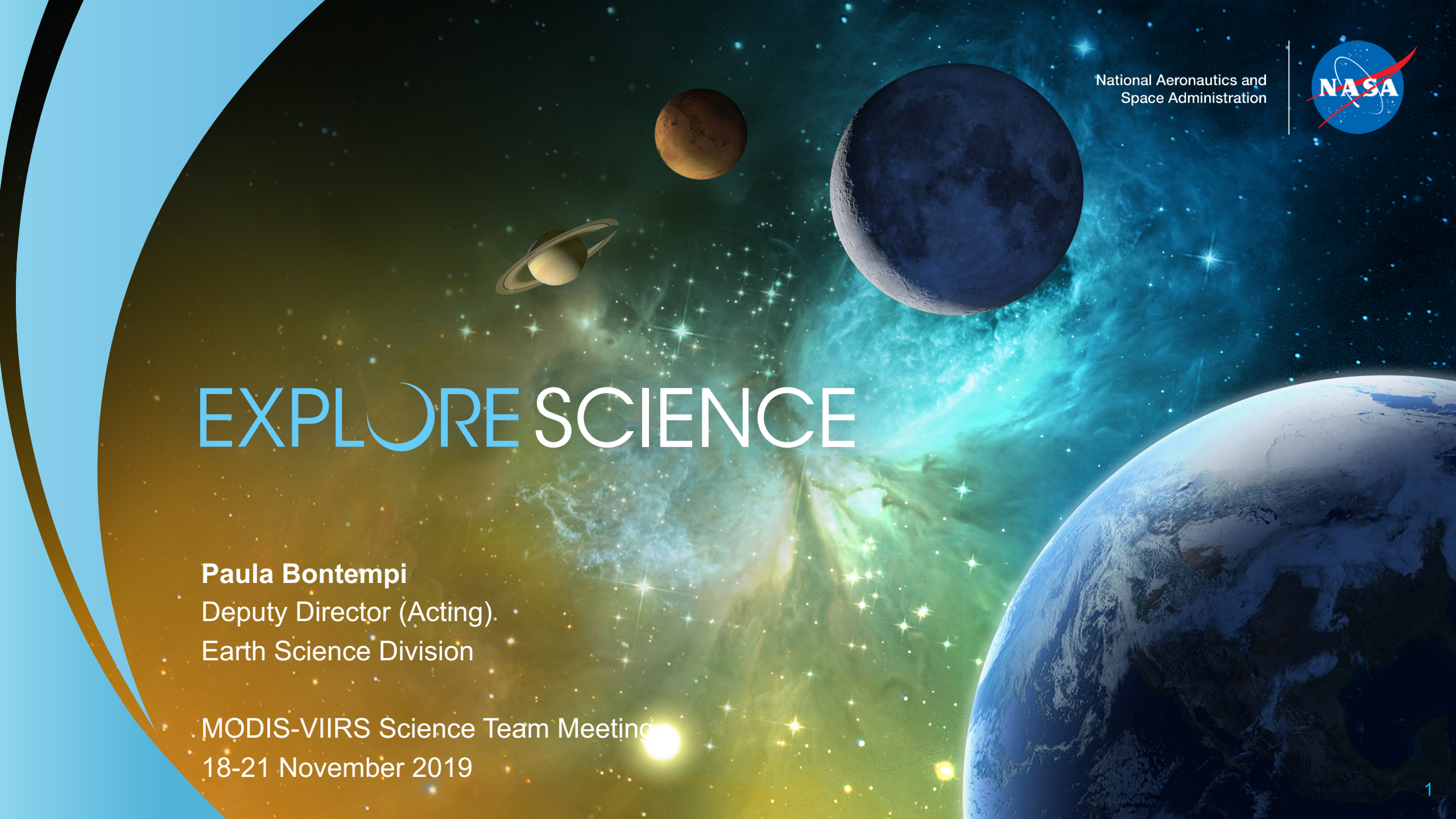


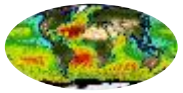
Paula Bontempi
Deputy Director (Acting)
Earth Science Division

MODIS-VIIRS Science Team Meeting
18-21 November 2019

NASA Earth Science Division Elements

Flight (incl. Data Systems)

Develops, launches, and operates NASA's fleet of Earth-observing satellites, instruments, and aircraft. Manages data systems to make data and information products freely and openly available.

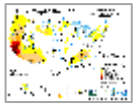


Research & Analysis

Supports integrative research that advances knowledge of the Earth as a system. Six focus areas plus field campaigns, modeling, and scientific computing.

Technology

Develops and demonstrates technologies for future satellite and airborne missions: Instruments, Information Systems, Components, InSpace Validation (cubesat and small-sat form factors).



Applied Sciences

Develops, tests, and supports innovative uses of Earth observations and scientific knowledge to inform private and public sector planning, decisions, and actions. Activities include disaster response support and capacity building.

NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

LANDSAT-9
NISAR
TROPICS (6)
SENTINEL-6A/B
SWOT
TSIS-2
MAIA
PREFIRE (2)
PACE
GEOCARB
TEMPO
GLIMR
ICESAT-2
GRACE-FO (2)
CYGNSS (8)
NISTAR, EPIC (DSCOVR/NOAA)
SORCE
CLOUDSAT
TERRA
AQUA
AURA
CALIPSO
GPM
LANDSAT 7 (USGS)
LANDSAT 8 (USGS)
OCO-2
SMAP
SUOMI NPP (NOAA)

ISS INSTRUMENTS

EMIT
CLARREO-PF
GEDI
SAGE III
OCO-3
TSIS-1
ECOSTRESS
LIS

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb

INVEST/CUBESATS

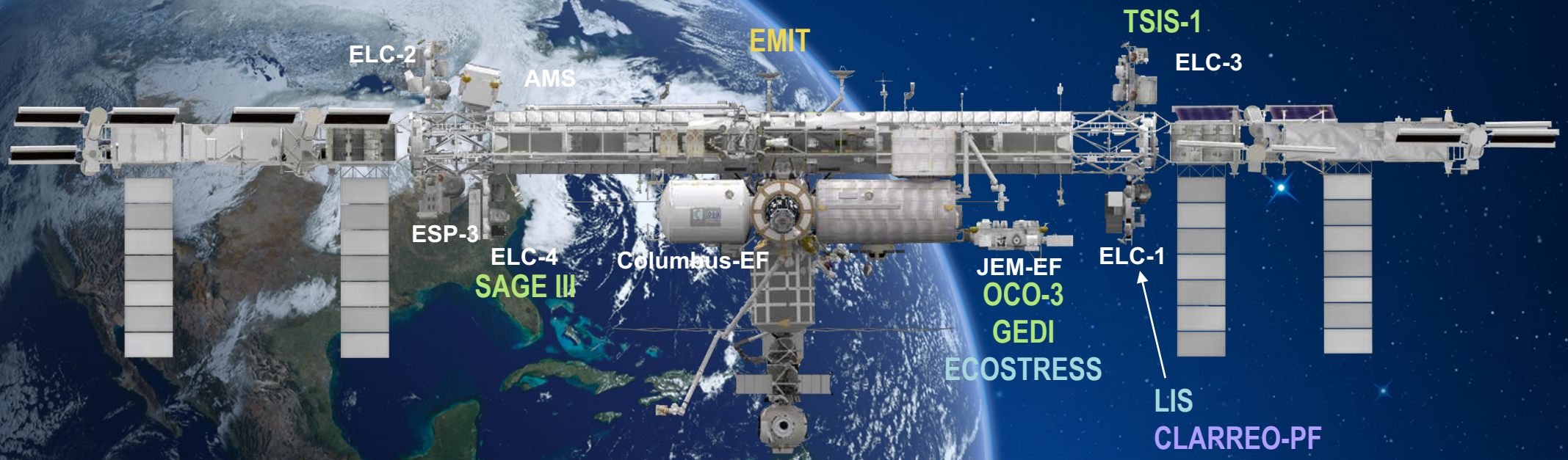
RAVAN
RainCube
CSIM
CubeRRT
TEMPEST-D
CIRiS
HARP
CTIM
HyTI
SNoOPI
NACHOS

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

10.04.19

INTERNATIONAL SPACE STATION

EARTH SCIENCE OPERATING MISSIONS

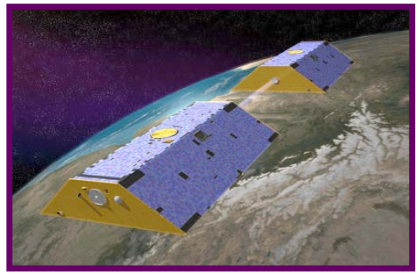


EXPRESS Logistics Carriers: ELC-1, ELC-2, ELC-3
External Stowage Platforms: ESP-3
Alpha Magnetic Spectrometer: AMS
Columbus External Payload Facility: Columbus-EF
Kibo External Payload Facility: JEM-EF

10.04.19

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

ESD Partnership Missions in Development



GRACE FO
Launched: May 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)

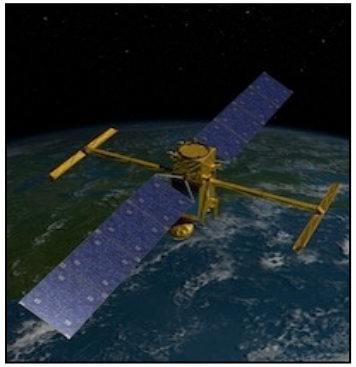
Partner: EUMETSAT

- 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

ABC=Agency Baseline Commitment

CubeSats, SmallSats, Constellations, Data Buy

- **Small Satellite Solutions**
  - **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
  - **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
  - **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
  - **PreFIRE:** 2-satellite CubeSat constellation to measure Far-IR emissions primarily from the Arctic
  - **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; leading to miniaturized science payload development - CSIM/TSIM development/test to replace TSIS-2 (2023 launch); SLI-T instrument development for Landsat-10, future SLI consideration (6 projects ongoing); Tempest-D produced exceptional precipitation measurements of Hurricane Dorian

- **Hosted Payload solutions**
  - TEMPO (instrument on NASA-arranged geo comsat)
  - MAIA (instrument on NASA-arranged LEO satellite – likely commercial)
  - GeoCarb (instrument on PI-arranged geo comsat)
  - Extensive use of ISS (ISERV, CATS, RapidScat, SAGE-III, LIS, ECOSTRESS, GEDI, TSIS-1, …)

- **Earth Observations from Private Sector Small Satellite Constellations Pilot**
  - Data buys of ***existing*** data products related to ECVs, ***pilot buys in 2018.***
  - On-Ramp RFI released in September. ***Currently evaluating responses.***

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 Jun & Dec 2018
EVS-2 (ACT-America, ATOM, NAAMES, 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	Radiation Budget Measurement	2018	2019	Delivery NLT 2024
EVM-3	Full Orbital	2019	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)

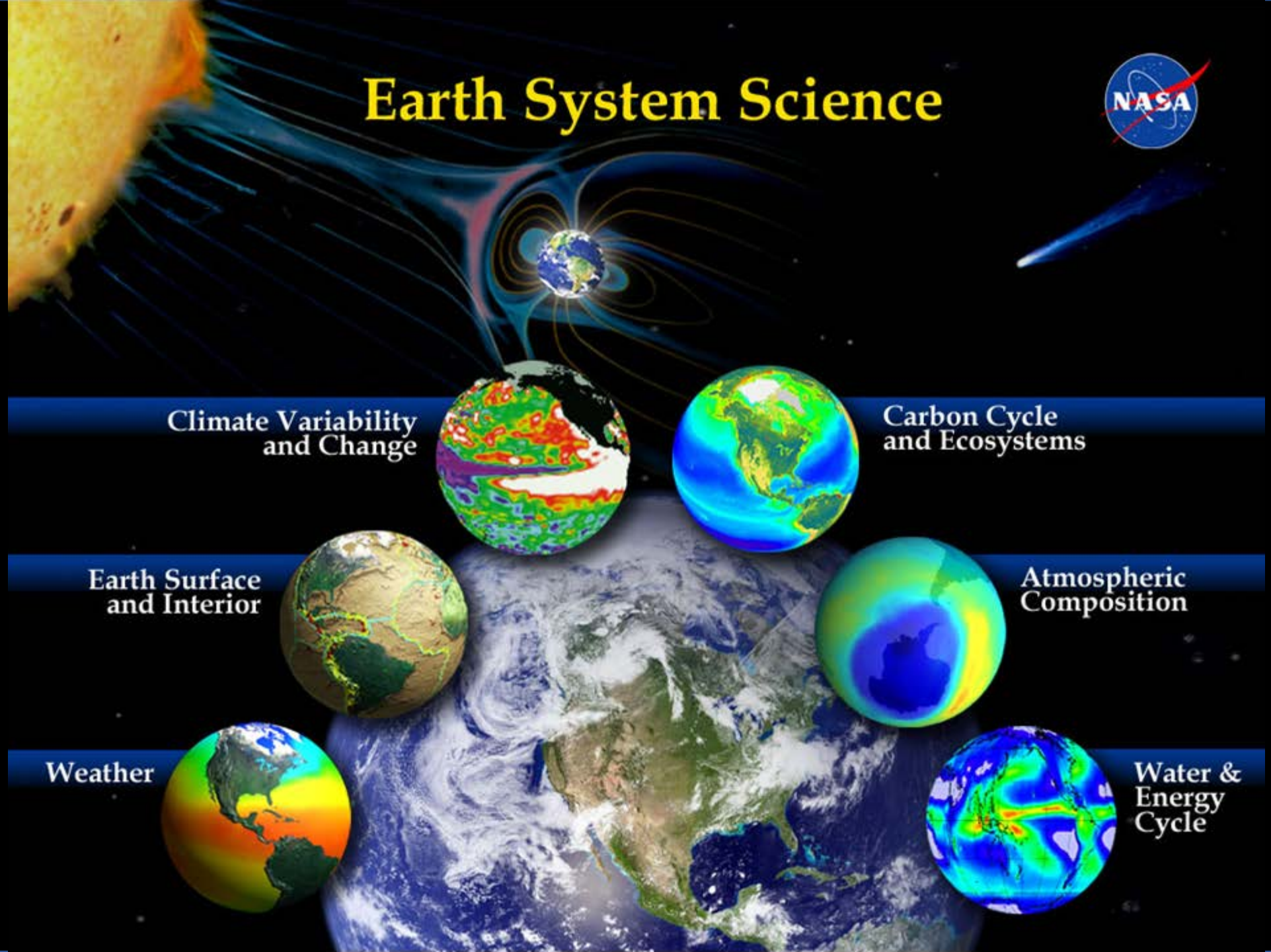
EVI

Full function, facility-class instruments Missions of Opportunity (MoO)

(~18 months)

Open solicitation - In Review

Completed solicitation


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

R&A Selected Highlights

Field Work

- 2019 - Cloud and Aerosol Monsoonal Processes Exp't (near Philippines); Firex-AQ (Idaho, Kansas, California/with NOAA); HyspIRI (Europe), Operation Ice Bridge (Arctic, Antarctic), ABoVE (Alaska/NW Canada), DAWN/HALO test flights (CA)

New Competed Science Programs (many ROSES calls)

- Selected next round of Earth Venture Suborbital (5 campaigns, most for 5 years), next round of MEaSUREs data set preparation tasks (5 years), competed science teams for PMM, CYGNSS, SAGE III, DSCOVR, open solicitation for ECOSTRESS ; selected new round of US Participating Investigators for US scientist engagement in foreign missions

Modeling and Data Assimilation

- All-sky microwave radiances from the GPM GMI instrument were introduced into the 4D assimilation system, resulting in improved analyses in and around cloudy regions
- NOAA-20 data (CrIS, ATMS, and OMPS) introduced into the GEOS analyses
- GEOS model is transitioning to include a new scale-aware representation of physical processes alongside the FV3 dynamical core
- GEOS CF (Composition Forecasting) is going live in March 2019, producing daily 25-km resolution analyses and forecasts for air quality etc.
- GEOS S2S system has been used to demonstrate for the first time the benefits of Aquarius and SMAP Sea-Surface Salinity observations on seasonal predictions of El Nino (this will transition to the next upgrade to the production version of GEOS S2S (in about 9 months)

Enabling Capabilities

- Advanced next-generation space geodesy network: installed new 12m Very Long Baseline Interferometry (VLBI) antenna at McDonald Observatory (TX); completed first dome for next-generation laser ranging stations
- Built the third modular computing facility at ARC and expanded SMD's supercomputing capacity to 19.5 pflops; expanded capacity at NCCS to 6.7 pflops.
- Completed the installation and dedication of two GOES Rebroadcast receiving antennas for GOES-16 and 17. Began serving GOES geostationary observation data to NASA Earth science research community.

Applied Sciences Program: Selected Highlights–2019

Water Resources, Disasters, Health & Air Quality, and Ecological Forecasting

New projects commence in all four applications areas. New efforts for greater replication of applications.

Missions & Applications

New efforts to engage applications communities early in satellite mission planning to further increase utility.

Communications

Full-scale implementation of new comms. plan with blend of technical, narrative, and personal stories.

Harvest

Food Security and Agriculture Consortium led by UMd to advance uses of Earth obs for humanitarian pursuits, domestic economy, and resilience in food systems globally and in the U.S.

Impact Assessments

VALUABLES Consortium conducting economic studies on Earth science; also arranging venues for Earth scientists wanting to learn about policy and economic terms/methods.

SERVIR

New Amazonia regional hub for South America is planned to open in Spring.

Solicitation for 3rd SERVIR Applied Science Team with start in Oct. 2019.

ARSET Trainings

New professional-level hands-on trainings on remote sensing for risk assessment, disaster scenarios, and Black Marble VIIRS Nighttime Data.

DEVELOP

New collaboration with Lenfest Ocean Program for projects on marine and coastal management issues.

Earth Science Technology

Advanced Technology Initiatives: ACT and InVEST

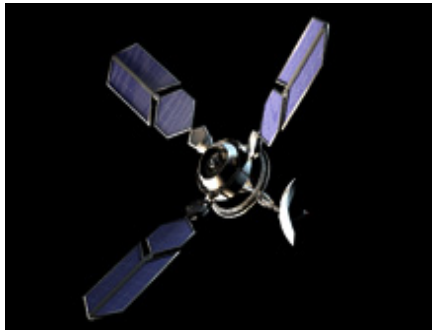
Advanced Component Technologies (ACT)
Critical components and subsystems for advanced instruments and observing systems
12 projects awarded in 2018.
Future solicitations planned in FY20, and FY23

In-Space Validation of Earth Science Technologies (InVEST)
On-orbit technology validation and risk reduction for small instruments and instrument systems..
Four projects selected in FY18.
Future solicitations planned in FY21 and FY24

Instrument Incubator Program (IIP)

Earth remote sensing instrument development from concept through breadboard and demonstration

17 projects awarded in FY17.
Future solicitations planned in FY19, FY22, and FY25



Advanced Information Systems Technology (AIST)

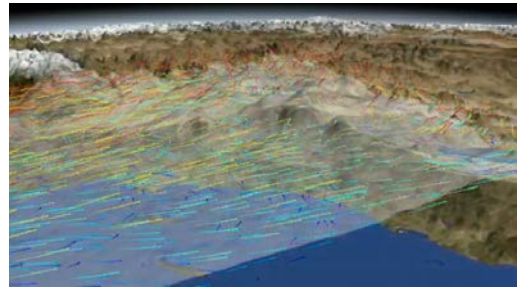
Innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products

22 projects awarded in FY17.
Future solicitations planned in FY19, FY21, FY23, and FY25

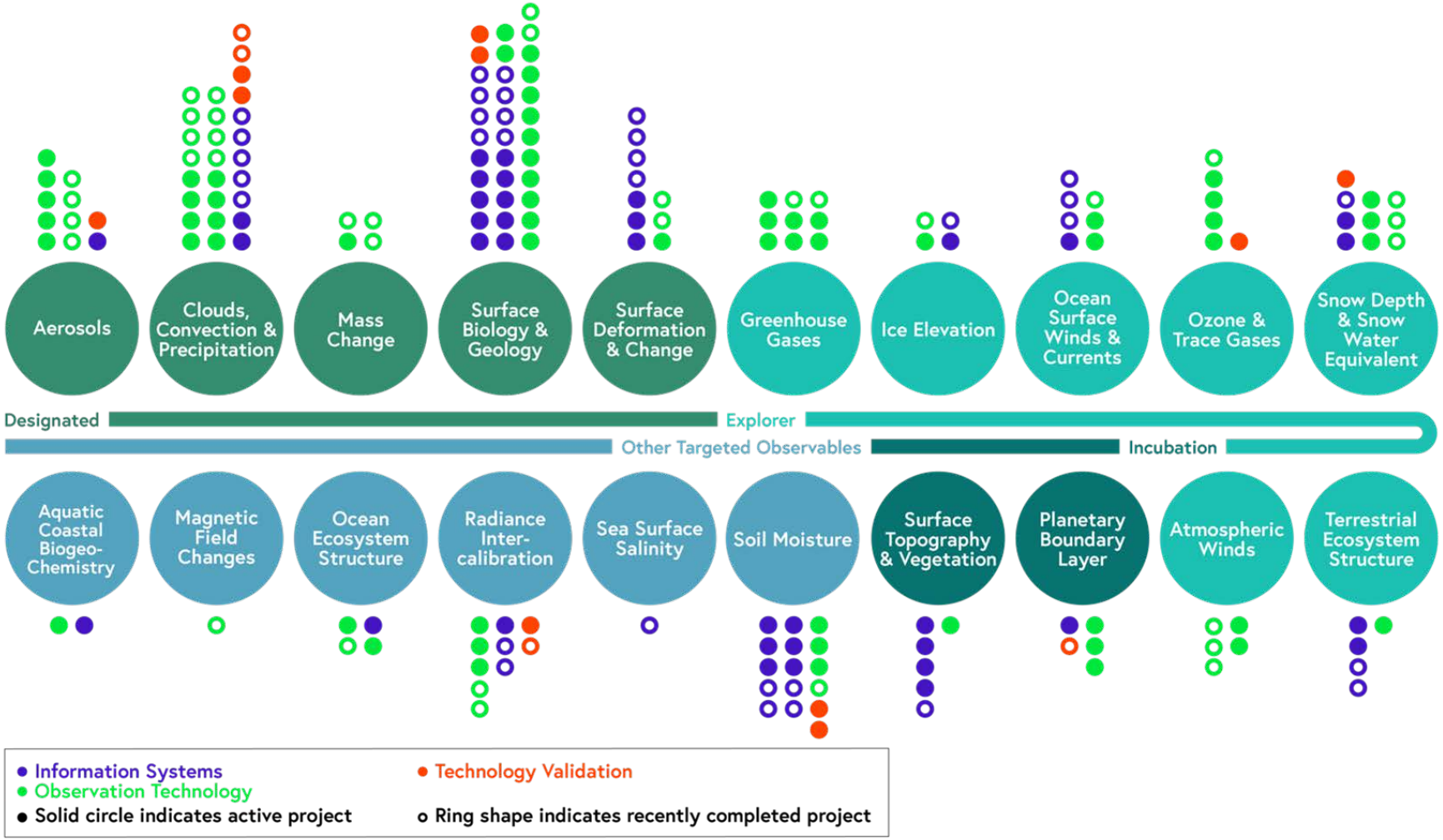
Decadal Incubation

Maturation of observing systems, instrument technology, and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables through technology development, modeling/system design, analysis activities, and small-scale pilot demonstrations

Future solicitations planned in FY19 and FY21

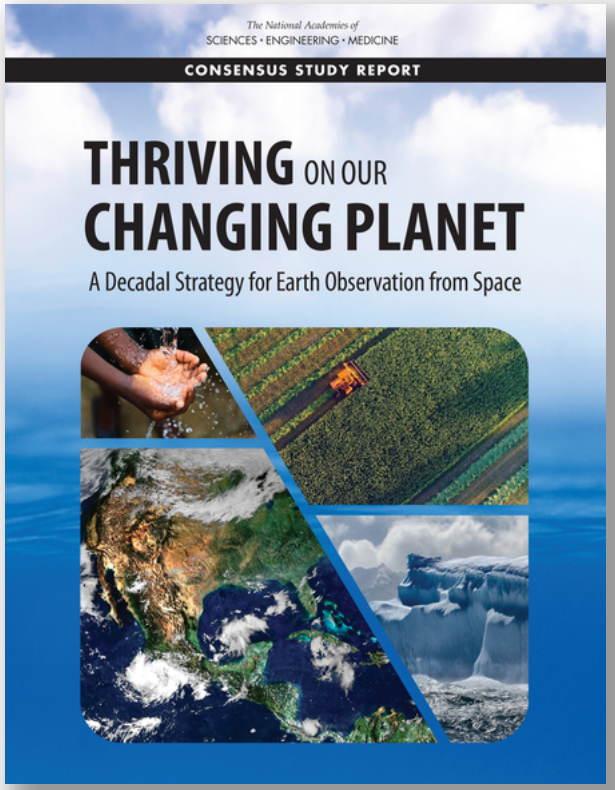


Technology Investments Mapped to ESAS 2017



- Mapping of ESTO awards to Targeted Observables shows current technology investments already addressing most priorities
- ESTO will coordinate Incubation program activities in collaboration with Research, Applied & Flight programs

2017 DECADAL SURVEY



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

2017 Decadal Survey Snapshot

- Publicly released January 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 “Incubator Program” between Technology, R&A, and Flight to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal)
- Decadal new mission budget wedge opens late FY21

2017 Decadal Survey Progress

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

Earth Science Explorers

- DS recommended a new competed Explorer flight line with $350M cost constraint: Greenhouse gases, ice elevation, Ocean surface winds and currents, ozone and trace gases, snow depth and snow water equivalent, terrestrial ecosystem structure, and atmospheric winds
- Implementation on hold pending budget developments

Designated Observables

- DS identified 5 Designated Observables for mandatory acquisition (*Aerosols; Clouds, Convection & Precipitation; Mass Change; Surface Biology & Geology; Surface Deformation & Change*)
- In 2018 ESD initiated 4 multi-center Designated Observables studies, continued in 2019:
  - *Combined Aerosols - Clouds, Convection & Precipitation (pre-Acquisition Strategy Meeting FY21 with over-guide)*
  - *Mass Change*
  - *Surface Biology & Geology (pre-Acquisition Strategy Meeting FY20/21 with in-guide)*
  - *Surface Deformation & Change*
- ESD is preparing to issues solicitations in 2019 to industry/academia in support of the DO studies

Incubation

- DS calls for Incubation Program to mature specific technologies for important — but presently immature — measurements (preparation for *next* Decadal)
- Solicitations for Science Teams released on March 14, 2019 - Planetary Boundary Layer and Surface Topography and Vegetation

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**

Big Data: Earth Science

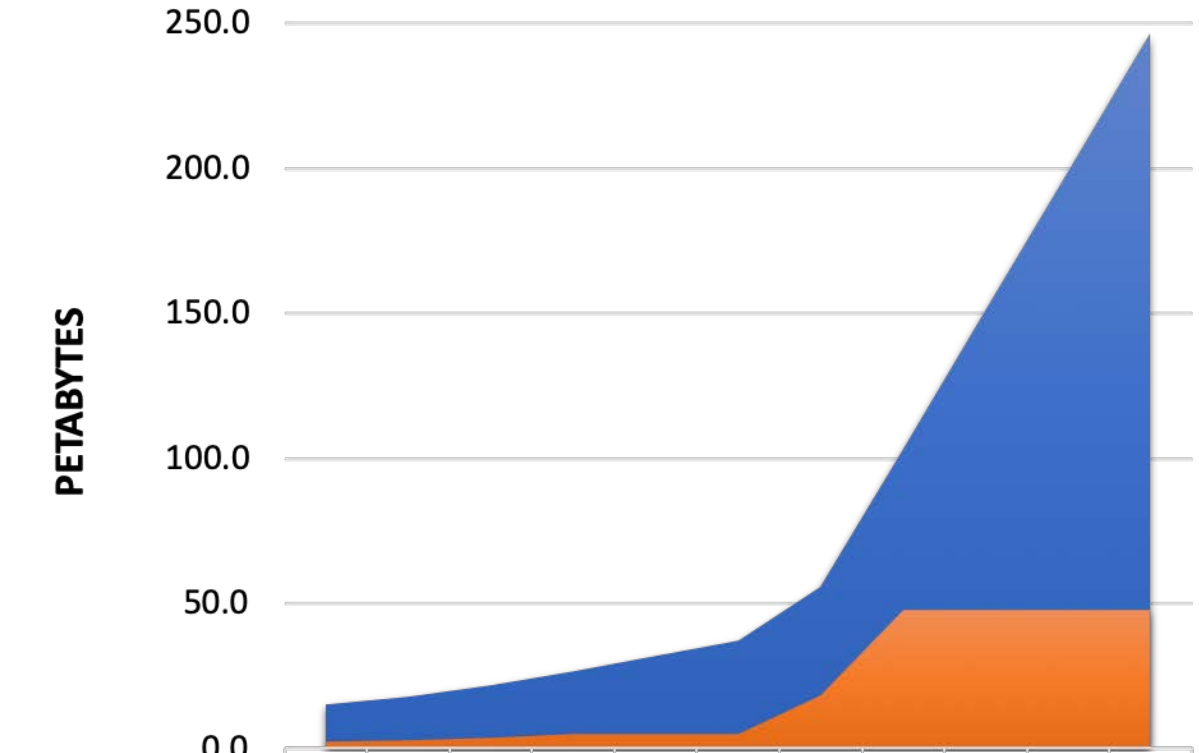
EARTH SCIENCE
DATA SYSTEMS
earthdata.nasa.gov

Challenge

- Volume of data in NASA Earth science archives to increase to 250 Petabytes by 2025.

Need

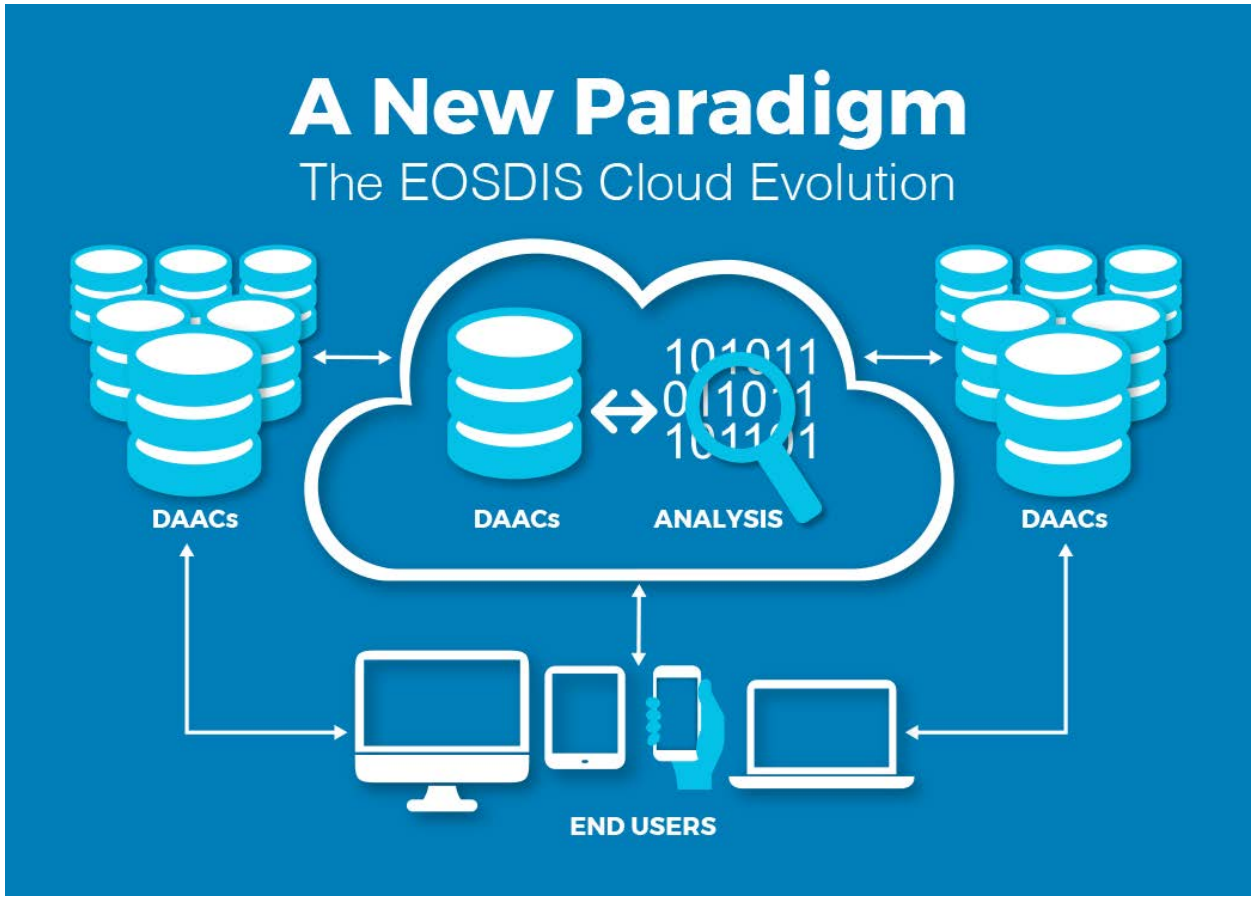
- Efficiently handle storage and computation needs for large data volumes through new data management technologies and architectures.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Archive Size (PB)	15.0	17.7	21.6	26.8	32.0	37.2	55.6	103.4	151.1	198.9	246.6
Annual Growth (PB)	2.6	2.8	3.9	5.2	5.2	5.2	18.4	47.7	47.7	47.7	47.7

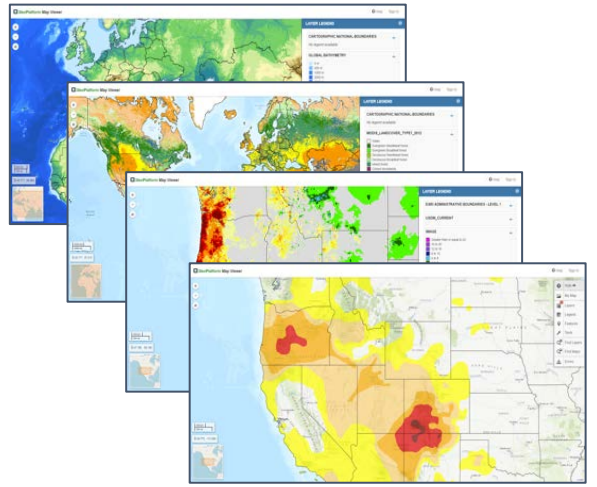
New paradigm for data system stewardship

- Cloud offers performance and cost benefits.
- Realize storage, processing and operational efficiencies.
- Improve cross-archive center collaboration.
- Enable users to work across multiple datasets managed by different archives without transmitting data over networks.



Strategic Public and Private Partnerships

- Demonstrate potential of cloud computing by bringing algorithms to the data to enable processing and analytics at scale.
- Improve discovery of NASA data, services, and tools through commercial search engines.
- Incorporate NASA Earth observation data into agency workflows.
- Improve the ability to find and access Earth observation data and information.



IMPACT
Interagency Implementation and Advanced Concepts Team

Into the Hands of Users

Enabling use of NASA Earth science data by all

Supporting time-critical application areas such as wildfire management, air quality measurements, and flood monitoring.

Land, Atmosphere Near real-time Capability for EOS (LANCE)

- Near real-time (NRT) data and imagery; available within three hours of observation.
- Supports monitoring a variety of natural and man-made phenomena.

earthdata.nasa.gov/lance

Worldview

- Interactively browse over 900 global, full-resolution satellite imagery layers; download the underlying data.
- Using LANCE-sourced imagery, shows the entire Earth as it looks “right now.”

worldview.earthdata.nasa.gov

NASA/ESD Funding/Appropriation

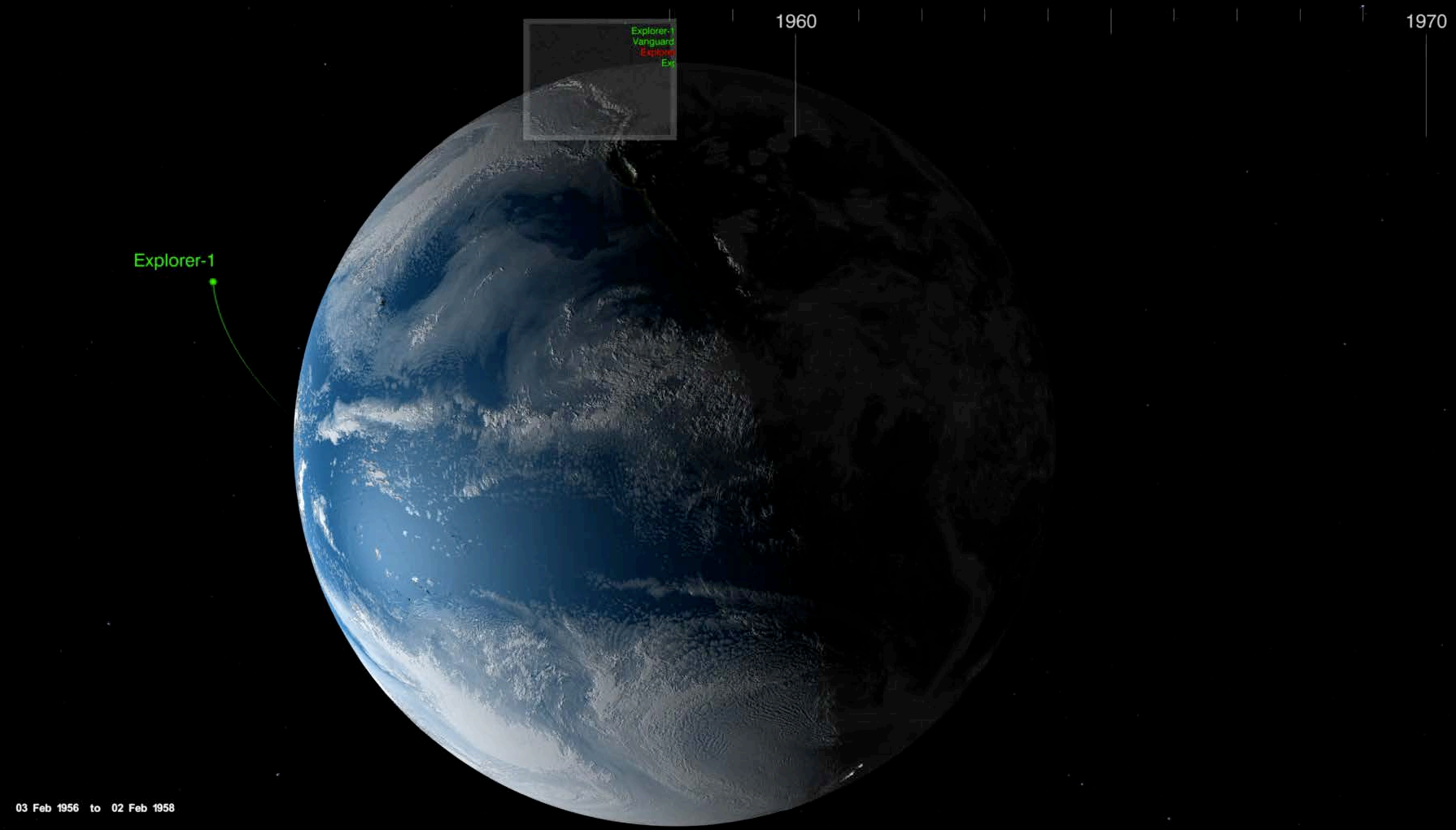
- FY19 (1 Oct 2018 – 30 Sept 2019) funding – appropriated via an Omnibus – was $1.931B

- Budget supports continuation of a balanced ESD portfolio
  - Funding for all remaining elements of the ongoing Flight Program of Record
    - Continues operations and development of Program of Record (including DSCOVR (3 March 2019) EPIC/NISTAR, PACE, CLARREO-PF, OCO-3 (4 May 2019)
  - 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

- The budget is consistent with, and partially addresses, the 2017 Decadal Survey recommendations
  - Supports DO study activities, EVC-1 solicitation, and incubation planning

- President's FY20-24 detailed budget proposal released March 11, 2018
  - Proposes FY20 ESD funding at ~$1.78B
  - Continues to propose termination of PACE and CLARREO-PF
  - CR through December 20

Questions?



NASA Earth Observing Satellites since 1958