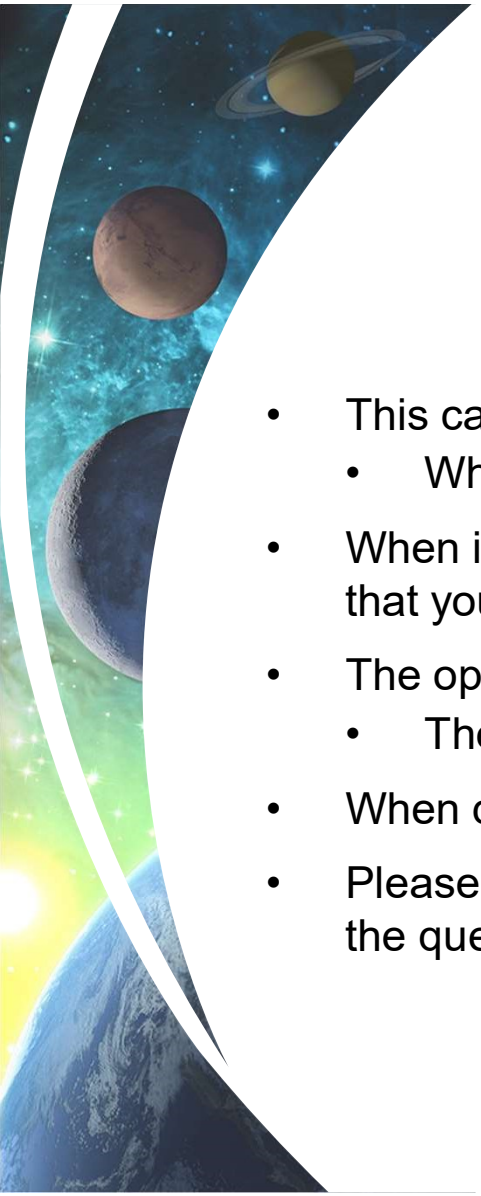
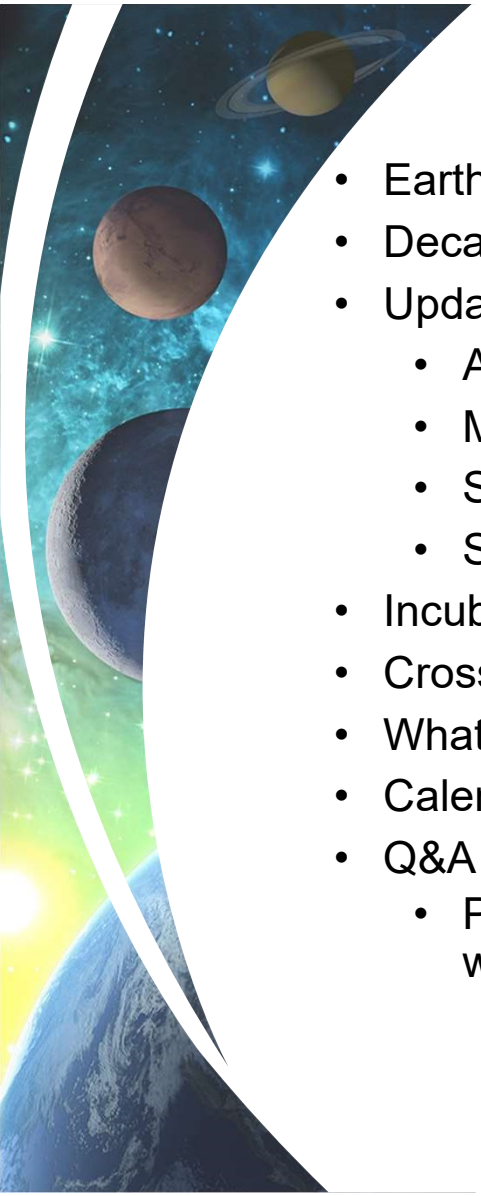
Earth Science Division
Decadal Survey Briefing with Stakeholders

Sandra Cauffman
ESD Director (Acting)
March 12, 2020



Questions Process

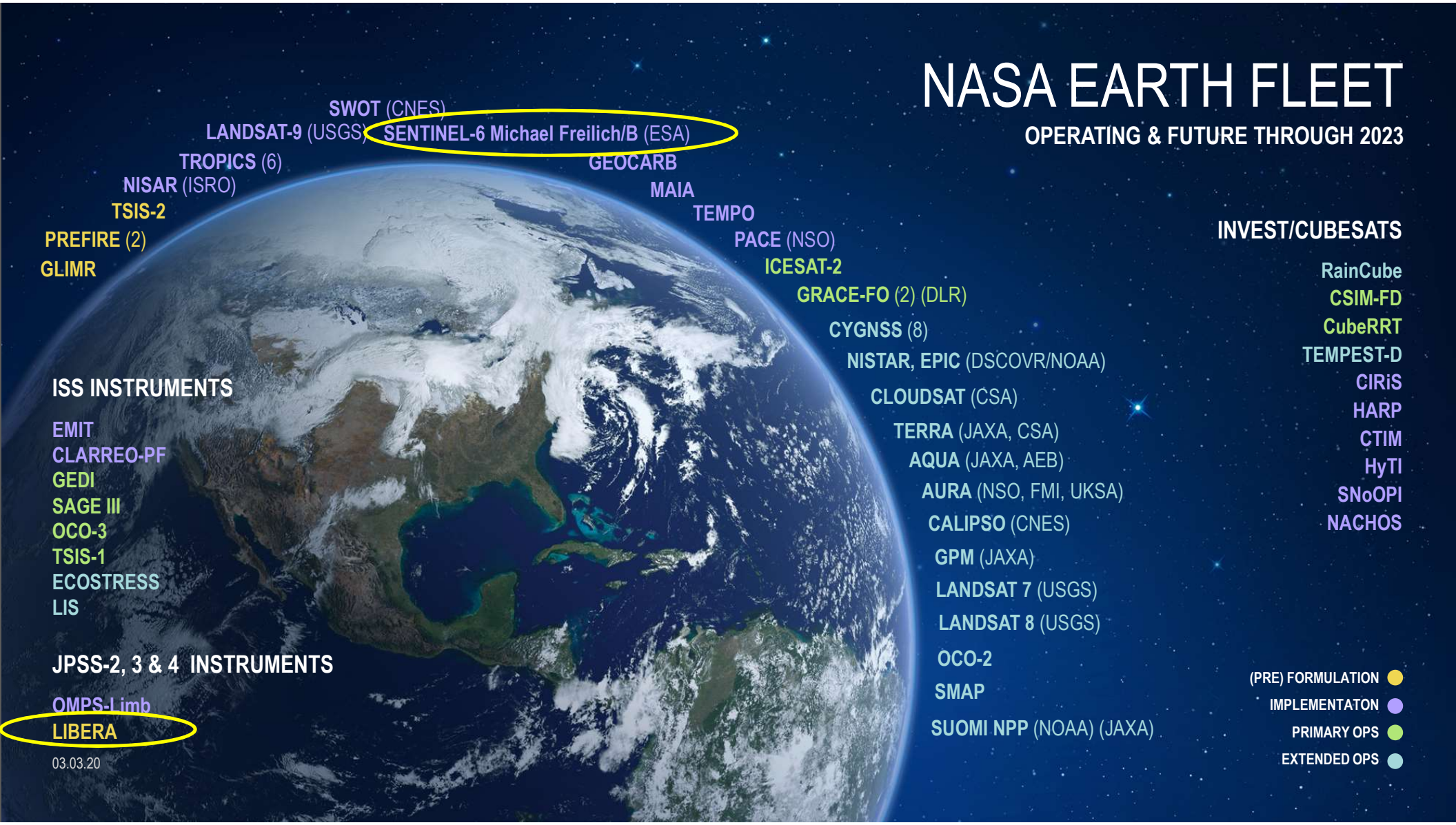
- This call is monitored by an operator
  - When you join the call, the operator will ask for your name
- When it is time for questions, please press *1 on your phone to indicate to the operator that you have a question
- The operator will introduce you by name and un-mute your line
  - Then you can ask your question and any follow up questions
- When done, the operator will re-mute your line and introduce the next person
- Please also email questions to **Amy Treat** at Amy.A.Treat@nasa.gov so we can post the question and its answer on our website

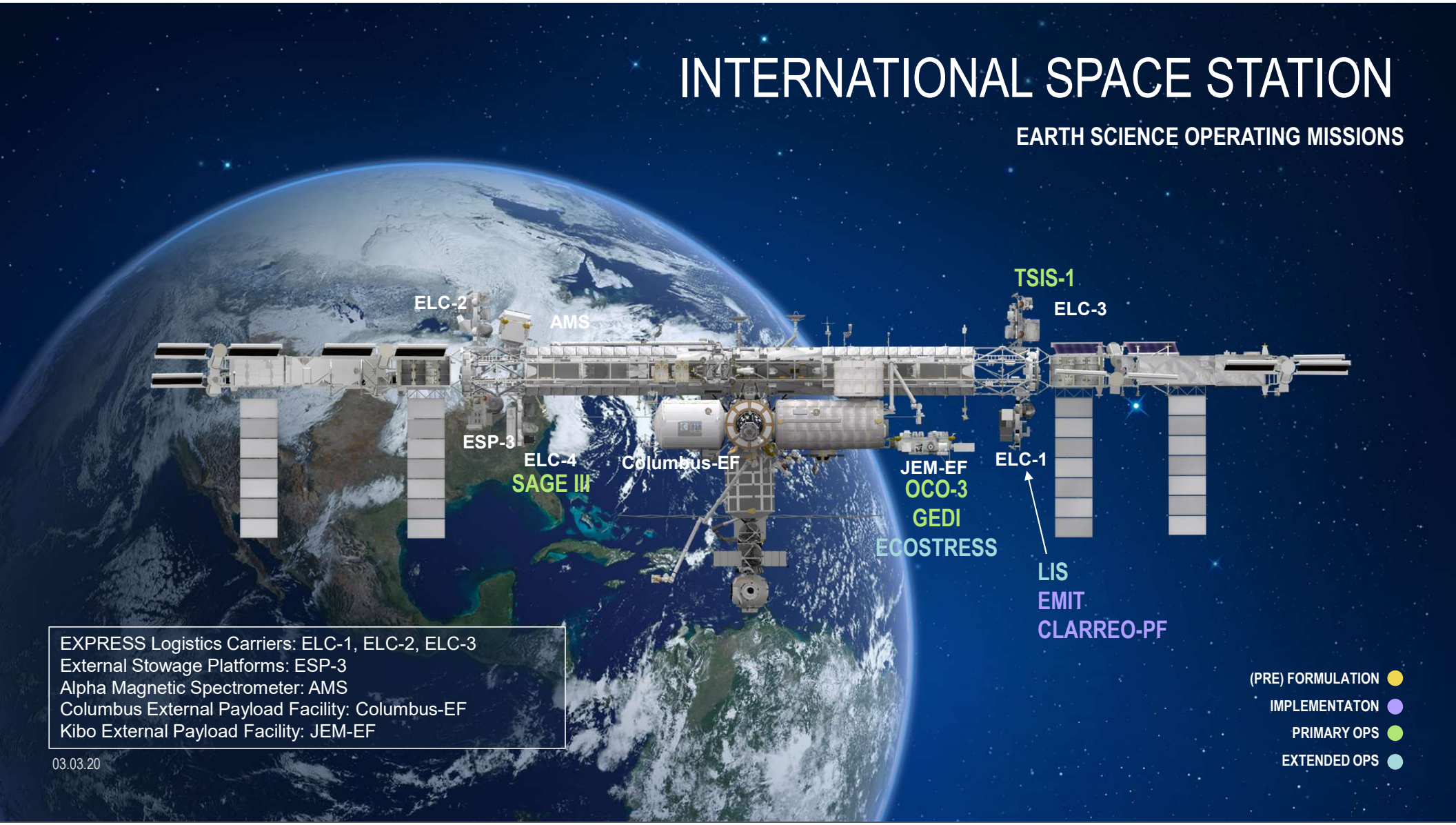


Outline

- Earth Science Division Overview
- Decadal Survey Overview
- Update of DOs
  - ACCP
  - MC
  - SBG
  - SDC
- Incubation Program
- Cross Benefits of Applications and Research
- What's Next?
- Calendar
- Q&A
  - Please email questions to Amy Treat at Amy.A.Treat@nasa.gov; the operator will open phone lines for questions at the end of the presentation

Earth Science Division Overview


NASA EARTH FLEET
OPERATING & FUTURE THROUGH 2023
SWOT (CNES)
LANDSAT-9 (USGS)
SENTINEL-6 Michael Freilich/B (ESA)
TROPICS (6)
GEOCARB
NISAR (ISRO)
MAIA
TSIS-2
TEMPO
PREFIRE (2)
PACE (NSO)
GLIMR
ICESAT-2
GRACE-FO (2) (DLR)
CYGNSS (8)
NISTAR, EPIC (DSCOVR/NOAA)
CLOUDSAT (CSA)
TERRA (JAXA, CSA)
AQUA (JAXA, AEB)
AURA (NSO, FMI, UKSA)
CALIPSO (CNES)
GPM (JAXA)
LANDSAT 7 (USGS)
LANDSAT 8 (USGS)
OCO-2
SMAP
SUOMI NPP (NOAA) (JAXA)
INVEST/CUBESATS
RainCube
CSIM-FD
CubeRRT
TEMPEST-D
CIRiS
HARP
CTIM
HyTI
SNoOPI
NACHOS
ISS INSTRUMENTS
EMIT
CLARREO-PF
GEDI
SAGE III
OCO-3
TSIS-1
ECOSTRESS
LIS
JPSS-2, 3 & 4 INSTRUMENTS
OMPS-Limb
LIBERA
03.03.20
(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS


INTERNATIONAL SPACE STATION
EARTH SCIENCE OPERATING MISSIONS
TSIS-1
ELC-2
ELC-3
AMS
ESP-3
ELC-4
SAGE III
Columbus-EF
JEM-EF
OCO-3
GEDI
ECOSTRESS
ELC-1
LIS
EMIT
CLARREO-PF
EXPRESS Logistics Carriers: ELC-1, ELC-2, ELC-3
External Stowage Platforms: ESP-3
Alpha Magnetic Spectrometer: AMS
Columbus External Payload Facility: Columbus-EF
Kibo External Payload Facility: JEM-EF
03.03.20
(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

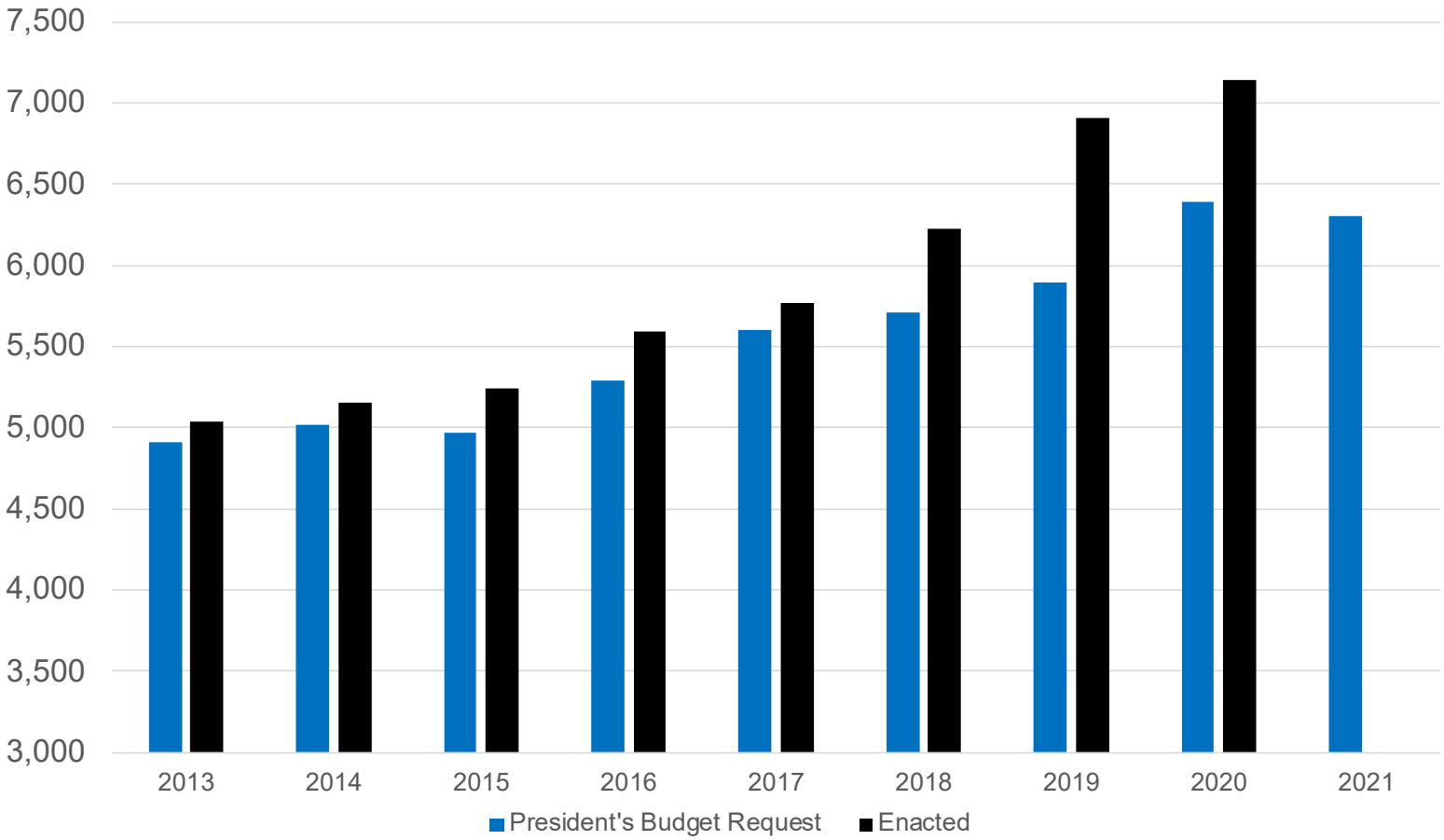
NASA ESD FY2020 Funding/Appropriation

- FY20 appropriations is $1.972B
- The FY20 budget supports continuation of a balanced ESD portfolio
  - Funding for all remaining elements of the ongoing Program of Record
- The FY20 budget is consistent with, and partially addresses, the 2017 Decadal Survey recommendations
  - Supports DO study activities, EVC-1 solicitation, and technology incubation activities
  - Implementation of Earth Science Explorers is on hold pending future budget developments
- FY21 President's Budget Request (PBR) released on Feb. 10, 2020

FY2021 Budget Agency Highlights

- One of the strongest budgets in NASA's history, investing more than $25 billion dollars for America's future in space; funding proposed represents an increase of about 12% over last year's request
- Keeps the agency on track to land the first woman and the next man on the Moon by 2024 and enables development of more than 15 science missions (including lunar, Mars, and Heliophysics) that inform Artemis work
- Provides valuable precursor experience for human exploration of Mars with bold new missions such as Mars Sample Return and Ice Mapper
- Implements a balanced and integrated science program with over 40 missions in formulation and development in FY 2021, including over 25 small missions
- Advances compelling science with priorities identified by the National Academies' decadal surveys including the James Webb Space Telescope, Europa Clipper, IMAP, and the first Earth Science Designated Observables mission
- Executes innovative partnerships with commercial and international partners; including through our Commercial Lunar Payload Services initiative, our industry partners will begin in 2021 to deliver science and tech payloads to virtually anywhere on the Moon, including the poles and far side

President's Science Budget Request and Enacted ($M)



Earth Science FY21 PBR Budget Features

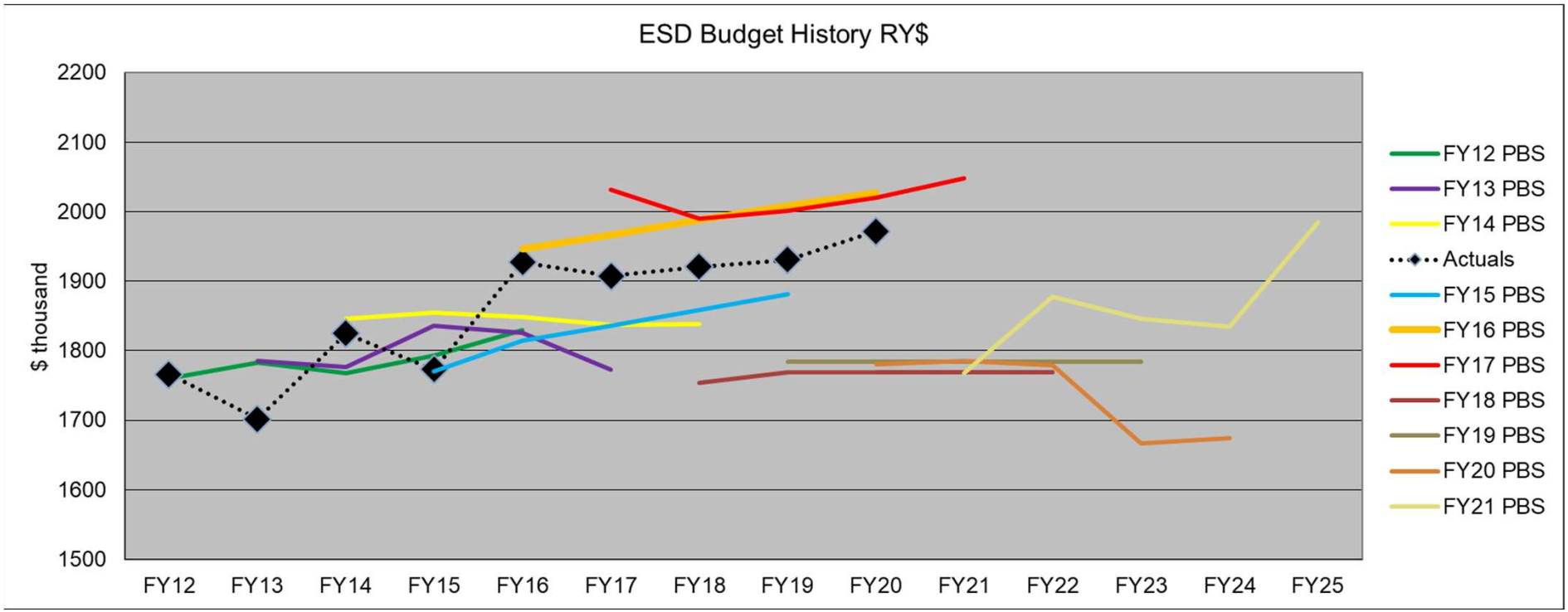
What's Changed

- Initiates first Designated Observables mission in FY21
- Selection of LIBERA as the first Earth Venture Continuity (EVC-1)
- Confirmation of the GeoCarb mission
- Additional resources to support interagency requirements as recommended by the Satellite Needs Working Group
- Sentinel-6A renamed "Sentinel-6 Michael Freilich" (recently retired ESD director)

What's the Same

- Supports 22 on-orbit missions, including instruments operating on the ISS
- SWOT, NISAR, Sentinel-6 Michael Freilich, Sentinel-6B, Landsat 9, TEMPO, GeoCarb, and MAIA remain on schedule for launch in budget window from FY21-FY25
- Maintains regular cadence of Venture Class solicitations (suborbital, mission, instrument); supports the first Earth Venture Continuity mission selection
- Sustainable Land Imaging supports the development of the next generation of Landsat observing systems as well as a focused program of land imaging technology studies
- Robust research and applied science programs, SmallSat/CubeSat investments, and commercial data buy activities
- Like FY18-20 Presidential Budget Requests, provides no funding for PACE and CLARREO-PF

ESD President's Budget Request (PBR) History



Earth Science Division's Venture Opportunities

Mission	Mission Type	Release Date	Selection Date	Major Milestone
EVS-1 (EV-1) (AirMoss, ATTREX, CARVE, DISCOVER-AQ, HS3)	5 Suborbital Airborne Campaigns	2009	2010	N/A
EVM-1 (CYGNSS)	SmallSat Constellation	2011	2012	Launched Dec. 2016
EVI-1 (TEMPO)	Geostationary Hosted Payload	2011	2012	Delivered to storage Dec. 2018
EVI-2 (ECOSTRESS & GEDI)	Class C & Class D ISS-hosted Instruments	2013	2014	Launched June & Dec. 2018
EVS-2 (ACT-America, ATOM, MAAMES, ORACLES, OMG, CORAL)	6 Suborbital Airborne Campaigns	2013	2014	N/A
EVI-3 (MAIA & TROPICS)	Class C LEO Instrument & Class D CubeSat Constellation	2015	2016	Delivery NLT 2021
EVM-2 (GeoCarb)	Geostationary Hosted Payload	2015	2016	Launch ~2021
EVSI-4 (EMIT & PREFIRE)	Class C ISS-hosted Payload & Class D Twin CubeSats	2016	2018	Delivery NLT 2021
EVS-3 (ACTIVATE, DCOTTS, IMPACTS, Delta-X, SMODE)	5 Suborbital Airborne Campaigns	2017	2018	N/A
EVI-5 (GLIMR)	Geostationary Hosted Payload	2018	2019	Delivery NLT 2024
EVC-1 (LIBERA)	Radiation Budget Measurement	2018	2020	Delivery NLT 2024
EVM-3	Full Orbital	2020	2020	Launch ~2025
EVI-6	Instrument Only	2020	2021	Delivery NLT 2025
EVS-4	Suborbital Airborne Campaigns	2021	2022	N/A
EVC-2	Continuity Measurements	2021	2022	Delivery NLT 2027
EVM-4	Full Orbital	2021	2024	Launch ~2029
EVI-7	Instrument Only	2023	2024	Delivery NLT 2028
EVC-3	Continuity Measurements	2024	2025	Delivery NLT 2030
EVS-5	Suborbital Airborne Campaigns	2025	2026	N/A

EVS
Sustained sub-orbital investigations
(~4 years)

EVM
Complete, self-contained, small missions
(~4 years)

EVI
Full function, facility-class instruments Missions of Opportunity (MoO)
(~3 years)

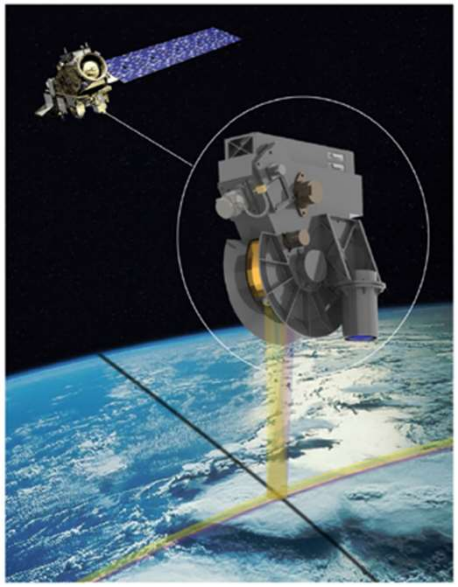
EVC
Complete missions or hosted instruments targeting "continuity" measurements
(~3 years)

Open solicitation - In Review

Completed solicitation

Earth Venture Continuity – 1: Libera

(Li'be-ra), named for the daughter of Ceres in ancient Roman mythology



Provides continuity of the Clouds and the Earth's Radiant Energy System (CERES) Earth radiation budget (ERB).

- Measures integrated shortwave (0.3–5 µm), longwave (5–50 µm), total (0.3–>100 µm) and (new) split-shortwave (0.7–5 µm) radiance over 24 km nadir footprint.
- Includes a wide FOV camera for scene ID and simple ADM generation to pave way for future free-flyer ERB observing system.

Innovative technology: Electrical Substitution Radiometers (ESRs) using Vertically Aligned Carbon Nanotube (VACNT) detectors; VACNT-coated blackbody calibrator.

- ESR: measured signal does not depend on gain of temperature sensor or thermal properties of system, improving calibration and accuracy.

Operational modes:

- Cross-track and azimuthal scanning.
- On-board calibrators.
- Solar and lunar viewing.

Flight:

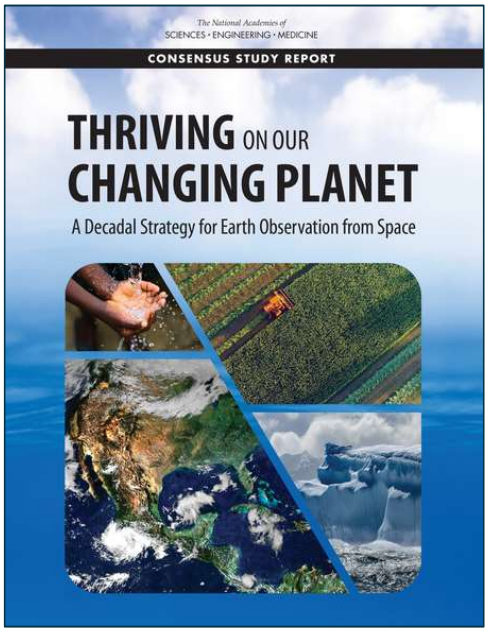
- JPSS-3.
- 2027 launch.
- 5-year mission.
- Follows pattern of CERES hosted on JPSS-1.

Participating Organizations

Investigation Management and Instrument Development		Science	
LASP	PI Institution, Mission and Investigation Leadership, L1 Data Processing, MOC	JPL/CSU	Deputy PI and Science Team Leadership
Ball	Flight Instrument Support, AI&T, Instrument and Calibration Science	LBL	Climate OSSE and Model Testing
NIST	Detector Development and Characterization	UA	Surface Energy Budget
Space Dynamics Laboratory	Pre-flight Calibration	CSU	Science Data Continuity Validation
		UM	Infrared Radiation Budget
		CIRES/ NOAA	Angular Distribution Models

Decadal Survey Overview

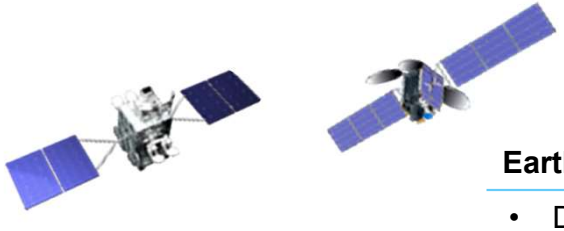
2017 Decadal Survey Snapshot



ESD is working with the community to translate the recommendations into an executable program and, for Flight, a portfolio of specific, realistic, launch-ordered missions and solicitations

- Publicly released Jan. 5, 2018
- Supports the ESD (and international) Program of Record and endorses existing balances in ESD portfolio
- Prioritizes observations rather than specific missions and allows implementation flexibility
- Emphasis on competition as cost-control method
- Explicitly encourages and notes value of international partnerships
- Recommends “Continuity Measurement” strand ($150M full mission cost cap) as an addition to the existing Venture-class program
- Identifies 5 “Designated” Observables for mandatory acquisition (Aerosols; Clouds, Convection & Precipitation; Mass Change; Surface Biology & Geology; Surface Deformation & Change)
- Introduces a new competed “Explorer” flight line with $350M cost constraint, 3 observables to be chosen by ESD from among 6 identified
- Calls for “Decadal Incubation Program” between Technology, R&A, and Flight to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal): Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (ST&V)
- Decadal new mission budget wedge opens late FY21

2017 Decadal Survey Progress Highlights



Earth Venture-Continuity

- DS recommended new Earth Venture Continuity Measurement strand ($150M full mission cost cap)
- In December 2018, ESD released EVC-1 solicitation targeted for radiation budget measurements
- Selection made in February 2020

Earth Science Explorers

- DS recommended a new competed Explorer flight line with $350M cost constraint
- Framework for program established
- Implementation on hold pending budget developments

Designated Observables

- DS identified 5 Designated Observables for mandatory acquisition

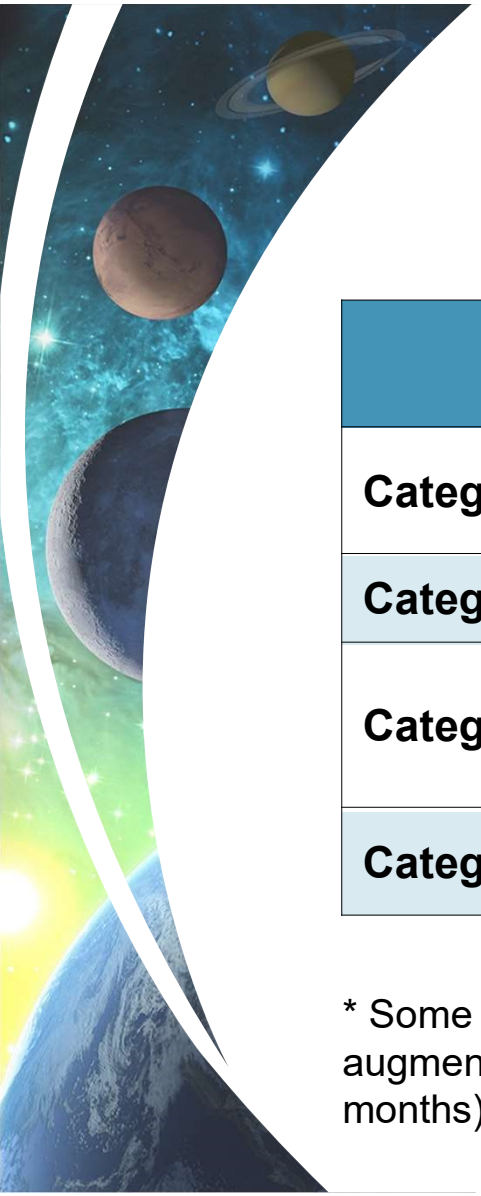
  In 2018 ESD initiated 4 multi-center Designated Observables studies, continued in 2019:
  - Combined: Aerosols-Clouds, Convection & Precipitation
  - Mass Change
  - Surface Biology & Geology
  - Surface Deformation & Change
- First Designated Observables Annual Review held in September 2019
- First Designated Observables Architecture Down Select by the end of Calendar Year 2020
- Fully funds a DO project to be initiated in FY21 through the budget window
- Initiates two more DO missions in FY22 and FY25

Decadal Incubation

- DS calls for Incubation Program to mature specific technologies for important — but presently immature — measurements (preparation for next Decadal)
- Solicitations for Study Teams (PBL and STV) released on March 14, 2019; selections made
- Decadal Incubation initiated and funded through the budget window

DO Study Points of Contact

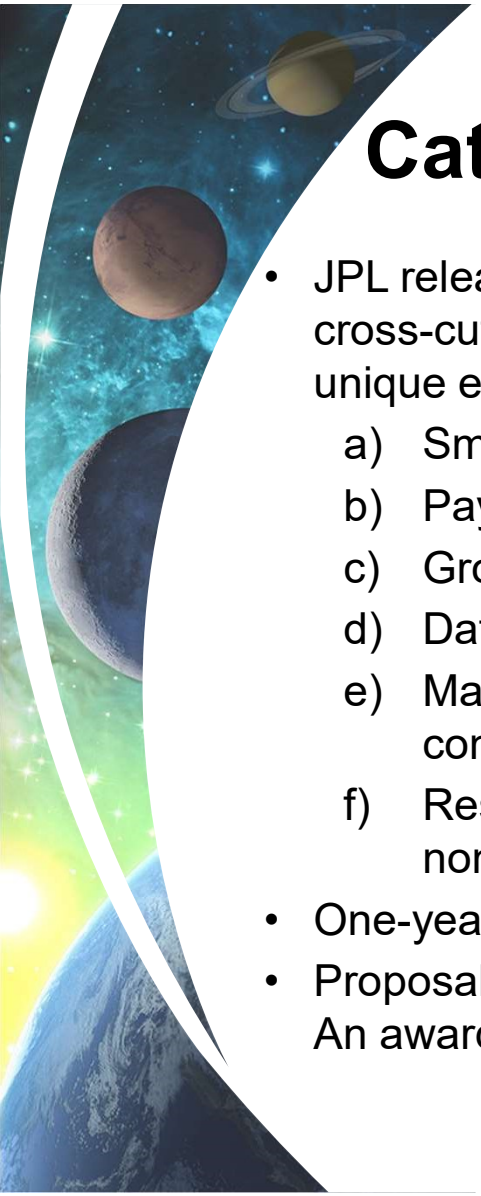
Study	Program Executive	Program Scientist	Program Applications Lead	Technology POC	Centers Study Coordinator
ACCP	Tahani Amer	Hal Maring (*Alternates*: Gail Skofronick-Jackson, Barry Lefer)	John Haynes (*Alternate*: David Green)	Amber Emory (*Alternate*: Bob Connerton)	Vickie Moran (GSFC)
SBG	Marissa Herron	Woody Turner (*Alternates*: Ben Phillips, Laura Lorenzoni)	Woody Turner (*Alternate*: Brad Doorn)	Bob Connerton (*Alternate*: Bob Bauer)	Jamie Nastal (JPL)
SDC	Mitra Dutta	Gerald Bawden (*Alternates*: Hank Margolis, Mike Falkowski)	Emily Sylak-Glassman	Bob Bauer (*Alternate*: Bob Connerton)	Paul Rosen (JPL)
MC	Amanda Whitehurst	Lucia Tsaoussi (*Alternate*: Jared Entin)	Brad Doorn	Bob Connerton (*Alternate*: Parminder Ghuman)	Bernard Bienstock (JPL)



DO Industry Engagement: Updates on Solicitations

	Description	Supported Activity	Date of solicitation
Category 1	Cross-cutting expertise in specific areas	All of the DOs	Dec 2019
Category 2	Support to HQ	HQ Decadal Strategy	TBD
Category 3	Technology Demonstrations	Specific to each DO	Inputs received from study teams*
Category 4	Applications Support	All of the DOs	March 2020

* Some of these requests overlap with existing ESTO or SBIR tasks, so those are being augmented. We are also looking into how to do quicker solicitations (2-3 months in lieu of 6-9 months) to have solicitations in FY20.



Category 1: Crosscutting support to DOs

- JPL released the Category 1 solicitations in support of the DO Architecture Studies in cross-cutting areas (i.e. capabilities that could apply to multiple DOs) where industry has unique expertise:
  a) SmallSat/CubeSat Constellations (one contract)
  b) Payload hosting on Commercial Satellites (one contract)
  c) Ground System Architectures (one contract)
  d) Data Processing/Data Storage/Cloud Computing (one contract)
  e) Market Research on out-of-the-box enabling commercial technologies (one contract)
  f) Research on non-traditional stakeholders and partnerships, such as philanthropists, non-profits, and foundations (one contract)
- One-year period of performance with options to renew on an annual basis
- Proposals are being reviewed for a) through c) and e). No proposals were received for d). An award for f) is being finalized.

Category 4: Applications Support to DOs

- ESD is working with JPL & LaRC to release the Category 4 solicitations to fund industry to help in the assessment of Applications Communities in support of the DO studies.
  - JPL is handling the Category 4 for SBG
  - LaRC is handling the Category 4 for A-CCP, SDC, and MC
- This industry support complements work by the DO team in identifying new users, preparing the Community Assessment Report, and on-going engagement with non-research users.
- Intent is to broaden engagement with user communities beyond traditional and customary ones (e.g., federal agencies) and reach new users and audiences, especially private sector and non-profits.
- One-year period of performance with options to renew on an annual basis

Aerosol, Cloud, Convection and Precipitation (ACCP)

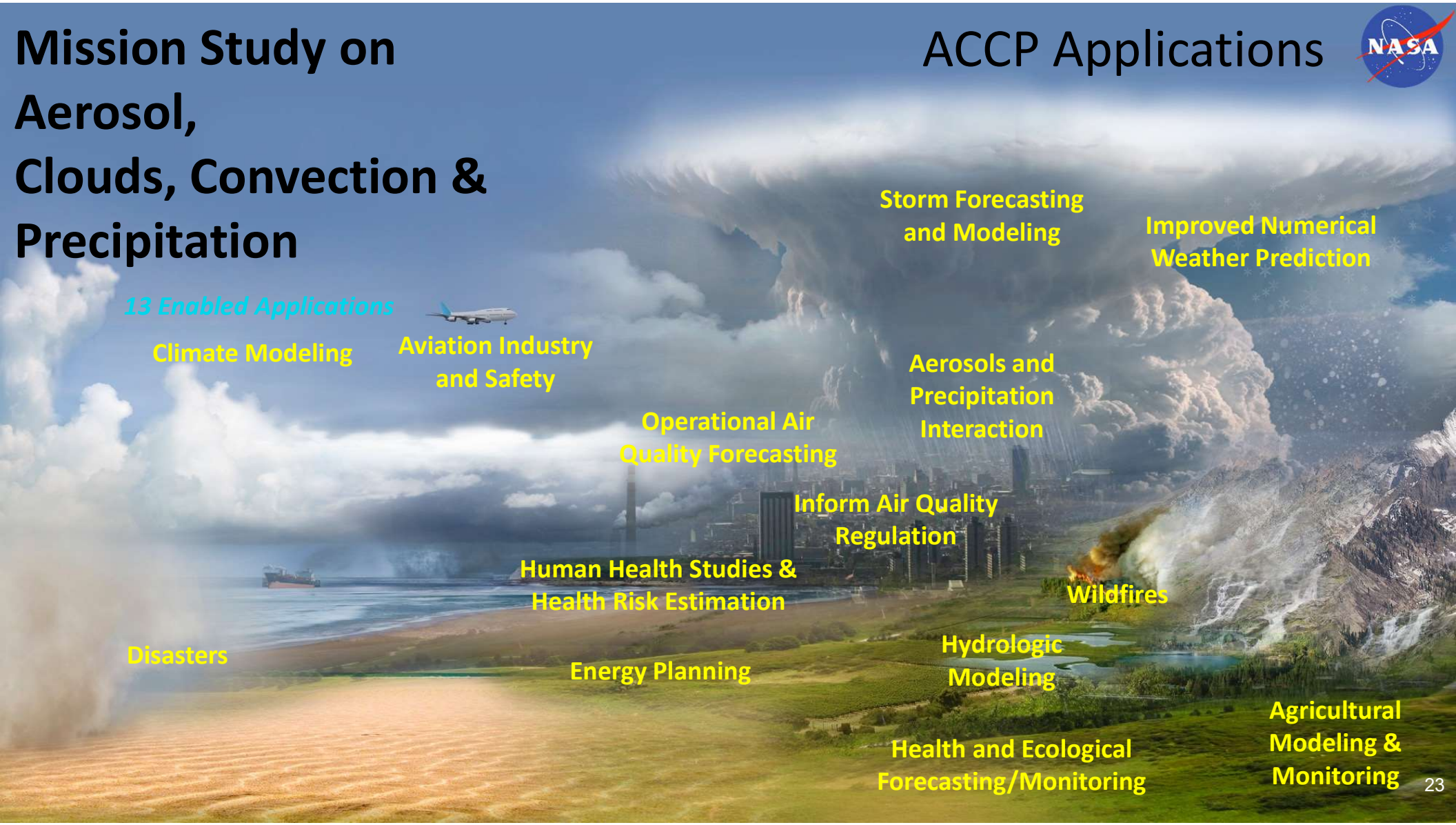
Mission Study on Aerosol and Clouds, Convection & Precipitation

ACCP Science

***8 Science Objectives** (see SATM for # Mapping)*
Traceable to the 2017 Decadal Survey

Mission Study on Aerosol, Clouds, Convection & Precipitation

ACCP Applications



Previously Presented Aspects of the ACCP Study

- Study Origin – DS, …
- Study Organization – Science + Engineering, Multiple Centers
- Science and Applications Topical Areas

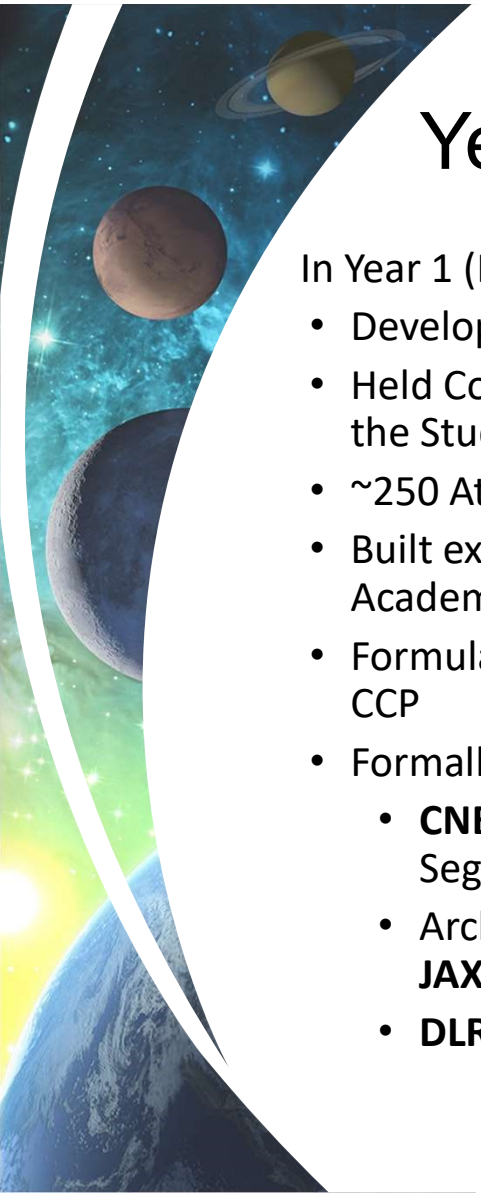
Science

- Aerosol Absorption, Direct and Indirect Effects on Radiation
- Low Cloud Feedback
- Aerosol Attribution & Air Quality
- Aerosol Redistribution
- Convective Storm Systems
- High Cloud Feedback
- Cold Cloud & Precipitation

Applications

- Aviation Industry and Safety
- Disasters
- Human Health Studies and Health Risk Estimation
- Energy Planning
- Climate Modeling
- Operational Air Quality Forecasting
- Improved Numerical Weather Prediction
- Wildfires
- Hydrologic Modeling
- Agricultural Modeling and Monitoring
- Storm Forecasting and Modeling
- Health and Ecological Forecasting/Monitoring
- Aerosol and Precipitation Interaction
- Inform Air Quality Regulation

- Science and Applications Traceability Matrix
- Value Framework

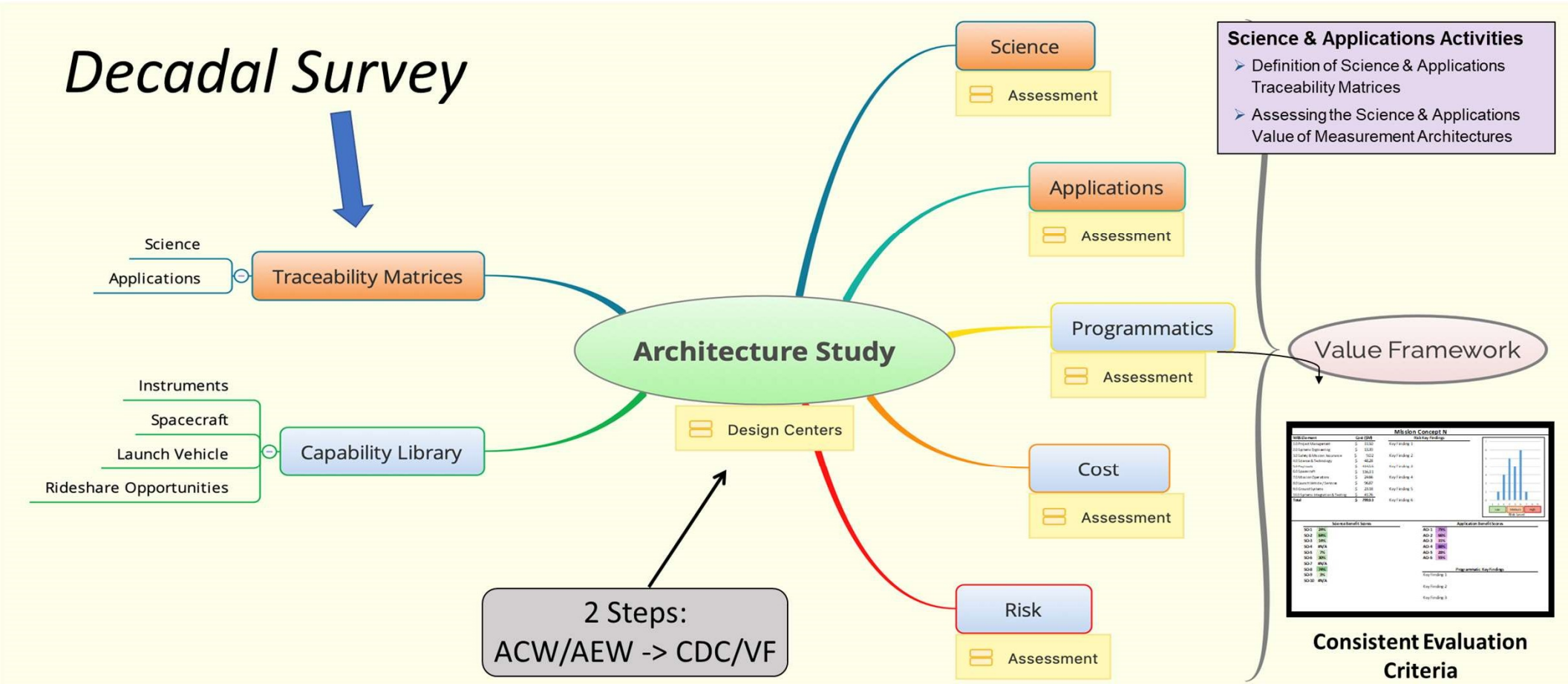


Year 1 Accomplishments

In Year 1 (FY19), the Study Team has:

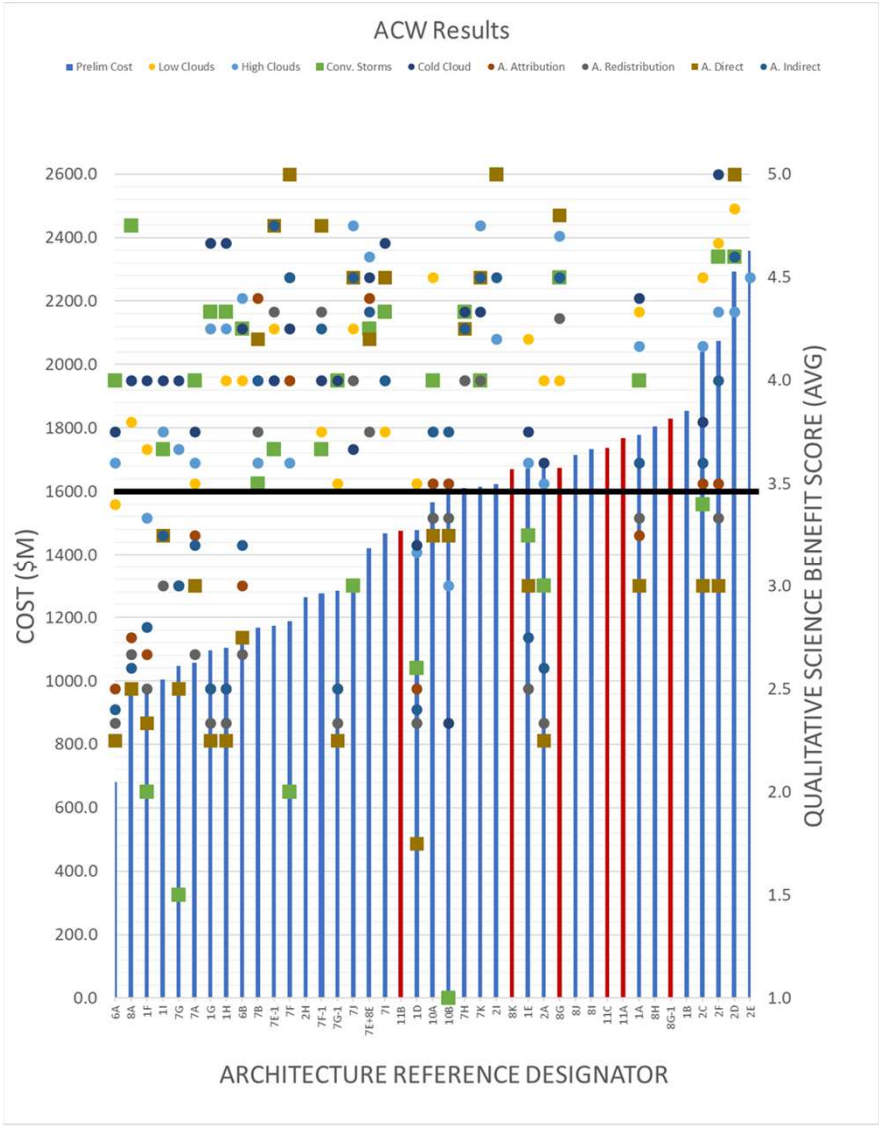
- Developed Science & Applications Traceability Matrix (SATM) (current rel F)
- Held Community Workshop in Pasadena, CA in April 2019 seeking feedback on SATM Rel C and the Study Process
- ~250 Attendees from NASA, Industry, Academia and 5 Countries
- Built extensive Instrument Library (>50 Request for Information (RFI) submissions from Industry, Academia, NASA and International Space Agencies)
- Formulated 41 candidate Space Segment Architectures to address the combined DOs for A and CCP
- Formally invited a number of international space/science agencies to participate in the Study
  - **CNES**, **CSA**, and **JAXA** are integrated into the Study Team involved in developing the Space Segment
  - Architecture Studies include sensor concepts submitted to the ACCP instrument library by **JAXA**, **CSA** and **CNES**
  - **DLR** is participating in the Sub-Orbital Working Group

ACCP Study Approach

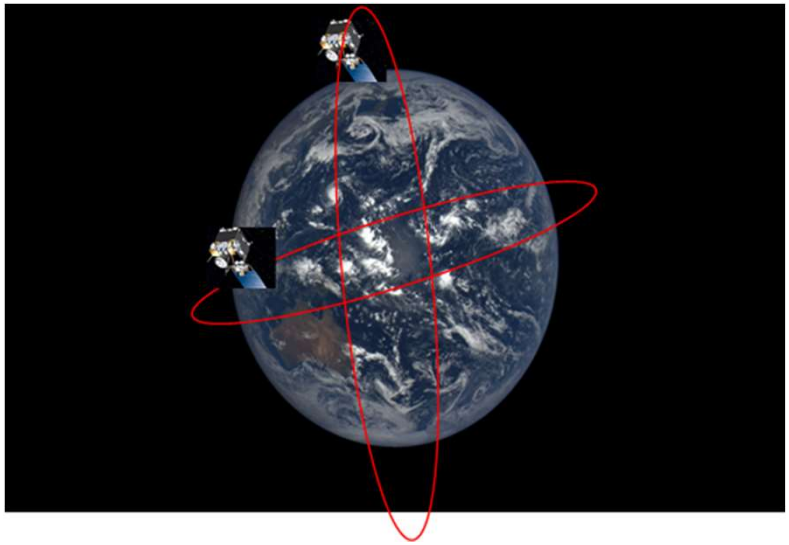


Architectures Constructed To Date

- *The bar chart to the right provides a summary of the 41 Observing Systems constructed to date*
- *Orbits considered so far are polar sun-synchronous 450km, 1:30p.m. Ascending Node Crossing and 407km, 65deg/35deg Incl*
- *The cost numbers are very preliminary and are used for relativistic assessment*
- *We expect to ultimately study multiple Mission Implementations associated with ~3 Science Implementations more deeply*
- *Completed detailed designs for Architecture 8G in October 2020 at GSFC and Architecture 8K in January 2020 at JPL with contributions from CNES and CSA*
- *Elements of Architectures 11A-11C and 8G-1 are in study now*



Architecture 8G (2 Med Sats)



SSG—1st Launch
GPM Orbit

Payload
Radar13
Lidar09
Radio9B
Radio10
Polar 07

Mass: 211kg
Power: 538W
Data: 99Mbps

Spacecraft
AICM Custom

SSP—2nd Launch
Polar Sun Synchronous Orbit

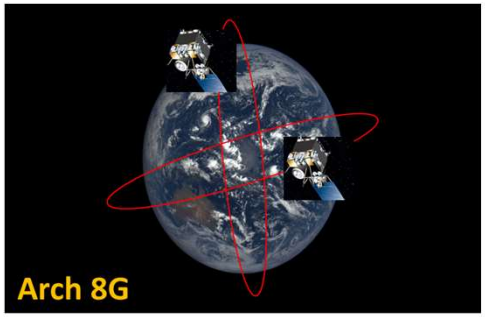
Payload
Radar13
Lidar 05
Radio07
Polar 07
Spec 03 TICFIRE

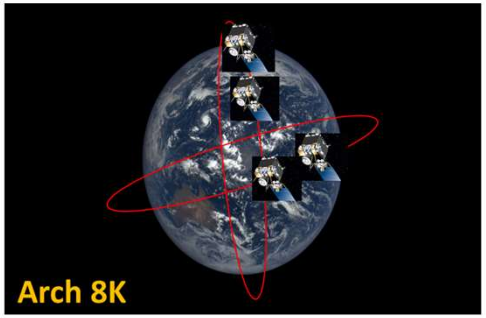
Mass: 551.9kg
Power: 841W
Data: 113 Mbps

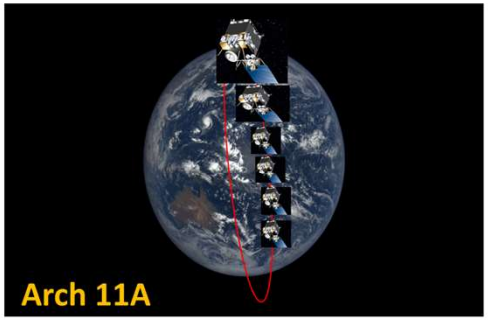
Spacecraft
LeoStar3 with Augmented Power

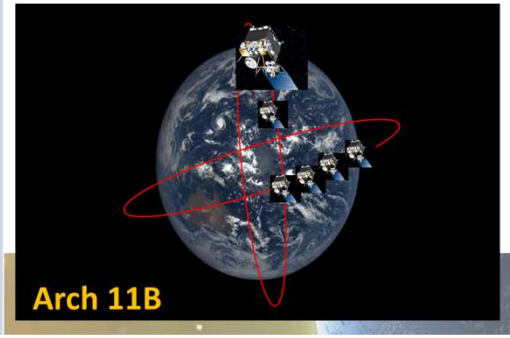
Architectures - Detailed Study

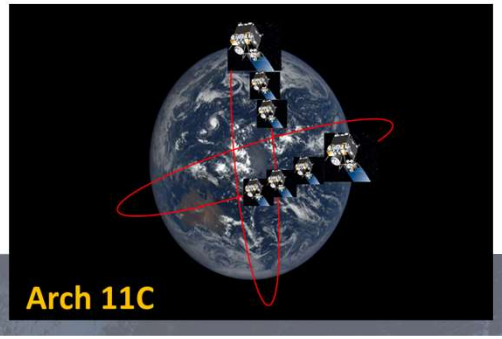
SATM Goals/ Objectives	Unique Science Implementation Strategies	Mission Implementation Strategies (CDCs)
SATM Rel F *5 Goals* *8 Objectives*	***Seasonal Vertically Resolved Cloud & Aerosol Process & AT VARIOUS TIMES OF DAY*** ***GPM + PSS***	***8G*** ***2 Med SC*** ***8K*** ***1 Med SC*** ***1 ESPA Grande SC*** ***2 ESPA SmallSats***
	Seasonal Vertically Resolved Cloud & Aerosol Process OVER SEVERAL MINUTE TIME SCALES TO GET TIME EVOLUTION ***PSS only***	***11A*** ***1 Med SC*** ***(Descoped)*** ***1 ESPA Grande SC*** ***4 ESPA SmallSats***
	Seasonal Vertically Resolved Cloud & Aerosol Process *OVER SEVERAL MINUTE TIME SCALES & AT VARIOUS TIMES OF DAY (Compromises Vertical Measurements for Sampling)* *GPM + PSS*	***11B*** ***1 Med SC*** ***5 ESPA SmallSats*** ***11C*** ***2 ESPA Grande*** ***5 ESPA SmallSats***











Study Status Update

- SCC/Community Independent Review of Architecture 8G Science Value conducted in 3 day workshop in December 2019
  - Architecture 8G evaluated by the SCC as "very high science value balancing the needs and desires of the various communities for ACCP science/measurements in A-Train and GPM orbits, while also being novel and transformative science"
  - Architecture 8G also balanced the interests of Centers, Industry, and International Partners (CNES and CSA)
- Special studies started at LaRC (to be completed in March/April 2020) to include JAXA radar contribution
  - Special Study #1--include JAXA radar in Architecture 8G
  - Special Study #2—JAXA radar on dedicated, optimized spacecraft as a separable element that could be included within other Architectures (e.g. Architecture 11C)
- Full team review of Architecture 8G initial **Science, Programmatic (Cost, Risk and Other Programmatic Factors), and Applications evaluations** completed 12-13 February 2020 (updates planned)
- 3rd Collaborative Design Center (CDC) Study started at MSFC (to be completed in April 2020) providing Small Sat building blocks for Architectures 11A-C
- Architecture 8K Science, Programmatic, and Applications evaluations underway (scheduled to be completed in late March 2020)

Upcoming Near Term Schedule

- 11-13 March 2020 Sub-Orbital Workshop
  - Add Sub-Orbital program to complete Observing Systems targeting aspects of the Science objectives that can only or best be achieved via in-situ measurements
- 13 March 2020 Complete JAXA Special Study at LaRC
- 17 March – 23 April 2020—Study Small Sats of Architecture 11A, 11B, and 11C at MSFC
- End March 2020—Complete Evaluation of Architecture 8K and Update Evaluation of Architecture 8G
  - science benefits (via Observing System Simulation Experiments (OSSEs) and other Simulations) performed by the SIT (refer to: *https://gmao.gsfc.nasa.gov/observing_sys_science/OSSE)*
  - technical feasibility/risk for the Instruments (via Technology Readiness Assessments)
  - programmatic feasibility/risk (via more Detailed Cost Modeling)
- May 2020 Architecture Study planned at LaRC & Complete Evaluation of Architectures 11A, 11B, 11C
- July 2020 Architecture Study TBD planned at GRC
- August 2020 Full Team Science Review
- September 2020 Sub-Orbital Workshop to design Sub-Orbital Architectures that meet Sub-Orbital Science Objectives from March Workshop
- October 2020 Architecture Study TBD planned at GSFC

Year 3 Plan (FY21)

- Down-select to ~3 Observing Systems, then
  - Further develop Space Segment and End to End Ground Segment
  - Further develop scope of Algorithm Development for Science Data Retrievals and Product Definition
  - Include role of Modeling in the Observing System Science and Applications Benefit Scoring with a Modeling Workshop planned for CY21
- Refine the following details in the documentation of the final report
  - Science
  - Mission Implementation
  - Management
  - Cost
- Seek independent review of Science and Technical/Management/Cost to provide a recommendation to HQ (FY21) for one Observing System to proceed to Mission Concept Review (MCR)/KDP-A before end of FY22

Mass Change (MC)

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Mass Change (MC) Study Update

Team accomplishments:

Mass Change **Science and Applications Traceability Matrix (SATM)** is completed and posted on the NASA MC website. Community engagement in the development of the SATM initiated at the Community Workshop (July 2019) and at a later stage with discipline focused telecons:

- Oct. 30: Earth Surface and Interior
- Nov. 15: Global Hydrological Cycle and Water Resources
- Nov. 19: Climate Variability and Change

MC SATM was presented at the **Mass Change Study AGU Town Hall,** Dec. 12, 2019.

Mass Change Applications Survey released online June 14, 2019

Mass change applications poster session at AGU on Dec. 13, 2019 confirmed great interest in mass change observations (e.g. applications related to water resources, agriculture, weather services). Performance targets involve increased spatial resolution, temporal resolution, and accuracy in data products relative to the current program of record

Mass Change (MC) Study Update (cont.)

Team accomplishments (cont.):

Three categories of architectures were identified: Satellite-to-satellite tracking (SST), Gravity Gradiometer (GG), and Precise Orbit Determination (POD). The team has communicated with the community the developed MC architecture tree, at the workshop and AGU, and it is considered complete and comprehensive.

The team has engaged the community, including international partners and the private sector, in inventorying technology development priorities, and scoping the associated maturity level and technology trade space.

Advancements and improvements in **accelerometer** technology

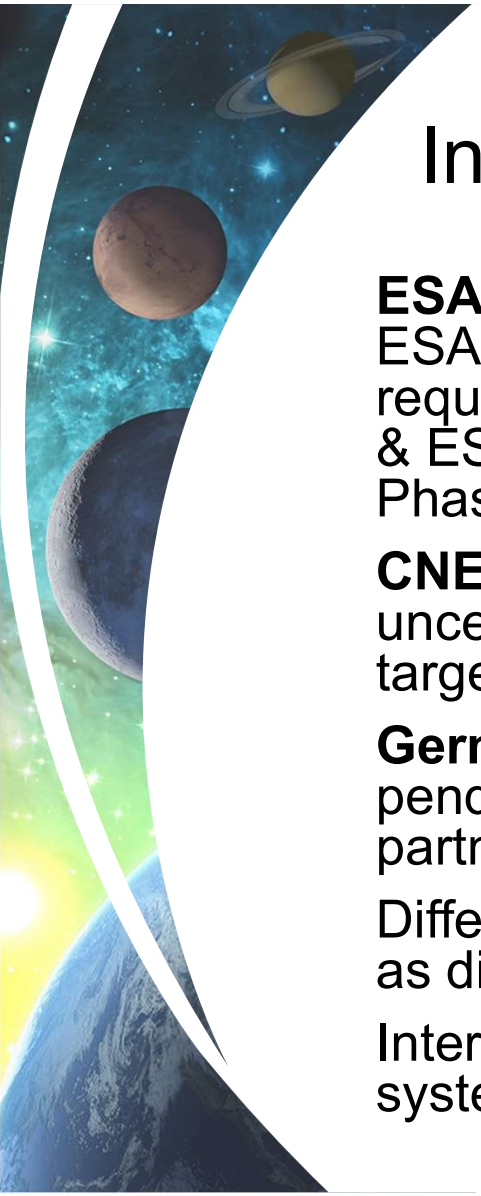
Laser Ranging Improvements - the future for SST measurements

Development to support Tech Demo opportunities to advance future technologies for:

CubeSat and **SmallSat** technologies

Gradiometer and Quantum Sensing technologies

Team Meeting at NASA Ames - Feb 11-12, 2020: the team discussed the value framework and the science performance simulations for the identified architecture options.



International Partnerships

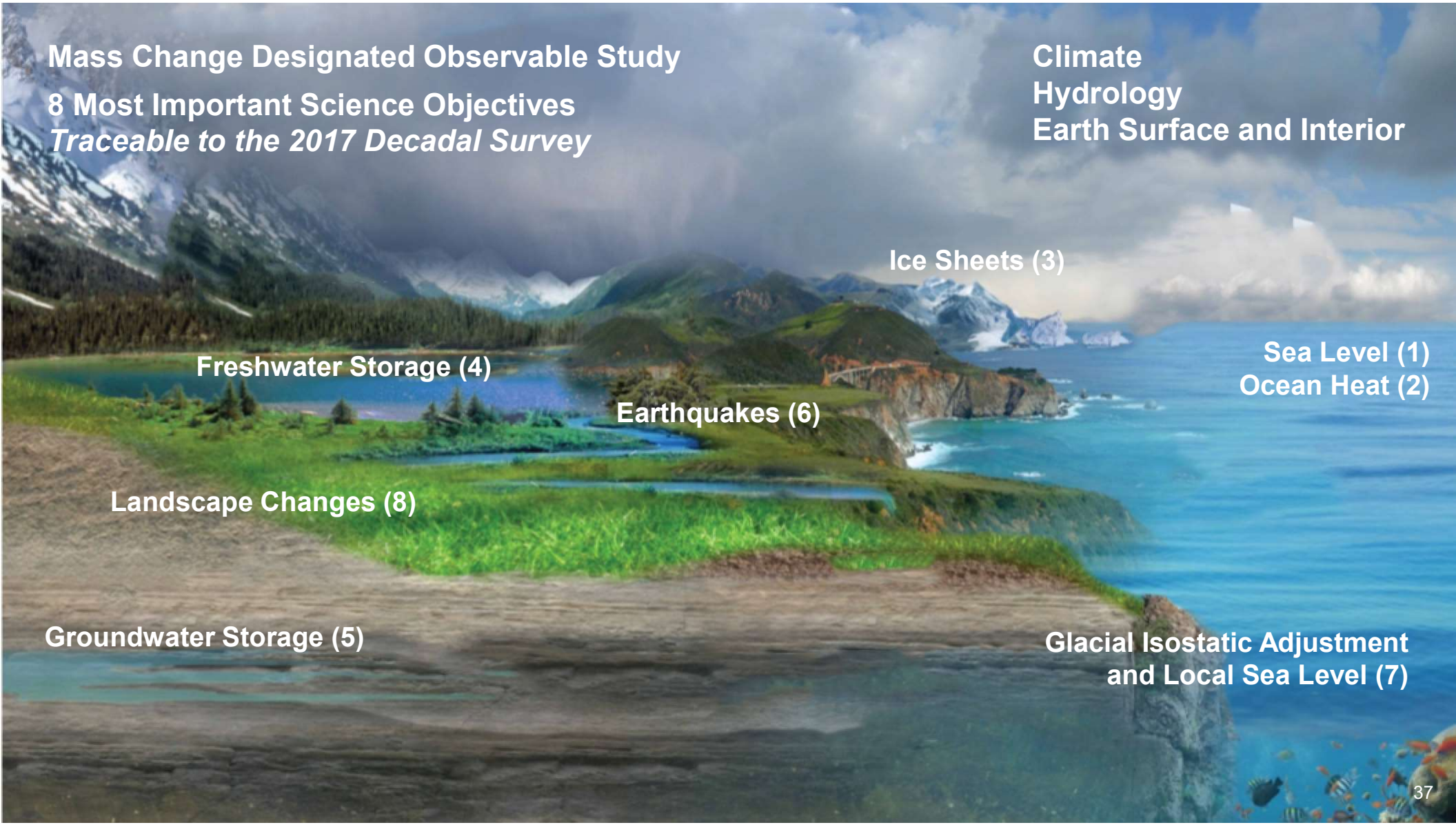
ESA: Phase 0 study complete, Phase A initiates next year. NASA & ESA letter exchange for joint studies and the development of mission requirements document for a potential joint future mission (NASA HQ & ESA). ESA prepares for a successful 2022 Ministerial such that Phase B can initiate (Bender constellation).

CNES: Phase 0 study began January 2020. Future schedule is more uncertain. Lower concept maturity (MARVEL constellation design targeting ITRF in addition to MC).

Germany (HGF/GFZ, DLR, MPI, AEI): Phase 0 funding request pending. Initiating discussions with DLR. High heritage with successful partnerships on GRACE and GRACE-FO.

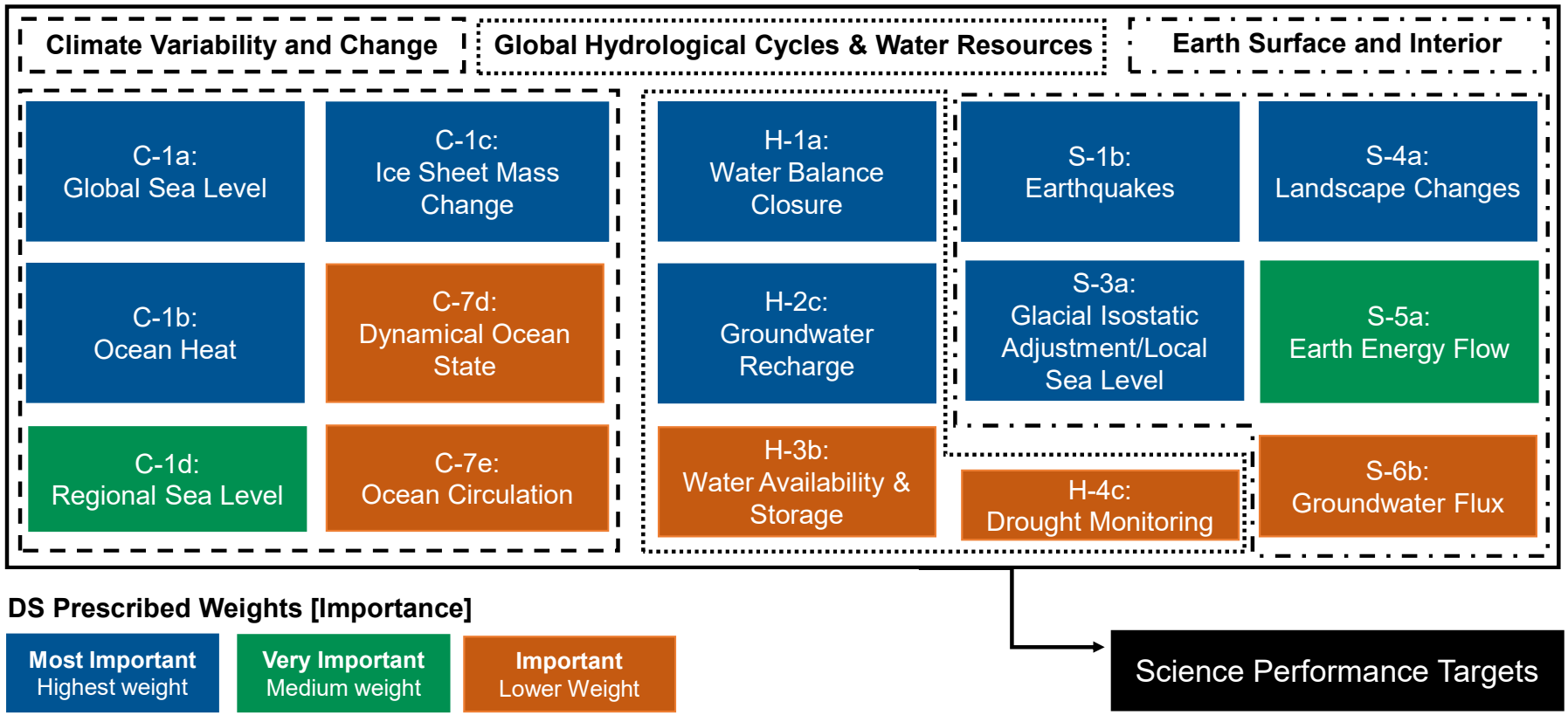
Different levels of maturity exist for each partnership concept, as well as different schedules.

International partnerships are a component of the MC observing system downselect, and will affect the cost of the future mission.

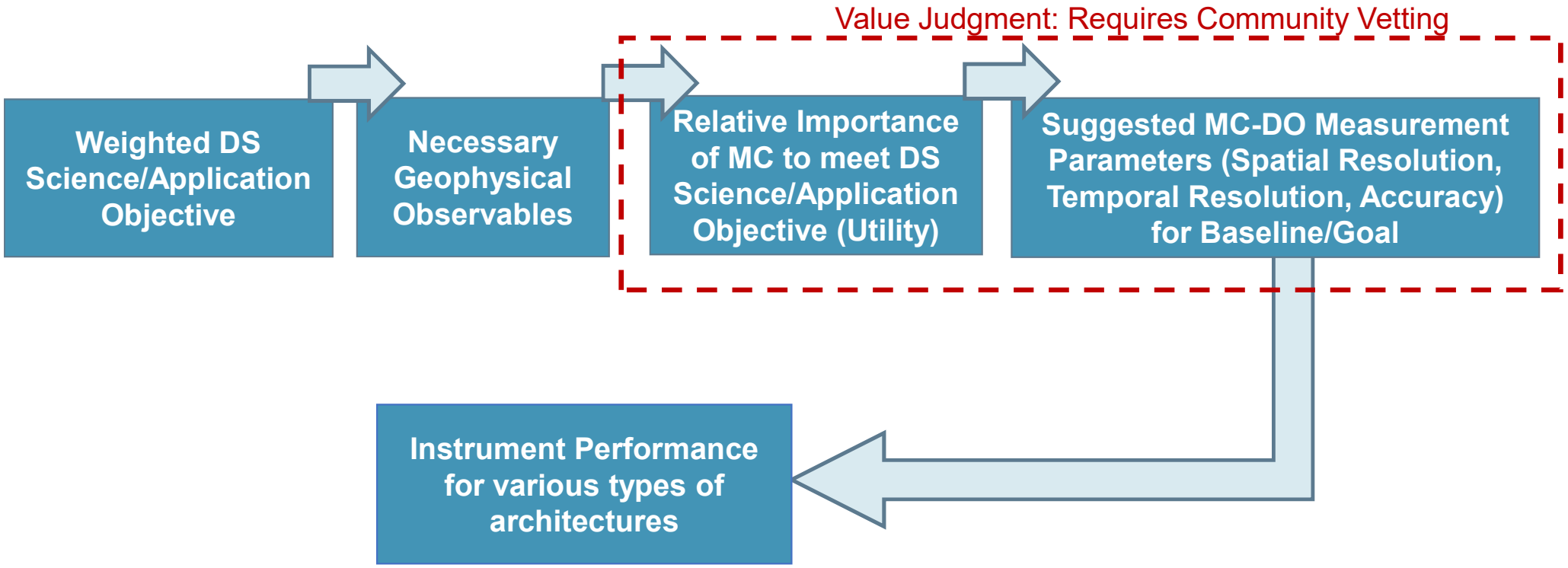

Mass Change Designated Observable Study
8 Most Important Science Objectives
Traceable to the 2017 Decadal Survey
Climate
Hydrology
Earth Surface and Interior
Ice Sheets (3)
Sea Level (1)
Ocean Heat (2)
Freshwater Storage (4)
Earthquakes (6)
Landscape Changes (8)
Groundwater Storage (5)
Glacial Isostatic Adjustment
and Local Sea Level (7)

Decadal Survey Science and Application Objectives for Mass Change

A Diverse Set of Objectives Spanning Three Panels

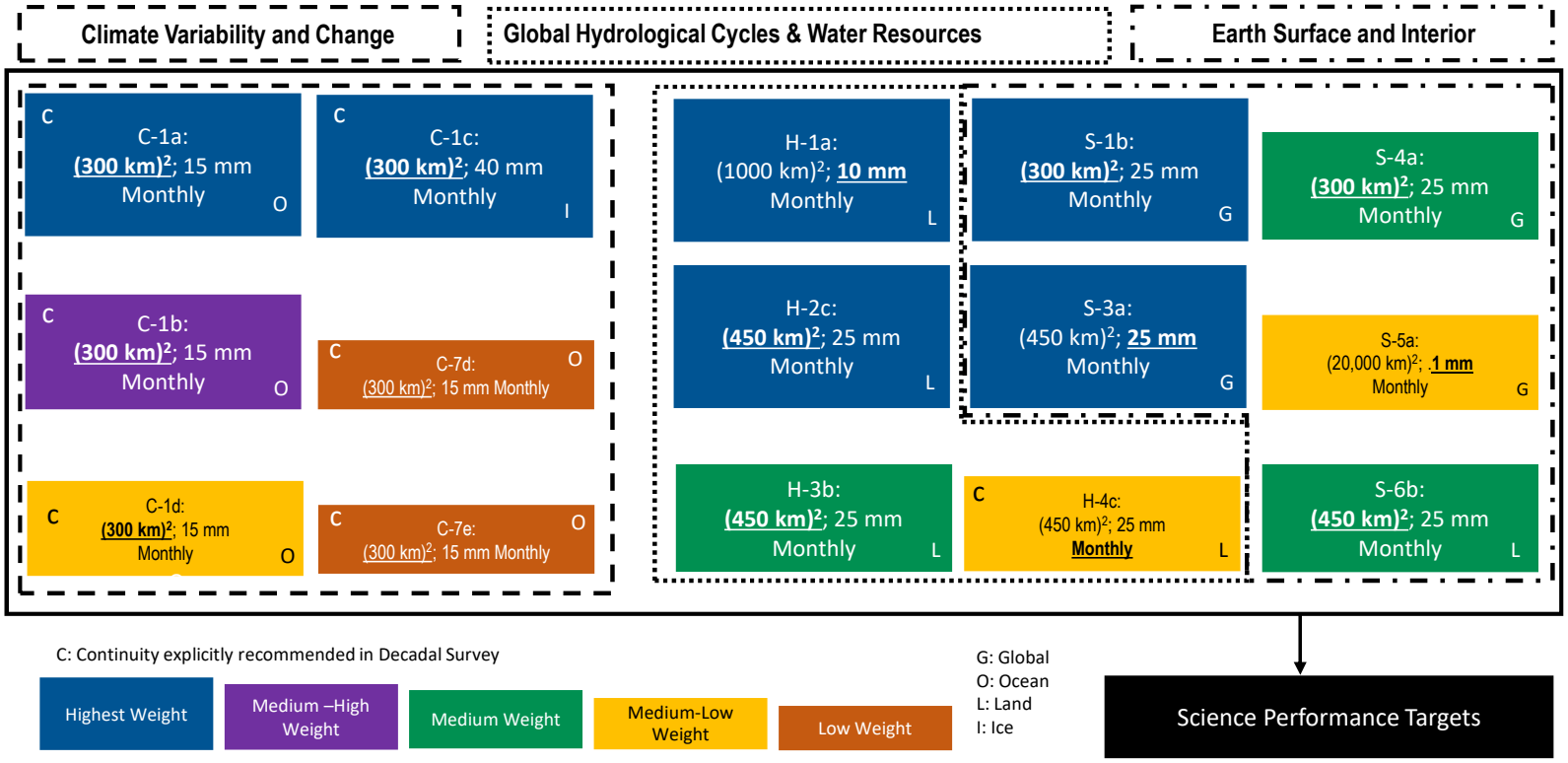


MC Interpretation of DS Objectives

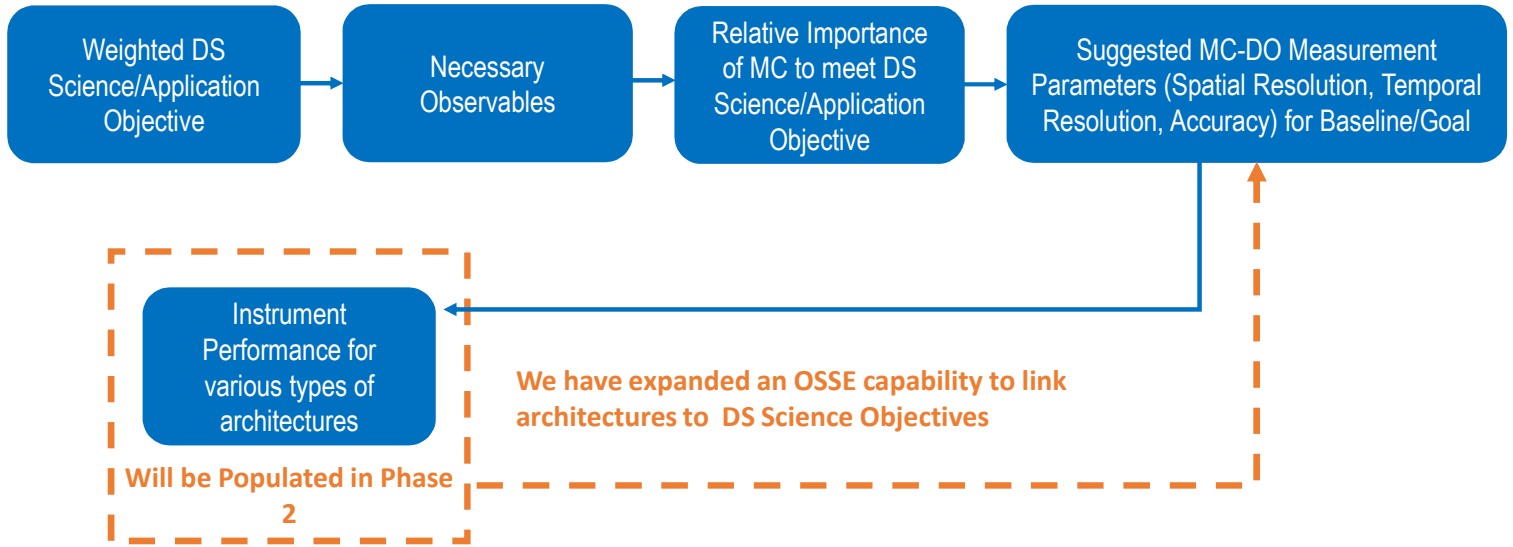


Suggested Measurement Parameters for Baseline

Weighting Combines DS Weights with MC Weights | Most Important Parameter Is Underlined | Units: Equivalent Water Height



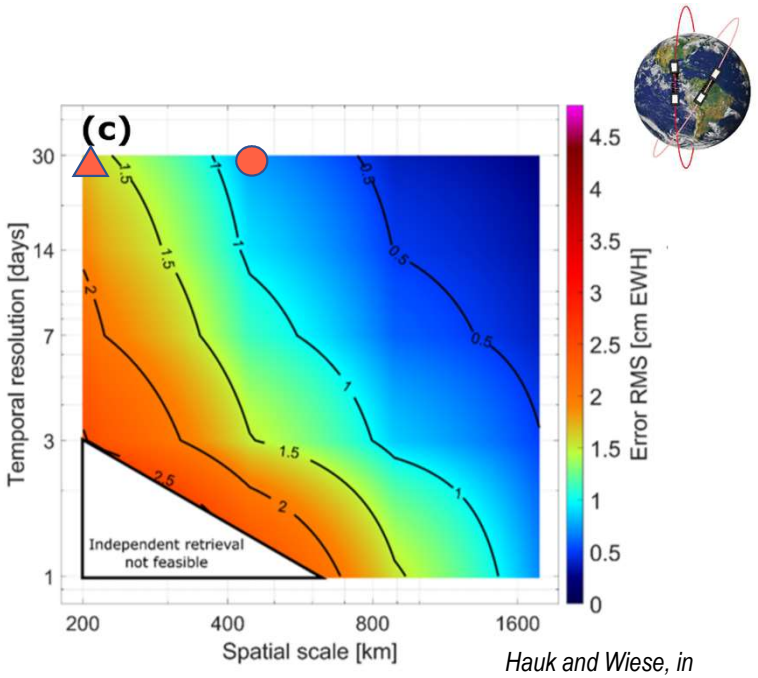
Linking Architectures to Science Performance



A Framework to Link Architectures to Science Objectives

Developed a framework to **simultaneously assess the performance of any architecture across a space-time continuum**. This allows for a direct relation between architectural choices and science performance.

- **H-3b Baseline:**
  (450 km)^2; Monthly; 25 mm
- **H-3b Goal:**
  (200 km)^2; Monthly; 25 mm



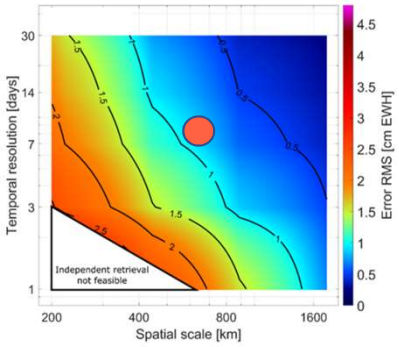
Hauk and Wiese, in prep

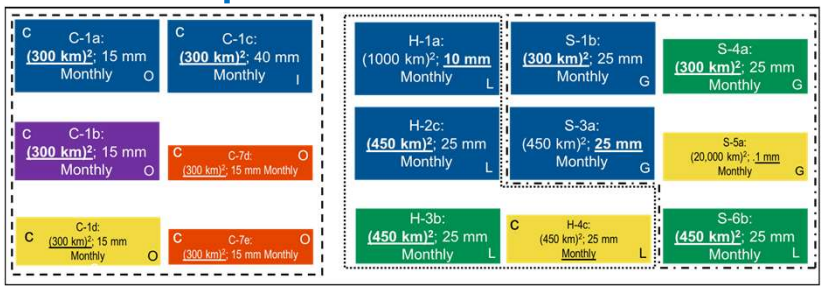
Determining Science Value in Phase 2

Must assign a science value to each architecture assessed in Phase 2 in an objective manner

The SATM has been constructed in a way to enable this

$$SV(a) = \sum_{n=1}^{15}(W_n)P_n = \sum_{n=1}^{15}\left(W_n \frac{Spatial\_Resn}{Spatial\_Res(a)} \frac{Temporal\_Resn}{Temporal\_Res(a)} \frac{Accuracy_n}{Accuracy(a)}\right)$$

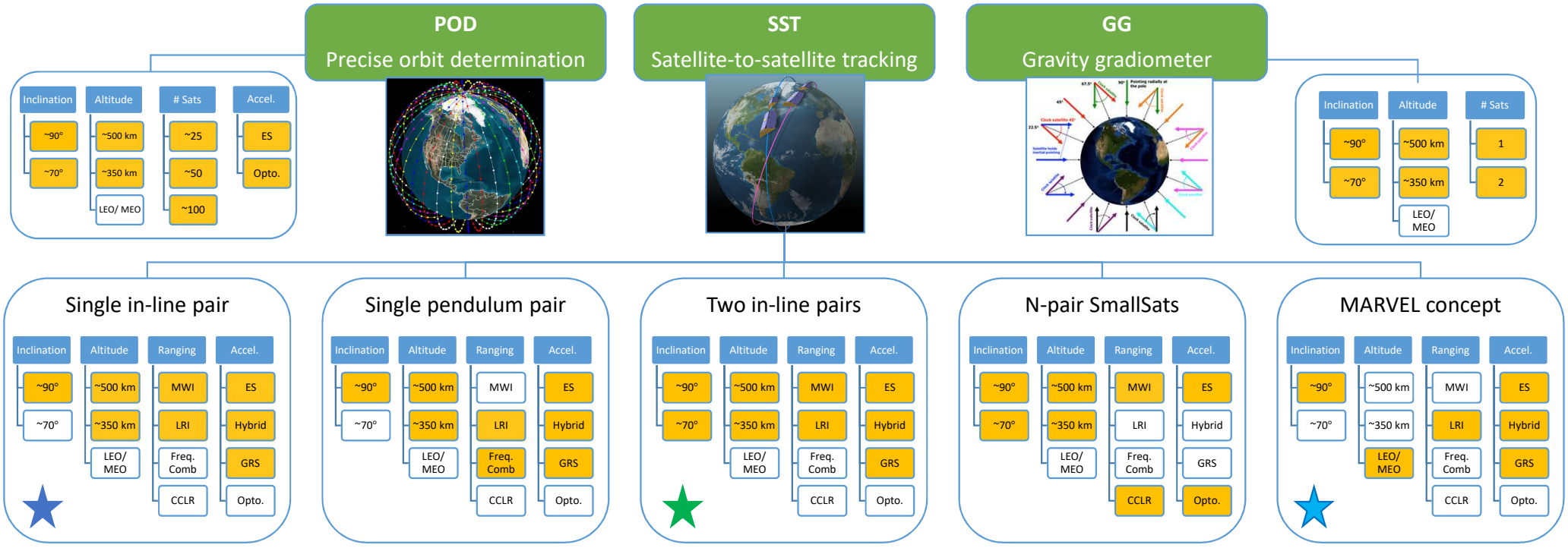




where:

- a is a specific architecture being considered
- W_n is the combination of prescribed DS weights with the mass change weights
- Two of three of $\frac{Spatial\_Res(a)}{Spatial\_Res_n}$, $\frac{Temporal\_Res(a)}{Temporal\_Res_n}$, and $\frac{Accuracy(a)}{Accuracy_n}$ will be held constant—the two to hold constant will depend on the specific n

Mass Change Architecture Summary



★ Discussions with DLR
★ Favored by ESA
★ Favored by CNES

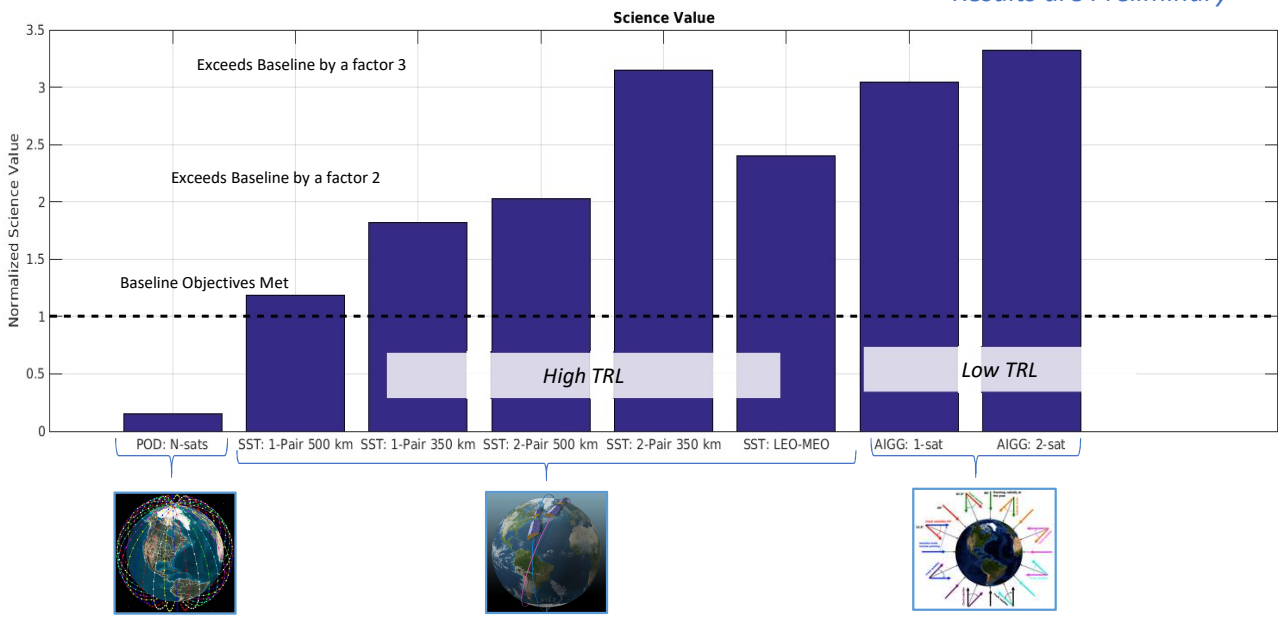
Highlighted boxes = Orbit & technology trade space

Science Value Methodology is Complete

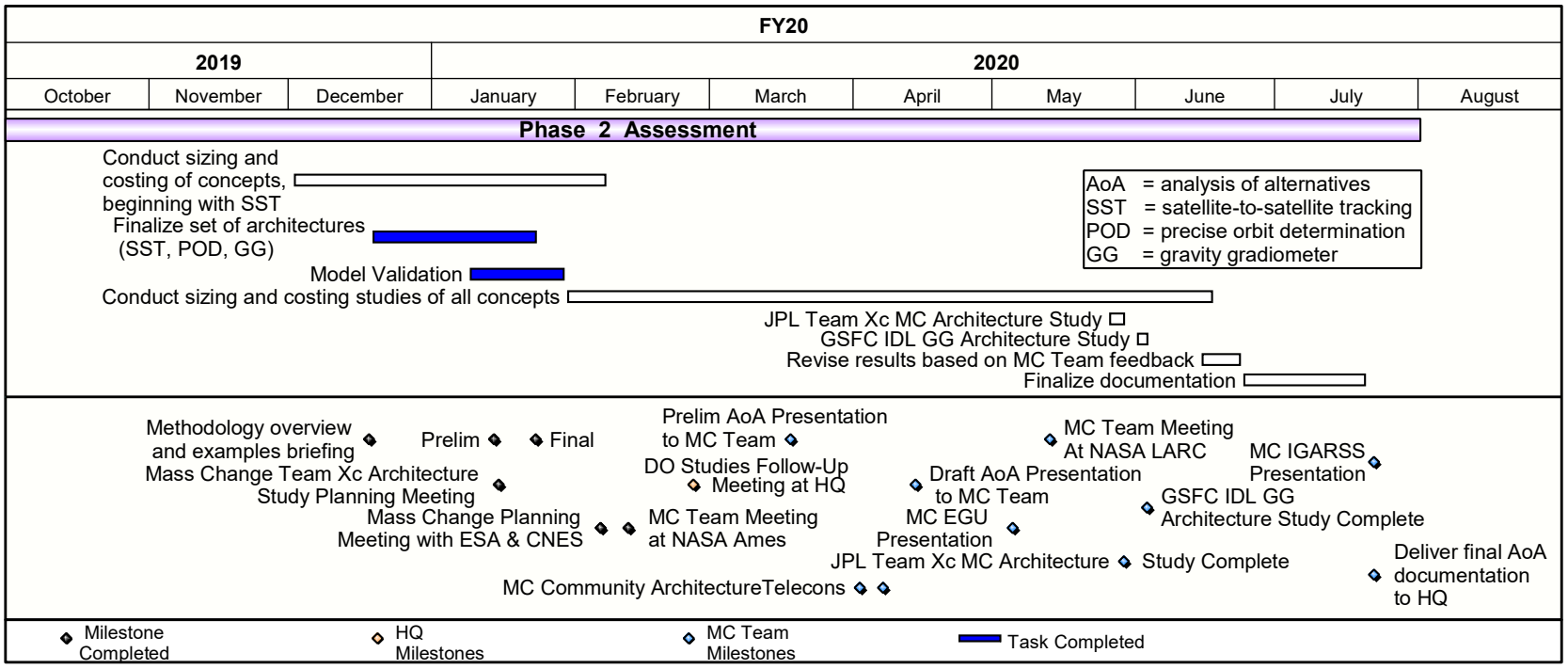
Architectures are assessed directly against targets in the SATM to provide a quantitative science value to each architecture

Architecture Performance

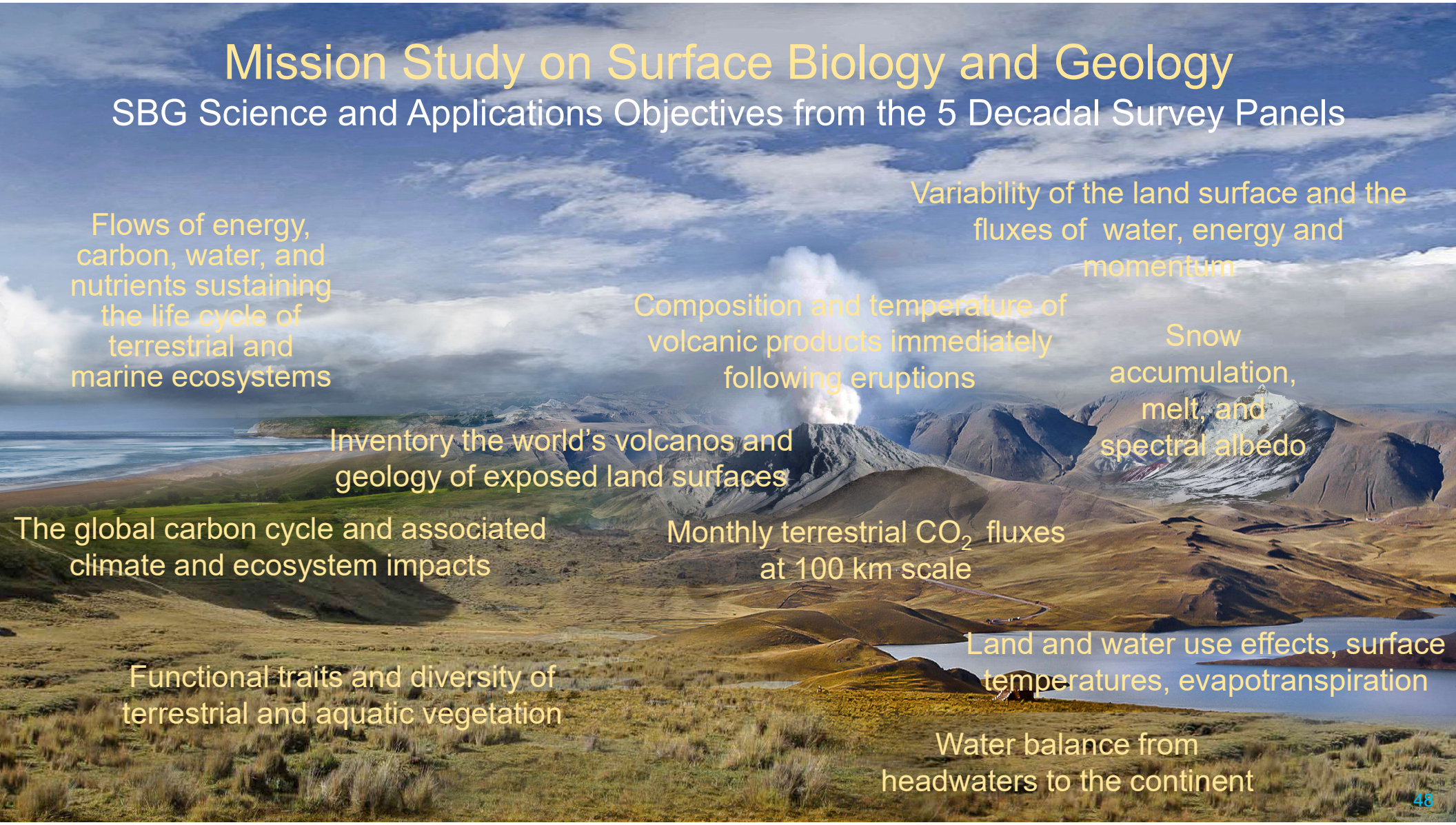
Results are Preliminary



Phase 2 Schedule



Surface Biology and Geology (SBG)


Mission Study on Surface Biology and Geology
SBG Science and Applications Objectives from the 5 Decadal Survey Panels
Flows of energy, carbon, water, and nutrients sustaining the life cycle of terrestrial and marine ecosystems
Variability of the land surface and the fluxes of water, energy and momentum
Composition and temperature of volcanic products immediately following eruptions
Snow accumulation, melt, and spectral albedo
Inventory the world's volcanos and geology of exposed land surfaces
The global carbon cycle and associated climate and ecosystem impacts
Monthly terrestrial CO_2 fluxes at 100 km scale
Land and water use effects, surface temperatures, evapotranspiration
Functional traits and diversity of terrestrial and aquatic vegetation
Water balance from headwaters to the continent
48

Surface Biology and Geology (SBG) Update

- Phase 2 Assessment of Architectures Well Underway
  - From ~61 Architectures to ~25 Architectures Currently
- RTI Applications Study Initiated
- December 13: AGU Sessions
- January 28 - 29: Co-Leads Meeting
- Request and Approval for Pathfinder and OSSE Precursor Activities
- ASI TIR Collaboration and Feasibility Study
- February 11 – 13: ECOSTRESS Science and Applications Team Meeting
- February 24 – 27: PACE Mission CDR
- February 26: DO Studies Follow-Up Meeting
- March 9: RFI posted (WH-01-20); Request for additional instrument information
  - https://beta.sam.gov/opp/2fa0878f18924a6d85dd40136329a2b2/view

SBG: Upcoming Key Dates

Date	Milestone
March 2020	ASI and ESA Technical Interface Meetings (Postponed by Coronavirus)
March 2020	Collaborative Design Session (LaRC Design Studio)
April 2020	Collaborative Design Session (JPL Team I/X)
May 2020	Collaborative Design Session (GSFC MDL)
May 27-29, 2020	SBG Community Workshop
July 2020	SBG Architecture Recommendations to HQ
Aug. - Sept. 2020	HQ Architecture Selection
December 2020	AGU Town Hall
2020 - 2021	SBG Study Final Report Preparation
2020 - 2021	SBG MCR Preparation
Spring 2021	SBG Community Workshop
September 2021	SBG MCR

SBG: International Collaboration

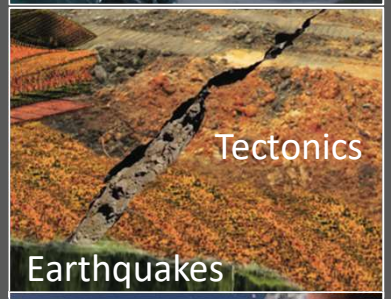
Partner	Correspondence	Instrument Type	Contribution	Science Benefit
ISRO	Discussions India-US Civil Space Nov 2019	VSWIR	Launch 2nd VSWIR instrument & satellite	4-day revisit
ASI	Exchange of letters & ASI commitment	TIR	Spacecraft, Launch, Operations	3-day revisit
CHIME (ESA)	Technical Interface Meetings	VSWIR	Data Exchange	2-3-day revisit
LSTM (ESA)	Discussions	TIR	Data Exchange	1-2-day revisit
TRISHNA (CNES, ISRO)	Discussions	TIR	Data Exchange	1-2-day revisit
Australian Space Agency	Discussions	N/A	Cal/Val	Reduced Data Product Uncertainty
DESIS (DLR)	Formal Data Buy	VSWIR	Data Exchange	Algorithm Maturation
HISUI (Japan)	Science Team Membership, NASA USPI Award (2019-2024)	VSWIR	Data Exchange	Algorithm Maturation
PRISMA (ASI)	Discussions	VSWIR	Data Exchange	Algorithm Maturation
EnMAP (DLR)	Science Advisory Group Participation USPI Award (2019-2024)	VSWIR	Data Exchange	Algorithm Maturation

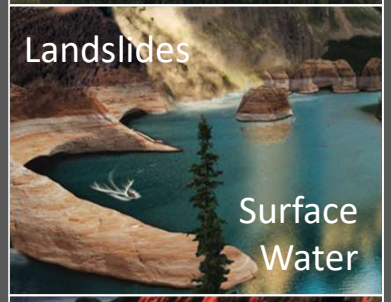
SBG: What Have We Learned

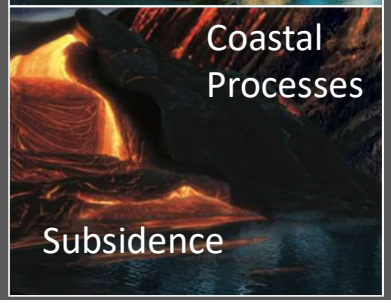
- SBG science and applications communities prioritize:
  - High spatial resolution, high SNR spectral imaging
  - Global sampling of land and coastal ocean
  - Shortest possible revisit frequency
- A single flagship/large VSWIR/TIR platform is cost prohibitive
  - Pursuing architectures with separate VSWIR and TIR components (=>2 spacecraft)
- Have cast the net widely and identified ~2 dozen high-value, affordable (<= $650M) SBG architectures
- International partnerships are critical to maximizing value within the budget guideline
- Have made significant progress in understanding Applications value as a function of latency and other factors
- Have assessed multiple calibration (both on-board and vicarious) and their applicability to specific architectures
- Websites: https://sbg.jpl.nasa.gov/; https://science.nasa.gov/earth-science/decadal-sbg

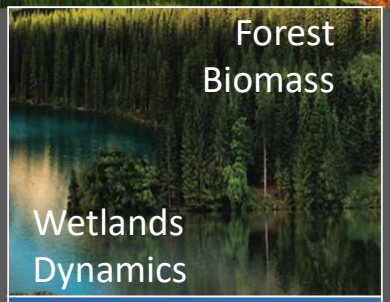
Surface Deformation and Change (SDC)

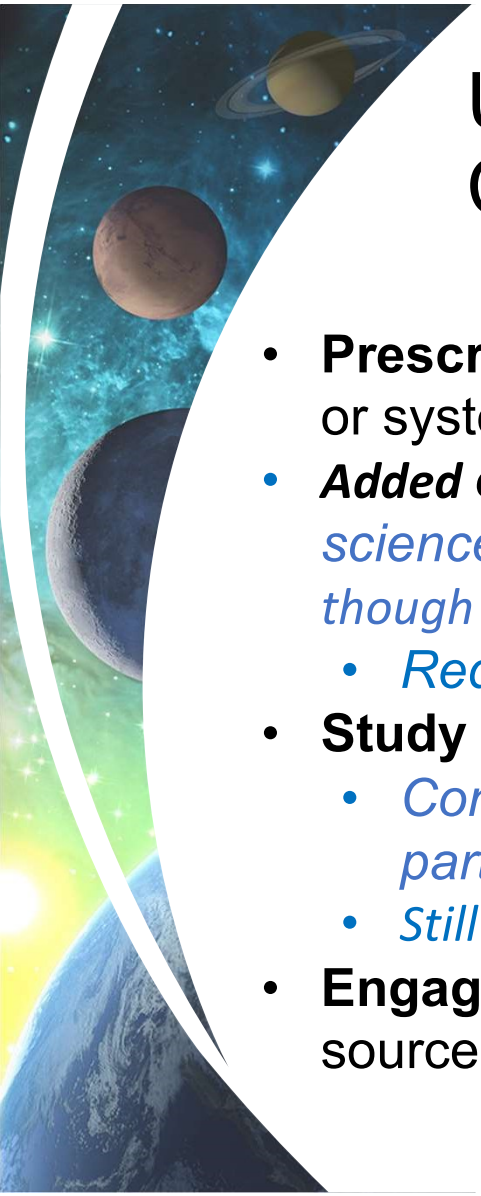
Surface Deformation and Change Observables





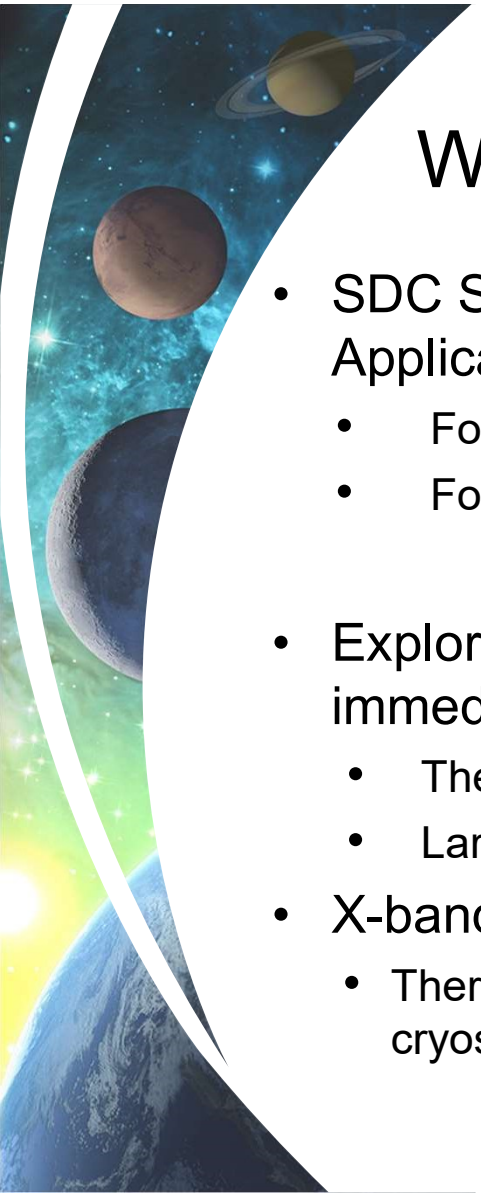






Unique Aspects of Surface Deformation and Change (SDC) Designated Observable Study

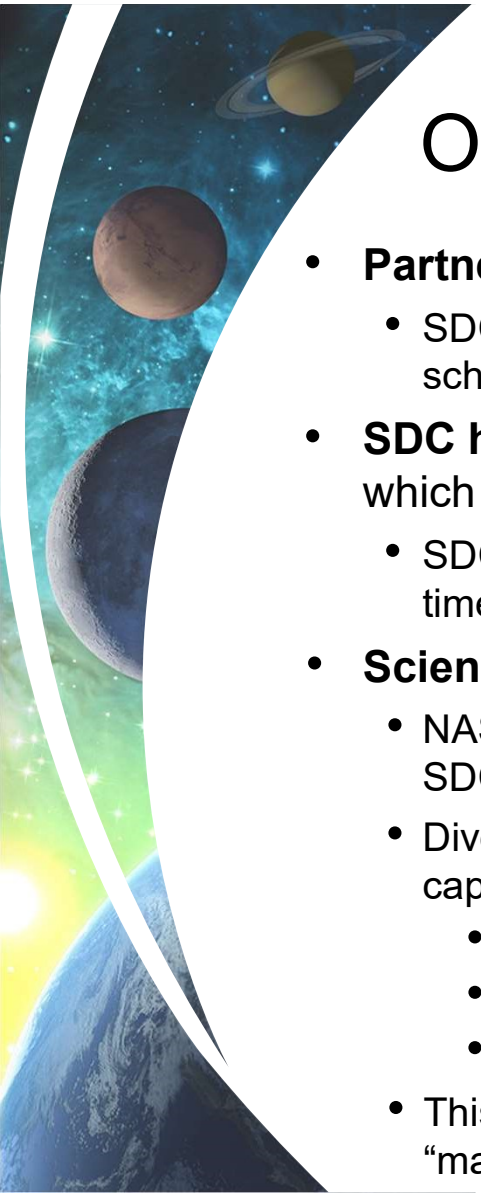
- **Prescribed sensor:** an *affordable synthetic aperture radar-based* system or systems that would meet the Decadal Survey recommendations
- ***Added observables:*** *Keep non-geodetic measurements and downstream sciences in the trade space (i.e. ecosystems, soil moisture, hydrology), though not emphasized in Decadal Survey*
  - *Requires additional exploration of SATM*
- **Study Duration:** *5 Years*
  - *Complicates the engagement with commercial and international partners which can be quite dynamic*
  - *Still 1-2 years away from down-selection*
- **Engagement:** There are literally dozens of potential *partnerships*, data sources, alliances, domestic and *international*



What SDC has learned to date

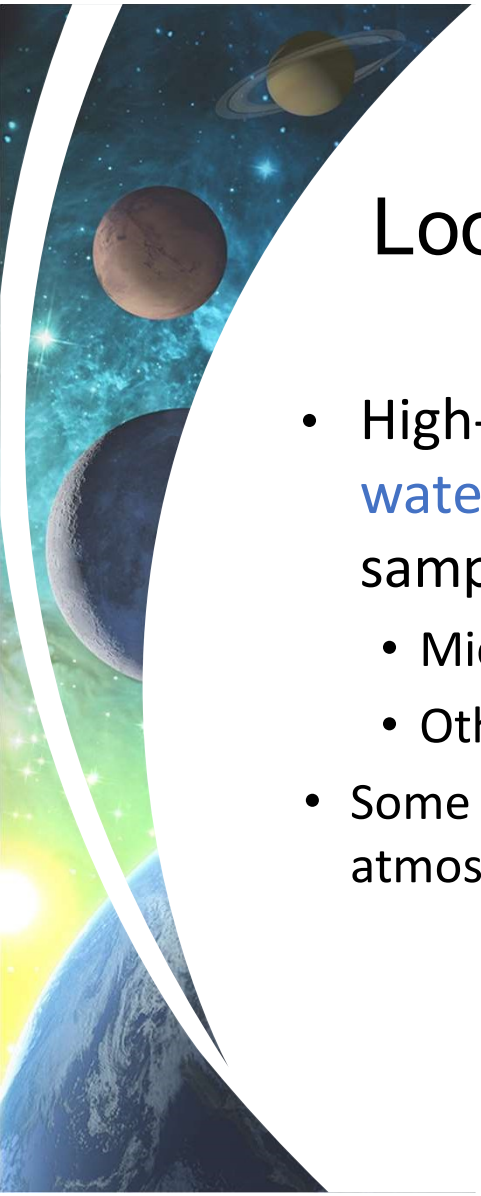
- SDC SATM development has uncovered a desire by Research and Applications community for expanded capabilities:
  - For InSAR, 12-days → 6-hr sampling
  - For SAR, strong national (applications) interest in the imagery and polarimetry

    ➔ $500M A-F cost cap will be a challenge
- Exploration of small-sat trade space and new technologies found no immediate silver bullets of cost reduction
  - The NASA Small Spacecraft Missions Program not designed for low-cost
  - Large antennas and power continue to dominate cost models
- X-band SAR commercial sector is blossoming
  - There is a potential for data buys for specific science targets and applications (e.g. cryosphere, urgent response)



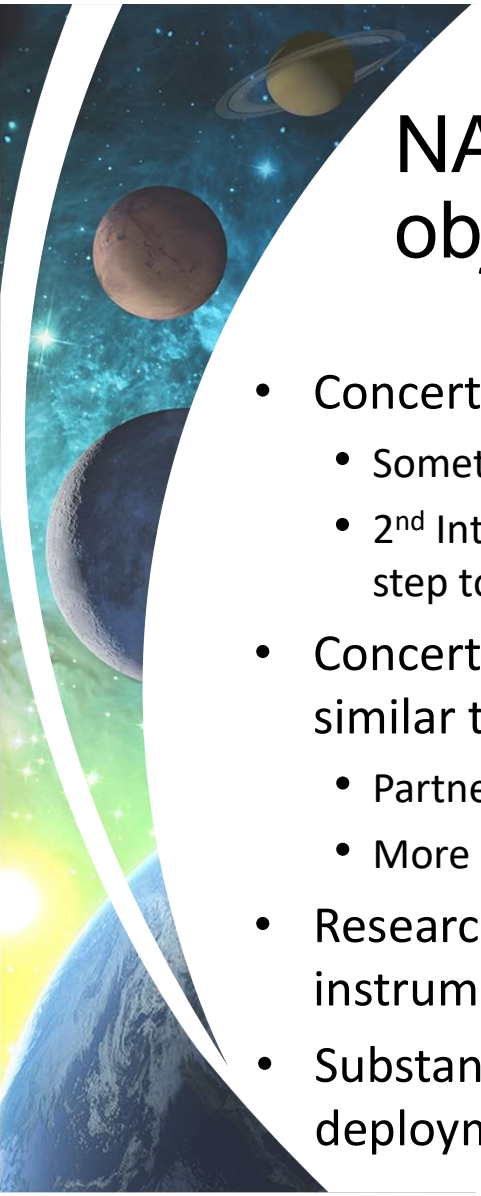
Opportunities

- **Partnerships to meet cost guidelines**
  - SDC's strategy is to identify opportunities to align NASA schedule with potential partners' schedules
- **SDC has the potential to influence the development of the commercial sector**, which is evolving rapidly
  - SDC strategy is to engage now to understand constellation configurations and pricing over time
- **Science and applications for SAR/InSAR are broad and deep**
  - NASA recognizes opportunities beyond the decadal survey recommendations and directed SDC to include these in the architecture trade space
  - Diverse communities have diverse observational needs leading to additional needed capabilities
    - Some high-resolution and targeted; others low resolution and global
    - Most demand fast temporal sampling
    - Polarimetric diversity, interferometric baseline diversity, wavelength diversity
  - This diversity provides opportunities to seek local optimizations in a vast trade space – "many good solutions"



Looking at possible game changers for SDC

- High-resolution (sub-km scale), near-simultaneous, atmospheric water vapor estimates would greatly relieve some temporal sampling pressure
  - Microwave radiometers can see through clouds, but are low resolution
  - Other radiometers are limited by cloud cover, but have higher resolution
- Some architectures being considered use vector measurements to estimate atmospheric water vapor along with geodetic changes.

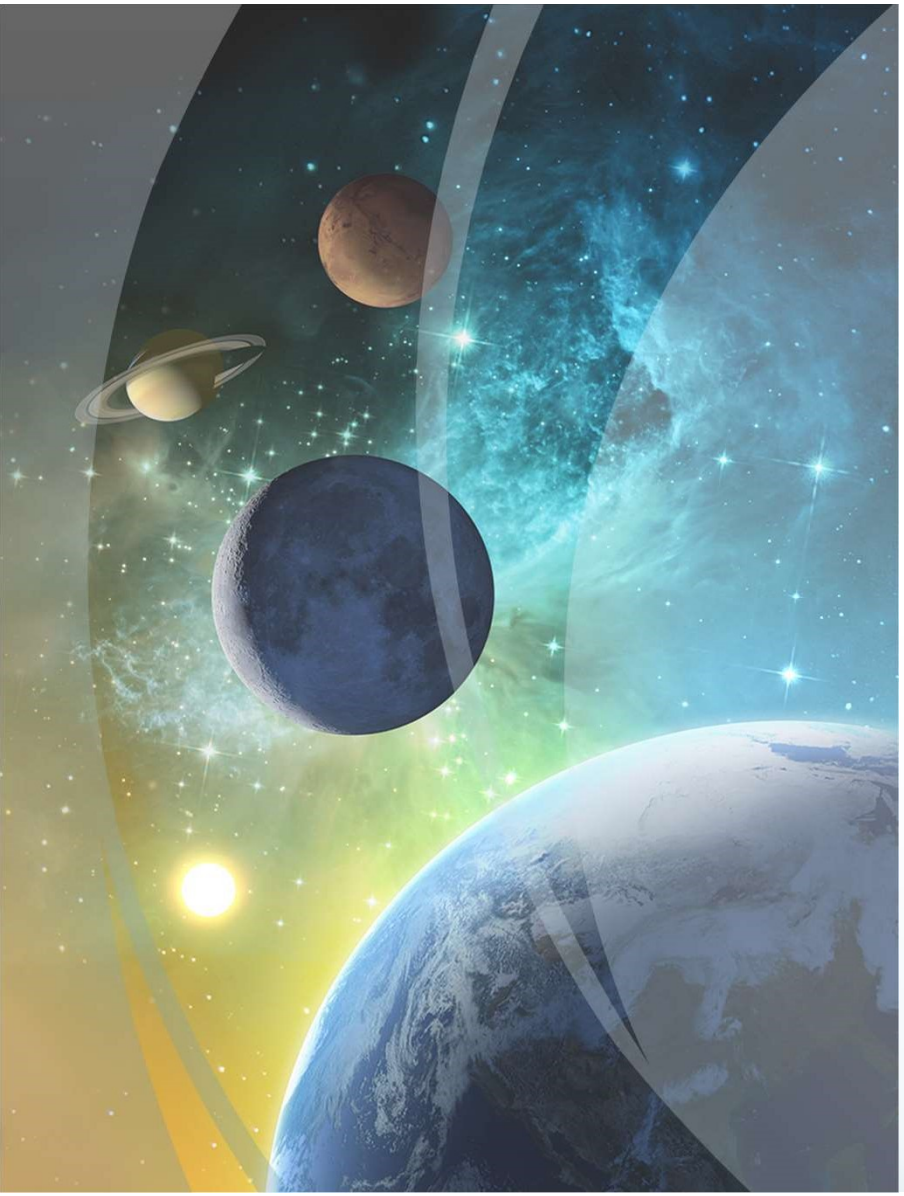


NASA program elements that could SDC objectives and needs

- Concerted agency-level coordination of SAR programs with strategic partners
  - Something akin to Polar Space Task Group, but for broader SAR programs
  - 2nd International SAR Coordination Workshop (27-29 May 2020, Frascati Italy) is another step toward this goal
- Concerted program for investing in and nurturing commercial SAR providers, similar to Defense Innovation Unit (DIU) approach
  - Partnership with DIU could be advantageous
  - More nimble acquisition and investment mechanisms
- Research opportunities for high-resolution, over-land water vapor instrumentation
- Substantial investment in antenna technology for light-weighting and deployment

On the SDC value framework

- SDC value framework (Phase 2) is to be finalized in March 2022 according to current schedule
- Key elements that must be included in the value metrics:
  1. Priority weights on science objectives and applications
  2. Traditional performance metrics for ***InSAR*** (spatial resolution, accuracy, temporal sampling, area coverage rate) parsed by science objective or application
  3. Traditional performance metrics for ***SAR*** (spatial resolution, radiometric resolution, calibration/accuracy, temporal sampling, area coverage rate) similarly parsed
  4. Cost & Cost risk
  5. Implementation risk
  6. Program of Record Evolution and Partnership opportunities
     - As relates to cost
     - As relates to measurement uniqueness or diversity



Surface Deformation and Change (SDC) Designated Observable Study Plan

2017 Earth Science Decadal Survey

Community Workshop
Surface Deformation and Change

SAVE THE DATE

May 19-21, 2020
California Institute of Technology, Pasadena, CA

Shape the future of synthetic aperture radar (SAR) research and applications following the 2017 Decadal Survey as an advocate for your community's needs, priorities and desired characteristics of observations.

We invite you to join us for our 2020 Community Workshop to:

- ***Present*** your research and applications to demonstrate the crucial contributions of current and future SAR missions.
- ***Refine*** the science and applications goals for SDC to inform the needs for specific observations acquired through potential supporting architectures.
- ***Finalize*** discussions initiated in our 2019 Research and Applications Workshop (), Technology Workshop () and AGU Town Hall session ().


Solid Earth


Ecosystems


Geohazards


Hydrology


Cryosphere

This workshop will be the last chance to discuss and share your thoughts before the SDC Study Team develops potential concepts for observing architectures and strategies. Be there!

For more information: *Ala Khazendar (ala@jpl.nasa.gov)*
Andrew Molthan (andrew.molthan@nasa.gov)
NASA SDC Team

Incubation Program Updates

Decadal Survey Incubation Program

- A new program element in the 2017 Decadal Survey, focused on investment for priority observation capabilities needing advancement prior to cost-effective implementation
- Two elements: Planetary Boundary Layer (PBL), and Surface Topography and Vegetation (STV)
- Supports maturation of mission, instrument, technology, and/or measurement concepts to address specific high priority science (for 2027-2037 decade)
- Assigned to ESTO to manage, however, will be run as a partnership between ESTO and R&A
- Anticipate a mix of Activities:
  - Technology development activities
  - Modeling/system design and analysis activities
  - Small scale pilot demonstrations
  - Typically 1-3 year activities

Incubation Observables Summary from the Decadal Survey

Observable	Science/Applications Summary	Candidate Measurement Approach	Measurement Requirements
Planetary Boundary Layer (PBL)	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights	Microwave, hyperspectral IR sounder(s) (e.g., in GEO or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar for PBL height	• From high resolution and diurnally resolved 2D/3D measurements of PBL – 200 m vertical resolution for 3D variables (Temp, Humidity, Horz. wind vector) with 2-3 hour temporal resolution and 20 km horizontal resolution
Surface Topography and Vegetation (ST&V)	**High-resolution global topography** including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar	• Contiguous 5m sampling with 0.1m vertical accuracy from space • Contiguous 1m sampling with 0.1 m vertical accuracy with aircraft • With seasonal repeat

Decadal Survey Incubation - Today

- ROSES-19 Element A.54 - **Decadal Survey Incubation Study Teams: Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV)**
  - Released March 2019; led by Program Scientists.
  - "…to identify methods and activities for improving the understanding of and advancing the maturity of the technologies applicable to these two TOs and their associated science and applications priorities.

- Two study teams selected in early Nov. 2019 – one for PBL, one for STV

- Each team is to produce a white paper that will help inform the next solicitation in FY21 and funding in FY22+
  - Outline potential future methods and activity areas, such as modeling and Observing System Simulations Experiments (OSSEs); field campaigns; and a range of potential observing system architectures utilizing emerging sensor and information technologies.
  - Other deliverables include: an interim report; presentations to NASA Headquarters; and a preliminary Science and Applications Traceability Matrix (SATM)
  - Each Study Team is required to collect community input for white papers

- Nine 1-year (FY20) augmentations of existing projects also made (PBL & STV)

PBL Selected Study Team

Science Lead: Joao Teixeira (JPL)
Technology Co-Lead: Jeff Piepmeier (GSFC)
Tech. Deputy Co-Lead: Amin Nehrir (LaRC)

11 Additional PI Team Members:

Chi Ao	JPL
Matthew Lebsock	JPL
Carol Anne Clayson	Woods Hole Oceanographic Instit.
Ann Fridlind	NASA GISS
Will McCarty	NASA GSFC/GMAO
Joe Santanello	NASA GSFC
Dave Turner	NOAA
Haydee Salmun	Hunter College CUNY
Xubin Zeng	University of Arizona
Zhien Wang	University of Colorado
Shuyi Chen	University of Washington

Community Workshop to be held May 19-21, 2020 in Columbia, MD for more information go to https://sites.google.com/view/pblmeeting/home

For more information send "subscribe" to PBL-study-announcements@lists.nasa.gov

Augmentations

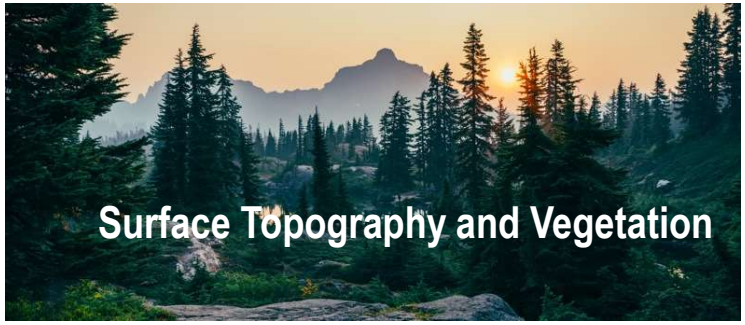
- *Ceilometer Data Analysis*, PI: Milt Halem (UMBC)
- *Satellite Lidar PBL Height Retrieval*, PI: Steve Palm (GSFC/SSAI)
- *Atmospheric Boundary Layer Lidar Pathfinder (ABLE)*, PI: Amin Nehrir (LaRC)
- *Vapor In-Cloud Profiling Radar (VIPR)*, PI: Matthew Lebsock (JPL)

STV Selected Study Team

Science Lead: Andrea Donnellan (JPL)
Technology Co-Lead: David Harding (GSFC)

9 Additional PI Team Members:

Alex Gardner	JPL
Cathleen Jones	JPL
Paul Lundgren	JPL
Yunling Lou	JPL
Sassan Saatchi	JPL
Marc Simard	JPL
Robert Treuhaft	JPL
Jason Stoker	USGS Reston
Konrad Wessels	George Mason University



Augmentations

- *G-LiHT Upgrade,* PI: Bruce Cook (GSFC)
- *Advanced Optical DEMS,* PI: Jim Tucker (GSFC)
- *ICESat-2-GEDI Fusion,* PI: Scott Luthcke (GSFC)
- *UAVSAR Imager,* PI: Andrea Donnellan (JPL)
- *Lidar Bathymetry (FINESST),* PI: Jeffrey Thayer (U of Colorado)

STV Community Workshop: planning for the week of August 3, 2020
For more information contact stv-leads@jpl.nasa.gov

Decadal Survey Incubation – Going Forward

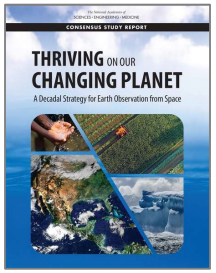
- Study Teams are expected to wrap-up in late CY20-to-early CY21
- Outcomes from the two study teams will be used to guide a ROSES solicitation for future work
- Expect a ROSES-21 call in ~Spring of 2021, for funding in FY22
- Details regarding total budget, duration, and the topics of interest for the solicitation, are TBD at this time
- ESTO will coordinate closely with HQ ESD R&A PBL and STV PSs

Decadal Survey Incubation – Points of Contact

Program Manager: Robert Bauer/ESTO (robert.bauer@nasa.gov)

Topic	Program Science Lead	Technology Lead
Planetary Boundary Layer (PBL)	Gail Skofronick-Jackson (gail.s.jackson@nasa.gov)	Amber Emory (amber.emory@nasa.gov)
Surface Topography & Vegetation (STV)	Ben Phillips (ben.phillips@nasa.gov)	Bob Connerton (robert.m.connerton@nasa.gov)

Cross-Benefits of Applications and Research



Amplify the Cross-Benefit of Applications and Research

	ELEMENTS OF DECADAL STRATEGY
I.	Embrace **Innovative Methodologies** for Integrated Science/Applications
II.	Commit to **Sustained Science and Applications**
III.	Amplify the **Cross-Benefit of Science and Applications**
IV.	Leverage **External Resources and Partnerships**
V.	Institutionalize **Programmatic Agility and Balance**
VI.	Exploit **External Trends** in Technology and User Needs
VII.	Expand Use of **Competition**
VIII.	Pursue **Ambitious Science**, Despite Constraints

Highlights from the DS's three paragraphs include:

- Curiosity-inspired science will always be central to Earth observation and analysis. But a growing portion of our science is use-inspired or closely related to the applications it enables.
- Inspiration goes both ways: science inspires applications scientists and engineers, and end-use needs can inspire research scientists and engineers.
- Embedding science in the applications process often reveals new and inspirational scientific questions driven by those end-uses not well-recognized by research scientists.
- … programs with both science and applications elements need to explicitly identify the connection, and define opportunities to amplify the cross-benefit, and organization structures and processes need to be adapted when possible to integrate, rather than segregate, science and operations/applications.

ESD & Cross-Benefit

NASA Earth Science has supported activities in research, applied research, and applications for years (not in equal proportions).

The Decadal Survey acknowledges some of ESD's activities to support the cross-benefit, yet it calls to amplify this work.

"Amplify" suggests both that more is needed and that more awareness is needed for the activities and successes that do occur.

- Issues of Production and Perception

Over last year, relevant pairs of ESD managers in R&A and Applied Sciences:

- Examined examples of successful two-way interactions to date
- Considered high-potential opportunities in the near- and longer-term

Efforts to Amplify Cross-benefit include:

- Activities by and across ESD Programs, especially R&A and Applied Sciences
- Activities within broader Earth science community (ESD in conjunction with other organizations)

Examples of ESD Activities Linking Applications & Research

Co-Managed Initiatives

Joint Team Meetings and Solicitations

Designed Funding Transitions

Applied Sciences Teams

Integrated Science Teams

Integrated Directed Work

Earth Science Trainings

Assessment Participation

Field Campaigns

High Mountain Asia
The High Mountain Asia initiative involves managers from both AppSci and R&A. Projects & team meetings foster research-policy-management discussions, helping to identify new and unique research questions.

Health & Air Quality Applied Sciences Team
AppSci's HAQAST sponsors researchers (historically funded by R&A) to meet with and listen to state & local officials. They discuss users' challenges and co-design projects. Dedicated funding supports agile, short-term "Tiger Team" applications projects. Researchers build capacity to talk with users and learn about users' pain points and challenges that may need new research.

Approach to Further Amplify Cross-Benefit

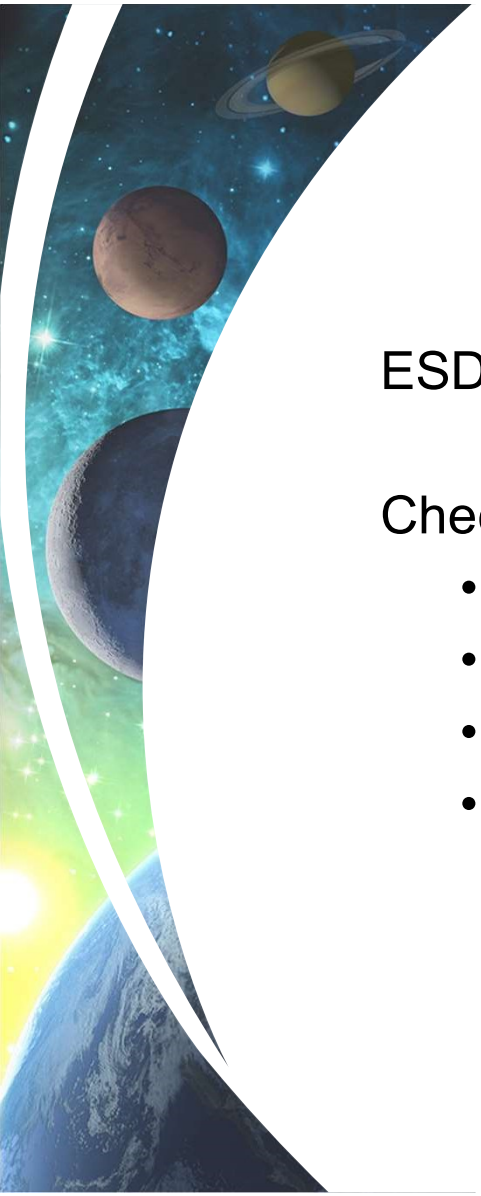
ESD is committed to enabling a more integrated approach that supports cross-benefit – create a continual interplay in enabling impacts for society and in the generation of fundamental and applied knowledge about the Earth system.

Involves the data we collect and the information products we provide

Involves consideration of questions and gaps collected from managers along with priorities of researchers (Designated Observables are examples)

- Applied team supports connections of users back to R&A in articulating gaps, re-doubles efforts to connect with R&A and stay abreast of research results
- R&A incorporates broader views, and Focus Areas include Applied colleagues more
- Involves Flight, ESTO, Data Systems, and all parts of ESD
- More connections to broader sets of organizations while also maintaining ESD's independence to explore fundamental research & experimental observations

What’s Next?

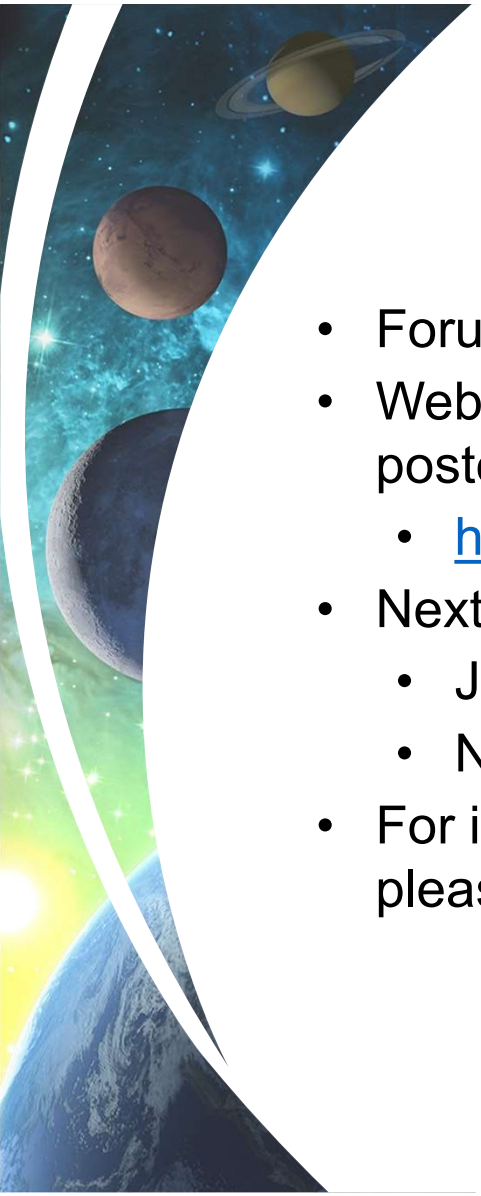


What's Next?

ESD Leadership Team continues to address additional DS topics

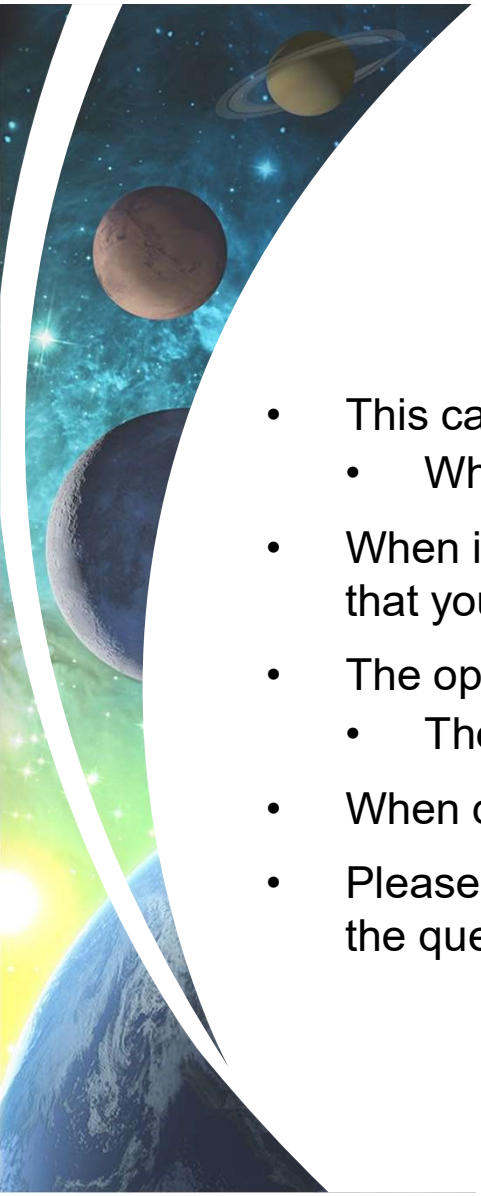
Check the ESD Decadal Survey web page to:

- Find meeting schedules and details
- Ask questions and see answers as they become available
- Review information in previous sets of charts
- https://science.nasa.gov/earth-science/decadal-surveys



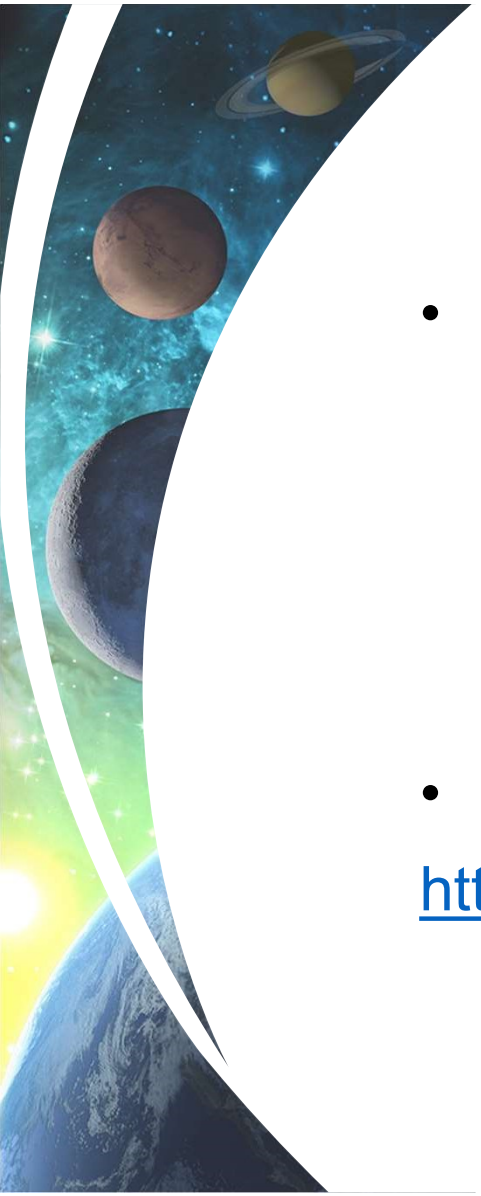
2020 Community Forums

- Forums will be held from 1-3 p.m. (Eastern)
- WebEx and telecon information, in addition to other updates, will be posted on the NASA ESD Decadal Survey website
  - https://science.nasa.gov/earth-science/decadal-surveys
- Next forums slated for:
  - July 16, 2020
  - Nov. 12, 2020
- For information about future Decadal Survey Community Forums, please send an email to Amy Treat at Amy.A.Treat@nasa.gov



Questions Process

- This call is monitored by an operator
  - When you join the call, the operator will ask for your name
- When it is time for questions, please press *1 on your phone to indicate to the operator that you have a question
- The operator will introduce you by name and un-mute your line
  - Then you can ask your question and any follow up questions
- When done, the operator will re-mute your line and introduce the next person
- Please also email questions to **Amy Treat** at **Amy.A.Treat@nasa.gov** so we can post the question and its answer on our website



How to Get Involved

- To join a working group or sign up for updates, send an email to:
  - **SBG:** sbg@jpl.nasa.gov
  - **MC:** masschange@jpl.nasa.gov
  - **SDC:** sdc-study@lists.nasa.gov
  - **ACCP:** a-ccp-comments@lists.nasa.gov
- General updates can be found on our website:

https://science.nasa.gov/earth-science/decadal-surveys/

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Amanda Whitehurst	amanda.s.whitehurst@nasa.gov

Backup

Targeted Observables Priorities

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	Aerosol properties, aerosol vertical profiles, and cloud properties to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection and Precipitation	Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	Large-scale Earth dynamics measured by the changing mass distribution within and between Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	Earth surface geology and biology, ground/water temperature, snow reflectivity, active geological processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperature Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	CO2 and methane fluxes and trends, global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar **		X	
Ice Elevation	Global ice characterization including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar **		X	
Ocean Surface Winds and Currents	Coincident high-accuracy currents and vector winder to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift	Radar scatterometer		X	

*** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables*

Targeted Observables Priorities

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Ozone and Trace Gases	Vertical profiles of ozone and trace gases (including water vapor, CO, NO2, methane, and N20) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth and Snow Water Equivalent	Snow depth and snow water equivalent including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	3D structure of terrestrial ecosystem including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation and forest degradation	Lidar**		X	
Atmospheric Winds	3D winds in troposphere/PBL for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	Diurnal 3D PBL thermodynamic properties and 2D PBL structure to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling and DIAL lidar; and lidar** for PBL height			X
Surface Topography and Vegetation	High-resolution global topography including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

*** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables*

Other ESAS 2017 Targeted Observables not allocated to a Flight Program element: Aquatic Biogeochemistry, Magnetic Field Changes, Ocean Ecosystem Structure, Radiance Intercallibration, Sea Surface Salinity, Soil Moisture

See: https://science.nasa.gov/earth-science/decadal-surveys

ESD has decided to treat Atmospheric Winds as Explorer