysis for environmental monitoring. The citizen science approaches will provide a personal linkage to real-time data that students can use to increase knowledge and better understand their exposure to hazards.

Finally, we will assess the feasibility of student-led citizen science in situ data collection augmented with EO data to monitor air quality and temperature in and around public schools. We will first assess the degree to which EO data captures the fine-grained spatial heterogeneity of air quality and temperature captured by the in situ measurement in the community the school serves. Second, through input from our teacher collaborators at high schools, we will gauge the effectiveness of the piloted student-based citizen science approach for increasing community monitoring of these twin hazards and the feasibility of working with public high school students in EJ communities to jump-start EJC students' knowledge and skills to employ EO data in their communities. By demonstrating the potential of this approach through a case study in New York City, we will show the feasibility of replicating this approach for other schools in the US.

Peter Ibsen/U.S. Geological Survey, Denver
Unequal Distributions of Commuter Exposure to Extreme Heat and Air Pollution at Neighborhood and Microscales: A Community-Based Feasibility Study Designed for NASA's Earth Science Applications focused on Equity and Environmental Justice
21-EEJ21-0064

The combination of urban population growth, global climate change and the negative effects of extreme heat and urban air pollutions drastically increased the number of individuals ill-health and morbidity. While recent studies have explored how to reduce heat and air pollution at a citywide or a neighborhood level, finer scale patterns are of great importance to human well-being and are yet less understood. When individuals are exposed to extreme temperatures and airborne pollutants, their patterns of activities may shift to avoid negative health-impacts. Furthermore, we find these health impacts and changes to activities can be inequitably distributed, as public transit is disproportionately utilized lower income populations. What is needed to address this problem is a framework that links urban planning, land cover patterns, distributions of extreme heat and air pollutants, and human health and activity.

Transit stops are surrounded by different types of land covers that influence environmental hazard exposures at multiple spatial scales. Transit users' degree of exposure to heat and air pollution is determined at both neighborhood and micro scales, when waiting at a stop, or when traversing through neighborhoods to arrive at a transit stop. To understand patterns of exposure risk and human decision making at transit stops, we must understand the land cover drivers of microclimate as well. Urban land cover types such as tree canopy, turf, and impervious surfaces all contribute to variations in temperature and air quality. These slight changes can have a significant effect on human health and activity. Increased exposure to extreme conditions can cause illness in at risk populations as well as reduce individuals' usage of outdoor municipal services, such as public transit. Given the increased risks of extreme urban climates, our goal is to explain links between patterns of land cover, measurable heat and air quality, and how this understanding could influence human decision making. We therefore pose a two-part research question: How do patterns in urban land cover drive microclimate and air quality at transit stops and human decision making, and how is the environmental health risks unequally distributed among urban residents?

In collaboration with Denver Regional Transportation District and the local stakeholders, we will determine relative transit stop usage and ridership data in relation to neighborhood and microscale thermal comfort and air quality. We hypothesize that transit stops with greater proportions of vegetated land covers and amenities will have lower instances of extreme temperatures and concentration of air pollution. However, these benefits will be unequally distributed due to inequities in land cover composition across the city. Moreover, as exposure to extreme heat and air pollutants increase, there will be an inequity in transit ridership. Higher-income households have more flexibility in transportation options; they are more likely to take other modes of transport on high-heat days or adjust their commuting times. In lower-income neighborhoods ridership will not decrease, even when individuals at health risks, due to the lack of other ridership options.

We will test our hypothesis through a synthesis of satellite derived surface temperature and air quality data, high-resolution land cover data, handheld microclimate and air quality sensors, census income and racial demographic data, and ridership data for transit stops in the Denver metro region. We will analyze inequities of land cover surrounding transit stops locations across demographic gradients and select key transit locations where we will collect handheld sensor-based measurements of temperature and air quality. Using satellite-derived data and sensor-based data, and the incorporation of census demographic data, our study will be able to scale the landcover drivers of urban health hazards across spatial and social gradients.

Megan Jennings/San Diego State University
Spatial Decision Support for Fire Management in Indigenous Cultural and Stewardship Practices
21-EEJ21-0037

Our multi-institutional team proposes to address NASA priorities to advance progress on equity and environmental justice (EEJ) through the application of earth science, geospatial, and socioeconomic information. Climate adaptation planning is critical to communities living in the wildland urban interface (WUI), notably for the 25 federally recognized Tribes in southern California. To enhance our understanding of the vulnerabilities and impacts of wildfire and shifting fire dynamics in the region, we will integrate geospatial data on the ecological and community impacts of altered fire regimes, socioeconomic factors associated with community vulnerability to wildfire, and cultural priorities and values associated with wildfire for Tribal communities. Our study area includes all southern California counties to the U.S.-Mexico and Arizona borders. This data integration project will build on and expand ongoing regionally-relevant research to establish a structured decision support process informing the development of adaptation strategies and responses to wildfire and the impacts of climate change on regional fire regimes that can be adapted for other regions.

The specific objectives of the proposed project are to:

1. Conduct a region-wide assessment of community vulnerability to wildfire in southern California based on advanced integration of socioeconomic data,

environmental health information, and metrics of fire danger and risk, driven by NASA Earth Science Data (ESD) products;

2. Develop a spatial decision support tool that serves southern California's Indigenous communities through the integration of our assessment of community vulnerability and fire danger and risk with Tribal cultural practices and priorities to advance fire and climate preparedness planning in support of Tribal community and cultural resilience;
3. Support Indigenous communities by expanding a capacity-building training program integrating western science and Indigenous knowledges of fire and fuels management, native plant propagation, food sovereignty, and ecological restoration; and
4. Advance NASA ESD's understanding of issues faced by Indigenous communities and identify important steps to cultivate authentic collaborations through the transfer of training materials and a workshop on fostering meaningful engagement with Tribal communities.

Our project team is composed of researchers affiliated with San Diego State University, boundary spanning specialists at the Climate Science Alliance and Tribal members and staff from across southern California who participate in the Alliance's Tribal Working Group. Our team's unique combination of experience and expertise will allow us to have an impact on planning and implementation actions across the region with our integrated approach to building climate resilience and planning for climate adaptation in ecosystems and communities.

The proposed study is fully responsive to the NASA ROSES EEJ Data Integration solicitation by: 1) building on our experience in advancing EEJ activities with Tribal governments, non-government organizations, and university personnel as a multi-organizational project team, 2) examining spatial patterns of vulnerability to wildfire under a changing climate, through integration of value-added socio-economic and NASA ESD products and other biophysical data, and 3) developing a GIS-enabled SDSS that can be transferred and scaled-up to other domains subject to wildfire. Our proposed project will also support NASA's ESD Program in advancing understanding of EEJ issues for Tribal communities and identify important steps for ESD or other grantees to cultivate authentic collaborations with Indigenous communities. This research will inform adaptation planning and implementation, supporting the unique needs of historically excluded Tribal communities with integration and consideration of cultural resilience throughout the work, directly addressing an identified Tribal priority.

Hannah Kerner/University of Maryland, College Park
EO-Enabled Food Security Dashboard to Close Critical Data Gaps in Highly Food Insecure Maui County
21-EEJ21-0028

The Hawaiian islands are one of the most isolated populated lands in the world. Tri-island Maui County, which includes the islands of Maui, La?na‘i, and Moloka‘i, is particularly vulnerable to food shortages due to high reliance on agricultural imports and supply ships. Despite having a year-round growing season, only 15% of the food consumed locally is produced in Hawai'i. High food costs and food insecurity disproportionately impact lower-income residents. Food insecurity in Maui County is a key equity and environmental justice (EEJ) issue as small-scale, indigenous farmers that produce food for local consumption have been historically marginalized in state and national policies and investments, stifling their production of native crops and consequently their livelihoods. The goal of this project is to integrate datasets derived from Earth observations (EO) into a Food Security Dashboard that will focus on supporting small-scale, independent, and indigenous farmers in Maui County to support the county's and state's economic diversification and sustainability goals. This project is a partnership between team members at the University of Maryland and community-based institutions including Responsible Markets and non-profit Maui United Way who have been active in addressing key EEJ issues that would benefit from insights offered by NASA Earth Science information in Maui County. Our overall objective is to create new datasets for measuring and monitoring agricultural production in Maui County using EO data and integrate these EO-derived products with other relevant datasets (e.g., socioeconomic and price data) into a public, interoperable, GIS-enabled Food Security Dashboard to serve community decisions and actions, thereby advancing the integration of Earth science, geospatial, and socioeconomic information for EEJ communities. The agricultural datasets produced by this project using satellite Earth observations data will fill critical gaps in the knowledge of agricultural production at all scales across the county. The integration of these and other relevant datasets into a public Food Security Dashboard will enable decision-makers and members of the Maui County community to continuously monitor the status and conditions of crops grown locally and develop policies and programs to boost production by small and indigenous farmers in a sustainable and culturally appropriate way.

Lingling Liu/University of Minnesota
Investing In Equity and Environmental Justice: An Urban Decision-Support Tool Integrating Earth Observations, Socioeconomic Data, And Ecosystem Service Models
21-EEJ21-0070

Those who make decisions affecting equity and the urban environment must manage multiple, interacting challenges such as climate change, air and water pollution, flooding, heat waves, affordable housing, and public health. Investing in urban nature, or green infrastructure," can help address many of these challenges, offering solutions that concurrently deliver multiple benefits that diverse stakeholders want and need. However, leveraging the current data and tools that can best inform these decisions requires skills in Geographic Information Systems (GIS) and knowledge of ecosystem processes that are beyond most community stakeholders and planners. We will develop a green infrastructure planning tool that lowers technological barriers for urban planners and decision-makers to generate insights and inform investments in green infrastructure for sustainable and equitable cities. We will prototype this tool in San Antonio, Texas, where we have existing relationships with stakeholders in city government and NGOs. Our tool will be scalable to other US cities, using nationally available and regularly updated data inputs that ensure durability and resilience. The objectives of this research are fourfold:

Objective 1: Developing a Urban Ecosystem Services Workflow
We will develop an integrated urban ecosystem services modeling pipeline that transforms earth observations into decision-relevant metrics at a city scale. This will involve gathering and developing data inputs; assembling model parameters; creating an ecosystem service modeling pipeline using the InVEST software suite; and developing valuation modules for ecosystem services to translate biophysical results into metrics of human wellbeing (e.g., monetary valuation, health impacts).

Objective 2: Creating a Companion Socioeconomic Workflow
We will create a workflow to construct maps of socioeconomic inequalities from nationally available sources. We will apply spatially-decomposable disparity metrics that map multidimensional hot spots of socioeconomic and ecosystem service inequality, which can be aggregated to show rates of inequality at the neighborhood or city scale.

Objective 3: Producing a Web-Based User Interface and Visualization Platform
We will create a web application that allows users to develop and model planning scenarios and visualize their impact on ecosystem services and environmental inequalities. Our scenario-building interface will let users change areas of the city based on a proposed policy or development and calculate the impact on ecosystem services and environmental inequalities. Our visualization platform will synthesize the multidimensional modeling outcomes and allow comparisons across scenarios.

Objective 4: Engaging Decision-Makers in San Antonio, Texas
We will engage regularly with our local partners in San Antonio to co-develop the specific metrics, scenarios, and visualization methods used by our tool. We also plan to conduct a stakeholder engagement meeting and present a prototype tool at a city budget and planning meeting between April and September 2023, refining the visualization platform with additional city collaborators to ensure a useful and engaging interface.

This tool has transformative potential for urban planning in San Antonio and beyond. Our vision for describing the urban environment and socioeconomic system by integrating NASA earth observation data, ecosystem service models, and socioeconomic metrics will allow city planners and other stakeholders to explore, analyze, visualize, and synthesize information in new ways. Insights provided by our co-developed data integration tool will have great potential to inform smart investments in green infrastructure that improve the sustainability, livability, and equity of the urban environment.

Peter Marcotullio/Hunter College
Spatial and Temporal Variations in Land Surface Temperature, Vegetation, and Socio-Economic and Health Characteristics in Frontline EEJ Neighborhoods in New York City: Integrating Scientific Study with Community Perspectives

21-EEJ21-0025

This landscape project proposes a temporal and spatial accounting of the relationship between land surface temperature (LST), normalized difference vegetation index (NDVI), greening and climate-related policies, and socio-economic and health characteristics in different neighborhoods in New York City. Neighborhoods are defined by the Home-Owners Loan Corporation (HOLC) distinctions at the census tract level in New York City. We will examine temporal and spatial relationships from 1984 to 2021 to identify the role of greening and climate-related policies in biophysical and socio-economic and health change in frontline equity and environmental justice (EEJ) neighborhoods integrating community perspectives in the analysis.

There is increasing skepticism concerning climate-related and greening efforts in cities and particularly in low-income environmental frontline neighborhoods. Scholars have argued that urban greening interventions can induce exclusion, polarization, and segregation. In New York City neighborhoods, researchers argue that while positive for the environment, greening can increase inequality and thus undermine the social pillar of sustainable development. This creates a policy dilemma as HOLC redlined communities, which are centers of equity and environmental justice, suffer from both the lack of greening and higher temperatures compared to other neighborhoods. Outside of anecdotal evidence, however, the effects of greening in EEJ communities are not well understood. Including community engagement in the scientific analysis process, including NASA products, is critical to providing a better understanding of how to address heat, provide greening that enhances the quality of life of residents and reduce displacement in frontline environmental communities.

We propose to integrate community perspectives into a study of the contemporary history of heat, vegetation, greening, and climate-related policies, socio-economic and resident health changes in frontline communities in New York City. We define greening policies as those related to climate mitigation and adaptation strategies, including, inter alia, rooftop greening, cool roofs, increasing tree canopy cover and street tree numbers, swales, park renovations, bike lanes, and pedestrianization. We examine locations where these have occurred along with changes in socio-economic, health characteristics of the community, and biophysical changes (land surface temperature and vegetation). We will work closely with EEJ leaders, such as We Act and the Environmental Justice Alliance, and greening advocates, such as GrowNYC, the National Parks Conservation Association, the City Parks Foundation, The New York Restoration Project, and The Trust for Public Land, to identify the lived experiences of those in neighborhoods undergoing change.

The goal is to identify the relationships between biophysical indicators (land surface temperature and greening), climate- and greening-related policies, and socio-economic and resident health change in frontline communities. The objectives are to answer three questions:

1) Does LST differ over time both within and across HOLC defined neighborhood categories “C” and “D” versus “A” and “B”, at the neighborhood (across) and census tract level (within)?
2) Have biophysical greening in any parts of the HOLC neighborhoods changed over time at the census tract level?
3) What are the relationships between the LST, NDVI, city climate- and greening-related policies, and socio-economic and resident health characteristics in EEJ neighborhoods?

Miriam Marlier/University of California, Los Angeles
Mapping Vulnerable Populations in California to Climate-Related Hazards
21-EEJ21-0055

Many locations around the world are already facing adverse health consequences associated with climate change. In the State of California, two leading climate-related hazards, wildfire-contributed air pollution (“smoke pollution”) and extreme heat, have been increasing in frequency and severity over the past several decades. This trend is expected to continue with future climate change scenarios and is concerning to public health as exposure to smoke pollution and extreme heat are each independently associated with morbidity and mortality. Recent evidence also suggests that exposure to smoke pollution and extreme heat at the same place and time could interact to amplify these adverse health outcomes. In addition, certain communities are disproportionately affected by climate-related hazards, are more vulnerable to the health effects, or a combination of both. The State of California, however, currently lacks a comprehensive screening tool that considers recent climate-related hazards and connections to both population vulnerability characteristics and adverse health outcomes. To fill this gap, our study will integrate Earth science information and existing socioeconomic datasets to develop climate vulnerability assessments for environmental justice communities across California. First, we will map the distribution of exposures to climate-related hazards in California with Earth observations from 2008-2018. We will leverage atmospheric modeling simulations of smoke pollution at the daily scale and Earth observations of extreme heat index values to map individual and overlapping exposures to these hazards. Second, we will map population-level vulnerability characteristics and adverse health outcomes associated with exposure to these climate-related hazards. Finally, we will develop a publicly available online geospatial mapping tool to support environmental justice communities at the local level and across California. We will disseminate the tool through Tracking California to enhance climate resilience strategies in communities identified as highly vulnerable in our mapping tool. Our approach is scalable from the local to state level to support vulnerable communities in California with preparing for climate change.

Claire Masteller/Washington University

Community Feasibility Study: Urban Flood Modeling Using a Data-Driven, Community-Centered Approach in Centreville, IL
21-EEJ21-0017

Flood hazards have the most pervasive economic and social impacts in the United States. Flood impacts in urban areas can be highly variable within neighborhoods and across individual households due to differences in stormwater infrastructure, impervious area, and other local factors. The small-scale variability in flood impacts makes flood inundation difficult to predict, observe, and mitigate across urban communities. Low-income and minority communities are often vulnerable to frequent flooding due to lack of infrastructure for surface runoff mitigation practices and flood monitoring systems. However, due to lack of measured data, the assessment and modeling of flooding conditions in vulnerable communities remain. The primary objective of this Community Feasibility Study is to integrate satellite-based data with community-engaged monitoring and resident experiences to document ongoing flooding hazards in a low income, predominately Black community in Centreville, IL.

The investigators have an established and ongoing collaboration with Centreville residents and other stakeholders including the community-run Centreville Citizens for Change organization, Equity Legal Services, Inc., and the Metropolitan St. Louis Equal Housing and Opportunity Council (EHOC). Through these partnerships the research team has implemented a community-engaged flood monitoring system with guidance from residents. Preliminary results have documented persistent flooding in Centreville and informed a simple hydrologic model. However, the full extent of flooding in Centreville remains unquantified and the environmental drivers of flooding remain poorly constrained.

This proposal aims to leverage satellite-collected data products (precipitation, soil moisture, imagery, and radar data) to better quantify the environmental drivers of flooding in Centreville, map resulting inundation extent and variability across the Centreville community, and two develop a versatile, data-driven model for urban flooding using machine learning tools. The research team will leverage existing ground-based data to assess the ability of remotely sensed data sets to reflect both the drivers and response of flooding observed at a local scale. Following this assessment of these data products relative to their point-based counterparts, the investigators propose a synergistic application of these data to develop and validate a simple hydrologic model (HEC-RAS). The investigators also proposed to train a set of machine learning algorithms to better predict flooding extents, as machine learning approaches will better parse nonlinear relationships between variable antecedent conditions that affect flood response to a given rainfall event.

The investigators aim to integrate a community-centered approach in this work, engaging residents and accounting for their experiences in the planning of research activities. The work plan also aims to integrate these resident experiences into the assessment of study results and model performance. Successful dissemination of research activities will involve regular conversations with residents facilitated by our collaboration with

Centreville Citizens for Change. Conversations will inform aspects of the research program and provide opportunities to share initial findings. A final technical report of our findings will be provided to residents through Centreville Citizens for Change. In collaboration with colleagues at Equity Legal Services, Inc. and EHOC, we will also report our findings to relevant officials from St. Clair County and the Illinois Environmental Protection Agency with the aim of supporting efforts to define flood risk more accurately for Centreville. In sum, these research and engagement activities will leverage our findings, and by extension, a suite of satellite-collected data products, to help achieve community goals for environmental justice.

Mahbubur Meenar/Rowan University
From Green to GrEEEn: Utilizing an Environmental Justice Lens and Earth Science Data to Enhance Greenspace Equity, Exposure, and Experience
21-EEJ21-0007

Our proposal falls under the Landscape Analyses program element for NASA's Earth Science Division (ESD). We aim to follow participatory data collection and assessment processes to examine equity and environmental justice (EEJ) landscapes by analyzing one core issue environmental justice (EJ) and underserved urban communities face: greenspace access. In the urban context, greenspaces encompass publicly accessible areas with natural vegetation (e.g., grass, plants, trees), built environment features (e.g., parks, pocket parks), and less managed areas (e.g., woodlands and nature reserves). Our study is focused on the state of New Jersey and two of its EJ communities: Camden and Jersey City.

In order to better understand greenspace access in EJ communities, we aim to examine three significant topics that need further research: if greenspaces are equitably distributed in a community by offering easy walking access from residential parcels to nearby greenspaces in disadvantaged neighborhoods, if users have green exposure while walking on their way to nearby greenspaces, and if users experience spatial quality and green elements (e.g., land cover, tree types) while enjoying the greenspaces. Additionally, we aim to explore the ways that NASA, through their data and organizational involvement, could support EJ communities in analyzing and addressing these topics.

There are two main goals for our project. The first is to work with key stakeholders to identify how NASA can best support local community decision-making processes relating to EEJ by contributing earth science information towards those processes. We will (1) identify EJ communities' familiarity with, current use of, the potential to use, and barriers to using earth science information resources; and (2) identify opportunities for NASA to utilize its activities and data to address EEJ issues. We will collect and analyze stakeholder inputs by using two tools: a statewide survey of EJ communities and focus groups in two cities.

Our second goal is to use earth science data to examine greenspace equity, exposure, and experience in EJ communities to minimize gaps that may exist in EJ communities' use of earth science resources by comparing findings from two cities. We will conduct three analyses by using earth observation and other geo-spatial and socio-demographic/built environment data. The GrEEEN – Equity analysis will help us understand equitable greenspace access issues in EJ communities. The GrEEEN – Exposure analysis will demonstrate eye-level greenness along the sidewalk network connecting homes to nearby greenspaces. Finally, the GrEEEn – Experience analysis will create a weighted score of greenspaces based on four factors: (1) surrounding land use mix that is preferred by greenspace users; (2) accessibility or connectivity of greenspaces based on the sidewalk network data; (3) land cover characteristics within greenspace (e.g., wooded areas, grass, and other impervious surfaces); and (4) plant diversity (e.g., deciduous vs. evergreen trees, mixture of trees, shrubs, and bushes).

Deliverables of this 9-month project (Task 5) include a whitepaper, a technical report, and a web map console under NJ Map (a state-level online atlas, managed by a Co-I). The expected outcomes of this project will have a broader impact for several reasons such as academic and professional training and mentoring of graduate and undergraduate students in community-engaged and earth science data-driven research projects; and redistribution of NASA funds to minority-led community-based organizations. The project is expected to create awareness and provide guidance to environmental activists and policymakers in EJ communities; and increase NASA's understanding of the EEJ landscape, as well as organizations working directly with EJ communities to address greenspace-EEJ issues.

Mary Miller/Michigan Technological University
Addressing Inequitable Flood Risks in Southeast Michigan Through Green Infrastructure
21-EEJ21-0024

NASA data and modeling products can ensure Equity and Environmental Justice for underrepresented people in Southeast Michigan. We are partnering with the Southeast Michigan Council of Governments (SEMCOG) to create spatial datasets of flood risks due to rapidly changing water levels in the Great Lakes as well as increased flood risks from extreme weather due to changes in land cover and climate. SEMCOG's core mission is that "all people of Southeast Michigan benefit from a connected, thriving region of small towns, dynamic urban centers, active waterfronts, diverse neighborhoods, premiere educational institutions, and abundant agricultural, recreational, and natural areas". We will work with SEMCOG to support their mission by providing custom spatial water and flood risk datasets derived from models and NASA Earth Observations for their new online Equity Emphasis Areas (EEA) tool. The EEA tool is an online interactive GIS application that provides detailed summaries of key demographic variables at different geographies (regional, county, community, and census tract) across the seven-county region. The tool provides one location where communities, partner organizations, and residents can learn about Southeast Michigan's current socioeconomic indicators and have a data-driven understanding of community needs in order to assist in

effective planning to ensure equity and environmental justice (https://maps.semcog.org/EquityEmphasisAreas/).
In consultation with SEMCOG we plan to provide them with multiple datasets: 1) Maps and assessments of urban flood risks due to both changing water levels in the Great Lakes and extreme weather events. 2) Detailed spatial maps of wetlands along with estimates of their capacity to store runoff. and 3) Maps of potential wetland restoration areas and of living and hardened shorelines. We will also work with SEMCOG to identify priority areas for green infrastructure (GI) development, including urban green space and rain gardens, to achieve outcomes that are more equitable. Combined with demographic data, NASA data and modeling products can contribute to equity and environmental justice for underserved communities in Southeast Michigan. We will work with SEMCOG to create spatial products for the EEA tool towards the goal of ensuring the equitable distribution of infrastructure projects designed to mitigate increasing flood risks.

Nathan Morrow/Tulane University, New Orleans
Assessment of the Gulf Coast Environmental Justice Landscape for Equity (AGEJL-4-Equity)
21-EEJ21-0020

Four Equity and Environmental Justice (EEJ) networks will convene to map Southern Gulf Coast, primarily African American, underserved EJ communities and their priorities: the National Black Environmental Justice Network, Historically Black College and University-Community Based Organization Gulf Coast Equity Consortium, the Deep South Center for Environmental Justice (DSCEJ) Community Advisory Board, and the Environmental Justice Forum. Tulane University School of Public Health and Tropical Medicine and DSCEJ will provide capacity development-centered support through an open Earth science-focused adaptation of the tried-and-true Communiversity participatory assessment model. Author, EEJ organization leader, and White House Environmental Justice Advisory Council member, Dr. Beverly Wright will co-lead support with Dr. Nathan Morrow who together have more than 50-years of combined experience with inclusive participatory assessment. Dr. Morrow continues to apply geospatial analysis of NASA products to social and environmental challenges following-on from early research contributing to the MODIS, NPOESS, and Land-Use-Land-Cover-Change missions. Each EEJ network will be empowered with participatory mapping tools co-developed with Dr. David Padgett, an established NASA investigator, of Tennessee State University and supported with a common multi-disciplinary multi-perspective EEJ analytical frame.

Environmental ills and climate change related hazards are unequally distributed in communities on Earth, predictably collocated with marginalized groups and increasingly vulnerable underserved communities, in patterns that can often be observed from space. EJ community context, stakeholders, issues and drivers differ by region. The “Communiversity” model, advanced alongside the EEJ movement in the South, safeguards against a potentially extractive or exploitative process. By ensuring EJ communities are equal active participants in research and recognizing diverse knowledge contributions, university-based experts support presentation of environmental justice problems and policy solutions in a scientifically valid way.

Assessment of the Gulf Coast Environmental Justice Landscape for Equity (AGEJL-4-Equity) identified three objectives adapted for Southern coastal landscape analysis: 1. Advance Information – In first three-months, engage and capacitate four EEJ networks to map underserved EEJ stakeholder communities, EEJ priorities, ways of working, and knowledge of Earth science-based evidence to advance EEJ decision-making and action, to present as a network-level landscape analysis; 2. Advance Organizations -- Convene network representatives of underserved primarily, African American Gulf Coast communities, for a participatory workshop to compare and overlay EEJ network community mapping results, interrogate integrated geo-spatial, socio-economic and earth science data, highlighting NASA products and open source science resources, and explore existing and innovative ideas to address gaps in evidence to be addressed by current or planned NASA-related missions; 3. Advance Integration -- Synthesize learning in a comparative 20-page landscape analysis that leverages geolocation to map open Earth and social science integration to address evidence gaps and EJ community priorities; within 6-months, deliver a report that explicates barriers and opportunities unique to the Gulf Coast context and next steps to advance EJ organizations.

By leveraging existing networks and deep wells of located experiential expertise, AGEJL-4-Equity will have delivered a novel and comprehensive Landscape Analysis identifying gaps and opportunities for improved access and use of NASA open science products to advance EEJ in underserved communities along the Gulf Coast. Furthermore, NASA will have provided an example to the wider EEJ community of a validated engagement model that advances open Earth science capacities of EEJ networks and communities themselves.

Caitlin Mothes/Colorado State University
Leveraging Earth Science Data to Heighten Awareness of Environmental Injustices Within the U.S. Prison System
21-EEJ21-0001

Incarceration rates in the United States have increased 700% since 1970 and are the highest in the world, such that the U.S. constitutes 4% of the global human population but 25% of the world’s prisoners. This U.S. prison population is also made up of disproportionately poor people and people of color (3/5 of prisoners), and hence expands the current system of racial capitalism by exploiting unpaid or vastly underpaid (and oftentimes dangerous) labor to fund prison operations and generate revenue, while justifying it through claims of rehabilitation.

Within this system of inequitable incarceration and racial capitalism also lies many environmental injustices, as inmates have been forced to endure various environmental abuses. Documented burdens related to climate, air quality and toxic exposure have led to long-term and/or life-threatening illnesses and mortality, such as non-air-conditioned cells that reach 150 degrees Fahrenheit and nearby hazardous waste sites causing toxic air quality. While numerous cases of these environmental injustices towards prisoners have been exposed by journalists and activists, the examination of prisons as sites of environmental injustice is still understudied. Most prison facilities have not been scrutinized or evaluated for adverse environmental conditions and risks, likely given that prisoners are not often considered as environmental justice (EJ) communities, and these injustices are therefore commonly ignored by authorities. However, prisons are by definition EJ communities, as they are highly overrepresented by people of color, indigenous persons, and poor people, and recent work has highlighted that prisons are often subject to adverse environmental health threats, of which prisoners have no choice to endure.

This presents an opportunity to address these vital equity and environmental justice issues by leveraging NASA's Earth science data - including satellite, land cover, climate, and air quality datasets - in a novel way to characterize the environmental harms faced by prisoners across the U.S. The objectives of this proposal are to 1) quantify the environmental conditions at all state- and federally-operated prisons in the U.S. (n = 1,865) using NASA's various Earth science datasets and geospatial analysis, 2) calculate a standardized vulnerability index for each prison, developing a comparable metric of environmental risk faced by prisoners across the county, and 3) incorporate this information with our extensive dataset and mapping platform on prison agriculture, which includes specific agricultural activities and their drivers (i.e., benefits to the prison system) for over 600 state-run prisons.

The variables and methodology used to calculate the vulnerability index will be modeled after multiple established methods for measuring environmental risk. The method is based on averaging three component scores, namely climate risk (heat index, canopy cover, wildfire risk and flood hazard), environmental exposures (Ozone, PM 2.5, pesticide use, and traffic density) and environmental effects (proximity to superfund sites, nuclear power plants and hazardous waste sites). The final product of this project will be a GIS-enabled dataset with raw values and percentiles for each variable, averaged component scores, and a final environmental vulnerability index tied to all state and federal prisons in the U.S. As a geospatial dataset, it can be easily added to EJ mapping platforms (such as the EPA's EJScreen) and will highlight the spatially differentiated types and levels of risk faced by prisoners across the country. This dataset will be completely novel and allow for activists, researchers, policy makers, government agencies and beyond to become aware of and make informed decisions to mitigate environmental injustices faced by prisoners across the U.S.

Kevin Mueller/Cleveland State University

Improved Monitoring and Management of Urban Tree Equity: Integrating Metrics of Tree Quality with Tree Cover

21-EEJ21-0011

In the U.S., trees in cities provide ecosystem services valued at $18 billion dollars per year, but the urban forest in our nation is shrinking and stressed. This is evident in Cleveland, OH, where tree canopies are most sparse in the areas with residents who are most in need of the benefits trees provide. The canopy cover and ecosystem services in redlined neighborhoods with high poverty and pollution are often half or even a tenth of those in richer, whiter neighborhoods. Momentum is now building to reverse the decline of the urban forest and to enhance ‘tree equity’ in Cleveland and Cuyahoga County. The effort to regrow Cleveland’s urban forest is collaborative and coordinated by the Cleveland Tree Coalition. A primary goal of this coalition is to minimize socioeconomic and demographic disparities in tree equity by focusing efforts to maintain and expand the tree canopy in areas with unjustly lower tree cover and greater environmental burdens.

Currently, the Cleveland Tree Coalition relies on tree canopy cover data to map tree equity, and to make plans to minimize gaps in tree equity. Similar local and national efforts to map and mitigate tree equity are also based on canopy cover alone. But, the benefits provided by urban trees are a function of not only their quantity (i.e., canopy cover), but also their quality (e.g., the density and health of leaves in a canopy). Thus, in Cleveland and nationwide, current plans to mitigate tree equity are based on only half of the picture. We will work with community partners, including the Cleveland Tree Coalition, to demonstrate and optimize the ability of Landsat 8-derived vegetation indices and land surface temperatures to map, monitor, and mitigate ‘tree inequities’. We will use existing geospatial datasets managed by community partners to share the ability of common vegetation indices to explain spatial patterns of tree function and quality that are not represented in maps of tree canopy cover. This primary objective highlights the feasibility aspect of this project – do Landsat 8 products provide additional information that can be used to monitor and enhance tree equity in cities?

We will work with community partners to: i) evaluate the ability of Landsat 8 products to better characterize environmental injustice and assist in planning for improved tree equity; and ii) establish a workflow that provides sustainable delivery of Landsat 8 products and integrates these into existing, publicly available geodatabases. As part of our evaluation of satellite products, we will conduct ground surveys to quantify tree quality and function in select census blocks and greenspaces. This ground-truthing is designed to build our community partners’ confidence in, and understanding of, the relevance of Landsat 8 data to tree function and equity.

To further address historic inequities, we will provide field experiences and remote sensing workshops for members of a community outreach and workforce development program, the Holden Arboretum Tree Corps. This program was developed to increase accessibility of urban forestry and arboriculture to traditionally underserved community members. This activity promotes NASA ESD’s commitment to equity and environmental justice as aligned with increasing opportunities and accessibility of NASA science, applications and career opportunities. The science and applications proposed here directly respond to NASA’s interest in proposals that leverage NASA Earth-observing satellite measurements and derived geospatial products to further the ability of local governments and community-based non-profits to develop and implement programs and activities that advance environmental justice. Our approach will enable us to determine which Landsat 8 products best inform tree quality and function in urban settings, and to provide this information to further inform plans by our community partners to enhance tree equity.

Eileen Nalley/University of Hawaii, Honolulu
Understanding Contaminant Risk through Stories of ʻĀina (Relationships between People and Places) in Ke Awa Lau o Puʻuloa (Pearl Harbor)
21-EEJ21-0015

Understanding how pollutants move through ecosystems and accumulate is an essential component of managing healthy coastal ecosystems and communities. Different types of land use can result in the introduction of unique suites of toxins into the environment, which means that in the absence of comprehensive monitoring programs, knowing how land was used in the past is a critical element of anticipating risk at present. In Hawaii, Puuloa (Pearl Harbor) was once known for its numerous fishponds, calm waters, and abundant streams, but through time the land use in this area has shifted, causing changes not only to the landscape but also the health of the surrounding ecosystems and communities. Intensive agriculture (e.g., sugarcane), industrial development, military installations, and dense urbanization have all altered the ecosystems and introduced unique sets of contaminants into the environment. In this study we aim to understand how different types of land use have introduced contaminants into the ecosystem over time and whether these pollutants may be disproportionately affecting vulnerable communities.

To do this, we will aggregate and translate historic maps via georeferencing so that they can be used in ArcGIS to develop map layers of historic land use and analyze changes in land use over time in Puuloa. We will then use human health risk assessment methods to develop contaminant profiles based on the historic and current land use that represent the estimated and, when possible, measured contaminants in the area. Once the newly generated map layers are complete, we will integrate these contaminant profiles with socioeconomic data to evaluate the vulnerability of different communities in Puuloa, as has been done successfully in California with the CalEnviroScreen tool. Finally, we will use earth science data to evaluate how this vulnerability may shift with climate change impacts, such as sea level rise and flooding. Throughout the duration of the project, we will build capacity by training local students and community members in the use of the project products and other geospatial tools. Specifically, graduate and undergraduate research assistants with ties to Puuloa will be recruited to assist with this research project. We will also host a community workshop where participants are compensated for their contribution in providing feedback on the historic land use map layers, and at the end of the project, we will host a training workshop where students and community members can learn how to use the tools developed in this project, as well as other freely available geospatial data that may inform their future decision making and management.

This project directly addresses NASA's goals by integrating earth science, geospatial, and socioeconomic data to address specific needs expressed by communities who have been marginalized and disproportionately affected by environmental pollution. We are co-developing the project in partnership with community based nonprofits, and we represent a collaboration between the University of Hawaii and Leeward Community College, which is located in the heart of Puuloa. The individuals working on this project have direct ties to Puuloa, so rather than starting from scratch to build trust between researchers and community members, we are strengthening existing relationships. Finally, we are building capacity in the community by training students and community members to use the research products and other freely available geospatial data to answer questions in the future.

Mehdi Pourpeikari Heris/Hunter College
Developing an Interactive Data Portal for Connecting Vulnerable Communities to the Science of Urban Heat Mitigation
21-EEJ21-0016

Urban heat is a known problem that cities need to plan and prepare for its serious public health and energy consequences. Despite the extensive progress in the research and science of urban heat, its causes, its solutions, and its impacts on our vulnerable communities, local governments generally do not have established processes to incorporate this science into planning and policymaking. In partnership with two local governments and two community groups, this project aims to create a data portal to provide accessible information about existing urban heat conditions and their mitigation strategies to these decision-making stakeholders. One of the main gaps in facilitating this process is that urban heat data and science are complex and not easy to retrieve and interpret.

We will curate the urban heat knowledge to ensure planners in local governments, vulnerable communities, and advocacy groups can understand how to move toward a more heat resilient community through a participatory planning approach. We will test this idea in two cities: New York City, NY, and Jersey City, NJ. Despite strong connections and proximity, NYC and Jersey City represent two different data infrastructure and management levels. These cities will provide more insight into the potential use of our portal in other cities. Our tools will inform stakeholders in decision-making with estimates of impacts for tree planting and cool roof programs. Our project can illuminate the path for other communities to take similar approaches in developing infrastructure for climate knowledge dissemination.

We will develop new algorithms and data pipelines to automate key urban heat data products from earth observation data, weather stations, and socioeconomic variables to generate heat vulnerability maps. We will also develop core analytical models to connect heat vulnerability and heat mitigation strategies. Our research objectives include: (1) developing a data pipeline for automated production of the most recent and historical daytime surface temperatures, heat exposure, heat vulnerability, tree and vegetation cover, and surface albedo; (2) incorporating the mechanisms of urban heat-related decision-making processes of local governments in an interactive portal; (3) visualizing and communicating urban heat-related knowledge for the use of advocacy and community groups; and (4) developing guidelines for communicating and utilizing urban heat-related knowledge to local governments and community groups through story maps and other visualization methods. This guideline will be prepared with a vision that other cities and communities can adopt similar infrastructure and communication methods to connect academic groups, policymakers, and community groups.

This portal will offer innovative communication and visualization methods. For example, we will use techniques such as video and sound clips, story maps, interviews, maps, and charts to communicate science in an accessible way. The users will be able to see and download different formats of the existing and future urban heat conditions. Our target users will be advocacy groups and policymakers in local governments. Our partners are New York City's Mayor's Office of Climate and Environmental Justice, the City of Jersey City, and the "I love the Greenville" community coalition.

To collect the needs and insights of our users, we will work with our partners to hold focus groups and workshop sessions. The portal will be implemented by ESRI's ArcGIS Enterprise platform to deploy a single-machine architecture on a virtual machine hosted by Amazon Web Services. We will add a local computer for running most of the computational workflows to reduce the costs of cloud computation.

Narcisa Pricope/University of North Carolina, Wilmington
Green Infrastructure Solutions to Support Flood Mitigation and Adaptation in Coastal Low-Lying Disadvantaged Communities
21-EEJ21-0041

Coastal environments are essential ecosystems that play vital ecological roles and supply a wide array of ecosystem services, including flood control, especially in low-lying regions at the land-water interface. Coastal communities frequently impacted by natural hazards can face extensive and recurrent flood inundation and subsequent infrastructure damage with immediate and long-term detrimental effects on disadvantaged communities. Effective and adaptive coastal resiliency planning is becoming more necessary as the frequency and intensity of storms increase and coastal populations expand. Furthermore, climate change has disproportionate impacts on underserved and disadvantaged communities, with serious implications for equity and environmental justice. In this co-designed project, we will develop a green infrastructure suitability model in consultation with community groups to prioritize areas of implementation of nature-based solutions (NbSs) in a highly urbanized tidally influenced coastal county of the US Atlantic Coastal Plain region that is home to multiple disadvantaged communities at recurrent risk from flooding. Our project will develop a replicable methodology that establishes the evidence base for the effectiveness of NbSs in flood-vulnerable coastal watersheds and determines the feasibility of incorporating cutting-edge community engagement techniques into NbS implementation prioritization. We will accomplish our overarching goal through three main objectives:

1. Develop a cloud-computed, replicable remote sensing and GIS-based green infrastructure suitability index (GISI) methodology at the local scale in New Hanover County, North Carolina as a function of exposure to recurrent inundation and projected sea level rise and accounting for vegetation type and condition from time-series of remote sensing data.
2. Develop an environmental justice vulnerability index (at the block group level) using community-identified dimensions of environmental justice (EJ) with relevance to coastal planning for climate change (primarily flood mitigation) and adaptation measures and analyze the green infrastructure suitability index against it to identify areas of overlap between suitability for green infrastructure solutions and EJ communities that would most benefit from their implementation.
3. Use community engagement techniques (charrettes, surveys, focus groups, and/or community workshops) to elicit community input and feedback along four prioritization categories both during the development of the GISI and at the conclusion of the modeling efforts in order to prioritize solutions and produce implementation suggestions while engaging in community education on climate change impacts on EJ neighborhoods and green infrastructure as an adaptation strategy.

The outcomes of this project will include a community feasibility study proposing a reproducible and transferable methodology for identifying suitable NbS locations as a function of location, exposure to risk, socio-demographic makeup of the area and satellite remote sensing data on the one hand and, on the other, the perceptions, feedback and input of potentially targeted communities in terms of prioritization and education around possible implementation solutions. Green infrastructure/nature-based solutions enhance urban sustainability and address EJ issues through improving environmental conditions and human well-being, thus making urbanized areas more attractive and livable; restore degraded ecosystems and improve the resilience of ecosystems, especially wetlands and tidal marshes that deliver critical ecosystem services in low-lying areas; contribute to improved risk management and resilience planning by synergistically reducing multiple risks than grey infrastructure alone; and contribute to developing climate change adaptation and mitigation strategies that can be implemented in at risk EJ communities in coastal regions.

Amit Raysoni/University of Texas Rio Grande Valley
Integration of Satellite data on Air Pollution with Socioeconomic Indicators to Assess the Impacts of Agricultural Burning on Local Communities in the Lower Rio Grande Valley of South Texas
21-EEJ21-0061

This project will integrate: 1) air pollution NASA satellite data, 2) local ambient monitoring sites, 3) socio-economic indicators (Social Vulnerability Index), and 4) Local knowledges (Air Quality Perception scale) to characterize the PM2.5 trends due to agricultural burning in the Lower Rio Grande Valley Region of South Texas. This project will empower the air quality knowledge base of the local citizenry by providing them with access to a publicly available dashboard hosted by UTRGV. Agriculture is one of the important economic mainstays of this region; however, stubble burning is carried out almost entirely in the Valley on both sides of the international border. This results in elevated levels of particulate matter pollution with PM2.5 levels exceeding the USEPA's National Ambient Air Quality Standards (NAAQS), polycyclic compounds, black carbon, nitrogen dioxide, and methane. This project is based on the premise that high exposures to air pollutants is a matter of environmental injustice especially for this low-resourced majority minority region of the U.S.-Mexico border.

The Lower RGV includes Hidalgo, Cameron, Willacy, and Starr counties, and is home to 1,377,882 people (Census Bureau 2020). The area located at the southmost coastal tip of Texas, with its employment rate of 50.88%, and its median household income of $ 37,208 is a low-resourced majority-minority community comprising primarily of Hispanics/Latinos/as (over 90%). Region's rising population is accompanied with high economic activities and high environmental exposures due to traffic emissions, agricultural and trash burning, and high diesel emissions near the international ports of entries.

Texas Commission on Environmental Quality (TCEQ) operates one Central Ambient Monitoring Site (CAMS) each in Brownsville, Edinburg, Harlingen, Mission, and Port Isabel. Out of these only two CAMS sites regularly monitor PM2.5 and four monitor O3. These CAMS monitors are not an accurate representation of people's air pollution. Figures 1 and 2 display Environmental Justice (EJ) Mapper's output for EJ index for PM2.5 and National Air Toxics Assessment (NATA)'s Respiratory Health Index (HI) in the Lower RGV region.

Whereas this region is usually in compliance with the USEPA's NAAQS for criterial air pollutants except during fire events, it is important to increase the general awareness about the deleterious health impacts due to acute or chronic exposures to these pollutants.

This project, therefore, endeavors to utilize MODIS-Combined, VIIRS-NPP, ABI-GOES-East aerosol data in combination with PM2.5 data collected continuously from Purple Air Monitors that would be deployed at about 20 different locations in the Valley to accurately capture the pollutant trends, both temporally and spatially for a period of one year. This period will also capture the change in pollutant levels – especially from October to May – peak season for agricultural stubble burning. The air pollution datasets – both satellite as well as ground based- will then be combined with socio-economic indicators and Air Quality Perception scale to assess perceptions about air pollution issues facing this community. The socio-economic data are based on the Social Vulnerability Index (SVI) and its' four themes: socioeconomic status, household composition & disability, minority status & language, housing type & transportation (Flanagan, Hallisey, Adams, & Lavery 2018). Real time information pertaining to the air quality trends in tandem with the socioeconomic indicators and results of the Air Quality

Perception analysis will be available in a GIS-enabled dashboard operated by the University of Texas Rio Grande Valley.

This research work will address the existing gaps in air quality knowledge pertaining to this specific region of Texas and it is our firm belief that fundamental questions about environmental justice and equity are addressed by this research endeavor.

Jacelyn Rice-Boayue/University of North Carolina, Charlotte
Exploring Synergistic Opportunities Between Charlotte-Area Environmental Justice Initiatives and NASA Earth Science Information
21-EEJ21-0045

Communities are challenged with managing environmental, health, and quality of life issues for its members. Special consideration is also needed to address current inequities in environmental pollution exposure, which can be advanced through the lens of environmental justice (EJ). Empowering vulnerable communities to take action to ensure safer and healthier environments is a way to circumvent greater health disparities. To support this, community based participatory research (CBPR) is increasingly being used to heighten awareness of common problems and strengths, mobilize the setting of priorities and goals, and collaboratively develop strategies to achieve these goals. EJ issues require an understanding of community and neighborhood assets and problems at the micro-scale. As such, community groups often have access to their data sets and local knowledge that is frequently lacking in professional datasets. Public participation geographic information systems (PPGIS) refer to the way GIS technology can support public participation with the goal of inclusion and empowerment of marginalized populations. Access to spatial information has vastly increased due to the advent of several open source internet mapping technologies; however, government adoption of PPGIS for inclusion in environmental decision-support has lagged. Here we aim to conduct a gap analysis by setting the goal as future PPGIS to support current Charlotte EJ stakeholder initiatives. In agreement with the CBPR approach, we will partner with community and neighborhood entities at the onset. Stakeholders will include neighborhood organization leaders and city council leaders representing Charlotte neighborhoods at increased hazard for EJ-related issues, targeting those that have a 90% or higher EJ air toxics respiratory hazard index (provided by EPA’s EJ Screen), and formal NC EJ entities. Due to remaining effects of historic segregation and subsequent EJ landscape, this project will pose significant benefits to the larger Charlotte, NC community. The goal of the proposed work is to further our understanding for the potential of NASA datasets to advance Environmental Justice (EJ) initiatives local to Charlotte, NC. This central research goal will be accomplished through the following objectives: (1) identify and summarize opportunities for utilizing geospatial data science to advance understanding of environmental health concerns and inequities; (2) conduct a needs assessment workshop to elucidate the needs, priorities, and challenges of Charlotte EJ stakeholders; and (3) conduct a gap analysis to develop a strategy and recommendations for Charlotte EJ stakeholder’s use of NASA Earth Observation Data to advance current initiatives. The proposed work directly aligns with the aim of NASA’s

Earth Science Data Systems Program to advance progress on domestic equity and environmental justice by furthering the understanding of how Earthdata can be applied in Charlotte, NC, a city historically plagued by socio-economic disparities. This work will take place over the course of 9 months, and be led by Dr. Jacelyn Rice-Boayue (PI) and Dr. Laurie Garo (consultant). As an Assistant Professor at the University of North Carolina at Charlotte (UNCC), Dr. Rice-Boayue leads research to understand complexities in human-water systems, towards the protection of public and environmental health. She has served on the Mecklenburg Soil and Water Conservation District Advisory Board where she helped set policy initiatives and participated in community events. Dr. Garo is an UNCC Senior Lecturer Emeritus with over 25 years of experience in teaching, research and project work with GIS in the US, and 8 years of international teaching and research with remote sensing, GIS and cartography. She has developed a trauma vulnerability index to model risk for children's exposure to environmental toxins in a study on potential for brain development delays among infants and small children.

Karen Seto/Yale University
Earth Observations to Reduce Greenspace and Health Inequities: Applying Multi-Decadal and Multi-Scale Satellite Imagery to Characterize Tree Canopy and Heat Exposure to Improve Policymaking and Community Well-Being
21-EEJ21-0038

The relationship between tree canopy cover and urban heat is well established. So is the inverse relationship between tree canopy cover and household income levels. The increasing frequency and intensity of extreme heat events is both a physical and mental health hazard, especially for low-income and minority communities, who often have unequal access to both tree cover and ecosystem service benefits from canopy cover. Compounding the lack of access to lower tree cover, EJ communities are more likely to have lower health care access, higher rates of cardiovascular issues, and lower levels of air conditioning ownership, making them more vulnerable to heat stress. Urban tree cover provides many important health benefits including cooling, stress reduction, and reduced risk of psychiatric disorders in adulthood. Although increasing canopy cover can mitigate urban heat and simultaneously improve community well-being, urban land managers and policymakers have limited information on where to target and prioritize interventions that will have the largest impact on reducing heat exposure and improving health outcomes for EJ communities. This proposal aims to fill this knowledge gap.

The overarching goal of the project is to characterize and monitor urban heat and tree canopy cover to identify communities most at risk to increasing urban heat and those with low access to ecosystem benefits of canopy cover (cooling, physical and mental wellbeing). Using multi-decadal and multi-scale satellite data from MODIS, Landsat, USDA's National Aerial Imagery Program, Microsoft's database of building footprints, and socioeconomic information, we will map for both the state of Connecticut and the city of New Haven: 1) trends in urban heat; 2) trends in tree canopy cover; and 3) EJ community access to tree canopy cover and risks of exposure to urban heat.

For Connecticut, we have partnered with the Department of Energy and Environmental Protection (CTDEEP) who will use the results to implement state-wide policies regarding environmental justice, including prioritizing interventions for at-risk communities. CTDEEP's Environmental Justice Program is in the process of creating a series of publicly accessible maps of EJ communities throughout the state and will incorporate our findings into these maps. Project outputs will also help CTDEEP's Urban Forestry Program to identify communities for targeted urban forestry investment to mitigate urban heat and increase the wellness of EJ communities, especially mental and physical health.

For New Haven, we have partnered with the South Central Regional Council of Governments (SCRCOG) which is a platform for cross-city coordination, cooperation, and decision-making. SCRCOG will use the New Haven scale output for hazard mitigation planning. We also have a community-scale partner through the non-profit Urban Resources Initiative (URI), who is the contractor for New Haven's tree planting. URI will use the output to identify neighborhoods and communities most at greatest risk of UHI impacts to prioritize street tree planting.

Significance: This project has the potential to catalyze policymaking and action and ultimately improve community wellness and reduce health inequities for over 350,000 Connecticut residents who live in poverty, over 31,000 of whom are in New Haven. This project is a unique collaboration among academia, state and local government, and a non-profit organization. The project is designed to integrate cutting-edge remote sensing science into policymaking and action. At the same time, the project objectives are designed to respond to the most urgent needs of policymakers and practitioners. This co-designed project has a very high likelihood of success of up-take of remote sensing science by decision-makers to develop more targeted and proactive approaches to improve the health and wellness of EJ communities.

Ashish Sharma/University of Illinois, Urbana-Champaign
e-JUST — Environmental Justice Using Urban Scalable Toolkit
21-EEJ21-0006

U.S. cities are facing a growing challenge to the high intensity of extreme heat events and corresponding air quality issues. These environmental threats aggravate poverty, environmental degradation, adverse health outcomes, violence, and social stressors such as structural racism and injustice. To mitigate these threats in vulnerable urban neighborhoods, this project will build resilience for environmental justice (EJ) communities in the Chicago region. This project will recognize the needs of local stakeholders to address environmental and economic inequities within the Chicago region. Specifically, the project aims to achieve the following objectives.

Objective 1. Develop e-JUST architecture with capacity for scale and portability.
Objective 2. Co-identify extreme heat and air quality threats to health, equity, and crime.

Objective 3. Integrate health and equity-informed planning and decision-making in e-JUST.
Objective 4. Empowering communities with evidence-based measures to improve health equity and reduce crime.

This project is encouraged by the outcomes of the nationally award-winning 2021 Climate Action Plan for the Chicago Region. Our highly collaborative project team already works in the Chicago region on EJ issues and is well-positioned to contribute cutting-edge expertise in climate change, open-source GIS development, urban issues and resilience, public health, and regional planning. We will develop a web GIS-based "e-JUST — Environmental justice using urban scalable toolkit." e-JUST will provide a scalable and portable architecture for urban decision-support using multiple urban dimensions and geographies using NASA Earth science information and other complementary environmental and social datasets. Equity and environmental justice (EEJ) lenses will be central to our e-JUST architecture development, outreach, and education, as well as engagement with communities and practitioners.

Within the e-JUST project framework, we will develop a novel concept of regional climate atlas (RCA) with climatic balancing functions within e-JUST. RCA will maps thermal and air quality stress at the micro-local level through "climatopes" that identify areas with similar micro-climate characteristics. These novel developments in the open-source GIS framework will allow us to co-produce knowledge and empower underserved and EEJ communities, thus integrating health and equity focus into municipal planning and operation. The outcomes of this project will serve EEJ communities with the goal of adopting short-term no-cost solutions as well as strategic learning and preparing for long-term solutions to advance EEJ actions for the Chicago region. One of the key outcomes of our continued research and outreach efforts via our e-JUST project will be to establish trust in historically underinvested communities in developing effective communication strategies.

This project will fulfill the following NASA's Earth Science Division (ESD) goals for the EEJ program by (i) bridging barriers and gaps with opportunities for evidence-based measures to EEJ decisions, (ii) strengthening trust and partnerships with EJ communities via town halls and workshops, and (iii) using trans-disciplinary approaches to integrate physical and social science using NASA datasets. To increase workforce from minority institutions in the project and provide leadership examples from our own actions, we plan to recruit a Ph.D. student from Historically Black Colleges and Universities (HBCU) to work on this project. The project will also train two undergrad students in the summers. These efforts in STEM education will develop technical skills in big data as well as much-needed opportunities to obtain training working with EEJ communities at an undergraduate level.

Julie Silva/University of Maryland, College Park
Environmental Injustice and Deaths of Despair: Lessons from Montana's Tribal Lands

21-EEJ21-0050

‘Deaths of Despair’ – premature mortality caused by suicide, alcohol, and drug use – have steadily increased over the past twenty years among middle-aged White Americans without a college degree, a stark contrast to the declining mortality rates among Black and Hispanic Americans. However, Native Americans, a group which exhibits the highest premature mortality in the United States, remain excluded from most studies of declining life expectancy. The emerging consensus within the social science literature is that material poverty alone fails to account for the phenomenon and that other mechanisms must be unidentified. This is especially the case for Native American communities, where the challenges of economic hardship and social marginalization long predate declining American life expectancy. To date, limited attention has been paid to the role of environmental injustice and how it may exacerbate or add to the existing socio-economic challenges contributing to deaths of despair. The previous empirical literature suggests that environmental factors may have particular relevance for social distress in Native American communities whose struggles for environmental justice (EJ) have been extensively chronicled. The proposed project uses the case of Native American Lands in Montana to examine how experiences of environmental distress over time interacts with other socio-economic challenges on tribal lands.

The goals and expected outcomes of the proposed project fit perfectly with the solicitation of co-designed proposals that (1) use Earth science information to better understand and advance EJ in underserved American communities and (2) access the adequacy of existing data products to achieve that goal. Specifically, the research team will assess the feasibility of using EJ indicators derived from Earth observation data to inform analyses of premature mortality on tribal lands. Guided by the Double Exposure conceptual framework, the proposed project will investigate the dynamic interactions between environmental change and socio-economic conditions, in order to identify potential pathways whereby environmental hardship may contribute to (and result from) forms of socio-economic distress linked to deaths of despair. The project will address multiple NASA objectives with regards to EJ through extensive use of Earth observation data integrated with socio-economic information, theory-driven data analysis, state-of-the-art visualization methods, and collaborative efforts between social and Earth scientists at the University of Maryland and journalists affiliated with the American Communities Project (ACP) at Michigan State University. The research team will leverage ACP’s existing networks with tribal members and stakeholders on Native American reservations in Montana to address the user needs of a community that has confronted EJ challenges since the arrival of European colonists in the Americas. The main deliverables of the project will be an integrated, county-level dataset of socio-economic and Earth science information, EJ profiles for Native American Lands in Montana, and a conceptual model of pathways linking EJ issues to social distress and rising mortality. These products will be made available for public download through the ACP website (https://www.americancommunities.org/).

Genee Smith/Johns Hopkins University

Equity, Environmental Justice, and Extreme Heat: Leveraging Earth Observations to Strengthen Community Driven Climate Mitigation Strategies
21-EEJ21-0048

Extreme heat is a significant and growing health hazard. Poor and minority urban communities are disproportionately impacted by the effects of extreme heat, making this a significant environmental justice concern. While heat mitigation strategies often occur at the city-level, significant within-city spatial differences in heat exposure reveal that heat vulnerability in underserved and populations may not be adequately characterized, resulting in heat mitigation strategies that are insufficient to address community needs. In efforts to address this gap, many urban communities have begun to develop their own heat reduction strategies, but these can lack a strong scientific grounding for implementation and feasibility to reduce temperatures within a specific community setting. Collaboration between researchers and local communities is critical to effectively define, evaluate, and iterate heat mitigation strategies to be feasible, effective, and transferrable to other neighborhoods. This proposal builds upon existing partnerships between Johns Hopkins University research scientists and neighboring communities and leverages already proposed community driven strategies for heat mitigation, ongoing collaborative data collection, and existing remote Earth Observation data to inform heat mitigation planning with neighborhood-scale resolution in Baltimore city. We will begin by generating a prioritized set of proposed strategies that are driven by community stakeholders. In partnership with the community, we will collect and integrate in situ data with remote Earth Observations to generate high resolution maps of temperature and heat index at daily time scale. To ensure the development of equitable and environmentally just heat maps, we will further integrate these high-resolution temperature maps with census block level demographic and socioeconomic data, informed by vulnerability metrics aligned with the primary concerns of community members and produce time varying heat vulnerability indices. Additionally, we will estimate the heat reduction effectiveness of proposed community strategies to mitigate local heat conditions. The proposed project will result in a retrospective tool that can be used to discuss spatio-temporal variability in heat risk and integrate risk over time in six Baltimore City neighborhoods. Working through an equity lens, this collaborative project will result in scientifically sound and environmentally just strategies for heat mitigation which can be adapted by urban communities across the US.

Michelle Stuhlmacher/De Paul University
Designing for Just Green Enough: A Data Integration Tool for Informing Community Green Space Planning
21-EEJ21-0012

Our data integration project will expand the capabilities of ChiVes—an open source geospatial web dashboard prototype—in order to advance green space and environmental remediation initiatives in environmental justice (EJ) communities like Pilsen. Pilsen is a neighborhood in Chicago that is underserved by green space and overburdened by environmental toxins. The community is concerned, however, that greening Pilsen will increase the desirability of the neighborhood and trigger further gentrification and displacement. In Pilsen and around the United States, EJ communities are confronted with the paradox of how to improve environmental conditions in their community without displacing the very people the improvements are intended to benefit. Our work is framed in the "just green enough" approach, which posits that real environmental improvements can be realized in a community while keeping the risk of gentrification low if the improvements are driven by the needs and values of the community (as opposed to what is valuable to outside real estate developers). In this extension of ChiVes, we will integrate a wide variety of new Earth Observation (EO), environmental, and social indicators driven by community input. In addition to collating and standardizing variables of interest to the community, we will add functionality that allows users to combine and weigh indicators to create customized indices that reflect their values. Our goal is that community members in Pilsen, and similar EJ communities, have the information they need to make data-driven decisions about green space and greening efforts corresponding to their values.

The proposed work builds on a seventeen year partnership with community members and leaders in Pilsen to advance affordable housing, equity, and inclusion in the city's decision-making processes. Initial partnerships were formed in 2004 with the grassroots organization, the Pilsen Alliance. The former executive director of the Pilsen Alliance is now the Alderman for the 25th ward (the ward in which Pilsen is located) and our main partner for this project. This tool will contribute to several ongoing projects in the neighborhood. First, one of the largest vacant lots in Pilsen was recently acquired by the City of Chicago for the development of affordable housing. With community support, the development of this lot presents an opportunity to provide greater green space in Pilsen, and our proposed tool can be used to ensure that the community has the information they need to advocate that their values are reflected in the design. Second, local leaders are in conversations with the Environmental Protection Agency (EPA) about air pollution from current industrial sites as well as remediation of Superfund sites in the neighborhood. Our proposed user-driven tool will complement these conversations, helping to identify areas of highest priority for the community. While we will work with community members to fine tune the tool to their needs, ChiVes is an open-source, city-wide platform that can be used by community groups throughout the city and ultimately be adapted to other US communities. Over 50% of the data that will be integrated into the dashboard is international or national, allowing the core of the tool to be transferred to a variety of contexts and then customized to fit the needs of the new context.

Christopher Tessum/University of Illinois, Urbana-Champaign
An Observation-Driven Framework for Air Pollution Equity and Justice Intervention Modeling
21-EEJ21-0019

From highways to industry, construction to residential energy use, Black people and other people of color in America are disproportionately affected by nearly every major source of air pollution. This exposure shortens life expectancy, increases incidence of disease, and compounds historic injustices and economic disadvantage. As the U.S. energy, industrial, and transportation systems evolve, communities need access to air quality information to participate fully in decision-processes and advance equitable solutions.

The only existing tool to support scalable community-level pollution attribution and future-oriented decision-making is the Intervention Model for Air Pollution (InMAP), developed by P.I. Tessum and colleagues. However, three major factors limit the utility of InMAP for equity and environmental justice (EEJ) analysis: 1) Model biases limit its value at the city scale; 2) Outdated emission inventories limit its relevance to immediate EEJ concerns; and 3) No web-based interface exists for U.S. cities to support non-technical users. With support from the NASA Applied Sciences program, our team will use satellite data and satellite-derived data products to correct these issues. In doing so, we will create a new platform that combines the causal nature of InMAP with the accuracy of NASA satellite observations—Satellite-enabled InMAP (SenMAP).

We will use the new SenMAP platform to develop, test, and demonstrate sustained use of a web-based, GIS-enabled EEJ assessment tool. This new decision-support tool will provide near-surface annual PM2.5 data for the continental U.S., with high resolution in population centers (up to 1 km x 1 km), attribution to sources, and support for easy decision analysis. This data integration project advances through partnerships with the American Lung Association, the Respiratory Health Association (of Illinois), and the City of Milwaukee Health Department and the City of Madison Mayor's office (both in Wisconsin). Through the three phases of the project we will: 1) Apply InMAP and satellite data to the short-term decision needs of our partners, growing our understanding of their priorities, needs, and data use; 2) Develop the web-based SenMAP platform, informed by our partners' experiences and feedback; 3) Expand the utility of SenMAP through webinars, case studies, how-to guides, and a discussion board to support a sustained user community.

SenMAP will leverage InMAP's ability to simulate relationships between (changes in) emissions and (changes in) the resulting PM2.5 concentrations, human health effects, and environmental injustice, while incorporating the up-to-date, observationally constrained strengths of Earth observations. To update NOx emission inventories we will nitrogen dioxide (NO2) from the Ozone Monitoring Instrument (OMI) and Tropospheric Ozone Monitoring Instrument (TROPOMI). To correct InMAP biases in urban areas, we will incorporate satellite-derived speciated fine particulate matter (PM2.5) estimates from the Washington University North American Regional Estimates (V4.NA.03). This approach uses the best available data today, and builds an adaptable framework to benefit from NO2 and SO2 observations from the Tropospheric Emissions: Monitoring Pollution (TEMPO) mission and speciated PM2.5 from Multi-Angle Imager for Aerosols (MAIA) in future years.

This proposal directly responds to topic 3 of the Request for Proposals—Data Integration Projects—in that it is community oriented and provides scalable assessments with integrated socioeconomic data. Our project team includes academic scientists and EEJ-oriented policy organizations at the local, state, and national levels, and we will use standard data formats and protocols and generate extensive documentation to facilitate the reuse and extension of our data and approach.

Joseph Wilkins/Howard University, Inc.
Assessment of Wildland Fire-Related Environmental Exposure Issues Impacting Vulnerable Populations in California
21-EEJ21-0066

Many Federal agencies such as NASA and the Environmental Protection Agency have made a stark commitment to Equity and Environmental Justice (EEJ) national challenges and have been purposely collecting data related to informing longer-term EEJ efforts. One of the major target areas of the Federal EJ 2020 plan is to place emphasis on communities with poor air quality and low-income populations. Low-income populations are among those most at-risk to adverse health effects as they may experience disproportionately high exposures and may have limited adaptive capacity. As wildfire frequency and severity has increased in California and other fire-prone regions around the world over the past several decades. This trend is projected to continue with future climate change. The second phase of the EJ 2020 plan states that there is a need to explore potential development of additional national EJ measures and associated strategies. One of those strategies is to understand extreme climate related events. Wildfire emissions contribute to increases in particulate matter with a diameter equal to or less than 2.5 micrometers (smoke PM2.5), which has previous been linked to numerous adverse morbidity outcomes and mortality. Compared to PM2.5 from urban sources, smoke PM2.5 has been found to have a greater negative impact on human health as it is more prone to large spikes in concentrations, potentially more toxic chemical compositions, and smaller particle size. Communities located in the rural versus the urban wildland-urban interface (WUI) may be particularly vulnerable to smoke PM2.5 exposures due to their close proximity to fire sources, but there is limited research on health outcomes in these specific communities. In addition, while communities in the WUI may benefit from land management activities such as prescribed burning that reduce future catastrophic wildfire risk, this may simultaneously add a new exposure category if frequent, low-intensity prescribed burning strategies are implemented. This proposed study will examine smoke PM2.5 exposures in the WUI via a spatial community vulnerability index. Our study will integrate Earth science information and socioeconomic datasets to inform climate vulnerability assessments for environmental justice communities across the State of California building on the efforts of the transdisciplinary team Science for Nature and People Partnership (SNAPP). In this study, we propose integrating Earth science information and socioeconomic datasets to inform vulnerability assessments for environmental justice communities. At current, there is a lack of scientific data on the specific smoke PM2.5-related vulnerabilities for communities located at the WUI. Thus, the aims for our research are two-fold: (1) map a decadal distribution of exposures to smoke PM2.5 in California’s WUI areas, and (2) assess vulnerability characteristics and health implications due to these exposures.

Ann Marie Wolf/Sonora Environmental Research Institute Inc
GPM, IMERG Precipitation Estimate in an Arid, Environmental Justice Area of Tucson, Arizona, USA
21-EEJ21-0014

Economically disadvantaged communities are disproportionately affected by environmental problems such as pollution, water scarcity, and rising temperatures. The Sonora Environmental Research Institute, Inc. (SERI) is an environmental justice organization that has been working in Tucson, Arizona and the Arizona-Mexico border region since 1994. SERI's environmental justice projects include a low income rainwater harvesting program; evaluation of the safety of harvested rainwater, and tree planting in economically disadvantaged Tucson communities.

To guide its environmental justice research, SERI needs high resolution precipitation data. For example, SERI staff use the annual precipitation rate to calculate the correct cistern size for a rainwater harvesting system. Precipitation data also help inform the selection of drought resistant tree species for the SERI tree planting programs. Direct measurement of precipitation with rain gauges is costly, and provides only site specific information. Indirect precipitation measurement from satellites such as Global Precipitation Measurement (GPM) sensors provides consistent information over larger areas

SERI proposes downscaling GPM products such as Integrated Multi-satellitE Retrievals for GPM (IMERG) to obtain higher resolution precipitation data for an environmental justice community in Tucson. SERI will use 1 km, Moderate Resolution Imaging Spectroradiometer (MODIS), Normalized Difference Vegetation Index (NDVI) data, and linear regression and geographically weighted regression to downscale the satellite data. SERI will also ordinary kriging. ordinary kriging of the residuals, and inverse-distance weighting to create a raster surface of the rain gauge data. The proposed 45 square km, environmental justice study area has a high poverty rate and a low percentage of green space. To access the unscaled and scaled validation measures of bias, precision, and accuracy of satellite measurements, SERI will deploy a network of approximately 160 rain gauges operated by citizen scientists who live within the study area. Many of the citizen scientists will be low income and Spanish speaking, a demographic that is difficult to reach with conventional outreach campaigns.

Danielle Wood/Massachusetts Institute of Technology
Applying the EVDT Integrated Modeling Framework for Environmental Justice Applications
21-EEJ21-0029

In recent years, researchers and journalists have highlighted a pattern of prison landscapes being exposed to environmental hazards such as air pollution, poor water quality, proximity to hazardous waste facilities, and inadequate mitigation in the face of extreme weather conditions - a pattern frequently referred to as “prison ecology”. Community organizers, lawyers and other environmental justice activists have needs for empirical evidence of the environmental injustices occurring in and around prison landscapes in order to advocate for the rights of incarcerated peoples to live in conditions that are free of life-threatening conditions. Geospatial data combined with sociodemographic information about prison populations can elucidate spatial patterns of vulnerability to environmental hazards and support decision-making workflows to advance equity and environmental justice (EEJ) in these underserved landscapes with over representation by low-income people of color. To this end, this project pursues an objective to co-design and prototype an operational geographic information system that responds to data needs in decision-making workflows for prison ecology activist organizations. This objective is part of an ongoing partnership between MIT and community-based organizers affiliated with the Campaign to Fight Toxic Prisons (CFTP) which is a national collective of environmental justice organizers, formerly and currently incarcerated people and their loved ones, organizing resistance at the intersection of incarceration and environment. Preliminary landscape analyses have identified several EEJ decision-making geospatial data needs from the perspective of the CFTP. Geospatial data can support immediate efforts to improve the material conditions of incarcerated people or longer term efforts to affect policy and governance of controversial prison projects in toxic landscapes. The project applies peer-reviewed remote sensing methods using data from a suite of sources such as Landsat, SEDAC, Sentinel 1/2/5 for monitoring of disasters and other ecological forecasting relevant to EEJ. The Geographic Information System (GIS) visualizing these analyses will be prototyped by Blue Raster, a firm that specializes in designing interactive web mapping applications. The Space Enabled Research Group led by Professor Danielle Wood has experience applying remote sensing to study invasive plant species, flood inundation, air pollution, deforestation and other ecological forecasting applications. PI Wood is well prepared to coordinate with the needs of end users based on experience as the Applied Sciences Manager at Goddard Space Flight Center and based on over a decade of research studying the application of space for development. Collaborator Professor David Pellow is a sociologist and top EJ scholar with academic expertise on environmental racism and prison ecology, among other topics. PI Wood's technical expertise, combined with the leadership and knowledge from CFTP and Professor Pellow of EEJ needs in the prison ecology space, and the web design expertise from Blue Raster, make our team well situated to perform the proposed research. This research, including thesis work by graduate student Ufuoma Ovienmhada, will be the first comprehensive national study of prison ecology using measurements from satellites and will elevate an issue that has been relatively invisible in broader environmentalism movements. The outcomes of this project will enhance the capability of prison environmental justice activists to apply satellite remote sensing data to support community management to advance EEJ for underserved populations in prison landscapes. In the government domain, the research will consider how remote sensing could improve screening tools or legal processes to prevent prison ecology issues. In the public domain, the research will consider how remote sensing could inform strategy to support real-time grassroots organizing for just outcomes.

Hua Zhang/Texas A&M University - Corpus Christi
Toward Environmentally and Socially Equitable Stormwater Management Fees: The Case of Corpus Christi in Texas
21-EEJ21-0005

To address water quality and environmental issues, a growing number of communities across the United States have levied a separate utility fee particularly for the impact of surface water runoff to provide a dedicated funding source for local stormwater management. Stormwater runoff arises from precipitation like rain or snowmelt that flows over land or impervious surfaces, such as building rooftops and driveways. In the context of environmental and social equity, the objective of this project is to explore the technical and economic feasibility to design or modify a local stormwater utility fee (SUF) program from satellite data. Analyses are drawn from comparisons of individual land parcels and different neighborhoods in Corpus Christi, a mid-sized city in Texas. The city began levying a Storm Water Utility Fee in 2022. Instead of an actual measure of impervious area, the scheme applies the same water runoff factor for all single-family homeowners of comparable land property sizes.

There is no consistent guideline on how impervious areas are estimated for the collection of stormwater fees. Existing methods either lack spatial heterogeneity or are prohibitively costly, and there is little attention to satellite data even though they are increasingly accessible with improved spatial resolution. To fill this gap, this project brings together a cross-disciplinary team to integrate Earth science, geospatial, and socioeconomic information to advance analyses in satellite-derived impervious area assessment in the context of environmental and social equity. This community-based feasibility study begins with the development of a cost-effective method for estimating impervious coverage of individual land parcels. Using deep learning models, parcel-scale imperviousness is estimated from multi-resolution geospatial datasets, including the Global Man-made Impervious Surface (GMIS) dataset, the NLCD percent imperviousness dataset, PlanetScope microsatellite imagery, LiDAR point cloud, and high-resolution aerial imagery.

The project consists of three interlinked components: geospatial analysis, equity assessment, and community decision support. In the context of environmental equity, the data allow us to investigate three research questions: 1) Can satellite data provide a cost-effective method to estimate parcel-scale imperviousness? 2) What is the extent of deviations from the assumed 50% impervious surface coverage across individual residential properties in Corpus Christi? 3) Do spatial patterns across neighborhoods of varying socioeconomic statuses exist in the observed measurement gaps?
The social equity objective of this project will be achieved by addressing three research questions: 1) Does Corpus Christi’s Storm Water Utility Fee structure adequately reflect the environmental impacts of properties across different socioeconomic groups, especially the underserved neighborhoods? 2) Is the stormwater fee structure socially equitable in the context of its economic burden on different communities, especially low-income and minority neighborhoods? 3) What are the limitations of applying solely

environmental and social equity criteria in the design of stormwater utility fees? The findings will help advance the design of a more socially equitable stormwater fee program under an evaluation framework that also includes other criteria, including operational and economic efficiency, political and administrative feasibility, and sustainability in providing a reliable revenue source.

The feasibility study contributes to the state of knowledge in environmental and social equity through the application of remote-sensing data and methods. Corpus Christi is a Gulf Coast city with a diverse population that is vulnerable to severe coastal and inland flooding. Beyond engaging local community stakeholders, the methodology and findings bear broad implications for the design of more equitable stormwater fee programs across communities nationwide.

NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH21ZDA001N-S2SHYD
A.50 Subseasonal-to-Seasonal Hydrometeorological Prediction
Abstracts of Selected Proposals

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC has selected proposals for the ROSES 2021 Element A.50: Subseasonal-to-Seasonal Hydrometeorological Prediction in support of the NASA Earth Science Division (ESD) Research and Analysis Program. The solicitation seeks advanced research and development investigations that exploit NASA and other agency satellite observations, as well as modeling resources that may lead to increased understanding of Earth system predictability and increased predictive skill of hydrometeorological processes and quantities at subseasonal-to-seasonal (S2S) time scales. More specifically, this program element seeks projects that may improve (a) hydrological S2S prediction/predictability for land surface variables such as soil moisture, groundwater, evapotranspiration, surface runoff/river discharge, and snowpack, or (b) the understanding the role of hydrology in S2S prediction/predictability, such as how initialization of soil moisture, groundwater and/or snowpack leads to improved S2S prediction.

The NASA ESD has selected 13 out of a total of 57 proposals for the funding of $8.9M over three years. The projects selected through this solicitation include those that seek to quantify and understand the predictive skills of land surface hydrology, characterize impacts of land surface hydrological properties on prediction, improve hydrological models for use at S2S time scales, predict extreme events at S2S time scales, and assimilate hydrological variables into coupled modeling systems.

Eunsang Cho/University of Maryland, College Park
Groundwater Impact on S2S Snowmelt Flood Predictability
21-S2SHYD-21-0055

Catastrophic snowmelt floods routinely impact local and regional communities across the U.S. The 2019 midwestern spring floods on the Missouri and Upper Mississippi Rivers, caused by rapid snowmelt and persistent rainfall combined with saturated antecedent ground conditions, affected nearly 14 million people and caused $20 billion in damage. The 2017 Oroville dam crisis in California, which had at least $1 billion of damages, was exacerbated by early snowmelt combined with large rain-on-snow events. Decision-making in the vulnerable communities begin several weeks to months (S2S timescales) in advance of potentially disruptive conditions to minimize socioeconomic damages, save lives and properties, and maximize the efficacy of limited resources. Despite the anticipated benefits of improving the S2S predictive skills of snowmelt floods, limited advancements have been made. Accurate flood forecasts are challenged by the complex mechanism of snow-driven flooding including the partitioning of meltwaters into infiltration and runoff which is very much dependent on the antecedent soil water state.

The premise of this proposal is that better accounting for winter groundwater and antecedent soil moisture within the water balance will improve subsequent spring snowmelt flooding predictions, with consequent benefits for society in snow-dominant regions through the enhanced capability of these S2S flood predictions. The overarching goal of our project is (1) to improve the physical understanding of the groundwater impact on snow-driven streamflow and flood events and (2) to enhance the predictive skill of snowmelt floods on S2S timescales using ground- and satellite observations (GRACE, GRACE-FO, and SMAP), retrospective land surface modeling, and data assimilation techniques.

The proposed effort aims to achieve the goals with three main tasks:
1. Quantify spatiotemporal changes in groundwater and soil water storage and its impacts on partitioning of melted water into streamflow with S2S lead times (2 – 6 weeks or more) using ground- and satellite observations
2. Identify the role of antecedent groundwater and soil moisture conditions in the snowmelt flood generation mechanism using observational and modeling approach, with a focus on historical snowmelt flood events in an S2S prediction context
3. Implement data assimilation of groundwater and total water storage observations into a retrospective land surface model to enhance the large-scale snowmelt flood predictability at S2S timescales

The proposed work will unravel one of the crucial issues “groundwater impact” that currently hampers S2S snowmelt flood predictability. The output of the work will provide critical information about how much the uncertainties related to groundwater can be reduced in snowmelt prediction. In addition to the scientific advances, this work would also advance the state of practice for current operational efforts (such as the NWS National Water Model which implements the Noah-MP as a core-component to represent land surface hydrologic processes). Subsequently, the proposed work will contribute to increasing the benefits of the S2S flood predictability: effective snowmelt flood risk management strategies, lowering the costs of flood emergency management, and sub-optimal water management decisions for state and federal governments and communities.

The project team has sufficient capacity to accomplish the proposed research goals with combined expertise of snow hydrology, GRACE and SMAP mission data sets, process-based hydrological modeling, and NASA LDT/LIS system. The proposed work is directly relevant to NASA Earth Science Division goals and NASA’s S2S Hydrometeorological Prediction Program objectives by improving our understanding of the physical processes involved in land hydrometeorological prediction as well as by enhancing the predictability of hydrometeorological extremes at S2S timescales.

Robert Emberson/University of Maryland Baltimore County
Spatiotemporal Analysis of Extreme Event Characteristics Using S2S Forecasts to Inform Hydrometeorological Hazard Assessment

21-S2SHYD-21-0021

Extreme rainfall is a critical precursor to a range of natural and anthropogenic hazards around the world, ranging from flooding, damage to crops, soil erosion, and rainfall-triggered landsliding. The intensity and duration of intense precipitation is of primary importance in determining the impact of such hazards. However, in many cases by the time information on storm characteristics reaches disaster response decision makers the damage has already occurred. As a result hazard forecasting remains a significant challenge. Disaster preparedness would significantly benefit from seasonal or sub seasonal forecast estimates of the likely probability and extent of extreme rainfall so that disaster response resources can be distributed in advance across the areas likely to be affected.

The incidence of flooding has been linked to in several settings around the world, and recent work by our team has linked the incidence of intense rainfall likely to trigger landsliding to El Nino globally. However, a more general model of the connections between seasonal teleconnections and extreme rainfall is still an outstanding research question for advancing hazard forecasting. In particular, the Goddard Earth Observing System subseasonal-to-seasonal (GEOS-S2S) forecast models have not been exploited to analyse the incidence of extreme rainfall at a global scale. Absolute values for extreme rainfall remains challenging to forecast with S2S products over longer timeframes, and this represents a significant knowledge gap. This proposed project will assess three key outstanding research questions, utilizing GEOS-S2S products and developing scientific understanding of extreme rainfall in forecast products.

First, we will compare the statistical characteristics of extreme rainfall events derived from the GPM IMERG v07 dataset with the forecasted rainfall derived from GEOS-S2S. In particular, we will conduct an intercomparison using a rainfall normalization approach, since this technique has been recently demonstrated to be essential for comparison of extreme rainfall between IMERG, MSWEP, and GSMAP. This analysis will test the extent to which the forecast skill of GEOS seasonal precipitation forecast can replicate the characteristics of extreme rainfall events. We will explore whether statistical methods can be used to extract information from the various ensemble GEOS-S2S retrospective forecasts (hindcasts) that can be used to approximate the frequency, intensity, and duration of extreme rainfall observations.

Secondly we will explore the degree to which extreme rainfall events are influenced by critical atmospheric teleconnections. This will build upon our previous work focusing on ENSO, but expand the scope to include other teleconnections (Madden-Julian Oscillation, North Atlantic Oscillation). Recent work has demonstrated the use of teleconnection indices to improve seasonal rainfall predictions, and we will exploit these novel developments in conducting our investigation. Using S2S reforecast data, we will determine if the accuracy of S2S forecast extreme precipitation varies depending on large scale teleconnections that lead to hydro-meteorological hazards. This will establish whether there is variability in forecast accuracy between normal conditions and when teleconnection indices are most extreme.

Finally, we will assess the implications for key hydro-meteorological hazards of S2S rainfall forecasts and the skill of those predictions. This analysis will establish the key locations globally where S2S data can be most effectively be used to predict extreme rainfall, and establish which hazards are most relevant in these settings. This will provide a framework for future applications of S2S forecast extreme rainfall to inform hydro-meteorological hazards around the world and inform stakeholder preparations for hazardous upcoming seasons. We will also provide feedback to S2S modelers to support future improvements to model development.

Manuela Girotto/University of California, Berkeley
Hydrological Predictability and Prediction Skill Associated with Agricultural Practices
21-S2SHYD-21-0006

Problem Statement: Soil Moisture dynamics contribute to the accuracy of sub-seasonal to seasonal forecasts. While natural processes driving soil moisture dynamics (such as precipitation-induced soil wetting) are included in global atmospheric circulation models, anthropogenic processes (such as irrigated agriculture) are rarely modeled. The impact of irrigation on soil moisture variability and soil evaporation depends on the irrigation technique. Innovations in irrigation infrastructure have allowed humanity to utilize previously inaccessible water resources, irrigation techniques, and planting practices to enhance agricultural productivity, often converting rain-fed croplands to irrigated lands. While agricultural intensification is a promising approach to meet the increasing food needs of humanity, it is still unclear to what extent the expansion of irrigated areas, and the related agricultural practices will affect the local, regional, and global climates via teleconnections across temporal scales.

Hypotheses: Our primary hypothesis is that an improved representation of land atmosphere dynamics can be accomplished if irrigation processes are explicitly coupled within current state-of-the-art Earth Modeling Systems. Specifically, we hypothesize: H1) The explicit representation of agricultural practices allows for improved forecasts skill of the NASA sub-seasonal and seasonal models. H2) Through land-atmosphere feedback, agricultural practices may alter the local precipitation regime at the sub-seasonal and seasonal timescale, thereby locally changing the irrigation water needs and availability with the potential to reshape the distribution and extent of areas suitable for irrigation. This feedback may involve teleconnections between irrigation in one region and hydroclimatic conditions in another region.

Approach: To assess predictability and influence of irrigation practices, we propose to use both observations and model analyses. We will introduce an irrigation scheme in the existing GEOS Subseasonal to Seasonal (GEOS-S2S) modeling frameworks. By introducing the anthropogenic influence on the boundary layer regulating land-atmosphere feedback, we aim on improving S2S forecasts skill. We propose to analyze variables that might be influenced by irrigation practices (e.g., land surface temperature, soil moisture, evapotranspiration, and precipitation) and are readily available from satellite derived products. We will also carry out regional teleconnections assessment of forecast predictability due to the inclusion of agricultural practices. This will be done using statistical decomposition analysis on the ensemble of produced hindcasts. Relevance: Our project primarily addresses the S2SHYD theme of “Investigations into quantifying and improving predictive skill for S2S hydrologic prediction”. We will investigate predictability and GEOS-S2S forecast skill improvements leveraging NASA assets (e.g., satellite, reanalysis datasets, modeling efforts). The proposed scientific investigation allows to answer one of the key societal and scientific questions also identified by the recent Decadal Survey: “How do anthropogenic changes in land use, water use […] interact and modify the water and energy cycle locally, regionally, and globally and what are the consequences” on a S2S-time frame?

Uniqueness: Our research team is particularly suitable to execute the proposed research because of our expertise in water resources and agricultural practices (co-I D’Odorico), the hydrology, and the modeling of GEOS land surface hydrology (PI Girotto and Collaborator Koster), the GEOS-S2S forecast system (Collaborator Molod and PI Girotto), teleconnections and the land-ocean-atmosphere interactions (co-I Fung).

Peter Hitchcock/Cornell University
S2S Predictability of Hydrometeorological Parameters Following Sudden Stratospheric Warmings
21-S2SHYD-21-0047

Useful forecasts of hydrometeorological quantities on subseasonal timescales are most likely to arise during 'forecasts of opportunities': periods during which the climate system is in a persistently and predictably anomalous state. Sudden stratospheric warmings (SSWs) feature the rapid breakdown of the winter-hemisphere stratospheric polar vortex, after which anomalies in the stratosphere can persist for many weeks. Due to the influence of these stratospheric anomalies on the troposphere, SSWs are a potential cause of such forecasts of opportunities. In particular, periods following SSWs are associated with a persistent equatorward shift of the North Atlantic storm track. These circulation anomalies are likely to lead to significant precipitation anomalies; for instance, increased precipitation over Europe's Mediterranean coast has been noted by numerous studies. Recent work from the group of PI Hitchcock suggests the potential for additional signals over the west coast of North America. However, few studies have confirmed these signals in observations, and little is known about their impacts on hydrometeorological quantities such as soil moisture, snowpack, or streamflow. Especially over the Western U.S., where the moisture state of the land surface during winter and spring is an important predictor of the availability of water in the summer, even small and intermittent improvements in S2S skill are of great societal value. We propose to investigate the S2S predictability of these hydrometeorological quantities following SSWs. This will involve three efforts.

Firstly, we will analyze the response in NASA satellite observations, including TRMM/GPM measurements of precipitation, SMAP/AMSR-E/Aquarius retrievals of soil moisture, and Terra/MODIS observations of snow cover and snowpack. Where possible we will use merged datasets extending back to 2000 to identify any stratospheric signals; the record includes 14 SSWs. On this basis we will assess the reliability of longer-term reconstructions from several modern reanalysis products.

Secondly, we will exploit a new database of S2S forecasts generated by the SNAPSI project, led by PI Hitchcock. Targeting three recent stratospheric events, this model intercomparison project will produce ensemble forecasts from 11 S2S models with a more complete set of output data than is available from existing SubX and S2S databases. The experimental design includes a nudging component that has successfully isolated SSW responses in previous studies. The database will enable us to identify determinants of subseasonal skill in these case studies.

Thirdly we will carry out new S2S experiments using the GEOS-S2S forecast system. This will allow us to explicitly test hypothesized mechanisms and evaluate the skill of the GEOS-S2S model relative to other S2S models.

The work proposed here will exploit NASA satellite observations to make novel and substantial contributions to our understanding of the potential skill in subseasonal forecasts of precipitation, snowpack and soil moisture arising from SSWs. The use of a multi-model database of S2S forecasts, validated by recent and novel observations from NASA satellites will allow us to quantify the mechanisms underlying this skill and identify processes that lead to predictability in land surface variables. Finally the use of targeted experiments with GEOS-S2S will allow us to verify, evaluate, and validate these mechanisms in the NASA subseasonal modeling system. The project team is uniquely positioned to successfully carry out this research, combining expertise on atmospheric dynamics, hydrometeorology and subseasonal prediction. The project will benefit the scientific community through a better understanding of how forecasts of opportunities from SSW events cascade into land surface variables, and the general public by describing pathways by which these forecast opportunities can result in actionable information on subseasonal time scales.

Randal Koster/NASA Goddard Space Flight Center
Improved Hydrometeorological Prediction in an S2S System Through Improved Treatments of Evapotranspiration, Runoff, and Carbon Cycle Processes
21-S2SHYD-21-0018

This work will have two separate research focuses, both aimed at improving the forecast accuracy of hydrological variables in a full S2S forecast system:

(1) To a large extent, the land surface models utilized in S2S prediction systems can be characterized by two effective relationships: (i) that between soil moisture and evapotranspiration efficiency (ET/net radiation), and (ii) that between soil moisture and runoff efficiency (runoff/precipitation). Our past work has shown that the relative shapes and positions of these two relationships determines, to first order, the accuracy of the

mean simulated hydrological cycle. Importantly, we have recently shown (though in an idealized model setting) that a more accurate relative positioning of these two relationships leads to more accurate subseasonal forecasts of soil moisture and streamflow, with skill in the study being determined through a comparison against an extensive array of in-situ observations. These findings are ripe for application to NASA/GMAO's full S2S forecast effort. We will use extensive (but offline and thus inexpensive) simulations with the NASA/GMAO's Catchment LSM to calibrate the relative shapes and positions of its two effective efficiency functions. Repeating an appropriate subset of the GMAO S2S hindcasts with the full coupled model (using the enhanced land surface model) will allow us to quantify the resulting improvements attained in prediction skill.

(2) The NASA/GMAO S2S forecast system currently uses climatological descriptions of vegetation phenology. In so doing, it ignores a potential source of prediction skill: the state of the vegetation. In Nature, the leaf area index (LAI) of vegetation varies from year to year, and associated with these and other carbon cycle variations are variations in albedo and canopy transpiration conductance – key controls on the surface energy and water budgets. We hypothesize that predictability in variables like albedo and conductance can contribute to hydrometeorological prediction skill. In our proposed research, we will characterize, as a function of location and time-of-year, the "damping time scales" (the time scales over which anomalies are damped to climatology) of vegetation-related albedo and transpiration conductance based on analysis of MODIS data and multi-decadal offline simulations with a dynamic phenology version of GMAO's Catchment LSM (the CatchmentCN LSM). Rather than trying to include CatchmentCN in the full GMAO S2S system (currently a computationally prohibitive strategy), we will initialize the Catchment LSM with albedo information from MODIS and conductance information from an offline CatchmentCN simulation (driven with realistic meteorological forcing) and, during the actual forecasts, let these albedos and conductances damp to climatology with the determined time scales. An appropriate subset of S2S hindcasts would be repeated with this inclusion of phenology-related predictability to quantify improvements in subseasonal hydrometeorological prediction.

Together, the two research focuses should reveal valuable scientific insight into hydrometeorological predictability and prediction. As a practical benefit, they could eventually lead to permanent improvements in the GMAO S2S system.

Zhiming Kuang/President and Fellows of Harvard College
Improving Sub-Seasonal Temperature, Precipitation, and Hydrological Forecasts over North America Through Online Bias Correction
21-S2SHYD-21-0024

Sub-seasonal to seasonal (S2S) forecasts are of great societal interest. The proposed research is aimed at improving and quantifying the predictability of sub-seasonal forecasts of temperature, precipitation and hydrological fields over North America. The proposed research will systematically develop and extend online bias correction approaches in the Goddard Earth Observing System (GEOS) and the NCAR CESM models. These include improvements to the online state-independent bias corrections currently used at GMAO and novel approaches to construct state-dependent correctors, with a focus on hydrometeorological processes. The resulting hybrid dynamical-statistical models will combine decades of model physics development and recent advances in machine learning techniques. We will then use the corrected models in hindcast mode to assess their skills in sub-seasonal forecasts of temperature, precipitation, hydrological land surface variables over North America, where prior studies have shown potential predictability that is not fully captured in dynamical models. With the mean state (state-independent) biases as well as the most outstanding state-dependent tendency errors corrected, we will carry out intrinsic predictability studies using a perfect model approach. This will provide a benchmark to the prediction skills from the proposed hindcasts and those reported in the literature. The proposed research aims to demonstrate the “path to utility” of a generally applicable approach, namely online bias correction, for improving S2S forecasts, which can be applied to other models and other phenomena. Through detailed analysis of the model bias corrections and their effect on sub-seasonal predictions, the proposed research will also lead to improved understanding of key physical processes that contribute to sub-seasonal predictability. The proposed research will also make extensive uses of GOES-5, MERRA-2 and additional NASA satellite data, and will enhance both NASA modeling capability and the science return on NASA’s investment in space-based remote sensing observations of Earth.

Andrea Molod/NASA Goddard Space Flight Center
Land surface - Boundary Layer Feedbacks and Their Roles in S2S Predictability and Prediction
21-S2SHYD-21-0013

The presence and importance of land-boundary layer feedbacks in the climate system has been shown clearly by many studies. The positive feedbacks have been shown to reinforce both dry and moist anomalies when the feedback strength is important. The overarching goal of the proposed research is to increase our understanding of the role in sub/seasonal predictionand predictability played by active land-boundary layer feedbacks, and translate that understanding into increased prediction skill. A central hypothesis of the proposed work is that there is predictability inherent in these feedbacks, and that regions and times where the feedbacks are active provide conditions for increased forecast skill.

The specific goals of this proposal are to:
1) Calculate a selection of relevant existing metrics for the strength of land-boundary layer feedbacks in the first three months of each ensemble member of the GEOS-S2S-3 retrospectiveforecasts, and characterize the regions and times when the feedbacks are active.

2) Evaluate the difference in sub/seasonal prediction skill conditionally when the land-boundary layer coupling is active and when it is inactive to determine which feedbacks

contribute toincreased prediction skill. The most important fields to be evaluated are the precipitation, for which IMERG/GPM data will be used for validation, and the 2-M Temperature (T2m),for which both in situ and satellite-based estimates will be used for validation.

3) Calculate forecast initial condition perturbations using the patterns that capture the land-boundary layer feedbacks shown to contribute to increased skill. Forecast ensembles willbe conducted with these perturbations to ensure that the active feedbacks will grow. The increase in skill and forecast reliability related to the new ensemble perturbations will be evaluated.

Our proposed work will enhance the ability of the GEOS S2S forecast system to translate the predictability in land-boundary layer feedbacks to increased prediction skill.

The proposed work is directly relevant to the programmatic priority of ”improving understanding of the processes that are key to successful hydrometeorological prediction, in particular quantification of the mechanisms generating predictive skill”, as the role of well known land-boundary layer feedbacks in sub/seasonal predictability and prediction will be evaluated and exploited. The proposed work also is relevant for the priority of ”improving understanding of the role played by the initial state in S2S hydrometeorological prediction, including efforts to improve initialization and quantify the impact on S2S prediction skill”, as the perturbations used to construct the forecast ensemble will be improved so as to enhance the land-boundary layer feedbacks that are important for predictive skill.

Shraddhanand Shukla/University of California, Santa Barbara
Improving a Process Based Understanding of How Terrestrial Water Storage Can Improve S2S Hydrologic Forecasts Skill in Data Sparse Regions
21-S2SHYD-21-0030

Skillful subseasonal-to-seasonal (S2S) hydrologic forecasts, especially in the case of extreme events such as droughts and floods, are critical for mitigating losses of lives, livelihoods, and infrastructure, as well as supporting climate adaptation. They are particularly needed in food and water-insecure regions, which are also typically data sparse and have limited climate forecasts skill. One hydrologic variable that has strong potential to both fill in data gaps and potentially improve S2S hydrologic forecast skill is terrestrial water storage (TWS). TWS integrates information from a variety of important sources of moisture that have their own distinct temporal and spatial dynamics, including groundwater, soil moisture, and surface water storage. It can be simulated by land surface models and observed from satellites like GRACE/GRACE-FO, providing extensive spatial and temporal coverage in near-real time. TWS is therefore suitable for supporting operational S2S hydrologic forecasts that are needed to inform mitigation, management, and adaptation policies. Additionally, TWS anomalies also serve as an indicator of hydrologic extreme events such as droughts and flood potential. However although TWS' has been commonly used for hydrologic extreme monitoring it application for S2S scale hydrologic forecasting, especially in data-sparse regions such as Africa, has been limited at best. Here with the overarching goal of “improving S2S hydrologic forecasts skill in data-sparse regions,” we propose research to address three key questions (1) How does each component of terrestrial water storage (TWS) contribute to its persistence at lead times varying from one to six months in observations as compared to modeled TWS? (2) How do different components of TWS initial conditions influence S2S hydrologic forecasts of droughts and floods at different lead-times and hydroclimate states? (3) Can “real-time” S2S hydrologic forecasts skill be improved by TWS data assimilation? The proposed research will critically rely on NASA satellite and model datasets and tools to increase predictive skill of hydrometeorological processes and quantities at S2S time scales. The NASA datasets, the proposed research will use include GRACE/GRACE-FO, SMAP, GLEAM, GIMMS NDVI/LAI3g v1, MODIS NDVI/LAI/EVI, MEaSUREs altimetry-based lake and reservoir heights, MERRA-2 among others. This work will also heavily leverage from past NASA-supported operational S2S hydrologic forecasting system: FEWS NET Land Data Assimilation (FLDAS)-Forecasts (FLDAS-Forecasts), which provides routine drought and hydrologic forecasts and is operationally supporting the food insecurity early warning efforts by USAID’s Famine Early Warning Systems Network Team (FEWS NET). Therefore, improvement in S2S hydrologic forecasts skill through the proposed research will have a clear “path to utility” in supporting food and water insecurity early warning by the existing end users, such as FEWS NET. Hence, we believe that the proposed research directly responds to the programmatic priority of this program element, which is to fund efforts that can “demonstrate a ‘path to utility’ in the investigation structure and objectives.” Additionally, this work furthers two of the main science goals identified in NASA Science Plan, which are to: “Characterize the dynamics of the Earth’s surface and interior, improving the capability to assess and respond to natural hazards and extreme events” and “Further the use of Earth system science research to inform decisions and provide benefits to society.” Finally, although the proposed focus domain is Africa, the research will have much broader significance, in particular for other data-sparse regions, which generally have higher vulnerability to climate risks, as TWS, the focus variable of the proposed research, is monitored and simulated using NASA satellite and model resources, globally.

Guiling Wang/University of Connecticut
Understanding the Role of Vegetation in Flash Drought Early Warning and Predictability
21-S2SHYD-21-0044

Flash droughts are caused by heat, atmospheric aridity, precipitation deficit, or their combinations, and often lead to devastating effects in multiple sectors (e.g., water, agriculture, and energy). Due to the sudden onset and rapid intensification, flash drought presents a unique challenge for drought monitoring and early warning. Most of existing drought monitor and early warning tools are based on various hydrometeorological variables reaching thresholds of unusually low water content or unusually high evaporative demand, and cannot provide sufficiently long lead time to enable planning and adaptation actions. Developing improved understanding of flash drought predictability and improving flash drought prediction skills are critically important for ensuring food and water security as well as ecosystem health.

The overarching goal of this project is to improve flash drought early warning and to advance our understanding of flash drought predictability originated from vegetation feedback. Building upon our preliminary study on Solar-Induced Chlorophyll Fluorescence (SIF) at the development stage of flash drought, we propose to assess the predictive skill of the SIF rapid change index (RCI) as a flash drought early warning at the global scale, and to investigate the mechanisms underlying the SIF-derived flash drought predictability. Relative to other remotely sensed vegetation index, SIF responds more sensitively to drought and other environmental stressors. We hypothesize that 1) slower-than-usual increase or faster-than-usual decrease of SIF can provide early warning for flash drought over agricultural and grass ecosystems; 2) the predictive skill of SIF RCI results from vegetation feedback to the regional hydrometeorological conditions at the S2S timescale. We will achieve the research objectives and test these hypotheses based on analyses of multiple SIF products derived from remote sensing (GOME-2, GOSIF, TROPOMI, OCO-2 and OCO-3), soil moisture data from remote sensing and reanalysis products (SMAP, ERA5-Land, MERRA2-Land, GLDAS-2.1), and numerical experiments using an ecosystem model (CTSM) and a climate model (CESM2). We propose four research tasks:

(1) Developing a global inventory of flash droughts. We will define flash drought based on the soil moisture deficit index (SWDI) from multiple data sources. SWDI is directly relevant for both soil moisture and vegetation response (through the impact of wilting point), and does not require a long data record to define percentiles.

(2) Assessing the robustness of SIF RCI as a flash drought predictor. We will derive SIF RCI from multiple remote sensing products, and assess its skills in predicting the full spectrum of SWDI in general and in predicting the flash drought occurrence and intensity in particular, all with a lead time of two weeks to two months.

(3) Understanding the unusual SIF trajectories prior to flash drought onset. We will conduct both data analysis and CTSM numerical experiments to disentangle the impact of multiple stressors (heat, vapor pressure deficit, SWDI) and to identify the primary causes for the negative SIF RCI prior to flash drought onset.

(4) Characterizing the role of vegetation feedback in flash drought predictability. This aims to better understand the sources of predictive skills of SIF RCI as a flash drought early warning. We will conduct numerical experiments using CESM2 with different vegetation input to examine how vegetation-climate feedback at the S2S timescale may influence the predictability of flash drought.

The proposed project addresses an important S2SHYD topic on flash drought prediction and predictability, and will make use of multiple remote sensing and other NASA products. Findings from the proposed project are highly relevant to NASA's ongoing and planned model development effects incorporating the CTSM vegetation carbon physics parameterizations into the NASA S2S modeling system.

Andrew Wood/University Corporation for Atmospheric Research

Advancing S2S Hydrological Extremes Prediction Through Uncertainty-Aware Modeling, Data Assimilation, and Understanding of Conditional Hydrologic Predictability
21-S2SHYD-21-0054

At S2S time scales, hydrologic predictability arises from two major sources, initial land surface conditions (ICs) and future boundary conditions (BCs), the influence of which varies by season and location. ICs can be improved through better Earth Observations (EO), land modeling and data assimilation (DA); and BCs can be improved through better weather and climate forecasts and techniques for using them in forecasting. In the US, there is little formal framing of operational S2S forecast development based on predictability considerations, and inadequate community understanding of how leverage these elements to improve S2S hydrologic forecast capabilities. The proposed work addresses this gap, focusing on predicting sub-seasonal streamflow extremes, both pluvial and drought events.

The project significance will be to add rigor and rationality to the endeavor to improve S2S hydrologic forecasts, enabling more strategic development and adoption of methods, datasets and models to advance current capabilities. The work will improve our understanding of the appropriate complexity for models used in simulating and predicting hydrologic extremes. The work will also connect predictability insights with an analysis of their consistency with the effectiveness of using current Earth observations and climate forecasts to improve extreme event prediction skill.

The work will proceed in two major thrusts. The first is a predictability assessment that uses two process-oriented models (named SUMMA and CTSM), in a large-sample collection of approximately 780 North American watersheds to quantify hydrologic predictability for sub-seasonal streamflow associated with IC factors (such as soil moisture and snowpack) versus BC factors (future/forecast precipitation, temperature and other forcings) for different lead times and predictands. This analysis will also explore the impact of model complexity on the ability to reproduce extreme streamflow variability. We will further associate this predictability with watershed geophysical attributes to support more generalized mapping of predictability insights across the US or globally.

For the second, pragmatic thrust of the work, we will assess the extent to which the predictability can be harnessed into prediction skill and demonstrated for a smaller subset of basins (12-24), using the best models from the predictability analysis and applying forecast techniques in an experiment to highlight the impacts of data assimilation (DA) of Earth Observations to improve IC skill, versus sub-seasonal climate forecasting to improve BC skill. We will apply a formal DA streamflow, soil moisture from the SMAP mission, ET from the MODIS sensor, and snow water equivalent to improve ICs. For BC improvement, we will apply ensemble sub-seasonal climate forecasts from the SubX experiment, which includes the NASA GEOS5 climate forecast model. Lastly, we will synthesize the results to assess the consistency of the outcomes with the predictability findings. The project will benefit from the expertise of well-placed collaborators who have worked on predictability and prediction investigations for years.

The proposed work directly supports the NASA S2SHYD program goal to improve both understanding of Earth system predictability and increased predictive skill of hydrometeorological processes and quantities at subseasonal-to-seasonal (S2S) time scales, while using NASA earth observations. It will leverage and contribute to extensive operations-related work by the PIs, including a current Reclamation-funded, multi-agency Snow Modeling and Data Assimilation testbed, a USACE-funded effort to develop a new internal S2S prediction system in the Pacific Northwest, PI Wood's contributions to the NOAA NextGen National Water Model and the WMO global Hydrologic Status and Outlook System. NASA WWAO has also expressed interest in the testbed concept that would be augmented through this proposal.

Benjamin Zaitchik/Johns Hopkins University
Vegetation as a Mediator of Flash Drought Development and Predictability on S2S Time Scales
21-S2SHYD-21-0023

Rapidly intensifying "flash droughts" are climate hazards that have significant impacts on agriculture and ecosystems. They have also proven to be difficult to predict in Earth System Model ensemble subseasonal-to-seasonal (S2S) forecast systems. At the same time, empirical S2S forecasts based on Earth Observation (EO) of land surface and vegetation conditions have shown promise. This suggests that vegetation-mediated land-atmosphere interactions play an important role in flash drought development, and that they could contribute meaningfully to predictability in some contexts. Recognizing this opportunity, we propose to leverage EO and advanced dynamically-based modeling systems to (1) characterize vegetation dynamics relevant to flash drought onset and intensification, (2) evaluate representation of these processes in an Earth System model, and (3) assess the importance of these processes relative to other sources of uncertainty in ensemble S2S forecasts of flash drought.

To meet these goals, we propose a set of complementary observation-based and modeling objectives. First, building on recent work that our team has performed to define, inventory, and classify flash droughts across the Contiguous United States (CONUS), and to forecast flash droughts using statistical models with EO-derived predictors, we will apply interpretable statistical learning methods to empirical prediction of different classes of flash drought. The primary purpose of this objective is to characterize relationships between vegetation and land surface diagnostics and flash drought across lead times of weeks to months, in order to infer process and to evaluate the likely contributions of vegetation to drought development and predictability for different classes of event. Second, we will apply the NASA Land Information System (LIS) and Unified Weather Research and Forecasting (NU-WRF) modeling testbeds to simulate representative flash drought events. These modeling systems will be applied in sensitivity studies that test the importance of vegetation parameterizations, datasets, process representations, and land data assimilation to the simulation of flash drought. The purpose of this objective is to quantify the influence that different vegetation modeling strategies have on the ability of an advanced Earth System model to represent the rapid intensification that is characteristic of flash droughts, and to do so systematically for events selected from different classes of flash drought. Third, we will address the path to applications by considering flash drought in the GEOS-S2S v3 forecast system. This objective has two complementary components: first, we will inventory and classify flash droughts in the forecast system, and evaluate system performance for each class. Based on those results, we will select events from classes in which the forecast system scores poorly and perform ensemble NU-WRF simulations that use GEOS-S2S v3 for lateral boundary conditions. These simulations will test whether NU-WRF with vegetation settings identified under the second objective can meaningfully improve GEOS-S2S v3 forecasts relative to the ensemble spread of the forecast system.

The proposed work is responsive to the A.50 request for studies that advance understanding of hydrology in S2S predictability, as we will consider land surface hydrology as both a driver and a product of S2S dynamics. The study is also designed to contribute to improved S2S forecasts, as our results can inform forecast system development priorities for GEOS-S2S and for other dynamically-based S2S forecast systems.

Xubin Zeng/University of Arizona
Quantifying and Understanding the Subseasonal-To-Seasonal Predictability of Land Hydrology over the Conterminous United States
21-S2SHYD-21-0011

While weather prediction for up to 2 weeks is well established and successful in serving the society, subseasonal-to-seasonal (S2S) prediction from two weeks to 6 months is much less skillful and under-developed. A fundamental barrier to skillful S2S prediction is the lack of quantification and understanding of the intrinsic predictability of the Earth system. Such predictability over land at S2S time scales may come from the longer time scales of variability of land hydrology quantities such as snowpack, and from the remote effect of slowly-varying ocean quantities (e.g., sea surface temperature) and natural modes of variability (e.g., El Nino).

Based on our prior work on chaos, order, and predictability, on S2S predictions, on the time scales of hydrological variabilities, and on machine learning applications in atmospheric sciences and hydrology, the overarching objective of this project is to quantify and understand the land hydrology predictability at 1-6 month time scales over the conterminous U.S. (CONUS). To reach this objective, three questions will be addressed:

Q1: What is the intrinsic predictability at 1-6 month time scales of precipitation, snow water equivalent, soil moisture, runoff, total water storage, and evapotranspiration? In exploring this question, both the mean and extreme values will be characterized and both probabilistic and deterministic metrics will be utilized. To characterize hydrological quantities appropriately, two-digit hydrological unit code (HUC2) basins over CONUS will be used. We will use existing S2S model prediction results to quantify the predictability and address the robustness of the results. We will also compare the predictability of these hydrological variables and assess the variation of their predictability with seasons.

Q2: What is the actual prediction skill of these models compared with their intrinsic predictability? As models have deficiencies, the actual prediction skill is expected to be lower than the intrinsic predictability from Q1. We will first use two-stage model bias corrections. Then we will quantify the differences between predictability and actual prediction skill, and their dependence on seasons, climate regimes, and other factors.

Q3: What are the potential sources of predictability of hydrological quantities? To better understand the model-based results in Q1 and Q2, we will use observation-based data products (e.g., NASA SMAP, GPM, GRACE, MODIS, MERRA2) to quantify the potential sources of predictability in Q3. In general, this involves local hydrological quantities (e.g., snowpack effect on soil moisture) and remote effects (e.g., sea surface temperature). Both linear regression and nonlinear machine learning methods will be used. For local sources, the relevant physical processes will be identified from land data assimilation system. For remote sources, the physical pathway will be preliminarily illustrated through the 500 hPa geopotential heights (to represent the atmospheric circulation).

The final deliverables include: (1) quantification of the intrinsic predictability at 1-6 monthly time scales of hydrological quantities; (2) quantification of the potential (as represented by the difference between predictability and actual prediction skill) for future improvement of S2S prediction; and (3) identification of local and remote sources for predictability and the physical processes involved. These results will also inform future efforts in model sensitivity tests to further understand the pathways of remote effects. The proposed work will focus on the first research theme of this solicitation “Identification and quantification of Earth system predictability,” and it will also contribute to the other two themes. It is directly relevant to three of the six NASA Earth Science Focus Areas (water and energy cycle, weather, and climate). Extensive in situ measurements and NASA satellite products, reanalysis, and model output will be used.

Yu Zhang/University of Texas at Arlington
Improving S2S Hydrometeorological Predictions for the state of Texas Through Synergistic Infusion of Remotely Sensed SST and Land Surface Variables to a Coupled Modeling System
21-S2SHYD-21-0036

The state of Texas is known for its hydroclimatic extremes. Over the past two decades, the state experienced one of the worst drought episodes in recent history (2011-2014), and some of the most devastating coastal floods in the continental US, including that induced by Hurricane Harvey of 2017. Managing these extremes requires accurate predictions of precipitation and runoff beyond the medium range.

The National Weather Service (NWS) produces precipitation, soil moisture and streamflow forecasts for the S2S range. The skills of these forecasts, however, remain limited at present. The underlying reasons for the limited skill are multifold. First, contemporary hydrologic models often lack the ability to accurately depict soil moisture conditions or their latent impacts on runoff production (Johnson et al. 2018). Second, past research has pointed to many deficiencies in extant numeric weather/climate prediction models. These include the inability of the global forecast models to resolve organized convection that is a potent flood producer over long lead times, and the lack of realistic representations of land-atmosphere feedback. Many authors, e.g., Mccorcle (1988), Myoung and Nielson-Gammon,2010; Fernando et al. (2019), have demonstrated the ability of soil moisture in modulating convection. In addition, the inability of resolving mesoscale sea surface temperature anomalies have been cited as a possible deficiency (Case et al., 2008).

Proposed herein is an effort to establish a regional S2S prediction system for the State of Texas that is capable of producing forecasts of precipitation and streamflow anomalies for weeks 3-6. The system will be based on a coupling of a regional implementation of WRF-ARW with the National Water Model (NWM). In the proposed undertaking, the WRF-ARW will be set up for a domain that extends from the Gulf of Mexico to the Oklahoma/Arkansas, and from the eastern portion of Mexico to Alabama; it will be nested within the NWS Global Ensemble Forecast System (GEFS)-V12 grid. The coupled system will be reinitialized using remotely sensed soil moisture from SMAP, MODIS skin temperature, dynamic vegetation, and MODIS sea surface temperature. Two sets of forecasts will be produced running the coupled modeling system using GEFS-v12 control run as lateral boundary conditions. The first/second control run will be done without/with any infusion of remotely sensed land conditions to identify the impacts of data assimilation. The hindcast experiment will focus on windows surrounding the flood of 2015, Hurricane Harvey of 2017, and the flash drought of 2019. Forecasts of precipitation and other variables from the coupled model will be validated against surface observations and analyses. These forecasts will also be gauged relative to NWS S2S streamflow and soil moisture products to determine skills gained through improved representations of processes and data infusions.

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NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2021
NNH21ZDA001N-IPMSI
A.51 Increasing Participation of Minority Serving Institutions in Earth Science Division Surface-Based Measurement Networks

Surface-based measurement networks are an important component of NASA’s Earth Science Division (ESD) because of their ability to provide unique information about the properties of the Earth system and to provide calibration/validation information in support of the EO satellites. The combination of space-based, surface, and airborne measurements provides Earth System scientists with information for process studies, hypothesis testing, model initialization and testing, and development of products used for applied sciences. The surface-based networks also provide an opportunity to engage directly with those who are making the measurements and utilizing them for local, regional, and/or global studies. As part of NASA’s ongoing efforts to increase the diversity of its investigator community and to provide opportunities for those who have not traditionally been part of that community to become full participants in it, NASA is looking to enhance the participation of Minority Serving Institutions (MSIs) in these networks.

NASA received 22 proposals in response to this NRA and selected 15 for funding. The total funding to be provided for these investigations is approximately $7.5 million over 5 years. In addition to funding these investigations, NASA ESD is providing these institutions with the appropriate surface-based network instrumentation. The selected investigations are listed below. The Principal Investigator, institution, and investigation title are provided.

John Anderson/Hampton University
Hampton University's Participation in the NASA Earth Science Surface Based Measurement Networks
21-IPMSI21-0010

Hampton University (HU), a private, non-profit, non-sectarian, co-educational institution was founded 1868 in Hampton, Virginia. HU is a Historically Black College and University dedicated to the promotion of learning, character building, and preparation of promising students for the positions of leadership and service. The Department of Atmospheric and Planetary Sciences’ faculty members are actively engaged in related research sponsored by the National Aeronautics Space Administration (NASA), the National Oceanic and Atmospheric Administration, the Department of Defense and the National Science Foundation, and have significant experience in remote sensing. In particular, department personnel have considerable experience with NASA scientific spacecraft-based remote sensor developments and scientific leadership of missions.

HU intends to install CIMEL and Pandora instruments on the rooftop of the operations building on one of the islands of the Chesapeake Bay Bridge Tunnel (CBBT) Island-3.

This location is safe, secure and has access to electricity and internet. The site is accessible for routine maintenance and emergency procedures in advance of extreme weather events (tropical storms, Nor'easters, etc.). This location would add a vital marine site to these networks. Marine aerosol and trace gas information on a variety of time scales will be collected, analyzed and compared to coastal and purely continental sites. It would also add an off-shore TEMPO validation site for aerosols, column NO2 and O3.

HU also intends to install a surface tipping-bucket rain gauges similar to the one at NASA Wallops Flight Facility for GPM validation. The gauges will be placed in the field of regard of our newly acquired X-band radar system (SKYLER) which includes part of the Virginia peninsula and extends out over the lower portion of the Chesapeake Bay including the CBBT islands. Combining radar, satellite, and ground/water stations will provide a thorough validation for GPM and other precipitation measurements.

A portion of this research will be conducted by HU students under the guidance of faculty and potential NASA scientists. Our aim is to develop creative students in the area of atmospheric science and remote sensing. This NASA project will add a strong component to conduct this basic atmospheric research producing a pool of skilled graduates in this field, especially from underrepresented groups. The photometers, rain gauges and our existing lidar's and radar, for example, provide excellent multidisciplinary training in optics, lasers, detectors, electronics, computer programming, algorithm development, analysis techniques and atmospheric science. Studies will include air quality, precipitation, aerosol and cloud science, atmospheric transport, and participation in studies using instrument networks.

Ruben Delgado/University of Maryland-Baltimore County
University of Maryland, Baltimore County Ground Remote Sensing Integration and Training (UMBC GRIT)
21-IPMSI21-0007

UMBC has been supporting NASA Earth Science Division funded research for over 20 years. Promoting collaboration in areas of common interest to NASA related to development of new technologies, advancement of environmental remote sensing, and multidisciplinary research in Earth and planetary atmospheres, the solid Earth and planets, and hydrosphere using ground, aircraft, and space-based platforms.

The need to increase our understanding of coastal environments is evident in recent atmospheric measurement campaigns, especially the effect of land-water interaction on air quality. NASA's Deriving Information on Surface conditions from DISCOVER-AQ and OWLETS-2 sought to understand elevated pollution levels along the coasts of Maryland. Results from these field campaigns revealed a common theme: it is becoming increasingly imperative to fully understand differences in the vertical distribution of pollutants directly over bodies of water as compared to those on continental land masses. Although these studies aimed to increase our understanding of local coastal dynamics and chemistry, the short-term nature of these observations leaves open questions regarding the strength, frequency, and seasonal changes in coastal environments that only long-term observations can explore. Additionally, the effect of climate change on the coastal processes is also uncertain and requires ongoing long-term observations.

Therefore, is our intention to request in this solicitation a total of three NASA Earth Science Division (ESD) Surface Networks from the AERONET, PANDORA and Precipitation Measurement Validation Network to be deployed at Hart Miller Island in the Chesapeake Bay. The Baltimore-Washington region has historically represented a significant challenge for air quality investigations due to water-land boundary transition characteristics and a lack of measurements available over water. Both Earth observing satellites and forecast models face challenges in capturing the coastal transition zone where small-scale meteorological dynamics are complex, and large changes in pollutants such as ozone can occur on very short spatial and temporal scales. UMBC in-situ aerosol, gases and meteorological measurements, profiling remote sensing observations (lidar/radar/soundings) and retrievals allow for synergistic activities with the NASA ESD Surface Networks to observe atmospheric transport events and boundary layer processes, allowing for the identification of complicated convective transition processes that are relevant to coastal regions near the Chesapeake Bay. For this reason, we intend to have an observing strategy aimed at synchronously measure aerosol, gases and precipitation ‘on-land’ as well as directly ‘over-water’ focused on providing a more complete picture of their transition across a coastal boundary. Measurements will be also critical to developing satellite validation/verification strategies of upcoming missions, like TEMPO, and modeling/forecasting efforts.

In addition, Dr. Ruben Delgado applied for the position of IPMSI Science Team Lead based on the strength of his experience with working with NASA Earth Science Division in their surface networks and field campaigns. His strong credentials in network operations, mentoring of students and faculty of Minority Serving Institutions in interdisciplinary academic and research experiences make him a strong candidate to develop pathways and coordinate opportunities for student and faculty growth and training by expanding and deepening their Atmospheric and Environmental Science programs and links to NASA Earth Science Division research.

Joseph Felix/Texas A&M University - Corpus Christi
South and Central Texas MSIs Led Collaboration with AERONET and Pandora Network
21-IPMSI21-0018

The principal investigators (PIs) propose a collaboration with the Aerosol Robotic Network (AERONET) and the Pandonia Global Network (PGN) that will involve installing and operating Pandora (PAN 1S) spectrometer systems and Sun Sky Lunar photometers (CIMEL CE318-T) at the minority serving institutions (MSI) Texas A&M University – Corpus Christi (TAMU-CC) and St. Edward’s University (SEU), the latter located in Austin, TX. The PIs are uniquely qualified to participate in the surface-based measurement networks due to the PIs’ extensive experience operating and maintaining federal equivalent method and low-cost alternative air monitoring instrumentation and analyzing air quality measurements in Texas. Additionally, an unfunded collaborator brings the experience of currently operating four Pandoras and three CIMELs in the Houston area and has agreed to provide knowledge and guidance during the project. The PIs and trained students and technicians will work directly with AERONET and Pandonia Global network groups to adhere to routine instrument maintenance plans and calibration efforts with a primary goal of providing calibration/validation information in support of the satellites flown by NASA's Earth Science Division and its domestic and international partners.

The TAMU-CC and SEU locations will fill voids in the current Pandora and AERONET network coverage as the networks do not currently have instrumentation located in South Texas and Central Texas. The contrasting sites, one large metropolitan inland area and one small coastal city, will allow for an investigation of how varying atmospheric conditions and pollutant concentrations affect the validation of remote sensing data and help assess its efficacy. The Pandora and CIMEL measurements will be complemented by ongoing air quality measurements performed by the PIs in their respective regions, including federal equivalent method air quality networks, citizen science low-cost criteria pollutant monitoring networks, and potential ozonesonde deployments. The Pandora and CIMEL data will also be used to directly strengthen current and future student and PI research projects related to ozone dynamics, PM2.5 precursors, and NOx inventories. Instrumentation background and results will be presented to and by students in monthly atmospheric science program meetings involving both MSIs. NASA scientists will be invited to present and engage with the students either in-person or through cloud-based video conferencing.

This collaboration between two MSIs and NASA networks has four objectives (1) directly further the goals of the Pandora and AERONET networks "to support the validation and verification of more than a dozen low-earth orbit and geostationary orbit-based UV-visible sensors," (2) provide underrepresented students and communities the opportunity to be exposed to state-of-the-art instrumentation, (3) provide NASA with the opportunity to engage with diverse groups of young STEM investigators, and (4) provide additional data for ongoing research projects and air quality action plans.

Morewell Gasseller/Xavier University of Louisiana
XULA Surface-Based Measurement Initiative for Environmental/Air Quality Monitoring
21-IPMSI21-0023

Project Summary

Xavier University of Louisiana proposes a five-year ROSES-2021 project entitled the XULA Surface-Based Measurement Initiative for Environmental/Air Quality Monitoring that will use NASA's three Surface-Based Measurement Networks (Aerosol Robotic Network, Pandora Network and the Precipitation Measurement Validation Network) to expand participation in NASA's Surface-Based Measurement Networks at Xavier and in the surrounding community. The objective of the project is to leverage Xavier's existing STEM program and outreach capabilities to increase the awareness of NASA's Surface-

Based Measurement Networks by Xavier's STEM students and the surrounding community. This project is synergistic to the ECOSTEM Air Quality Monitoring project currently in progress at Xavier and the newly established Robotics and Mechatronics program at Xavier.

The three central goals of the XULA Surface-Based Measurement Initiative for Environmental/Air Quality Monitoring are: 1) Exposing many undergraduate STEM majors at Xavier to NASA's Surface-Based Measurement Networks and to the possibilities of research careers in Earth Science Systems.

2) Leveraging Xavier University's existing outreach activities to develop an awareness of NASA's Surface-Based Measurement Networks in the communities around Xavier.

3) Using NASA's Surface-Based Measurement Networks at Xavier to complement the NSF funded ECOSTEM Air Quality Monitoring project currently in progress at Xavier.

To accomplish these goals the XULA Surface-Based Measurement Initiative for Environmental/Air Quality Monitoring project will:

1.1 redesign the Advanced Earth Science (IPSC4010) course to including learning how to access and analyze AERONET data and create class projects that use actual real-time data to connect to the local meteorology.

1.2 identify special topics for the Earth Science (IPSC2020) that involves the use of data from these three instruments.

1.3 identify projects and research topics for the Engineering and Physics majors which involves the use of these 3 instruments and employ undergraduate student researchers to be responsible for the maintenance and upkeep of these instruments.

1.4 train students in the newly established Gulf Scholars Program at Xavier to use these state-of-the-art instruments for atmospheric studies to identify environmental challenges facing the Gulf of Mexico and propose solutions to these challenges.

2.1 engage with teachers and schools near Xavier to participate in projects that uses the three instruments through the GLOBE Teacher Training workshops held at Xavier

2.2 introduce the K-12 students who participate in the Saturday Morning Science@ Xavier program to NASA's Surface-Based Measurement Networks.

3.1 develop the remotely operated environmental air quality monitoring and control (ROEAQMC) systems.

3.2 expand the ECOSTEM Air Quality research to include characterization of tropospheric columns with a focus on ozone, NO2 and formaldehyde, using the Pandora instrument

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Yuri Gorokhovich/Lehman College
Surface-Based Precipitation Measurement Network in the Bronx: Science and Education Opportunities for Diverse and Minority Students
21-IPMSI21-0012

Installation of the NASA Reporting Rain Gauge at Lehman College, City University of New York will help to add practical educational components to existing courses on weather and climate, geospatial data integration, hydrology, and environmental science, providing local research experience to diverse and predominantly minority students of

Lehman College, using auxiliary NASA data, statistical and Geographic Information Systems (GIS) tools.

This project will produce a set of educational modules, research term projects for students, and STEM professional development seminars for middle and high school earth science teachers in the Bronx. Data from the NASA Reporting Rain Gauge will be used in developing educational modules on precipitation measurements by surface-based methods and satellites, data calibration, measurements and accuracy assessment.

Research projects will use data collected by the NASA Reporting Rain Gauge to involve students in analysis of surface measurements vs Global Precipitation Measurements (GPM), including analysis of data quality, filtering, and assessment. Using existing Mesonet weather data network (one station is already installed at Lehman College) we will engage students in comparative analysis between data from existing weather stations of MESONET network and NASA Reporting Rain Gauge and investigating the role of precipitation measurements in urban flood modeling and vulnerability assessment.

To increase broad impact of the proposed work we plan to organize STEM professional development seminars that will allow middle and high school earth science teachers to obtain professional credits to advance their careers, expand their teaching knowledge, and develop educational activities for students. This element in our proposal will increase the impact of NASA work in the Bronx where school poverty rates range between 52 and 97% (2019-2020 data for partner schools associated with Lehman College Educational Talent Search Pathways to College program). Our estimation of the broad impact of our proposal over five-year period is 15,625 middle-high school students in the Bronx.

Main methods and techniques in this proposal will include GIS analysis, programming, and statistics, learning NASA documentation on GPM, use of NASA analytical modules (e.g. Giovanni) and visualization tools (e.g. Panoply). Auxiliary data on urban structure, socio-demographic components, and environmental justice will be integrated in students' projects.

We expect the proposed work to significantly enhance participation in NASA activities and research by both Lehman College students (who are predominantly of minority status) and Bronx science teachers. Internship programs such as NASA's DEVELOP do not attract interest from our students, namely because of a lack of personal exposure to NASA methods and activities at an earlier stage. Our project aims to bridge this gap by introducing our students to NASA activities and methods through education and local research projects during classes and research work. Using our own surface measurement equipment for NASA data validation will play important role in this.

Guanyu Huang/Spelman College
Acquisition of Ground-Based Remote Sensing Measurement Networks for STEM Research and Research Education in Spelman College

21-IPMSI21-0011

We propose to acquire a Pandora spectrometer system and an Aeronet instrument to enhance STEM (Science, Technology, Engineering, and Mathematics) research and research education in Spelman College, a historically black college for women. Instruments will be strategically deployed to expand the capabilities of the nascent Pandora network in Atlanta, and to augment the long-established AERONET site located at Georgia Tech. The instrumentation and surrounding collaborations will be the foundation of a new PIPeline program for Research education (PIPRE) among Spelman College, Georgia Institute of Technology, Emory University and NASA Goddard Flight Center. The PIPRE program aims to increase the participation of underrepresented students in research fields relevant to NASA Earth Science's area.
We will establish Spelman College as a part of the global Pandonia network. This adds to the three Pandora-1S systems currently in or planned for Atlanta (South DeKalb (SDK), Georgia Tech, and a rural background location). The site is located centrally in Atlanta, in one of the most polluted areas of the city. It allows for frequent hands-on experience with Spelman students. The proximity to the Georgia Tech Pandora site offers a new ability to study pixel-to-pixel variation in satellite retrievals. The proposed 2S system would be the only of its kind in Atlanta, opening new ability to investigate Pandora-derived aerosol measurements.

We will establish South Dekalb (SDK) as an AERONET site. SDK is managed by the Georgia Environmental Protection Division (EPD) and classified as an urban background location. As a Photochemical Assessment Monitoring Station (PAMS) and National Air Toxics Trends Site (NATTS), it hosts continuous measurements of multiple air pollutants including NOx, VOCs (summer via GC-FID, specific species via canister measurements on a weekly/monthly basis), and meteorological parameters. A Pandora spectrometer and continuous formaldehyde (HCHO) monitor are deployed at this site as part of a separate NASA project led by Georgia Tech. An aerosol chemical speciation monitor (ACSM) will soon be added to the site as part of the Georgia-Tech led ASCENT project. The combination of in-situ and remote sensing observations makes SDK extremely well suited for satellite validation and long-term studies of atmospheric composition.
We will build a pipeline Program for Research Education (PIPRE) to attract and retain underrepresented students. The program leverages the density of Historically Black Colleges and Universities (HBCUs) in the Atlanta region and the research expertise of faculty at Spelman, Georgia Tech, and Emory. PIPRE will follow the successful model of recruitment strategies demonstrated in the Summer Undergraduate Research in Engineering/Sciences (S.U.R.E.) program, and the successful model of effective mentorship demonstrated by PROGRESS (PROmoting Geoscience, Research, Education and SuccesS) Program. The program will be unique in its specificity to NASA-related research. PIPRE will also provide guides and assistance of graduate school for students. Overall, our goal is to increase the participation of underrepresented students and researchers in NASA earth science fields through the proposed instruments and PIPRE program. The proposed instruments will significantly enhance our research and education capability in air quality, atmospheric chemistry, and research fields relevant to NASA earth science area. We anticipate that numerous scientists, graduate, undergraduate and

high school students will benefit from our proposed instruments and PIPRE program, and attract more underrepresented students to work and study in STEM fields.

Sparkle Malone/Florida International University
The Pandora Project Miami: Air Pollution in Miami-Dade County
21-IPMSI21-0014

The Pandora Project Miami is prime for exploring patterns in air pollution, and how it changes with natural and anthropogenic conditions. Urban areas are known to suffer from high concentrations of pollutants, which are emitted to the atmosphere primarily during fossil fuel combustion. The proposed site is on the Florida International University (FIU) campus, in University Park, Florida. The site is on a 234 hectare public research university campus in a suburban area of Miami-Dade County. The site is in close proximity to three major highways (< 6 kilometers from the site) and just 13 km from the Florida Everglades. Within the most populous county in Florida, Miami-Dade County, the site is representative of the coastal peninsula geography. This region is surrounded by water, which greatly reduces the influence of transboundary air pollution and provides ideal conditions for the dispersal of local emissions. Air pollution in Miami-Dade County reach levels deemed “unhealthy for sensitive groups” as a result of transportation, domestic energy consumption, regional port activity, industry, power generation, and natural sources, including wind-blown salt and sand. The establishment of the Pandora Project Miami will support interdisciplinary student-led research on natural and anthropogenic drivers of air pollution in Miami-Dade County.

Alberto Mestas-Nunez/University of Texas San Antonio
An Air Quality Monitoring Station to Expand NASA’s Pandora Network to South Texas
21-IPMSI21-0020

As a fundamental contributor to both short-term impacts on human health and long-term global climate change, urban air pollution represents a key intersection of Earth’s natural environment and human society. The impacts of anthropogenic air pollution in South Texas coupled with climatic change are expected to be quite significant; in a warming world, South Texas air quality is expected to decay, most significantly in urban settings. Accurate monitoring and predictions of these environmental changes are needed to better inform air quality forecasts, urban planning, and both domestic and international policymaking. To provide accurate short-term forecasts and meaningful long-term climate projections, computer models must be initialized and constrained with accurate observations of the current state of the earth’s climate system. This is a challenging task considering the many environmental variables involved, but is greatly facilitated by the use of satellite observations which provide much better spatial coverage than any surface-based observational system. Satellite observations, nevertheless, depend on a network of surface-based stations for ground truthing. One of the NASA surface-based measurement networks for air quality is the Pandora Network which measures columnar values of ozone (O_3), nitrogen dioxide (NO_2) and formaldehyde (CH_2O). This observational network currently lacks stations in South Texas, which includes the City of San Antonio (29.4°N, 98.5°W) and the region stretching southward to the Mexican border and the Gulf of Mexico Coast. This region experiences air pollution from various sources including vehicular activities, the oil and gas industry, and seasonal agricultural fires in Mexico. Currently, the southernmost station of the Pandora Network in the contiguous U.S. is in the City of Houston, which is located just north of the latitude of San Antonio on the Gulf Coast, about 800 km north of the U.S. Mexico border.

In this project, we propose to expand NASA's Pandora global air quality network to South Texas by adding a station in the downtown campus of University of Texas at San Antonio (UTSA), a Hispanic Serving Institution in a rapidly-growing metropolitan region of the U.S. The proposed site has been chosen to target pollution from transportation exhaust, one of the main sources of air pollution in San Antonio, the 7th largest city in the U.S. Notably, the EPA ozone classification of San Antonio and surrounding areas was recently downgraded from marginal to moderate nonattainment, and is expected to worsen as the city continues to grow if no abatement measures are taken. The increased accuracy of satellite air quality measurements enabled by the new Pandora station will be essential for monitoring air quality as the city implements plans to mitigate air pollution over the next several years. Our proposed Pandora station is also timely, because it precedes the planned launching of the NASA's TEMPO (Tropospheric Emissions: Monitoring Pollution) mission in January 2023 which will measure hourly daytime air pollution, including ozone and nitrogen dioxide, with unprecedented spatial resolution over North America. The site chosen for the Pandora spectrometer is on the roof of a four-story UTSA building with data and internet connectivity, and is easily accessible for maintenance. Our research team includes remote sensing, engineering, and urban climatology scientists from UTSA's NASA MIRO Center for Advanced Measurements in Extreme Environments (CAMEE). The observations from the Pandora spectrometer proposed here along with the NASA satellite data involved in ground truthing will be used by UTSA scientists, students, and collaborators in air pollution, climate, and urban planning research. In addition, the observations and products from the associated research will be incorporated into UTSA undergraduate and graduate courses on atmospheric science, climate change, urban planning, and remote sensing.

Sandip Pal/Texas Tech University
Synergetic Surface-Based and Satellite-Borne Measurements of Arid-Region Aerosol and Precipitation (S3-MAAP)
21-IPMSI21-0006

In a rapidly changing climate regime of the 21st century, a better understanding and then forecast and projection of weather and climate features became a critical need for the society while climate model projections clearly indicated an increasing frequency of severe precipitation events and natural disasters like droughts, tornadoes, and hurricanes, and resultant increase in economic damages. Over the US, overall costs due to weather and climate disasters from 1980–2019 exceeded $1.7 trillion. There remains a large uncertainty in the projections for different future climate scenarios. Thus, we need to obtain a large number of observations across the globe and monitor different climate-relevant parameters on routine basis to improve these models. Among all the climate relevant parameters, high-quality and high-resolution simulations of dust particles and rainfall remained most challenging. Additionally, level of scientific understanding on how dust particles impact radiation and help form clouds, remained either low or very low. On the other hand, forecasting rainfall on all time-scales (short through medium to long range forecasts) remained one of the most challenging forecast issues in the community while rainfall has huge impact on the society and the ecosystem. Thus, obtaining high-accuracy, high-resolution information of both precipitation and aerosol loading for all weather conditions over land, in particular, over drylands remained critical. For instance, ~ 2.5 billion people live in drylands. Obtaining a better scientific understanding of the climate processes by the entire community, in particular, the minorities remained a challenge, though they are affected most due to their socioeconomic status. The American Council on Education showed evidence that there is a strong need to increase education and research activities in Minority Serving Institutions (MSI) including Hispanic-Serving Institutions (HSIs), Predominantly Black Institutions (PBIs), and Historically Black Colleges and Universities (HBCUs).

This project aims to (1) affiliate TTU' experimental site with two of the surface-based measurement networks of NASA's Earth Science Division (Aerosol Robotic Network and Precipitation Measurement Validation Network) via hosting a number of instruments measuring aerosol optical depths, rainfall and rain rate and rain drop sizes; (2) engage and train undergraduate and graduate students in an MSI for hands-on research and help gaining experiences in acquiring, and analyzing data sets, publishing research results, and communicate for the societal impacts of research outcome of the project, and (3) leverage our existing ground-based remote sensing facilities of Texas Tech University (TTU) including a 200-m meteorological tower, West Texas Mesonet, etc.
TTU achieved the status of HSI in 2019. As of fall 2020, TTU's undergraduate enrollment of Hispanic students reached 29.6%. This project will help accelerate engagement of an underrepresented group of students of TTU within the NASA's surface based observation network. We envisioned this project to be an excellent platform for innovative academic activities, training and outreach centered around research and technological work related to two networks. Since research, education, and training of the TTU minority students for atmospheric science related research involving these two networks are important themes here, this project is divided into two efforts: exploring classroom education and outreach activities in the community and performing quality research work through using technology and research components of the project. Also, research work using combined aerosol, precipitation and meteorological measurements when segregated according to weather types, severity, aerosol regimes, in particular, length of extreme poor visibility, will have important societal impact including people's weather-awareness related to poor air quality conditions and extreme rainfall events.

Peter Peterson/Whittier College
Installation of Pandora and AERONET Sites at Whittier College

21-IPMSI21-0002

This proposal aims to increase Whittier College student participation in Earth science research and remote sensing through the installation of Pandora and AERONET sites on the Whittier College campus located approximately 20 km southeast of downtown Los Angeles. Measurements at Whittier College would complement existing Pandora instruments in the Los Angeles region increasing the network density in a highly polluted and heterogenous area. The proposed sites proximity to an existing site in Pico Rivera would allow for evaluations of the ability of TEMPO and TROPOMI NO2 retrievals to resolve small scale features accurately. A Pandora would represent a substantial upgrade to existing instrumentation at Whittier college, which can only conduct 1D MAX-DOAS measurements. Installation of a Pandora would also enable students to use the 1D instrument in field campaigns without compromising the long term dataset at Whittier College, increasing options for students to be involved in research and for these instruments to be used in the classroom. The installation of an AERONET site would provide a much needed measurement site in Eastern Los Angeles as the existing network is mainly concentrated near the coast and the northern portions of the LA basin. Given the heterogeneity of urban aerosol particles, expanding the footprint of this network in the LA basin is a critical need. An AERONET site would also provide complementary information that would improve profile retrievals from co-located MAX-DOAS measurements.

The research enabled by the installation of this instrumentation at Whittier College will provide new insights into spatial gradients in pollution in southeast Los Angeles, provide additional evaluation opportunities for high resolution satellite observations over a polluted urban environment, and expand research opportunities in Earth Science for undergraduate students at Whittier College, a Hispanic Serving Institution. This instrumentation would be integrated into the educational mission of the college through laboratory experiences in upper division analytical and environmental chemistry courses offered at Whittier College.

John Randazzo/North Park University
Installation of an AERONET Sensor at North Park University, Chicago to Increase Minority Engagement in STEM
21-IPMSI21-0005

We propose installation of an AERONET apparatus in the urban environment of North Park University. The investigators have specific plans outlined in this proposal to enhance the undergraduate curricula in their extensive and varied class load. The investigators also have extensive research experience relevant to atmospheric science in general and aerosols in particular. This proposal also outlines research projects involving undergraduate students which synergize well with AERONET measurements and goals.

Aerosols in the atmosphere are especially important in urban environments which have a high density of vehicles and industry. Installation of an AERONET sensor at North Park, which is in the dense urban environment of Chicago would be rich and interesting to the project. North Park in particular is located near two major interstate highways serving Chicago, I-90 and I-94, and North Park is close to several industrial corridors in Chicago. There are currently no AERONET sensors in Chicago, which is the largest Midwestern city and third largest city overall in the United States. According to the AERONET website, the closest sensor is in Zion, IL, 55 km from North Park in a very different environment. Therefore, an AERONET sensor at North Park would give a unique environment in this region. Moreover, the measurements may prove to be impactful for the millions of people living in and around the immediate Chicago area (particularly for the tens of thousands of people in the several square kilometers around North Park). These measurements may also shed light on how residents in these urban environments are affected by air quality.

As a city-centered institution, North Park aims to serve our diverse Chicago neighborhood and the city at large. As such, North Park is honored to be designated a minority serving institution. Students, faculty, and staff at North Park strive to create an inclusive environment, including in STEM programs. This proposal aims to increase the engagement and recruitment of our minority students in STEM fields. Additionally, the existing Catalyst program at North Park enables strong and regular connections between North Park and the surrounding community.

In order to have the strongest impact on North Park students, the investigators would incorporate the instrumentation, data-analysis, and results into their course curricula. In particular, the investigators teach a variety of STEM courses ranging from foundational lower-level courses to capstone and research-centric upper-level classes. The courses outlined in this proposal have clear places in the curricula where live environmental measurements, like the ones proposed here, would make a strong connection to existing course content. The investigators are also committed to utilizing local AERONET measurements into their existing and future research projects.

Ram Ray/Prairie View A&M University
Characterizing Precipitation Distribution Using In Situ and Satellite Measurements Over the Agricultural Watershed
21-IPMSI21-0017

Satellite-based precipitation datasets are invaluable in providing near real-time, high spatial resolution, wide-area coverage precipitation data used for water resources management and climate adaptation decision making. In the contemporary world, where rapid weather and climate extremes are happening, satellite-based precipitation datasets provide high spatial coverage precipitation data. Satellite datasets are essential, particularly in regions where ground observations are lacking or low in density in watersheds, deserts, and developing regions. Over the last decades, several high-resolution gridded precipitation products have been developed using remote sensing satellites, ground observations, and numerical modeling. For further advancement, several meteorological satellites are focusing on the atmosphere and land imageries, retrieval algorithms, and interpolation techniques.

The Global Precipitation Measurement Mission (GPM) of NASA is among these missions that emphasize improving the estimation and provision of precipitation data for a wide range of applications. Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager are the advancements of GPM over TRMM. There are also efforts from NASA to increase ground validations by increasing the density of rain gauges and radars over different regions of the Earth. Concurrent to the mission of NASA to increase the network of ground observations in Minority serving institutions, this project is intended to install a GPM rain gauge on the research farm of the Cooperative Agricultural Research Center of Prairie View A&M University (PVAMU). The main goal of the project is to install a GPM rain gauge and use it for the evaluation and calibration of IMERG precipitation data and use them in water resources research at PVAMU. The GPM rain gauge and IMERG precipitation datasets will be further used for hydrological model simulation and other water and climate-related applications. The project will be helpful to involve students in field measurements, data pre-processing, and application of the data for climate, hydrology, and watershed management-related research.
The proposed research project, therefore, has the following specific tasks;

1. Install GPM rain gauge in an agricultural watershed/research farm in Southern Texas
2. Evaluate the performance of IMERG precipitation datasets in simulating in-situ (e.g., NCDC, USDA-NRCS SCAN, EC Flux Tower) and GPM rain gauge precipitation datasets;
3. Develop calibrated and validated IMERG precipitation datasets using GPM rain gauge precipitation
4. Use the GPM rain gauge and calibrated IMERG precipitation datasets for hydrological models simulation
5. Train students and early career researchers of PVAMU for the evaluation and characterization of GPM rain gauge and IMERG precipitation datasets

In general, this proposed project will provide micro-scale precipitation data which can be important to the following NASA Earth Science focus area: 1) Weather, 2) Climate Variability and Change, and 3) Water and Energy Cycle. The proposed user communities who will be benefited from this project include 1) University graduate and undergraduate students; 2) Hydrologists/Meteorologists; 3) State and Federal Agencies involved in climate change and water resources management and other stakeholders who are interested in weather and climate information.

Armin Sorooshian/University of Arizona
EXCITE: Expanding Reach of NASA Earth Sciences Research At a HSI In Southern Arizona (University Of Arizona)
21-IPMSI21-0001

The proposing team desires to integrate instruments from three NASA Earth Sciences networks (AERONET, Pandora, Precipitation network) in Tucson, Arizona, which is home to one of the largest Hispanic Serving Institutions (HSI), the University of Arizona (UA), in the United States with a rich experience of science and education in conjunction with NASA. The UA has hosted an AERONET station dating back to ~1993, but the proposing team has been more actively involved since its new positioning in recent years on top of the Gould-Simpson Building (32.23° N, 110.95° W; 779 m ASL). A unique opportunity afforded by the existence of a current AERONET station is the ability to add both Pandora and Precipitation Network instruments to provide a comprehensive view of the region. The Tucson basin and surrounding areas provide numerous other complementary monitoring sites for atmospheric variables that can strengthen the utility of the NASA network data collection being proposed.

Pandora and Precipitation networks on the UA campus co-located with the existing AERONET station provide easy accessibility and maintenance, efficient exposure to students who are on campus anyways, and co-location with other available instruments at UA. In addition to installing and maintaining the instruments, data will be collected, archived, and analyzed by our team, providing myriad education opportunities. A two-step approach will be used for broader engagement and outreach connecting diverse UA students with immersive research experiences, relying on (i) the Arizona Science, Engineering and Mathematics Scholars (ASEMS) as a feeder program into the (ii) newly-established Vertically Integrated Projects (VIP) Program. Co-Is associated with the project will integrate experiences and information about this project and the NASA network instruments into classes taught at both undergraduate and graduate levels. We will additionally develop multimedia educational tools to publish via UA's new online journal called "Science in Motion" that is being launched at Biosphere 2 and will have broad reach globally.

This work will directly address NASA's growing efforts to "increase the diversity of its investigator community and to provide opportunities for those who have not traditionally been part of that community to become full participants in it". The proposed research is directly relevant to NASA strategic goals as the collected data will help address how natural and human-induced changes alter air quality, as well as the planet's radiation balance, and the hydrologic cycle.

Wing To/Stanislaus State University
Increasing Diversity in Earth and Atmospheric Sciences with Courses, Outreach, and Research Programs (IDEAS-CORP) with NASA Instrumentation hosted at CSU Stanislaus
21-IPMSI21-0003

California State University Stanislaus (CSU Stanislaus) is a minority serving institution located in the Central Valley of California. With the support of both the College of Science and the Department of Physics, Geology and Physical Science, we submit this proposal to (a) host two NASA Surface-Based Instruments, the Pandora and AERONET, (b) fund the PI and Co-I in their research to engage students in atmospheric science, (c) improve and expand courses offered in Earth and Physical sciences related to our environment, (d) expose the local community of the Central Valley to NASA Earth system science through outreach events and collaborations with community colleges. If this proposal is funded, this will be the first time our university will receive a grant from NASA since our school's founding in 1965.

These instruments will be hosted on the roof of our main science building with an unimpeded 360 degrees view of the horizon. A dedicated room will be provided near the installation site, just below the proposed location of the instruments, for ancillary equipment, control units and computing devices with electrical power and internet access. Both exterior and interior locations have controlled access where authorized personnel such as the PI, Co-I and lab technician have access to the instruments 24/7. Additional equipment, machine shop and tools from the Department of Physics and Geology are available for installation, calibration and maintenance of these instruments.

This project will promote interests in atmospheric sciences, engage students in inquiry and research, and enhance the education of undergraduates at CSU Stanislaus. In Fall 2021, 62% of CSU Stanislaus undergraduates identified to from a minority group. We would like to recruit future atmospheric and Earth scientists from this diverse population with both research and course engagement. The PI and Co-I will both supplement their courses related to atmospheric science using data from these instruments. These courses will induct our undergraduates into research on the atmospheric effects of wildfires and air quality of the Central Valley currently conducted by the PI and Co-I.

Our local community have very limited exposure to NASA science, especially in the realm of Earth system science, this grant will also exhibit these instruments to our local community and colleges. We plan to create a display of live data feed from the instruments in the lobby of our main science building. This will allow our local residents to see NASA science at work in during outreach events held by our college or university. The PI and Co-I will also collaborate with local community colleges by creating activities using data from these instruments as recruitment tools for transfer students.

Feiqin Xie/Texas A&M University-Corpus Christi
Validation of Rain Drop Size Distribution in Tropical and Subtropical Rain Systems at Northwest Coast of the Gulf of Mexico
21-IPMSI21-0015

The main objective of this project is to sample rain Drop Size Distributions (DSD) in various tropical and subtropical rain systems at the northwest coast of Gulf Mexico by deploying a Parsivel disdrometer and two automatic rain gauges at the campus of Texas A&M University-Corpus Christi (TAMUCC), a Hispanic Serving Institution. The project will engage and inspire the minority and under-representative students in the field experiments and scientific exploration, and enhance the STEM programs at TAMUCC.

Though NASA Wallops Island has extensive observations of precipitation from various instrument, the tropical oceanic systems are not well captured at the Wallops Island site.

Corpus Christi is located at the northwest coast of Gulf Mexico. Due to the warm Gulf sea surface, the surface temperature at Corpus Christi rarely reaches below freezing level. Although the rain frequency is not as high as Houston area, various precipitation systems pass over Corpus Christi in different seasons, including local warm rain in summer, tropical systems (depressions, storms and occasionally hurricanes) in September-October, thunderstorms and squall lines in spring and fall, and cold fronts in winter. This provides a great opportunity to collect samples of DSDs in different types of precipitation (rain) systems at a single site. With a heavy refinery industry located to the northwest of the campus, depending on the surface flow and sea breezes, it is also possible to investigate the warm rain cases with different aerosol loads. This makes Corpus Christi a unique ground validation site for rain microphysics in various tropical and subtropical rain systems.

The PI team will deploy a Parsivel disdrometer at the campus of TAMUCC, which is located on an island surrounded by the Oso and Corpus Christi Bay, about 15-mile northwest of the coast of Gulf Mexico. The initial installation of these instruments is planned in Spring of 2023. We also plan to collect the measurements of rain drop sizes and rain rates in different types of rain systems at the TAMUCC campus site for five years. During the project, we will examine the variations of DSD in different types of rain systems, along with the existing Micro-Rain Radar (MRR) observations that is funded by NASA Precipitation Measurement Mission (PMM) program. The Multi-Radar Multi-Sensor (MRMS) radar and precipitation products will be used to provide an overall horizontal and vertical structure of the rain systems. Finally, the team plans to develop low cost disdrometers with 3D printing and Raspberry PI in the lab. Then use these instruments to educate undergraduate students in the field observations.

TAMUCC has a relatively young atmospheric science bachelor degree program that was established by the PI, Co-I, and another colleague in 2015. Our program maintains a weather observatory equipped with a fully operational 20-foot weather tower mounted with a full set of traditional weather instruments, which provide real-time local weather conditions. An enclosed area of the observatory will securely host new NASA instruments on campus. The new instrument and measurements will enhance atmospheric/environmental sciences course development. We also plan to create internships to involve undergraduate students in the field to collect and analyze precipitation data to understand the cloud and precipitation process in the gulf region. These hands-on experiences would be invaluable for students and help the retention of the program.