# Science Mission Directorate (SMD)

## Earth Science Division (ESD)

# Program of Record

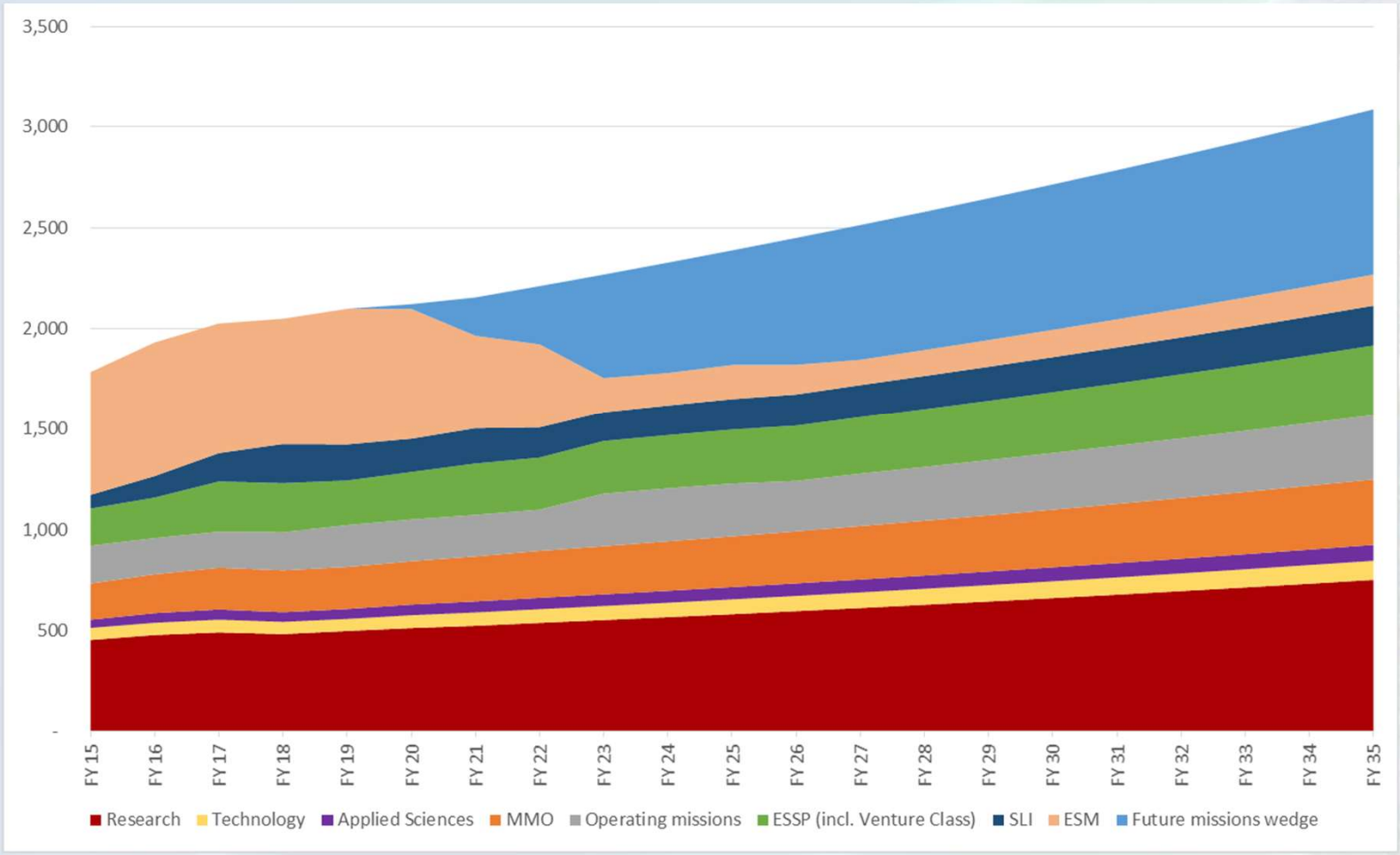
**September 6, 2016**

# Summary

1. FY17 President's budget Request
2. Flight Element
   a. Earth Systematic Missions (ESM)
   b. Sustainable Land Imaging (SLI)
   c. Earth System Science Pathfinder (ESSP) Missions
   d. Operating Missions
   e. Multi-Mission Operations (MMO) Program
3. Research & Analysis Element
4. Applied Science Element
5. Earth Science Technology Element

# 1 . FY17 Presidents Budget Request

# ESD Projected Outyears ($M)




Decadal wedge opens in late FY20

# ESD Budget Sand Chart Data

| | appropriated | appropriated | | | | | |
|---|---|---|---|---|---|---|---|
| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 |
| Total ESD | 1,784 | 1,927 | 2,027 | 2,064 | 2,101 | 2,123 | 2,152 |
| Future missions wedge | | | | | | 24 | 190 |
| ESM | 612 | 705 | 646 | 624 | 676 | 646 | 461 |
| ESSP (incl. Venture Class) | 184 | 201 | 249 | 244 | 221 | 235 | 255 |
| SLI | 68 | 63 | 141 | 194 | 179 | 166 | 176 |
| Operating missions | 187 | 179 | 179 | 188 | 208 | 207 | 206 |
| MMO | 180 | 192 | 206 | 208 | 208 | 215 | 223 |
| Technology | 60 | 61 | 63 | 60 | 60 | 64 | 66 |
| Applied Sciences | 40 | 48 | 51 | 48 | 49 | 53 | 55 |
| Research | 453 | 478 | 492 | 497 | 501 | 514 | 522 |

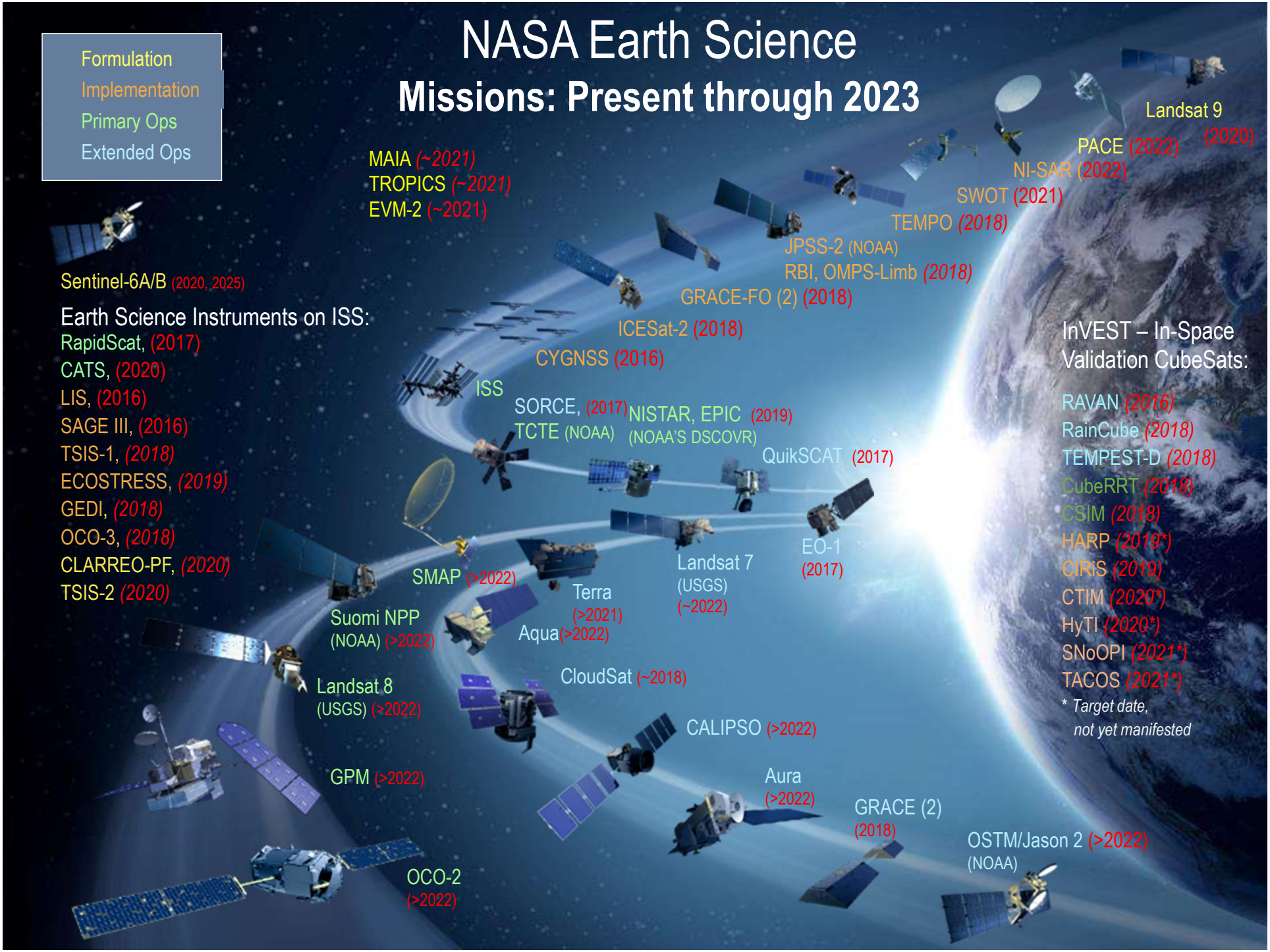
Notes:

- Corresponds to FY17 Presidents Budget
- FY22-35 assumes the percentages outlined in the following pages remain constant.

# 2 . Flight Element

# Flight Element (~70% of ESD budget)

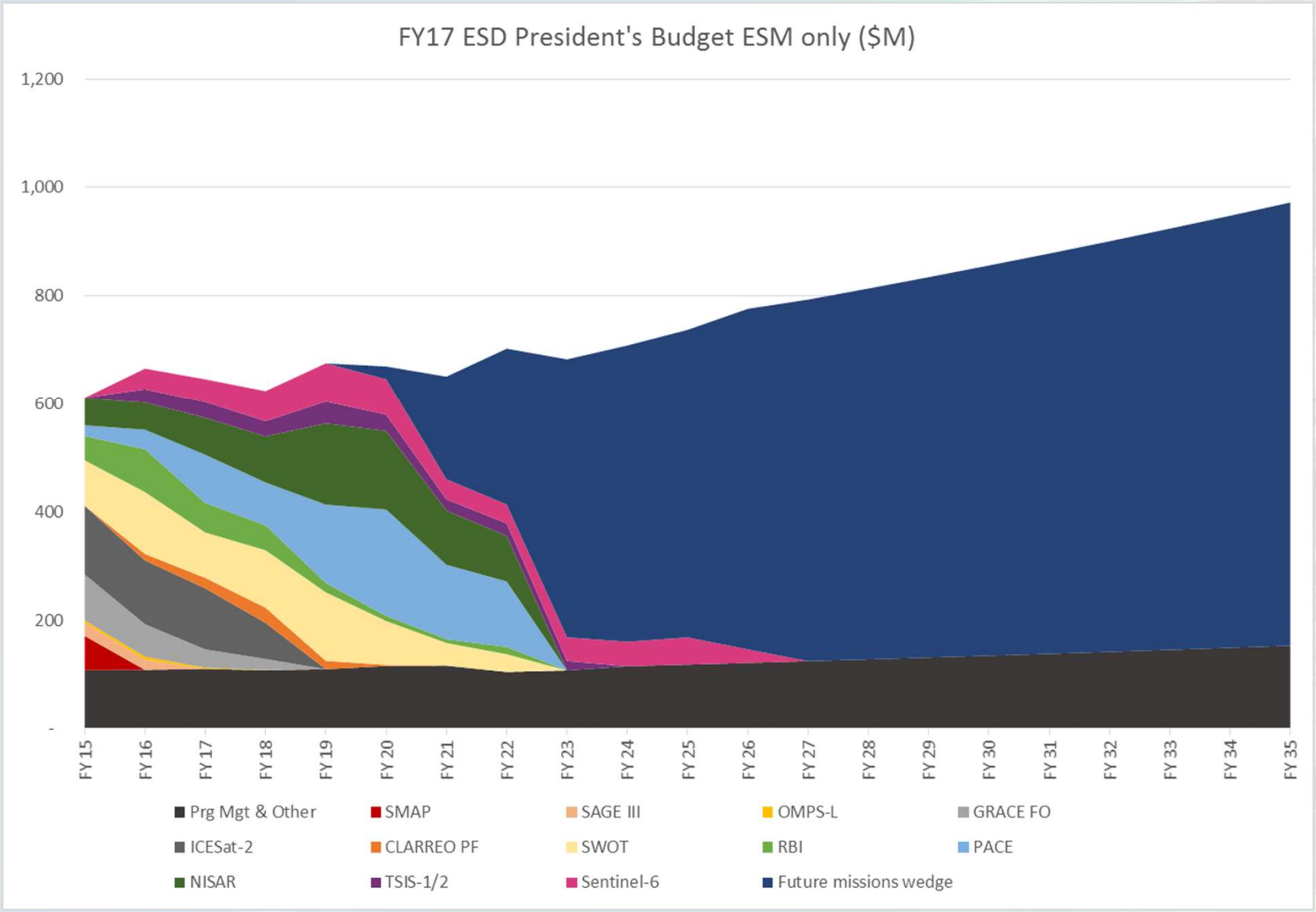
- The Flight Element includes the formulation, development and operation of all flight missions
  a. Earth Systematic Missions
  b. Sustainable Land Imaging
  c. Earth System Science Pathfinder (ESSP) Missions
  d. Operating Missions
  e. MMO (Multi-Mission Operations data systems)
- Chart 8 list all of the missions, present through 2023. Dates highlighted in red indicate:
  - *For operating missions:* the date is the expected life
  - *For satellites/missions in Implementation:* the date is the official agency launch readiness date - exceptions are the 2 imminent launches (SAGE-III and CYGNSS).
  - *For satellites in Formulation:* the date is the target launch date
  - *For **instruments** in Implementation:* the date is the delivery date from NASA, for integration to the host platform
  - *For **Instruments** in Formulation:* the date is the target for delivery from NASA to the host platform


Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
MAIA (~2021)
TROPICS (~2021)
EVM-2 (~2021)
Landsat 9 (2020)
PACE (2022)
NI-SAR (2022)
SWOT (2021)
TEMPO (2018)
JPSS-2 (NOAA)
RBI, OMPS-Limb (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (2016)
Sentinel-6A/B (2020, 2025)
Earth Science Instruments on ISS:
RapidScat, (2017)
CATS, (2020)
LIS, (2016)
SAGE III, (2016)
TSIS-1, (2018)
ECOSTRESS, (2019)
GEDI, (2018)
OCO-3, (2018)
CLARREO-PF, (2020)
TSIS-2 (2020)
ISS
SORCE, (2017)
TCTE (NOAA)
NISTAR, EPIC (2019)
(NOAA'S DSCOVR)
QuikSCAT (2017)
EO-1 (2017)
Landsat 7 (USGS) (~2022)
SMAP (>2022)
Terra (>2021)
Aqua (>2022)
Suomi NPP (NOAA) (>2022)
CloudSat (~2018)
Landsat 8 (USGS) (>2022)
CALIPSO (>2022)
GPM (>2022)
Aura (>2022)
GRACE (2) (2018)
OSTM/Jason 2 (>2022) (NOAA)
OCO-2 (>2022)
InVEST – In-Space Validation CubeSats:
RAVAN (2016)
RainCube (2018)
TEMPEST-D (2018)
CubeRRT (2018)
CSIM (2018)
HARP (2019*)
CIRiS (2019)
CTIM (2020*)
HyTI (2020*)
SNoOPI (2021*)
TACOS (2021*)
* Target date, not yet manifested

# 2.a Earth Systematic Missions (ESM) (~32% of the total ESD Budget)

- The Earth Systematic Missions budget includes only the formulation and development, through launch and on-orbit checkout, of the following missions:
    i. ICESat -2
    ii. NISAR
    iii. SMAP
    iv. CLARREO
    v. TSIS-1 & 2
    vi. SAGE- III
    vii. SWOT
    viii. Sentinel 6
    ix. OMPS-Limb
    x. RBI
    xi. GRACE-FO
    xii. PACE
- Operations activities/costs are represented in a separate budget category (see section 2.c).
- The Sustained Land Imaging Program is presented in a separate budget category (see section 2.b)

# Decadal Wedge - ESM Only



# FY17 ESD Budget *ESM only* Sand Chart Data

| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 |
|---|---|---|---|---|---|---|---|
| ESM | 612 | 705 | 646 | 624 | 676 | 646 | 461 |
| Future missions wedge | | | | | | 24 | 190 |
| ICESat-2 | 126 | 117 | 112 | 67 | Moves to Operating missions line | | |
| SMAP | 63 | Moved to Operating missions line | | | | | |
| SAGE III | 24 | 10 | Moves to Operating missions line | | | | |
| GRACE FO | 85 | 60 | 34 | 21 | Moves to Operating missions line | | |
| SWOT | 84 | 114 | 84 | 106 | 126 | 81 | 42 |
| RBI | 45 | 79 | 54 | 46 | 17 | 9 | 7 |
| TSIS-1/2 | 1 | 22 | 29 | 28 | 40 | 30 | 20 |
| OMPS-L | 4 | 6 | 2 | | | | |
| Sentinel-6 | | 38 | 43 | 56 | 71 | 66 | 37 |
| NISAR | 51 | 72 | 68 | 85 | 150 | 145 | 100 |
| PACE | 20 | 75 | 89 | 79 | 144 | 196 | 137 |
| CLARREO PF | | 1 | 19 | 28 | 15 | 2 | |
| Prg Mgt & Other | 109 | 110 | 111 | 109 | 111 | 117 | 117 |

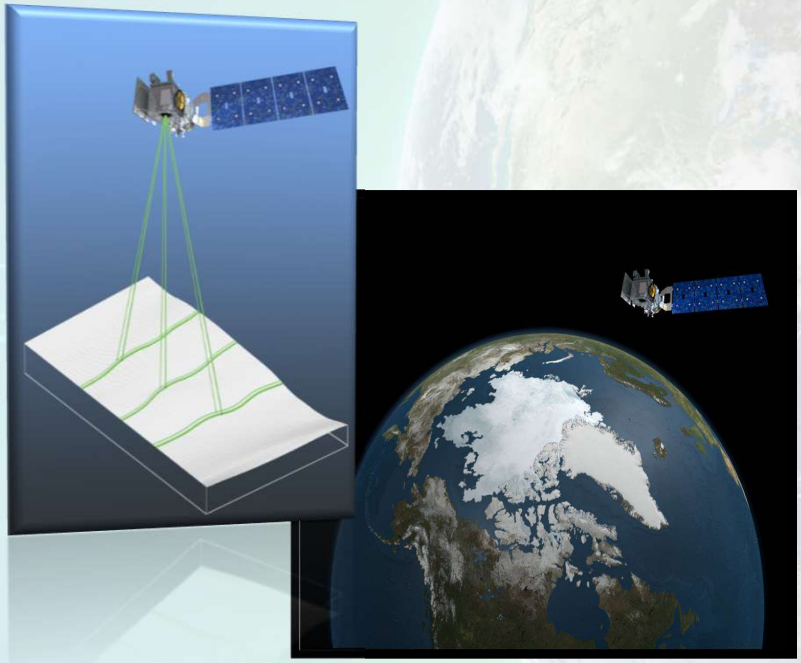
Notes:

- Excludes Operating missions and SLI (Sustainable Land Imaging)
- FY22-35 budget is assumed to be constant

# Ice, Cloud, and land Elevation Satellite (ICESat) – 2: Mission Summary

Benchmark Earth Observing System mission for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristic

- ICESat-2 is a Tier-One mission recommended by the 2007 *Earth Science and Applications* ***Decadal Survey***
- ICESat-2 is a spaceborne mission designed to collect precision laser altimeter measurements of the Earth's surface, ***optimized*** to measure ice sheet heights and polar ice freeboard, and ***contributing*** vegetation canopy height measurements for ecosystem studies.
- ICESat-2 is a Category 1 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- ICESat is in Phase C
- Primary mission operation is planned for 3 years
- Life Cycle Cost: $1064M
- Development Cost: $764M
- Development Cost to go: $268M
- Launch Readiness Date: 6/2018 – *under review*

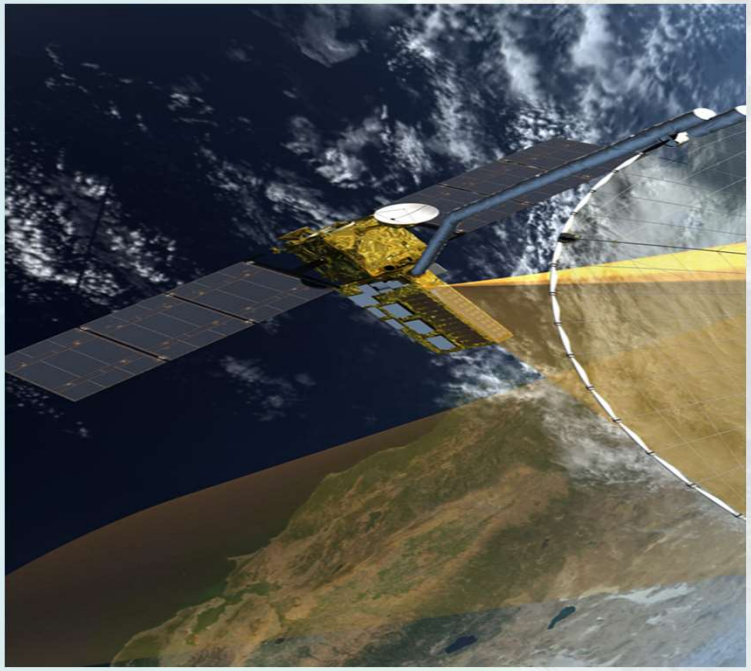


| $M | FY 15 | FY 16 | FY 17 | FY 18 |
|---|---|---|---|---|
| ICESat-2 | 126 | 117 | 112 | 67 |

# NASA-ISRO SAR Mission (NISAR): Mission Summary

The NISAR mission will be the first NASA radar mission to systematically and globally study the solid Earth, the ice masses, and ecosystems.

- NISAR is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- The NISAR Mission, a collaboration between NASA and the Indian Space Research Organization (ISRO)
- NISAR is a dual frequency (L+S band) Synthetic Aperture Radar Mission
- NISAR is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- Primary mission operation is planned for 3 years
- NISAR is in Phase C
- Life Cycle Cost: $867M
- Development Cost: $661M
- Development Cost to go: $656M
- Launch Readiness Date: 09/2022

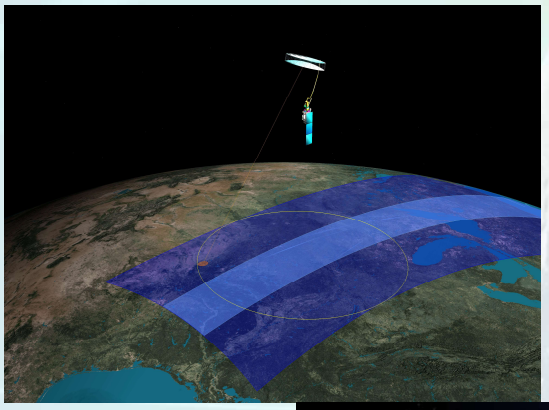


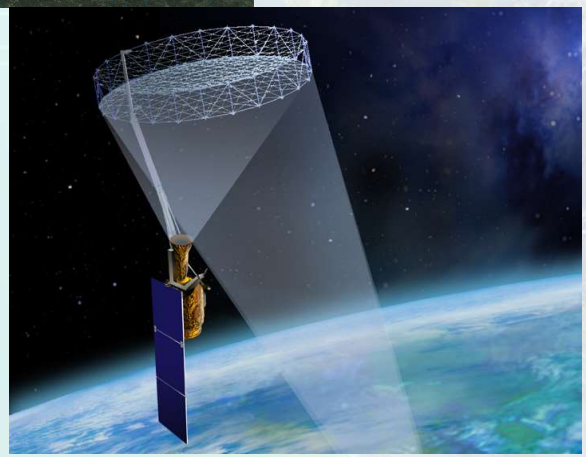
| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 |
|---|---|---|---|---|---|---|---|---|
| NISAR | 51 | 72 | 68 | 85 | 150 | 145 | 100 | 84 |

# Soil Moisture Active Passive (SMAP): Mission Summary

SMAP is providing global measurements of soil moisture and its freeze/thaw state

- SMAP is a Tier-One mission recommended by the 2007 *Earth Science and Applications* ***Decadal Survey***
- SMAP was designed to combine low-frequency microwave radiometer and synthetic aperture radar measurements of surface emission and backscatter to estimate soil moisture and freeze-thaw cycling globally
- Following failure of the active radar instrument, SMAP continues to provide unprecedented measurements of soil moisture
- SMAP is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SMAP is in Phase-E (operations) with primary mission operations planned for 3 years
- Life Cycle Cost: $890M
- Development Cost: $454M
- Development Cost to go: $0 (in operations)
- **Launch Date: January 31, 2015**



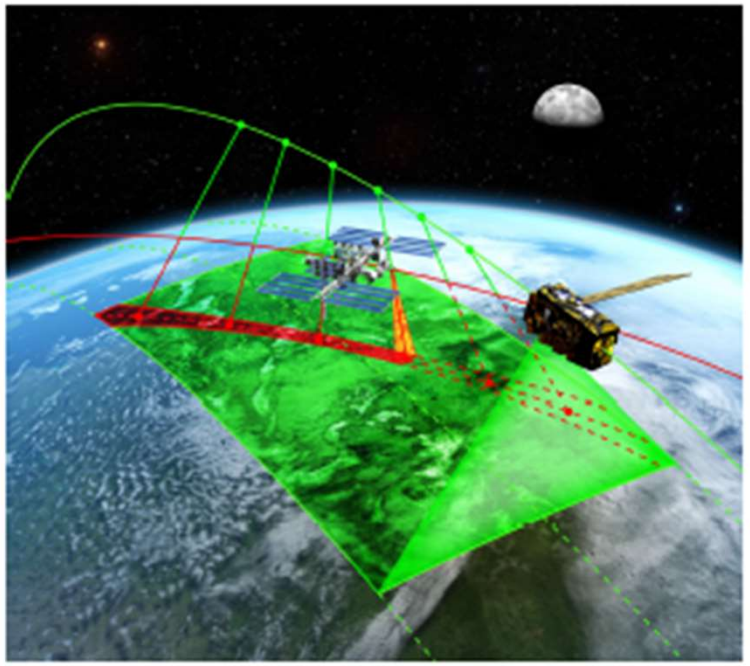


| $M | FY 15 |
|---|---|
| SMAP | 63 |

# Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder: Mission Summary

CLARREO produce highly accurate climate records to test climate projections in order to improve models and enable sound policy decisions.

- CLARREO is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- In 2016, the **CLARREO Pathfinder** (CPF) was initiated to demonstrate essential measurement technologies required for the full CLARREO mission.
- CPF, an instrument hosted on the ISS, will provide high accuracy measurements of reflected solar radiation
- CLARREO is a Category 3 project (NPR 7120.5E) & payload risk class D (NPR 8705.4)
- CLARREO PF is in Pre-Formulation (KDP-A on 7 Oct 2016)
- Life Cycle Cost range: $65-80M
- Target launch date: NET 2020

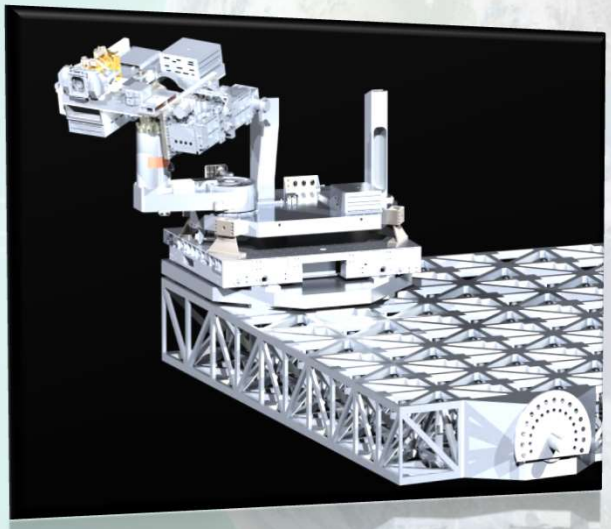


| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 |
|---|---|---|---|---|---|---|
| CLARREO PF | - | 1 | 19 | 28 | 15 | 2 |

# Total and Spectral Solar Irradiance (TSIS – 1&2): Mission Summary

TSIS 1&2 will continue a 36 year data record of the Total and Spectral energy output of the Sun, measured at the top of the Earth's atmosphere

- TSIS was originally planned to be implemented by NOAA forflight on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) spacecraft.
- In 2010, TSIS was re-planned by NOAA for the Joint Polar Satellite System (JPSS) Polar Free Flyer (PFF).
- In the FY14 Presidents Budget, NASA assumed responsibility for the TSIS mission and will fly as instruments on the ISS
- TSIS instruments will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for accurate scientific models of climate change and solar variability.
- TSIS-1 is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- TSIS -1 is in Phase C
- Primary mission operations is planned for 5 year mission
- TSIS-1
  - Life Cycle Cost: $86M
  - Development Cost: $50M
  - Cost to go: $37M
  - LRD: 04/2018 (instrument manifested on SpaceX-13)
- TSIS-2
  - Life Cycle Cost range: $120-150M
  - Target launch date: NET 2022
- TSIS-2 will continue the measurements in the 2020 time-frame

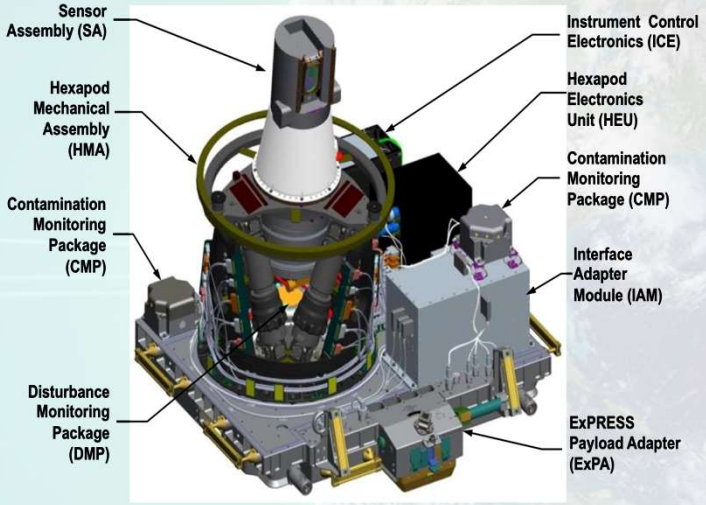


| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 | FY 23 |
|---|---|---|---|---|---|---|---|---|---|
| TSIS 1&2 | 1 | 22 | 29 | 28 | 40 | 30 | 20 | 23 | 17 |

# Stratospheric Aerosol and Gas Experiment (SAGE) III - International Space Station (ISS): Mission Summary

SAGE III's will provide global, long-term measurements of the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere.

- SAGE III is the third generation of solar occultation instruments consisting of a grating spectrometer that measures ultraviolet/visible energy.
- SAGE III will be robotically mounted on the ExPRESS Logistics Carrier on the International Space Station.
- SAGE III is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SAGE III is in Phase C
- Life Cycle Cost: $133M
- Development Cost: $92M
- Development Cost to go: $19M
- SAGE III is currently scheduled to launch on a SpaceX Falcon 9 November 2016.

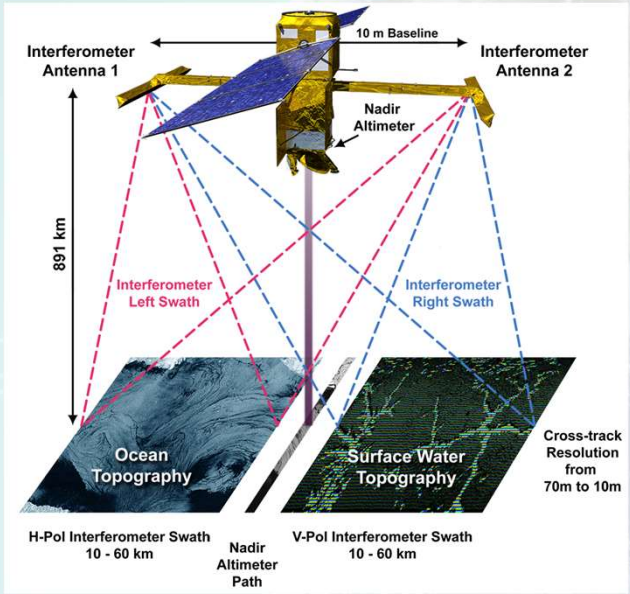



| $M | FY 15 | FY 16 |
|---|---|---|
| SAGE III | 24 | 10 |

# Surface Water Ocean Topography (SWOT): Mission Summary

SWOT will be the first wide-swath altimetry mission to measure ocean topography completely covering the world's oceans ***and*** large freshwater bodies with repeated high-resolution elevation measurements.

- SWOT is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- SWOT uses a Ka-band SAR interferometric system with 2, 50 km-wide swaths, to produce sea-surface and lake/river heights
- Partnered mission with Centre National d'Etudes Spatiales (CNES) & Canadian Space Agency (CSA)
- SWOT is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SWOT is in Phase C
- Science mission duration of 3 years
- Life Cycle Cost: $755M
- Development Cost: $571M
- Development Cost to go: $553M
- Launch Readiness Date: 04/2022




| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 |
|---|---|---|---|---|---|---|---|---|
| SWOT | 84 | 114 | 84 | 106 | 126 | 81 | 42 | 33 |

# SENTINEL 6: Mission Summary

The 2-satellite Sentinel-6 radar altimeter mission is a component of the European Copernicus Program of Earth observing satellites. Sentinel-6 will provide high-precision measurements of global sea-level, extending continuous ocean topography measurements beyond the TOPEX/Poseidon and Jason-1/2/3 time period (1992-present).

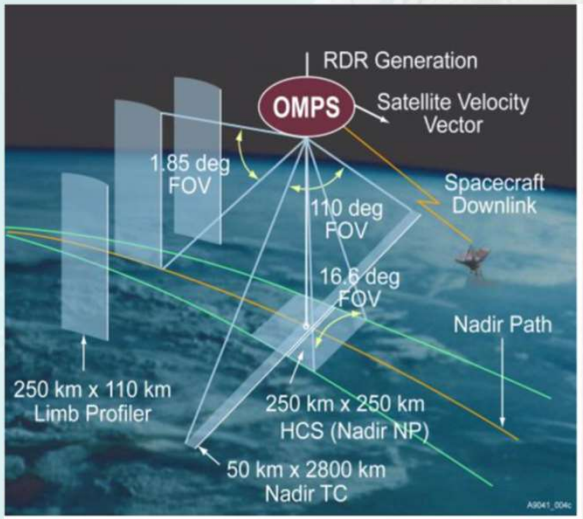
- The Sentinel-6 mission is a US-European cooperation involving NASA, NOAA, ESA, and EUMETSAT
- NASA will provide the payload and launch the Sentinel-6A and -6B satellites.
- In the FY16 Presidents Budget, NASA assumed responsibility for the Sentinel-6 mission from NOAA.
- Sentinel-6 will continue high precision ocean altimetry measurements in the 2020–2030 time-frame.
- Sentinel 6 is a Category 2 project (NPR 7120.5E) & payload risk class B for the Altimetry payload and risk class C for the GNSS-RO payload. (NPR 8705.4)
- Sentinel 6 is in Pre-Formulation (combined KDP-A/B in Oct 2016)
- Primary mission operations is planned for 7.5 years
- Life Cycle Cost range: $480-530M
- Launch Readiness Date range: NET 2020 (Sentinel-6A) and 2025 (Sentinel-6B)

| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 | FY 23 | FY 24 | FY 25 | FY 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sentinel-6 | - | 38 | 43 | 56 | 71 | 66 | 37 | 35 | 44 | 45 | 50 | 25 |

# Ozone Mapping and Profiler Suite (OMPS) - Limb): Mission Summary

The advanced Ozone Mapping and Profiler Suite (OMPS)-Limb tracks the health of the ozone layer and measures the vertical profiles of stratospheric ozone in the Earth's atmosphere.

- The OMPS suite consists of three spectrometers: a downward-looking nadir mapper, nadir profiler and limb profiler.
- In the FY14 Presidents Budget, NASA assumed the responsibility for implementing the OMPS-Limb (OMPS-L) profiler from NOAA.
- The entire OMPS suite currently flies on board the Suomi-NPP spacecraft
- OMPS-L is scheduled to fly on the JPSS-2 satellite mission.
- OMPS-L is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- OMPS-L is in Phase C
- Life Cycle Cost: $20M
- Development Cost: N/A
- Development Cost to go: $13.7M
- Launch Readiness Date: Launch date driven by JPSS-2, scheduled for launch July 2021

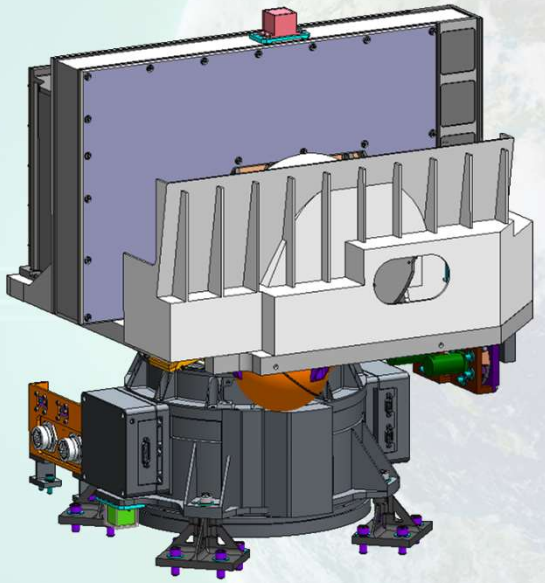



| $M | FY 15 | FY 16 | FY 17 |
|---|---|---|---|
| OMPS-L | 4 | 6 | 2 |

# Radiation Budget Instrument (RBI): Mission Overview

RBI will make accurate global measurements of Earth's emitted radiation, to help understand the links between the Earth's incoming and outgoing energy, and the properties of the atmosphere that affect it.

- In the FY14 President's Budget, NASA assumed responsibility for RBI development from NOAA.
- RBI is a scanning radiometer that will measure the sunlight reflected by Earth and the radiation the planet emits; RBI will extend the unique global measurements of the Earth's radiation budget provided by the Clouds and the Earth's Radiant Energy Systems (CERES) instruments since 1998.
- RBI is scheduled to fly on the JPSS-2 satellite mission.
- RBI is a Category 2 project (NPR 7120.5E) & payload risk class B (NPR 8705.4)
- RBI is in Phase C
- Life Cycle Cost: $305M
- Development Cost: $202M
- Development Cost to go: $102M
- Launch Readiness Date: Launch date driven by JPSS-2, presently scheduled for launch July 2021

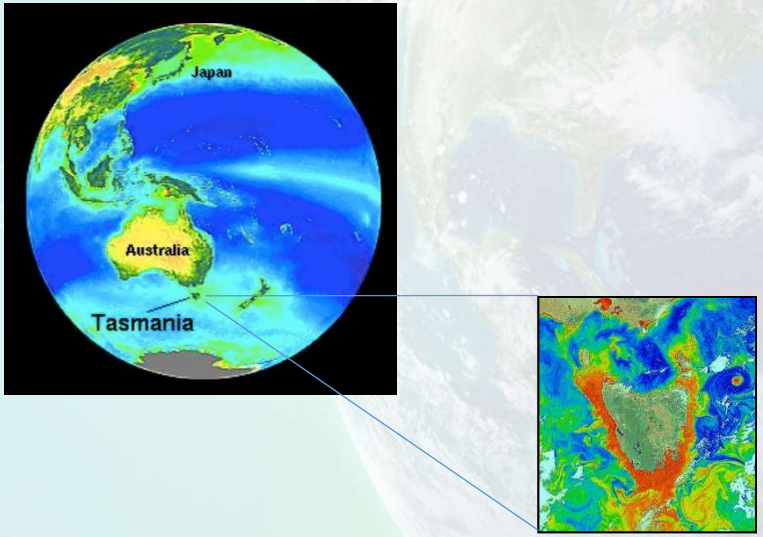


| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 |
|---|---|---|---|---|---|---|---|---|
| RBI | 45 | 79 | 54 | 46 | 17 | 9 | 7 | 13 |

# Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE): Mission Overview

PACE will expand on-going global observations of ocean ecology, biology, and chemistry, required to quantify aquatic carbon storage and ecosystem function in response to human activities and natural events

- The PACE mission is being formulated with a **design-to-cost** approach where the mission studies will be used to define the appropriate approach while maximizing the science capability at a high cost confidence.
- The PACE mission will utilize a hyperspectral scanner to make global ocean color measurements essential for understanding the carbon cycle and how it both affects and is affected by climate change, along with aerosol polarimetry measurements to extend data records on clouds and aerosols.
- PACE will make these measurements until the readiness of the more advanced Aerosol, Cloud, and Ecosystems (ACE) mission recommended as a Tier 2 mission by the 2007 National Academies **Decadal Survey**.
- Recommended as a Climate Continuity Mission for global Ocean Color, Aerosol and Cloud science in NASA's 2010 Climate Architecture document, *Responding to the Challenge of Climate and Environmental Change*.
- PACE is a Category 2 project (NPR 7120.5E) & payload risk class is to be determined by the start of Phase B (NPR 8705.4).
- PACE is in Phase A.
- Primary mission operation is planned for 3 years
- Life Cycle Cost range: $805-850M
- Targeted launch: NET 2022

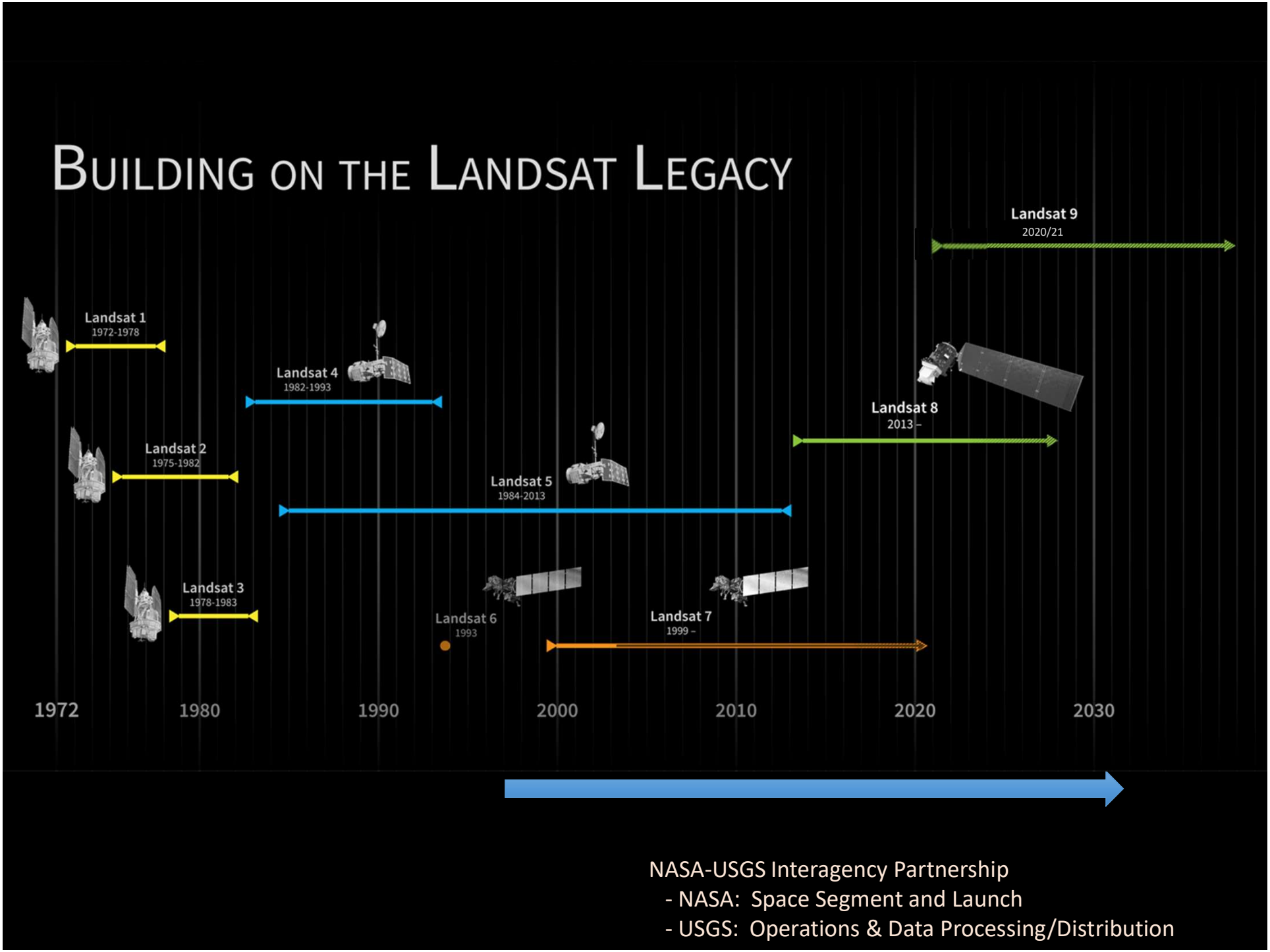



| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 |
|---|---|---|---|---|---|---|---|---|
| PACE | 20 | 75 | 89 | 79 | 144 | 196 | 137 | 121 |

# 2.b Sustainable Land Imaging (SLI) (~7% of ESD Budget)

- A 3-component program – in partnership with USGS – for a sustainable, continuous, global land imaging system through 2035, consistent with the existing 45-year Landsat record:
  - **Landsat 9** (fully Class-B rebuild of Landsat 8) targeted to launch in FY 2021
    - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B – includes 30 m res. multispectral and 120-m thermal IR measurements (like Landsats 7, 8)
  - **Land Imaging Technology and Systems Innovation**
    - Hardware and data processing investments to reduce risk in next generation missions and inform future system architecture decisions
  - **Landsat 10** (Class B multispectral and Thermal IR) to launch ~2027-2028
    - Mission architecture to be informed by the technology investments (2015-), leading to mission definition ~2020

| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 |
|---|---|---|---|---|---|---|---|
| **Total SLI** | **64** | **59** | **137** | **190** | **177** | **164** | **174** |
| Landsat-9 | 60 | 56 | 131 | 179 | 166 | 128 | 109 |
| SLI Tech | 4 | 3 | 6 | 11 | 11 | 11 | 11 |
| Landsat-10 | | | | | | 25 | 54 |



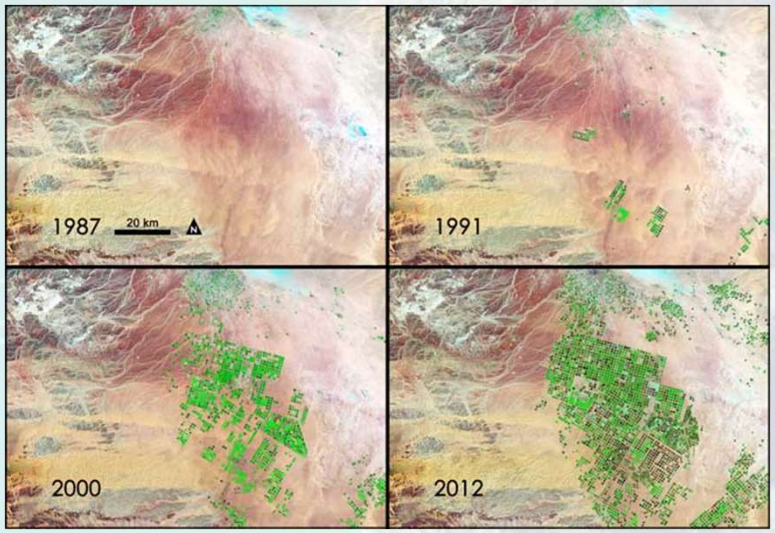

NASA-USGS Interagency Partnership

- NASA: Space Segment and Launch
- USGS: Operations & Data Processing/Distribution

# Landsat 9: Mission Overview

Landsat 9 will provide continuity in the multi-decadal land surface observations to study, predict, and understand the consequences of land surface dynamics

- Landsat 9 is Core Component of Sustainable Land Imaging Program
- Partnership: NASA & United States Geological Survey (USGS)
- Landsat 9 will retrieve data on surface properties, land cover, and vegetation condition utilizing reflective-band push-broom imager (15-30m res) with 9 spectral bands at 15 - 30m
- Landsat 9 will retrieve surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration utilizing a thermal infrared (TIR) push-broom imager with 2 TIR bands @ 120m resolution
- Landsat 9 is a Category 1 project (NPR 7120.5E) & payload risk class B (NPR 8705.4)
- Landsat 9 is in Phase B
- Primary mission operation is planned for 5 years
- Life Cycle Cost range: $851-928M
- Targeted launch: NET Dec 2020




**Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)**

| $M | FY 15 | FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 |
|---|---|---|---|---|---|---|---|
| Landsat-9 | 60 | 56 | 131 | 179 | 166 | 128 | 109 |

# 2.c ESSP Missions – Overview (~12% of ESD Budget)

- The Earth System Science Pathfinder (ESSP) program now provides frequent, regular, Earth science flight and airborne data acquisition opportunities that address and advance new and emerging scientific priorities and measurement capabilities. Recommended in the 2007 Decadal Survey, ESSP funds relatively low-cost, schedule constrained, Principal Investigator-led, competitively selected, science-driven investigations and missions.

- The present ESSP Program consists of two primary sets of missions
  - **ESSP Missions:** On-orbit missions competitively selected and launched prior to the establishment of the Earth Venture program
    - ESSP AO-1: Gravity Recovery and Climate Experiment (GRACE; launched 3/2002)
    - ESSP AO-2: Cloudsat; Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO; launched 4/2006)
    - ESSP AO-3: Orbiting Carbon Observatory (OCO – launch vehicle failure 2/2009); Aquarius (joint with Argentine Space Agency; 6/2011– 6/2015)
    - Other: OCO-2 (launched 7/2014); OCO-3/ISS

  - **Earth Venture – 3 solicitation/mission strands**
    - Earth Venture – Suborbital: Airborne Investigations (solicited every 4 years)
    - Earth Venture – Instruments: Missions of opportunity on host platforms (solicited every 18 months)
    - Earth Venture – Missions: complete spaceflight missions (solicited every 4 years)

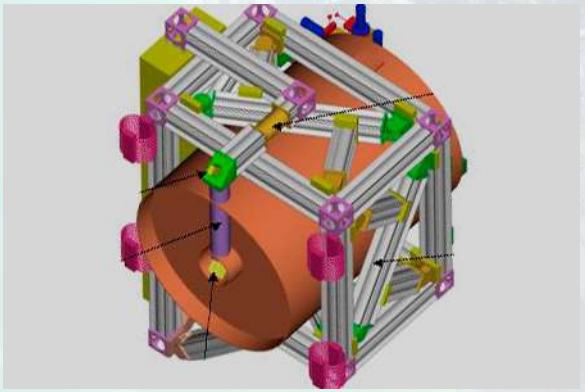
# ESSP Missions – Earth Venture Overview

- A sustained, successful Venture-class element is a priority from the Decadal Survey
  - Advances science/applications and promotes community involvement through frequent, regular proposal opportunities
  - Ensures overall program scientific flexibility and responsiveness through constrained development schedules
- Complement the systematic missions, provide flexibility to accommodate scientific advances and new implementation approaches
- Can provide complementary science to the Decadal Survey Missions but does not replace them.
- ***All ongoing and planned investigations, solicitations, and selections are on track and fully funded***

3 “Strands”

**Sub-Orbital**

**Small-sat/Missions**



**Instrument**

# ESSP Missions – Earth Venture Projects

- **Earth Venture – Suborbital**:
  - **EVS-1 Missions**: Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS); Airborne Tropical Tropopause Experiment (ATTREX); Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE); Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ); and Hurricane and Severe Storm Sentinel (HS-3)
  - **EVS-2 Missions**: Atmospheric Carbon and Transport – America (ACT-America); Atmospheric Tomography Mission(ATom); COral Reef Airborne Laboratory (CORAL); North Atlantic Aerosols and Marine Ecosystems Study (NAAMES); ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES); and Oceans Melting Greenland (OMG)

- **Earth Venture – Instruments**:
  - Tropospheric Emissions: Monitoring of Pollution (TEMPO); Global Ecosystem Dynamics Investigation Lidar (GEDI); ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS); Multi-Angle Imager for Aerosols (MAIA); Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)

- **Earth Venture – Missions**:
  - Cyclone Global Navigation Satellite System (CYGNSS)

# 2.d Operating Missions (~8% of ESD budget)

- Operating missions: missions that are currently active and providing science data, beyond the on-orbit commissioning period.
- Operating missions may be in their *primary operational phase* or in an *extended operational phase*.
  - 19 missions now in operation (2016), rising to 25 missions in operation by 2022
- The bi-annual NASA HQ Science Mission Directorate Senior Review process, as implemented by the Earth Science Division, is used evaluate and recommend extended mission operations.
  - The Senior Review examines mission contributions, with the primary evaluation factor being the scientific value of the mission producrs, with attention to the value of both the science and the contributions to other-agency "operations" that will be enabled by the extension of the mission. All missions which have completed prime operations are included in the Senior Review.
- As part of mission termination, funding is normally provided to the mission team to finalize the dataset with a final reprocessing using updated calibrations and algorithms.
  - Currently two ESD missions are in decommissioning/Disposal and Closeout activities (Phase F) : TRMM and Aquarius.

# ESD Operating Missions Status Summary

| Mission | Program Scientist | Launch | Phase E | Approved Through |
|---|---|---|---|---|
| QuikSCAT | E. Lindstrom | 6/19/1999 | Extended | 9/30/2017 |
| Terra | G. Gutman | 12/18/1999 | Extended | 9/30/2017 |
| NMP EO-1 | G. Gutman | 11/21/2000 | Extended | 9/30/2016 |
| GRACE | L. Tsaoussi | 3/17/2002 | Extended | 9/30/2017 |
| Aqua | R. Kakar | 5/4/2002 | Extended | 9/30/2017 |
| SORCE | D. Considine | 1/25/2003 | Extended | 9/30/2017 |
| Aura | K. Jucks | 7/15/2004 | Extended | 9/30/2017 |
| Cloudsat | D. Considine | 4/28/2006 | Extended | 9/30/2017 |
| CALIPSO | D. Considine | 4/28/2006 | Extended | 9/30/2017 |
| OSTM | E. Lindstrom | 6/20/2008 | Extended | 9/30/2017 |
| Suomi-NPP | P. Bontempi | 10/28/2011 | Prime | 10/28/2016 |
| GPM | R. Kakar | 2/27/2014 | Prime | 5/29/2017 |
| OCO-2 | K. Jucks | 7/2/2104 | Prime | 10/12/2016 |
| RapidScat | E. Lindstrom | 9/19/2014 | Prime | 9/30/2017 |
| CATS | H. Maring | 1/10/2015 | Prime | 12/31/2017 |
| SMAP | J. Entin | 1/31/2015 | Prime | 5/30/2018 |
| DSCOVR Instr | R. Eckman | 2/11/2015 | Prime | 9/30/2017 |

Earth Science Missions with no NASA Phase E MO&DA funding

| Mission | Program Scientist | Launch | Phase E | Approved |
|---|---|---|---|---|
| LAGEOS 1 | B. Phillips | 5/4/1976 | Extended | n/a |
| LAGEOS 2 | B. Phillips | 10/23/1992 | Extended | n/a |
| Landsat 7 | G. Gutman | 4/15/1999 | USGS | n/a |
| Landsat 8 | G. Gutman | 2/11/2013 | USGS | n/a |
| Jason - 3 | E. Lindstrom | 1/17/2016 | NOAA | n/a |

# 2.e Multi-Mission Operations (MMO) program (~10% of ESD budget)

- The Earth Science Multi-Mission Operations (MMO) program acquires, processes, preserves, and distributes observational data from operating spacecraft to support Earth Science research focus areas.
- The overall MMO heterogeneous data system consists of:
  - **Earth Observing System Data and Information System (EOSDIS**), in operations since 1994, creates earth science data products from satellite data that arrives at the rate of more than 10 terabytes per day. EOSDIS distributed 1.4 billion products to over 2.5 million users in FY2015. EOSDIS consists of:
    - 15 Science Investigator-led Processing Systems (SIPS) – Process instrument data
    - 12 Distributed Active Archive Centers (DAACs) – Archive and distribute data
    - Common Services/Tools – Provide Access to Data among systems
    - Earth Science Data System Working Group (ESDSWG) – Support community involvement
  - **Competitive Programs**
    - Making Earth System Data Records for Use in Research Environments (MEaSUREs)
    - Advancing Collaborative Connections for Earth System Science (ACCESS)
    - Citizen Science for Earth System Science
    - Science Portals
  - **International and Interagency Coordination and Development**
    - CEOS Working Group on Information Systems and Services (WGISS)
    - Office of Science and Technology Policy Climate Data Initiative (CDI) and Big Earth Data Initiative (BEDI)
    - NASA-European Space Agency (ESA) Bilateral
    - Group on Earth Observation (GEO) Data Sharing Working Group (DSWG)
    - USGEO Data Management Working Group (DMWG)

# 3. Research & Analysis Element Major Program Areas (~25% of ESD Budget)

- Competed individual investigator science – ~1300 awards at NASA centers, universities, laboratories of other government agencies, and private/non-profit sectors
  - *Disciplinary-based programs* - Solicitations tied to individual and/or closely-related programs within each of NASA's six interdisciplinary science focus areas;
    - Carbon Cycle and Ecosystems
    - Climate Variability and Change
    - Atmospheric Composition
    - Global Water and Energy Cycle
    - * Earth Surface and Interior
    - * Weather
  - *Interdisciplinary and cross-disciplinary programs* – Solicitations that cut across traditional disciplinary and/or focus area boundaries, or support entire R&A program;
  - *Competed science teams for NASA missions* – Solicitations tied to individual or closely-associated NASA satellite missions;
  - *Field campaigns that integrate surface-based, airborne, and satellite observations using large scale models* – Solicitations for short-duration field campaigns to study Earth system processes and contribute to or benefit from satellite observations.
- Enabling capabilities
  - *Airborne Science* - Maintain and operate a fleet of aircraft and associated systems and associated systems that support the entire Earth Science program;
  - *Scientific Computing* - Maintain and operate high end computing systems that support Earth system modeling, data assimilation, and large scale data analysis;
  - *Calibration/Validation and Complementary Surface Observations and Facility Airborne Instruments* - Provide capability that supports and complements NASA's satellite program;
  - *Modeling and Assimilation Systems for Community Use* - Maintain and further develop modeling systems for use by the entire NASA earth science community.

# 4. Applied Sciences (~2.5% of ESD Budget)

- The NASA Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to: enable near-term uses of Earth science knowledge and discoveries; demonstrate new applications; and facilitate early adoption of applications by public and private sector stakeholder organizations.
- The Program funds projects that enable innovative uses of NASA Earth science data in organizations' policy, business, and management decisions. Project results and enhanced decision-making improve the quality of life and strengthen the economy.
- The Applied Sciences program activities includes three main foci:
  - **Applications Development/Research** addresses disasters, ecological forecasting, health and air quality, water resources, and wild fires.
  - **Capacity Building** works with users in the U.S. and developing countries to improve skills and workforce by applying Earth observations.
  - **Satellite Mission/Information Use Planning** engages users to envision potential applications for future Earth-observing satellites, helping them prepare to use the data and further enhance the value of each satellite mission.

# 5. Earth Science Technology (~3% of ESD budget)

- Advanced technology plays a major role in enabling Earth research and applications.
- The Earth Science Technology Program (ESTP) enables new science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development time of earth science instruments and information systems.
- A rigorous approach to technology development is used through analyses of science requirements for technology needs; selecting and funding technologies through competitive solicitations and partnership opportunities; actively managing funded technology development projects; and facilitating the infusion of mature technologies into science campaigns and missions.

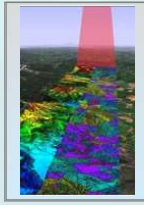
**Advanced Technology Initiatives (ATI)**

**Advanced Component Technologies (ACT)** - development of critical components and subsystems for instruments and platforms
*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 that could not otherwise be fully tested on the ground or in airborne systems
*Future solicitations planned in FY20 and FY23*

**Instrument Incubator Program (IIP)** - robust new instruments and measurement techniques
*Future solicitations/selections planned in FY19 and FY21*

**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
*Future solicitations/selections planned in FY18, FY20 and FY22*



**Decadal Incubation -** Observing systems, instruments, models and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables
*Future solicitations/selections planned in FY19 and FY21*

# Backup

# ESD ***Notional*** Budget FY22 – FY35

| $M | appropriated FY 15 | appropriated FY 16 | FY 17 | FY 18 | FY 19 | FY 20 | FY 21 | FY 22 | FY 23 | FY 24 | FY 25 | FY 26 | FY 27 | FY 28 | FY 29 | FY 30 | FY 31 | FY 32 | FY 33 | FY 34 | FY 35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total ESD | 1,784 | 1,927 | 2,027 | 2,064 | 2,101 | 2,123 | 2,152 | 2,208 | 2,266 | 2,325 | 2,385 | 2,447 | 2,511 | 2,576 | 2,643 | 2,712 | 2,782 | 2,855 | 2,929 | 3,005 | 3,083 |
| Future missions wedge | | | | | | 24 | 190 | 285 | 510 | 543 | 564 | 625 | 663 | 680 | 698 | 716 | 734 | 753 | 773 | 792 | 813 |
| ESM | 612 | 705 | 646 | 624 | 676 | 646 | 461 | 414 | 169 | 161 | 169 | 147 | 126 | 129 | 132 | 136 | 139 | 143 | 147 | 150 | 154 |
| ESSP (incl. Venture Class) | 184 | 201 | 249 | 244 | 221 | 235 | 255 | 259 | 261 | 264 | 269 | 275 | 281 | 289 | 296 | 304 | 312 | 321 | 329 | 338 | 347 |
| SLI | 68 | 63 | 141 | 194 | 179 | 166 | 176 | 150 | 145 | 149 | 153 | 157 | 161 | 165 | 170 | 174 | 178 | 183 | 188 | 193 | 198 |
| Operating missions | 187 | 179 | 179 | 188 | 208 | 207 | 206 | 204 | 260 | 263 | 262 | 250 | 260 | 267 | 274 | 281 | 289 | 296 | 304 | 312 | 320 |
| MMO | 180 | 192 | 206 | 208 | 208 | 215 | 223 | 233 | 239 | 245 | 251 | 258 | 264 | 271 | 278 | 286 | 293 | 301 | 308 | 316 | 325 |
| Technology | 60 | 61 | 63 | 60 | 60 | 64 | 66 | 68 | 70 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 88 | 90 | 92 | 95 |
| Applied Sciences | 40 | 48 | 51 | 48 | 49 | 53 | 55 | 56 | 58 | 59 | 61 | 62 | 64 | 66 | 67 | 69 | 71 | 73 | 75 | 77 | 79 |
| Research | 453 | 478 | 492 | 497 | 501 | 514 | 522 | 540 | 554 | 568 | 583 | 598 | 614 | 630 | 646 | 663 | 680 | 698 | 716 | 735 | 754 |