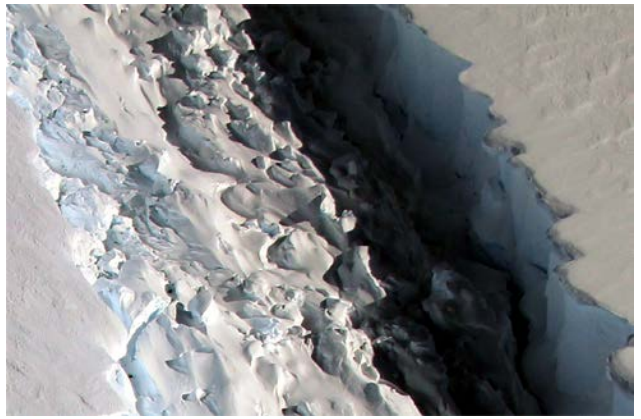
SCIENCE






Decadal Survey Briefing to Earth Science Stakeholders

Earth Science Division, NASA HQ

May 10, 2018

Attendance/Questions

- Please email your name to ensure you will be informed of future Community Forums
- During this presentation please email your questions.

TO: Amy.A.Treat@nasa.gov

Community Input Requested

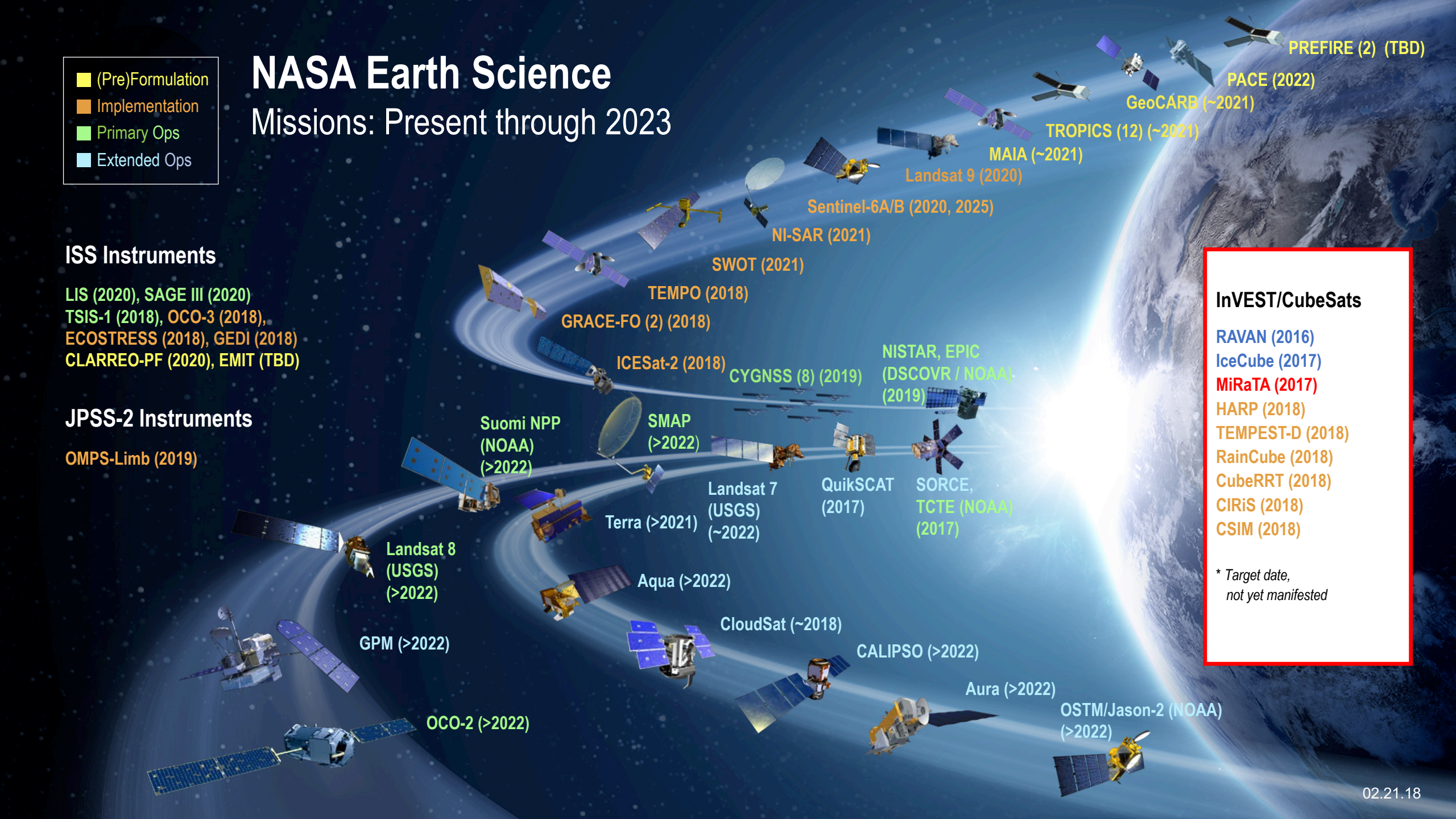
- ESD solicits ideas from the non-governmental/private sector on ways to participate in the strategic planning process associated with realistically implementing the Decadal recommendations.
- During the actual implementation, we will engage with industry in the traditional ways, such as via Announcements of Opportunity and Requests for Proposals.
- We also seek new ways to leverage the work and ideas in the private sector in order to increase mission/observing system/portfolio capability and/or to reduce costs.
  - This may involve exploiting emergent commercial technologies and capabilities, exploring concepts and methods traditionally not utilized by the government, expanded procurement of commercially available data, etc.

Outline

- Appropriation Status
- ESD Flight Program Status and Plans
- 2017 Earth Science and Applications from Space Decadal Survey
- ESD Responses and Plans: Progress and decisions
- Stakeholder Community Involvement
- Community Input Requested
- Questions

NASA/ESD Appropriation: FY18

- FY18 (1 Oct 2017 – 30 Sept 2018) funding – appropriated via an Omnibus – is at the **FY16/FY17** level (~$1.92B)
- Continues operations and development of FY17 Program of Record (including DSCOVR EPIC/NISTAR, PACE, CLARREO-PF, OCO-3 [to launch as manifested in late CY2018/early CY2019])
- Endorses ESD/SMD discontinuance of RBI
- President's FY19-23 budget proposal again proposes termination of CLARREO-PF and PACE development, and discontinuance of on-orbit DSCOVR/EO instruments and OCO-3
- FY19-23 President's Budget Proposal ***supports continuation of a balanced ESD portfolio***
  - Funding for all remaining elements of the ongoing Flight Program of Record
  - Landsat-9 remains on-track for 12/2020 launch; NASA portion of Sustainable Land Imaging Program funded
  - Venture-Class remains fully funded and on-track for planned solicitations and selections
  - Applied Sciences and Earth Science Technology Office programs flat-funded, including InVEST CubeSat validation program
  - Small-satellite Constellation Data Buy Pilot funded


(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2018),
ECOSTRESS (2018), GEDI (2018)
CLARREO-PF (2020), EMIT (TBD)
JPSS-2 Instruments
OMPS-Limb (2019)
PREFIRE (2) (TBD)
PACE (2022)
GeoCARB (~2021)
TROPICS (12) (~2021)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC
(DSCOVR / NOAA)
(2019)
Suomi NPP
(NOAA)
(>2022)
SMAP
(>2022)
Landsat 7
(USGS)
(~2022)
QuikSCAT
(2017)
SORCE,
TCTE (NOAA)
(2017)
Terra (>2021)
Landsat 8
(USGS)
(>2022)
Aqua (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OSTM/Jason-2 (NOAA)
(>2022)
GPM (>2022)
OCO-2 (>2022)
InVEST/CubeSats
RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018)
CSIM (2018)
* Target date,
not yet manifested
02.21.18

RECENT and UPCOMING NOTABLE FLIGHT PROGRAM EVENTS

- 2017 Senior Review recommended continuation of most on-orbit missions
- QuikSCAT to be terminated by October 2018
- Operation of TES instrument on Aura discontinued (low availability resulting from hardware issues)
- CATS (ISS) mission ended owing to instrument failure
- RBI discontinued by NASA for technical, cost, schedule issues; work underway to develop an affordable and capable replacement for launch in JPSS-3 timeframe (2026)
- GRACE mission ended
- Jason-2/OSTM moved to lower orbit (IMU redundancy/temperature issues) – continues to provide near-real-time and geodetic measurements
- CloudSat moved to safe orbit below A-Train (loss of hardware redundancy) – continues to provide high-quality science data, near-term decision on Calipso orbit change plan
- TSIS-1 instrument successfully launched to ISS and operating
- NOAA's JPSS-1 mission successfully launched and operating
- ICECube, MIRATA CubeSats launched (MIRATA failed once on-orbit); MicroMAS-2 CubeSat successful on ISRO PSLV-40 launch

- OCO-3 completion and delivery to storage May, 2018 for launch likely by Feb, 2019
- GRACE-FO on-track for launch May 19, 2018
- TEMPEST-D, RainCube, CubeRRT, CSIM CubeSats/SmallSats, HARP manifested for launch in 2018 (3 on OA-9, May 20, 2018)
- ECOSTRESS on track for launch NET June 28, 2018
- ICESat-2 on-track for launch September, 2018
- GEDI delivery accelerated to allow launch as early as November, 2018
- EVI-4 selections: EMIT (hyperspectral aerosol mineralogy/composition) and PREFIRE (Arctic Far-IR emissions from dual CubeSats)

Earth Science Division's Venture Opportunities

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)
(~18 months)

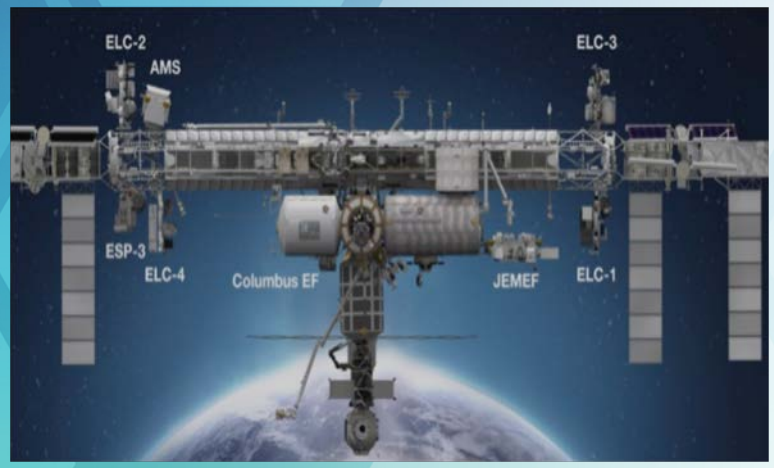
Mission	Mission Type	Release Date	Selection Date	Major Milestone
EV-1, aka EVS-1	5 Suborbital Airborne Campaigns	2009	2010	N/A
EVM-1, CYGNSS	Smallsat constellation	2011	2012	Launched Dec 2016
EVI-1, TEMPO	Geosynchronous hosted payload	2011	2012	Delivery NLT 2017
EVI-2, ECOSTRESS & GEDI	Class C & Class D ISS-hosted Instruments	2013	2014	Delivery NLT 2019
EVS-2	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
EVI-4	Instrument Only	2016	2018	Delivery NLT 2021
EVS-3	Suborbital Airborne Campaigns	2017	2018	N/A
EVI-5	Instrument Only	2018	2019	Delivery NLT 2023
EVM-3	Full Orbital	2019	2020	Launch ~2025
EVI-6	Instrument Only	2019	2020	Delivery NLT 2024

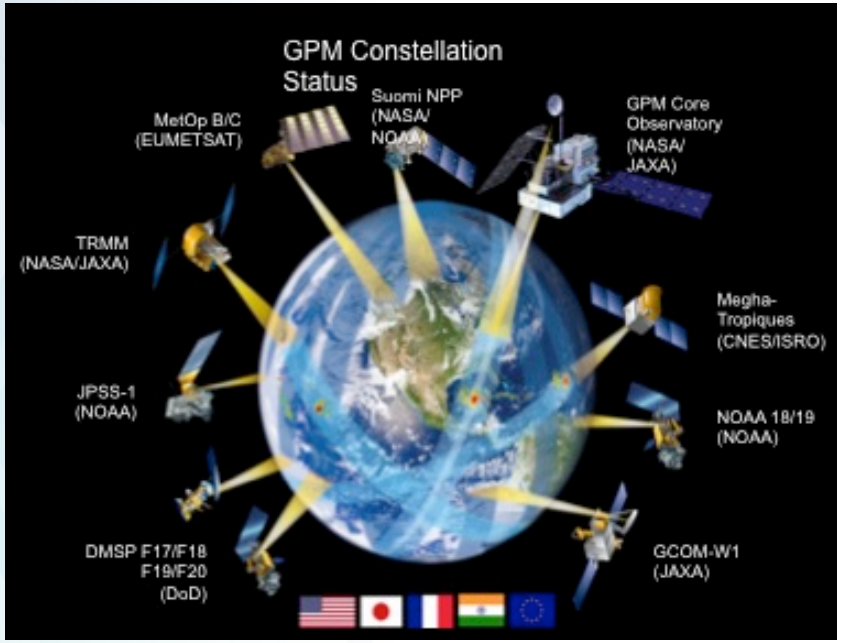
EMIT, PREFIRE selected for EVI-4

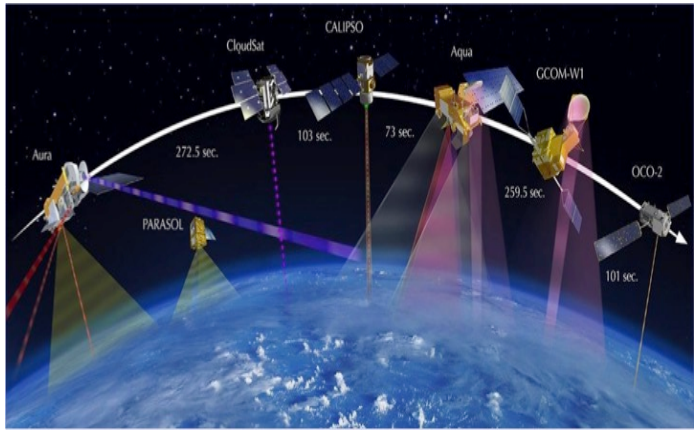
Open solicitation - In Review

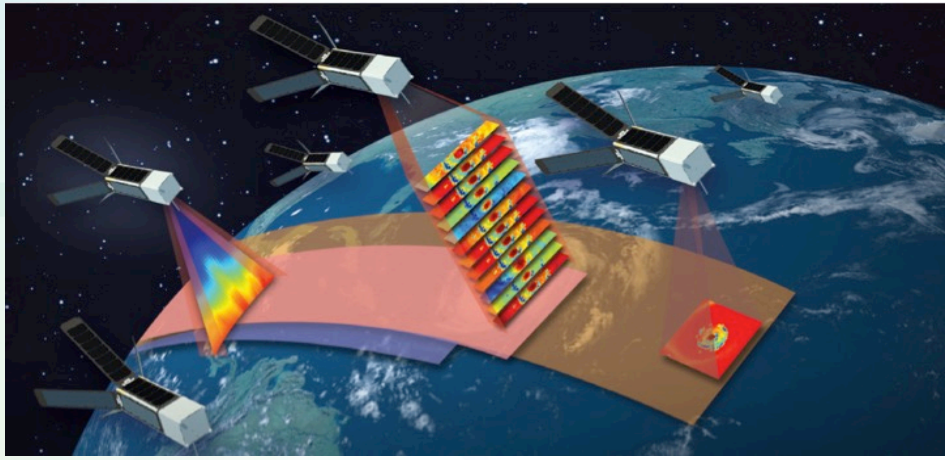
Completed solicitation

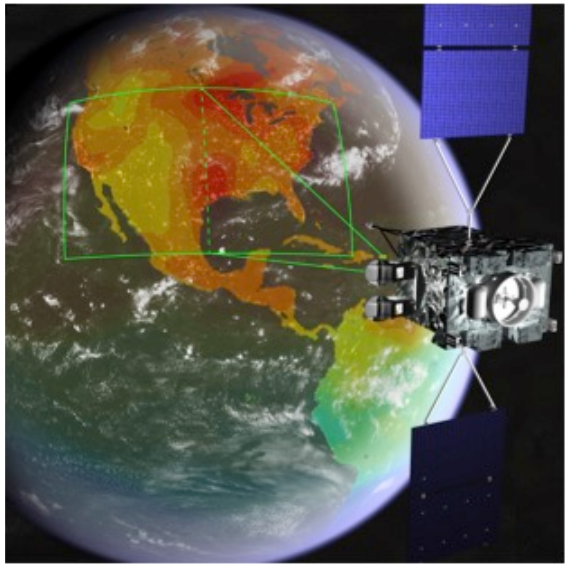
NASA Observing System *INNOVATIONS*











ESD's Small Satellite Observing System Solutions

ESD is pursuing a rich program of orbital missions using small satellites

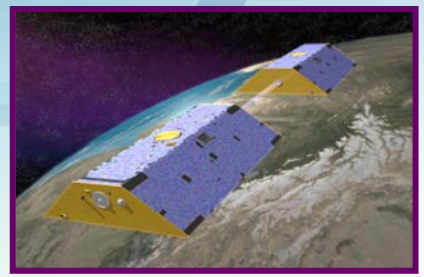
- **CYGNSS (Cyclone Global Navigation Satellite System)**: homogeneous tropical constellation of 8 ***micro-satellites*** using reflected GPS to measure surface winds/air-sea interactions, especially valuable/unique in the precipitation-dominated, dynamic, eyewalls of tropical storms and hurricanes – frequent tropical sampling from 1 orbit plane **SCIENCE**
- **TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats):** homogeneous tropical constellation of 6 ***CubeSats*** to measure atmospheric profiles in storms/hurricanes – frequent sampling from 2-3 orbit planes **SCIENCE**
- **In-Space Validation of Earth Science Technologies (InVEST):** on-orbit ***CubeSat-based*** technology validation and risk reduction that could not otherwise be fully tested using ground/airborne systems **TECHNOLOGY**
- **Venture Class Launch Services:** Investment in new, low-cost (<$15M/launch), commercial launch vehicles capable of orbiting small payloads to LEO – science control of launch schedule and orbits **ENABLING**

Private Sector Small-Satellite Constellation Pilot

Data buys of ***existing*** data products related to ECVs, derived from private sector-funded small-satellite ***constellations*** (3-satellite minimum constellation, full longitude coverage); ***for evaluation by NASA researchers to determine value*** for advancing NASA research and applications activities and objectives; ***pilot buys in 2018***

- **RFIs released 12 August 2016 and 5 Dec 2017** requesting capability statements
  - 5 responses received to 2016 RFI (3 qualifying)
  - 11 responses received to 2017 RFI (4 qualifying)
- **Sufficient FY18 funding is available ($10M)**
- **Issuing sole-source contracts to all qualifying respondents (in process)**
- **Have identified a broad set of ESD-funded researchers who will be supported to *assess the value of the geophysical information in the products for advancing NASA research and applications objectives***
  - 1 year evaluation period
  - Participants primarily chosen from existing ESD-funded community – evaluation support as budget augmentation
  - Written reports to ESD (not scientific papers)
  - Quality of geophysical information
  - Data availability (latency) and subdistribution rights vs. cost
  - Vendor plans for constellation maintenance/evolution

ESD Partnership Missions in Development



GRACE FO
LRD: Apr 2018
Global mass & water variation

Partner: GFZ
- Science & science processing
- Mission operations
- Optical
- components of Laser Ranging Instrument
- Launch Services

Sentinel 6A/B
ABC: 2021/2026
Ocean Altimetry

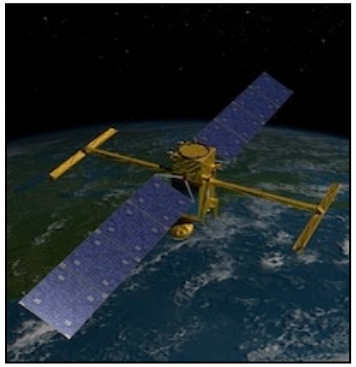
Partner: NOAA
- Science data dissemination
- Ground stations

Partner: ESA
- Spacecraft bus
- Science instruments (Poseidon-4 Altimeter, DORIS, GNSS POD)
- Satellite control center (during LEOP)

Partner: EUMETSAT
- Mission/System coordinator,
- Satellite control center (Ops)
- Science data processing
- Science data dissemination
- Data archiving
- Ground stations

Landsat 9
ABC: 2021
Land Imaging

Partner: USGS
- Ground system
- Mission Operations



SWOT
ABC: Apr 2022
Sea surface & fresh water height, slope

Partner: CNES
- Spacecraft bus
- Science instruments (Nadir Altimeter, DORIS, KaRIn RF Unit subsystem)

Partner: CSA
- Klystrons for KaRIn

Partner: UKSA
- Duplexers for KaRIn

NISAR
ABC: Sep 2022
Cryosphere, ecosystems, deformation

Partner: ISRO
- S-Band SAR
- Spacecraft bus
- Spacecraft operations
- Science Downlink
- S-Band processing

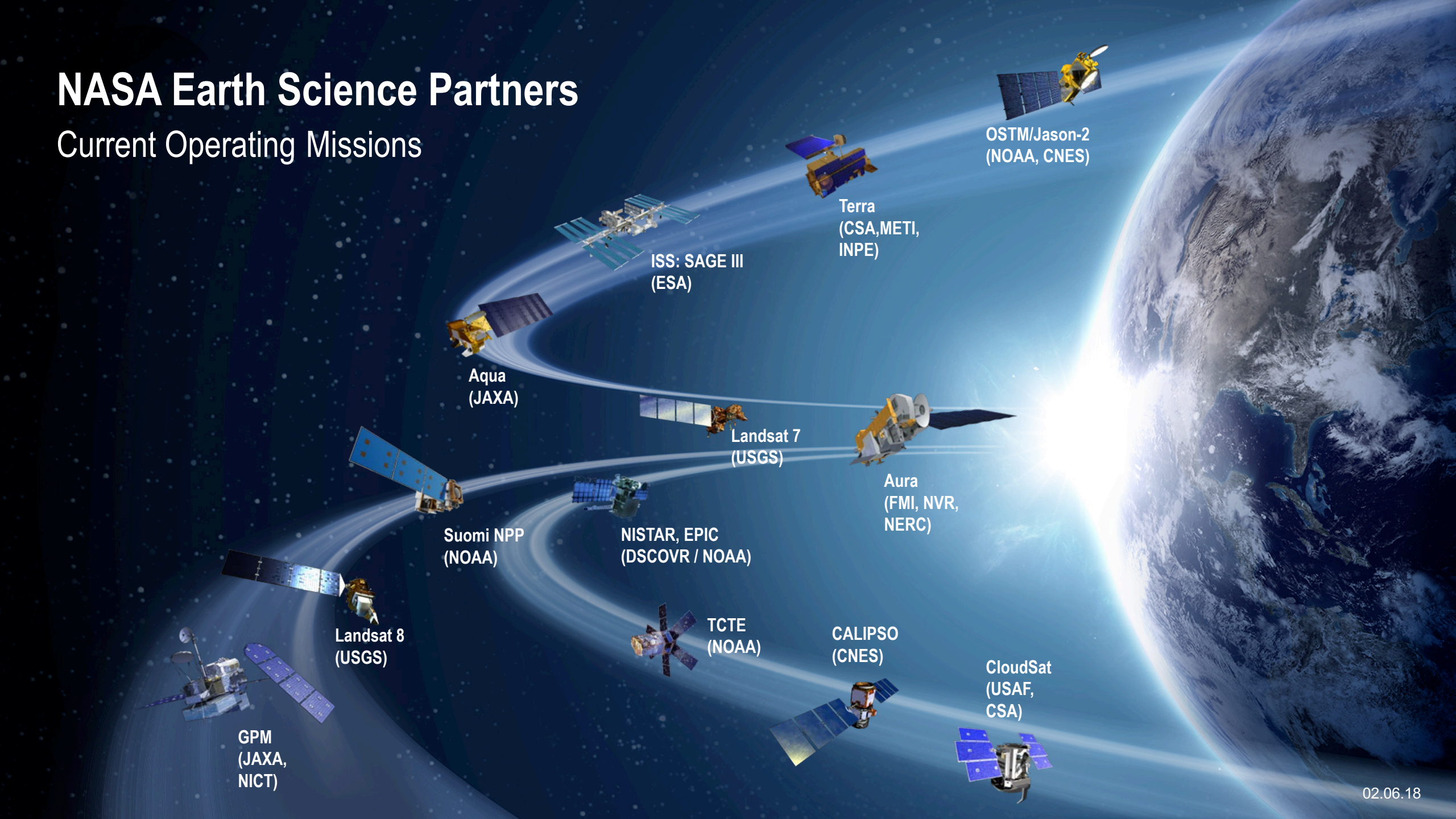
** Implementation = Phase C/D*

***Delivery of payload to host*

ABC=Agency Baseline Commitment

NASA Earth Science Partners

Current Operating Missions



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2017 Decadal Survey Overview – in their own words

ESAS 2017 Comparison to ESAS 2007

- **Prioritization Method.** Prioritize science and applications targets instead of missions
- **Budget Resources.** Align with planned budgets instead of aspirational
- **Large Missions.** Avoid having one recommended activity grow at expense of all others
- **Innovation.** Consider “new space” technology and business ideas
- **Policy.** Existence of recent high-level US government policy guidance regarding Earth observations
- **International.** Increased recognition of important role of international partners

Strategic Framework for Leveraging Resources & Advancing

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

Panels

I. Global Hydrological Cycles and Water Resources

Co-Chairs: Jeff Dozier, UC Santa Barbara and Ana Barros, Duke University

The movement, distribution, and availability of water and how these are changing over time

II. Weather and Air Quality: Minutes to Subseasonal

Co-Chairs: Steve Ackerman, University of Wisconsin and Nancy Baker, NRL

Atmospheric Dynamics, Thermodynamics, Chemistry, and their interactions at land and ocean interfaces

III. Marine and Terrestrial Ecosystems and Natural Resource Management

Co-Chairs: Compton (Jim) Tucker, NASA GSFC and Jim Yoder, WHOI

Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services

IV. Climate Variability and Change: Seasonal to Centennial

Co-Chairs: Carol Anne Clayson, WHOI and Venkatachalam (Ram) Ramaswamy, NOAA GFDL

Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System

V. Earth Surface and Interior: Dynamics and Hazards

Co-Chairs: Dave Sandwell, Scripps and Doug Burbank, UC Santa Barbara

Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate

Progress Since ESAS 2007

Mission	Geophysical Variables	Status
OSTM/Jason-2**	Ocean Surface Topography	Launched 2008, operating
OCO**	CO_2	Launch failure
Glory**	Aerosol and cloud particle size and optical thickness	Launch failure
Aquarius**	Sea surface salinity	Mission ended
Suomi NPP**	Multiple variables (ATMS, VIIRS, CrIS, OMPS, CERES)	Launched 2011, operating
LDCM**	Land use and land surface temperature	Launched 2013, operating
GPM**	Precipitation (rain and snow)	Launched 2014, operating
OCO-2	CO_2	Launched 2014, operating
CYGNSS*	Hurricane Winds	Launched 2016, operating
SMAP*	Soil moisture; freeze/thaw state; surface salinity	Launched 2017, operating
SAGE-III (on ISS)	Stratospheric O_3, aerosols	Launched 2017, operating
GRACE-FO	Changes in Gravitational Field	In Development (2017)
ICESat-2*	Ice sheet elevation change, sea ice thickness, vegetation canopy height	In Development (2018)
ECOSTRESS*	Plant temperature and water stress	In Development (2018)
GEDI*	Ecosystem structure and dynamics	In Development (2018)
TEMPO*	Air pollution (O_3, NO_2, …)	In Development (2018)
MAIA*	Aerosols	In Development (2021)
TROPICS*	Precipitation and storm intensity	In Development (2021)
GeoCARB*	Carbon exchanges between land and atmosphere	In Development (TBD)
PACE	Phytoplankton communities	In Development (2022)
NISAR*	Surface changes from ice-sheet collapse, earthquakes, tsunamis, volcanoes, and landslides	In Development (late 2021)
SWOT*	Ocean (and freshwater) high resolution elevation, providing water storage and ocean circulation	In Development (2021)
CLARREO-Pathfinder on ISS*	High accuracy spectral reflectance with on-board calibration	In Development (2021 timeframe)
OCO-3 (on ISS)	CO_2	In Development (2018)

Finding 2A: The **NASA ESD program has made important progress during the decade, partially recovering from the underfunded state it was in a decade ago . . .**

Finding 2B: NOAA progress during the decade was hampered by major programmatic adjustments . . .

Finding 2C: The **USGS has transformed the Landsat program via the Sustainable Land Imaging (SLI) program . . .**

Quick Summary of Recommendations

1

VISION & STRATEGY

"Thriving on our Changing Planet"

2

SCIENCE & APPLICATIONS

Address **35 key science/applications questions,** from among hundreds suggested. Highest priority objectives fell into **six categories**:

- Coupling of the Water and Energy Cycles
- Ecosystem Change
- Extending & Improving Weather and Air Quality Forecasts
- Sea Level Rise
- Reducing Climate Uncertainty & Informing Societal Response
- Surface Dynamics, Geological Hazards and Disasters

3

OBSERVATIONS

Augment the **Program of Record** with **eight priority observables**:

- **Five** that are specified/designated to be implemented:
  - *Aerosols*
  - *Clouds, Convection, & Precipitation*
  - *Mass Change*
  - *Surface Biology & Geology*
  - *Surface Deformation & Change*
- **Three** others to be selected competitively from among six candidates
- Structure **new mission program elements** to accomplish this

4

PROGRAMMATICS

- CROSS-AGENCY
- NASA
  - Flight
  - Technology
  - Applications
- NOAA
- USGS

Summary of Top Science and Applications Priorities*

* Complete set of Questions and Objectives in Table 3.3

Science & Applications Topic	Science & Applications Questions addressed by **MOST IMPORTANT** Objectives
Coupling of the Water and Energy Cycles	**(H-1)** How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods? **(H-2)** How do anthropogenic changes in climate, land use, water use, and water storage interact and modify the water and energy cycles locally, regionally and globally and what are the short- and long-term consequences?
Ecosystem Change	**(E-1)** What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? **(E-2)** What are the fluxes (of carbon, water, nutrients, and energy) *between* ecosystems and the atmosphere, the ocean and the solid Earth, and how and why are they changing? **(E-3)** What are the fluxes (of carbon, water, nutrients, and energy) *within* ecosystems, and how and why are they changing?
Extending & Improving Weather and Air Quality Forecasts	**(W-1)** What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean and sea ice) exchanges of energy, momentum and mass, and how do these impact weather forecasts and air quality simulations? **(W-2)** How can environmental predictions of weather and air quality be extended to seamlessly forecast Earth System conditions at lead times of 1 week to 2 months? **(W-4)** Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do? **(W-5)** What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems?
Reducing Climate Uncertainty & Informing Societal Response	**(C-2)** How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies?
Sea Level Rise	**(C-1)** How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage? **(S-3)** How will local sea level change along coastlines around the world in the next decade to century?
Surface Dynamics, Geological Hazards	**(S-1)** How can large-scale geological hazards be accurately forecasted and eventually predicted in a socially relevant timeframe?

Observing System 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, & 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 the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic 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 & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	**CO_2 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 & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.	Radar scatterometer		X	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth & 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 & 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 DIAL lidar; and lidar** for PBL height			X
Surface Topography & 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

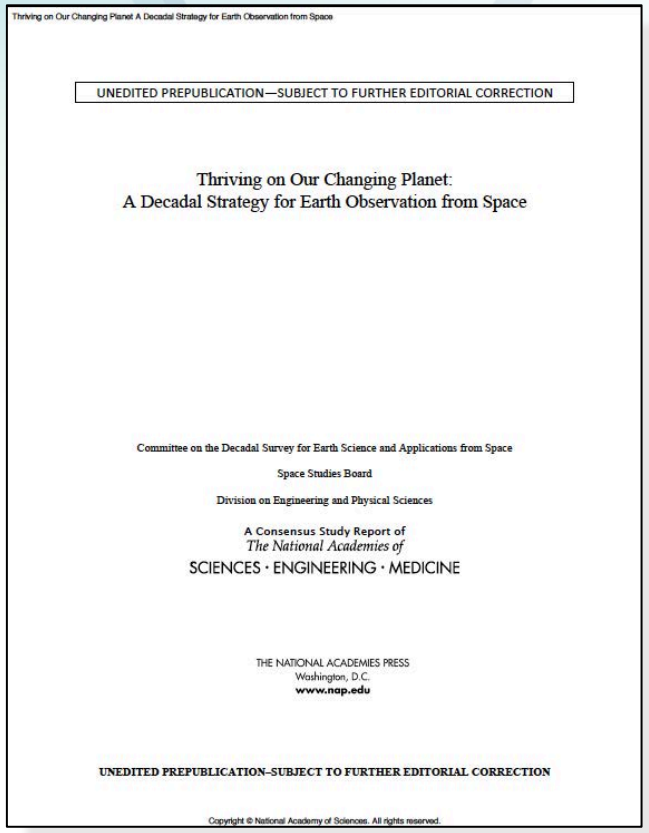
Other ESAS 2017 Targeted Observables, not Allocated to a Flight Program Element

Aquatic Biogeochemistry	**Radiance Intercalibration**
Magnetic Field Changes	**Sea Surface Salinity**
Ocean Ecosystem Structure	**Soil Moisture**

2017 Decadal Survey Highlights – ESD's Interpretation

2017 Decadal Survey Snapshot

2017 DECADAL SURVEY


Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space

UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION

- Publicly released January 5, 2018
- Supports the ESD (and international) *Program of Record*
- Prioritizes *observations* rather than specific missions
- Emphasis on *competition* as cost-control method
- Explicitly allows *implementation flexibility*
- Explicitly encourages *international partnerships*
- Endorses *existing balances* in ESD portfolio

NASA Earth Science

FY17 Program of Record

- (Pre)Formulation
- Implementation
- Primary Ops
- Extended Ops

ISS Instruments

CATS, LIS (2020), SAGE III (2020)
TSIS-1 (2020) OCO-3 (2018),
ECOSTRESS (2018), GEDI (2018)
CLARREO-PF (2020)

JPSS-2 Instruments

~~RBI (2018)~~, OMPS-Limb (2018)

Landsat 9 (2020)
PACE (2022)
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ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC (DSCOVR / NOAA) (2019)
SMAP (>2022)
Suomi NPP (NOAA) (>2022)
Landsat 7 (USGS) (~2022)
QuikSCAT (2017)
SORCE, TCTE (NOAA) (2017)
Terra (>2021)
Landsat 8 (USGS) (>2022)
Aqua (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OSTM/Jason-2 (NOAA) (>2022)
GPM (>2022)
OCO-2 (>2022)

Invests/CubeSats

RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018*)
~~CIRAS (2018*)~~
CSIM (2018)
LMPC (TBD)

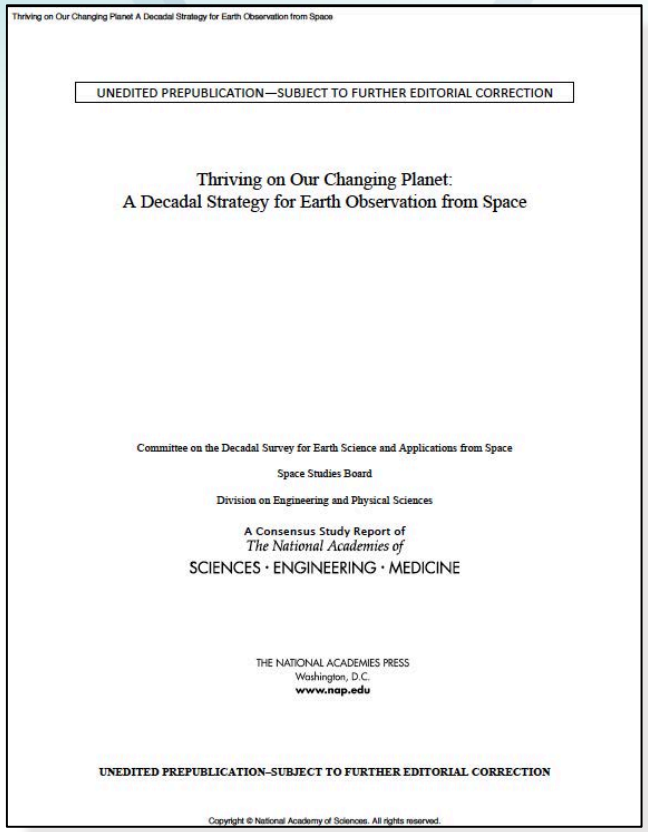
* *Target date, not yet manifested*

Program of Record (example, 1 of 10)

ESAS Consolidated POR									17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
NASA + NOAA + ESA + EUCOM																							
Mission Family	**Mission**	**Instrument Name**	**Instrument Type**	**Mission Agencies**	**Mission Status**	**Launch Year**	**Design Life**	**Expected EOL**															
ADM-Aeolus		ALADIN	Doppler lidar	ESA	Development	2018	3	2021															
Aqua		AMSU-A	Absorption-band MW radiometer/spectrometer	NASA, JAXA, INPE	Operations	2002	6	2023															
		CERES	Broad-band radiometer	NASA, JAXA, INPE	Operations	2002	6	2023															
		AIRS	Medium-resolution IR spectrometer	NASA, JAXA, INPE	Operations	2002	6	>2022															
		MODIS	Medium-resolution spectro-radiometer	NASA, JAXA, INPE	Operations	2002	6	>2022															
Aura		TES	High-resolution nadir-scanning IR spectrometer	NASA, NSO, FMI, NIVR, UKSA	Operations	2004	6	>2022															
		OMI	High-resolution nadir-scanning SW spectrometer	NASA, NSO, FMI, NIVR, UKSA	Operations	2004	6	>2022															
		MLS (EOS-Aura)	Limb-scanning MW spectrometer	NASA, NSO, FMI, NIVR, UKSA	Operations	2004	6	>2022															
BIOMASS		SAR-P	Imaging radar (SAR)	ESA	Development	2021	5	2026															
CALIPSO		CALIOP	Atmospheric lidar	NASA, CNES	Operations	2006	3	>2022															
		IIR	Multi-purpose imaging Vis/IR radiometer	NASA, CNES	Operations	2006	3	>2022															
		WFC	Multi-purpose imaging Vis/IR radiometer	NASA, CNES	Operations	2006	3	>2022															
CATS-on-ISS		CATS	Atmospheric lidar	NASA	Operations	2015	3	2020															
CLARREO Pathfinder-on-ISS		CLARREO Pathfinder Reflected Solar Spectrometer	Spectrometer	NASA	Development	2020	1	2022															
CloudSat		CPR (CloudSat)	Cloud and precipitation radar	NASA, DoD (USA), CSA	Operations	2006	2	2018															
COSMIC	FM1	GOX	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Operations	2006	2	2008															
	FM2	GOX	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Operations	2006	2	2008															
	FM4	GOX	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Operations	2006	2	2008															
	FM5	GOX	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Operations	2006	2	2008															
	FM6	GOX	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Operations	2006	2	2008															
	2A (Equatorial)	TGRS	GNSS radio-occultation receiver	NOAA, NSPO, UCAR	Development	2017	5	2022															
	2B (Polar)	TGRS	GNSS radio-occultation receiver	NOAA, UCAR	Development	TBD	TBD	TBD															
CryoSat-2		Laser Reflectors (ESA)	Laser retroreflector	ESA	Operations	2010	3.5	2019															
		SIRAL	Radar altimeter	ESA	Operations	2010	3.5	2019															
		DORIS-NG	Radio-positioning system	ESA	Operations	2010	3.5	2019															
CYGNSS	CYGNSS	DDMI (CYGNSS)	GNSS receiver	NASA, NOAA	Operations	2016	2	>2018															
DMSP	F-14	SSM/T-1	Absorption-band MW radiometer/spectrometer	NOAA, USAF	Operations	1997	4	2016															
		SSM/T-2	Absorption-band MW radiometer/spectrometer	NOAA, USAF	Operations	1997	4	2016															
		SSM	Magnetometer	NOAA, USAF	Operations	1997	4	2016															
		SSM/I	Multi-purpose imaging MW radiometer	NOAA, USAF	Operations	1997	4	2016															
		OLS	Multi-purpose imaging Vis/IR radiometer	NOAA, USAF	Operations	1997	4	2016															
	F-15	SSM/T-1	Absorption-band MW radiometer/spectrometer	NOAA, USAF	Operations	1999	5	2017															
		SSM/T-2	Absorption-band MW radiometer/spectrometer	NOAA, USAF	Operations	1999	5	2017															
		SSM	Magnetometer	NOAA, USAF	Operations	1999	5	2017															
		SSM/I	Multi-purpose imaging MW radiometer	NOAA, USAF	Operations	1999	5	2017															
		OLS	Multi-purpose imaging Vis/IR radiometer	NOAA, USAF	Operations	1999	5	2017															
	F-16	SSM	Magnetometer	NOAA, USAF	Operations	2003	5	2018															
		SSM/IS	Multi-purpose imaging MW radiometer	NOAA, USAF	Operations	2003	5	2018															
		OLS	Multi-purpose imaging Vis/IR radiometer	NOAA, USAF	Operations	2003	5	2018															
	F-17	SSM	Magnetometer	NOAA, USAF	Operations	2006	5	2019															
		SSM/IS	Multi-purpose imaging MW radiometer	NOAA, USAF	Operations	2006	5	2019															
		OLS	Multi-purpose imaging Vis/IR radiometer	NOAA, USAF	Operations	2006	5	2019															
		SSM	Magnetometer	NOAA, USAF	Operations	2009	5	2021															

2017 Decadal Survey Snapshot (cont.)

2017 DECADAL SURVEY


Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space

UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION

- 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)*
- Calls for "cost-capping" essentially all missions
- Introduces a new competed "Explorer" flight line with $350M cost constraint, 3 observables to be chosen by ESD from among 6 identified
- Calls for "Incubator Program" between Technology, R&A, and Flight to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal)
- ***ESD is conducting focused community forums (for ~18 months) to translate the recommendations into an executable program and, for Flight, a portfolio of specific, realistic, launch-ordered missions and solicitations.***
  - Decadal new mission budget wedge opens only in late FY21

ESD Strategic Approach to Implementation

- Initial task was to identify and prioritize key implementation actions to be addressed.
- Overall implementation will take ~18 months
- **The top priority actions in terms of urgency and importance were**:
  - Establishing a sustained communications approach for the range of stakeholders – done.
  - Framework for implementing Earth Venture-Continuity (EVC) observations – done.
    - *(Decisions are included in this briefing.)*
  - Framework for implementing Designated Observations – underway.
    - *(Top-line decisions are included in this briefing.)*

Communicating our plans and progress

- Weekly listening sessions with ESD staff
- Calls at 4-month intervals with external stakeholder communities
- Engagement with interagency and international partners
- Town halls at professional society meetings
- ESD's Decadal Survey web page:
  https://science.nasa.gov/earth-science/decadal-surveys
- Use the web page to…
  - See meeting and telecon announcements
  - Ask questions
  - Find answers to questions, as they become available
  - View records of progress and decisions

International Engagement

- ESD has conducted focused Decadal Survey telecons/meetings with key international partners
  - CNES, CSA, DLR, ESA, EUMETSAT, ISRO, JAXA
  - Bilateral, HQ-level, face-to-face meetings planned over the next 6 months
  - Some directed international partnerships may originate from ESD/HQ
- Centers are explicitly encouraged to discuss and explore possible observable implementation approaches with international partners
  - Multi-center joint efforts appreciated
  - Keep ESD leadership informed
- ESD will make final partnership determinations and then codify necessary international agreements

Earth Venture Continuity (EVC) Decisions

EVC as Described in the DS

- EVC specifically seeks to lower the cost for long-term acquisition of key “continuity” observations, rewarding innovation in mission-to-mission cost reduction through technology infusion, programmatic efficiency, and/or other means.
- ESAS envisioned EVC to be similar to the EVM strand, including full mission implementation costs whether for instruments, spacecraft, and launch vehicles OR hosted payloads with hosting services included.
- ESAS did not specify initial measurement candidates for the EVC program.
- ESAS recommended two projects that are <$150M each in this DS period.

ESD Top Level Approach to EVC

- ESD will use EVC to demonstrate a technique/approach for making long-term measurements with the appropriate characteristics (a “continuity demonstration”)
- Criteria for selecting an EVC project:
  - Capability of the instrument/characteristics of the data
  - Cost of future copies
  - Accommodatability
  - Producibility
  - Ease of downstream technology infusion
- Payload Classification will be Class C or D, as stated in the specific solicitation
- EVC will ***NOT*** address continuity beyond the demonstration
  - Minimum demonstration period is 1 year beyond on-orbit commissioning
  - Additional on-orbit acquisition will not be under the cost constraint
- The ESD objective will be to fly 3 EVC missions in the decade

Types of Missions Solicited Under EVC

- ESAS envisioned EVC to be similar to the EVM strand, including full mission implementation costs whether for instruments, spacecraft, and launch vehicles ***or*** hosted payloads with hosting services included.

- While the ESAS references EVM, ESD will exercise flexibility to implement any of the following arrangements for EVC:
  - Full mission implementation – like CYGNSS
  - PI arranged instrument hosting – like GeoCarb
  - NASA provided hosting for a MOO – like TEMPO or MAIA

- ESD may solicit ALL of these implementations in a single solicitation, as follows:
  - $150M for full mission or PI arranged hosting
  - $110M-$120M for MOO; with $30M-$40M for accommodations

EVC will involve Targeted Solicitations

- Given the RBI termination, EVC-1 will be a targeted AO for radiation budget capability
- Future EVC solicitations may:
  - Target a single observation for a given imperative (similar to EVC-1)
  - Target a set of observations (e.g. solar irradiance, ozone, and CO2)
- ESD will maintain the flexibility to pursue either of the above options, but it is expected that most will be single observation targeted
- However, once we know what we want to do with the next EVC, ESD will alert the community to our intentions

EVC-1 Solicitation Assumptions

- Cost-constrained at $150M
- Solicitation targeted for radiation budget science capability
- One-step solicitation process
- All RBI hardware will be offered as GFE in the AO
- EVC-1 will be a Class C payload
- EVC-1 will have a mission duration requirement appropriate for radiation budget continuity
  - This is specific to EVC-1 and not precedent setting, as the primary objective of EVC is to demonstrate a technique/approach for making long-term measurements rather than providing a mechanism for actually acquiring the measurements over the long term
- Solicitation to be released by December 2018
- Draft solicitation to be released for community comments

Designated Observables (DO) – Preliminary Decisions

DO as Described in the DS

- A “new” program element for cost-capped medium- and large-size missions/observing systems to address observables essential to the overall program
- Addresses five of the highest-priority Earth observation needs, suggested to be implemented among three large missions and two medium missions. Elements of this program are considered foundational elements of the decade’s observations.
- Missions/observing systems can be directed or competed at the discretion of NASA.
- The ESAS maximum recommended development costs are considered expected development (including launch and science) costs for **substantial** (not minimum) capability missions/observing systems. ESAS expected NASA to identify implementation approaches which achieve the recommended objectives for *less than the identified maximum*.

Designated Observables Summary

Observable	Science/Applications Summary	Candidate Measurement Approach	ESAS maximum cost
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multichannel/multi-angle/polarization imaging radiometer flown together on the same platform	CATE Cap $800M
Clouds, Convection, And Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	CATE Cap $800M
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	Est Cap $300M
Surface Biology and Geology	**Earth surface geology and biology**, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	CATE Cap $650M
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	Est Cap $500M

ESD Prioritization of Current and Future Activity

- ESD issued letters directed the close-out of the five 2007 DS studies:
  - ACE – close in FY18; transition of activities to Aerosols/CCP
  - ASCENDS – close in FY18
  - CLARREO – close in FY18
  - GEO-CAPE – close in FY18
  - HyspIRI – close in FY18; transition of activities to SBG
- The ESD prioritization of the designated observables:
  - The first two D.O.s that will be transitioned to missions/observing systems (in the 2020/2021 timeframe) are:
    - Surface Biology & Geology
    - Aerosols and/or Clouds, Convection, and Precipitation (or some hybrid of the two)
  - Subsequent D.O.s to transition to missions/observing systems (in the 2023-2027 timeframe) are:
    - Mass Change
    - Surface Deformation and Change
    - The remaining capabilities of Aerosols and/or Clouds, Convection, and Precipitation

ESD DO Programmatic Architecture

- Designated Observables Studies
  - Rapid solicitation for Multi-Center Study Proposals
  - Specific direction for expectations
  - A target KDP-A Date will be provided in early FY19 to the study teams for the first two D.O.s (SBG; Aerosols/CPP)
- Mission Responsibility
  - Directed to NASA Centers
- Instruments
  - Partner Contributions
  - Competed via Announcement of Opportunity (SMD/ESD selection)
- Spacecraft
  - Partner Contributions
  - RFP to Industry by the NASA Center responsible for the mission

Designated Observable Studies (1 of 2)

- DRAFT Scope of Mission Studies
  - Develop top-level objectives
  - Identify potential international and/or interagency partners, and/or private sector participation
  - Synergies with other D.O., ESD, or non-NASA missions
  - Identify needed technology refinement efforts, precursor campaigns, and post launch validation
  - Conduct Airborne campaigns
  - Run OSSEs
  - Develop required capability for mission and instruments
  - Sequencing/approach for instrument/spacecraft development (i.e. approach for designing the spacecraft without knowing the instrument interfaces, or vice-versa)
  - Recommend cost target for instruments
  - Application community assessments

- Study scope will be refined in the coming weeks and included in the call for multi-center mission study proposals

Designated Observable Studies (2 of 2)

- ESD will fund 6 mission/observing system studies
  - Surface Biology and Geology ($650M total for missions/observing systems)
  - Aerosols Study ($800M total for missions/observing systems)
  - CCP Study ($800M total for missions/observing systems)
  - *Aerosols and Clouds, Convection and Precipitation Study ($1.6B total for missions/observing systems)*
  - Surface Deformation ($500M total for missions/observing systems)
  - Mass Change ($300M total for missions/observing systems)
- ESD will solicit multi-center proposals to perform each of the studies (see next chart)
  - Targeting **May 2018** for release of the call for mission/observing system study proposals
- ESD will fund each of the mission studies at a baseline level of $2M per year

Designated Observables Studies Attributes

- Clarity, specificity, and comprehensiveness of study scope – esp. science
- Institutional history/accomplishments/ongoing activities
- Study plan approach/schedule, including specific planned reporting
- Specific people (by name) who will play key leadership roles in the study
- Study cost
- Plan for inter-center and international involvement in the study (plans for recruitment, existing agreements, etc.)
- Plan for involving industry (private sector, non-governmental) in the study
- Plan for examining non-traditional architectures (including commercial solutions or partial solutions, small-sat constellation solutions or partial solutions, etc.)

Designated Missions/Observing Systems Sequencing to Meet DS Objectives

- First two missions/observing systems
  - Surface Biology and Geology (Budget: <$650M)
  - Aerosol or CCP, or some form of hybrid (Budget: TBD range of <$800M to <$1,600M)
- Sequence of the first two missions/observing systems and the responsible Center for each mission/observing system will be established in early FY19
  - First mission/observing system will target KDP-A in late FY2020
  - Second mission/observing system will enter KDP-A as soon as budget allows
- Third Mission/observing system – TBD
  - Target KDP-A in late FY2023
- Fourth Mission/observing system – TBD
  - Target KDP-A in late FY2025
- Fifth Mission/observing system – TBD
  - Target KDP-A in late FY2027

These observation acquisition activities (SDC, MC, and whatever is left of A/CCP) will be prioritized based in the progress made in the studies and other ESD considerations

Stakeholder Community Involvement

- Stakeholders are encouraged to discuss and explore possible observable implementation approaches with Centers
- Since approaches will require competition elements, discussions can be established regarding the potential compositions of those teams.
- ESD is encouraging multi-center joint efforts, in partnership with private sector, academia, International and Interagency partners.
- We invite you to submit questions that you would like us to consider: https://science.nasa.gov/earth-science-decadal-inputs

Community Input Requested

- ESD solicits ideas from the non-governmental/private sector on ways to participate in the strategic planning process associated with realistically implementing the Decadal recommendations.
- During the actual implementation, we will engage with industry in the traditional ways, such as via Announcements of Opportunity and Requests for Proposals.
- We also seek new ways to leverage the work and ideas in the private sector in order to increase mission/observing system/portfolio capability and/or to reduce costs.
  - This may involve exploiting emergent commercial technologies and capabilities, exploring concepts and methods traditionally not utilized by the government, expanded procurement of commercially available data, etc.

What's next

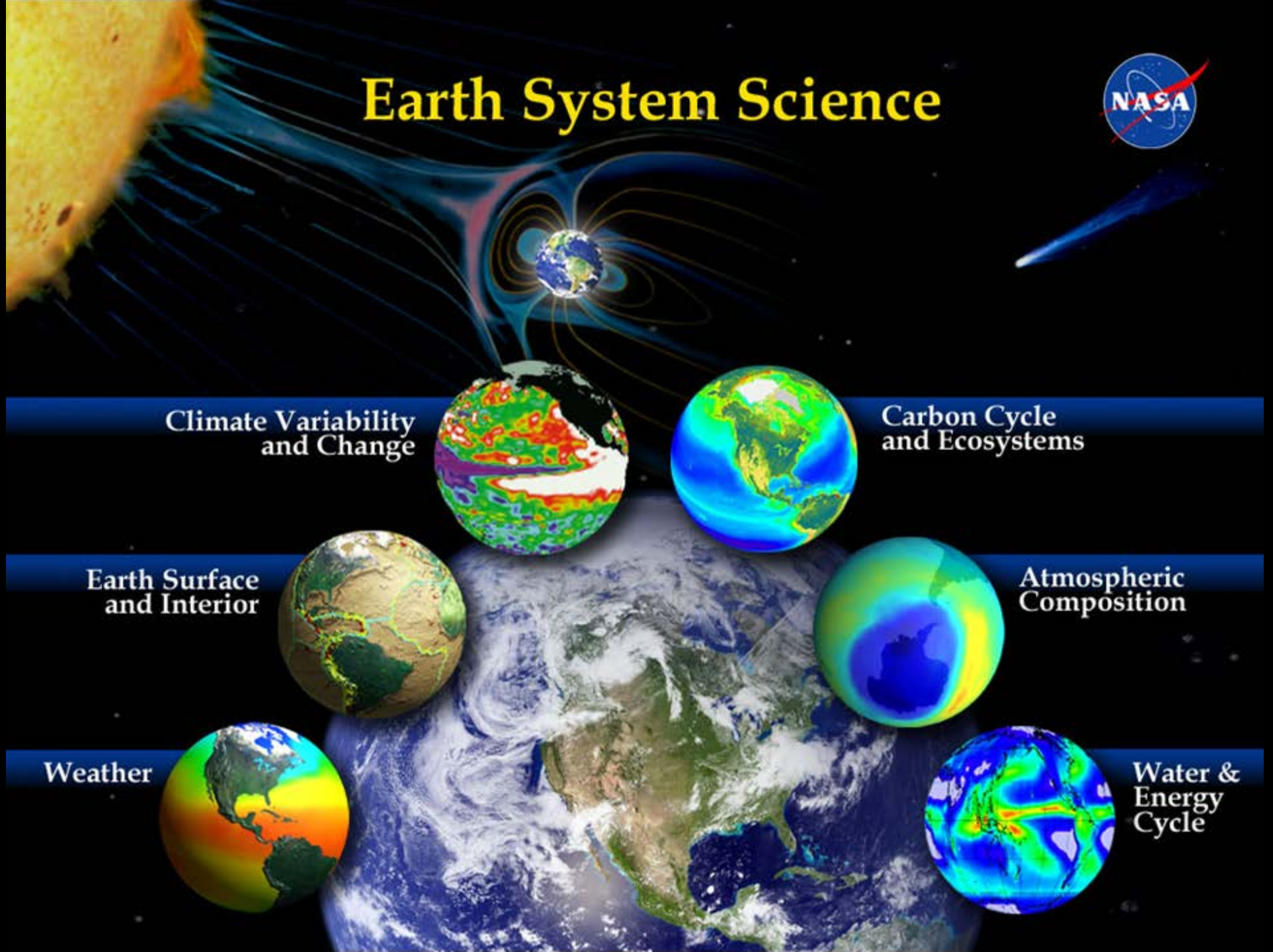
- ESD Leadership Team will continue to develop the framework for Designated Observables and address additional DS topics
- Community Forum (2st in the series) – September TBD, 1:00-3:00 EDT, in person and Webex
  - See https://science.nasa.gov/earth-science/decadal-survey-community-forum for details
- Check the ESD Decadal Survey web page to:
  - Find meeting schedules and details
  - Ask questions and see answers as they become available
  - View records of decisions and other posted material
  - https://science.nasa.gov/earth-science/decadal-surveys

Attendance/Questions

- Please email your name to ensure you will be informed of future Community Forums
- During this presentation please email your questions.

TO: Amy.A.Treat@nasa.gov

Backup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NASA
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle