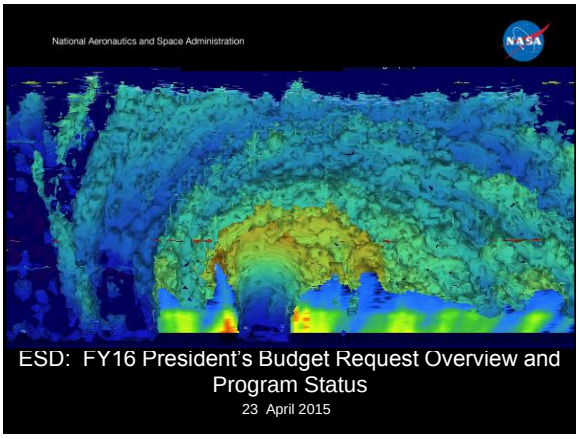
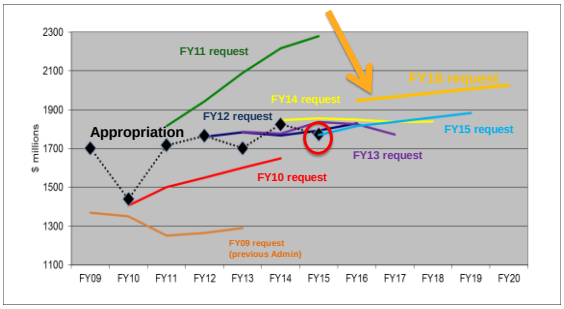


ESD: FY16 President's Budget Request Overview and Program Status

23 April 2015

Earth Science Budget: FY16 Request/FY15 Appropriation

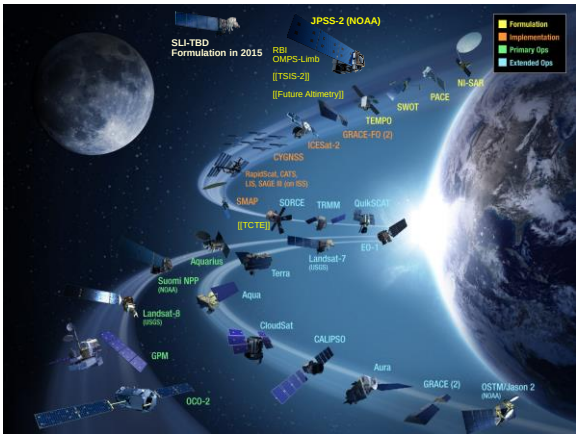


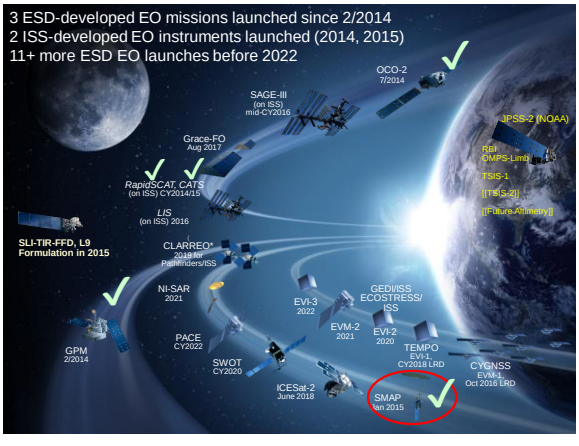
OVERALL SUMMARY (1 of 2)

- ESD budget increases significantly

	FY15	FY16	FY17	FY18	FY19	FY20
FY16	**1.730**	**1.894**	**1.913**	**1.932**	**1.952**	**1.971**
FY15		1.762	1.784	1.805	1.829	---

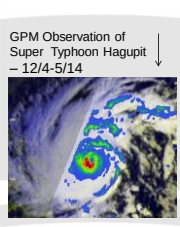
- NASA now has mandate for additional long-term measurements for the nation:
  - Altimetry after Jason-3
  - Solar Irradiance, Ozone Profile, Earth Radiation Budget all starting in FY16
- Sustainable Land Imaging Program (w/USGS; NASA funds flight hardware):
  - TIR-FFD (2019)
  - Upgraded Landsat-9 (2023)
  - Focused technology development to inform designs of Landsat-10+
- Continued development and launch of: SAGE-III/ISS, ECOSTRESS/ISS, GEDI/ISS, CYGNSS, TEMPO, GRACE-FO, ICESat-2, SWOT, NISAR, PACE
- Continue Venture Class on schedule with full funding
- OCO-3 completion and flight to ISS in late 2017
- CLARREO Technology Demonstration instruments on ISS - development and flight in late 2019 (2 instruments, Reflected Solar/HySICS and IR Pathfinder)

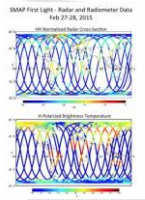




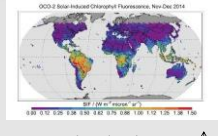
Images from 2014-2015 ESD Launches

GPM Observation of Super Typhoon Hagupit – 12/4-5/14

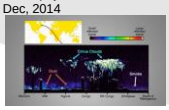




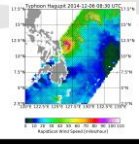
SMAP First Light Radar and Radiometer Data – 3/27-28/25



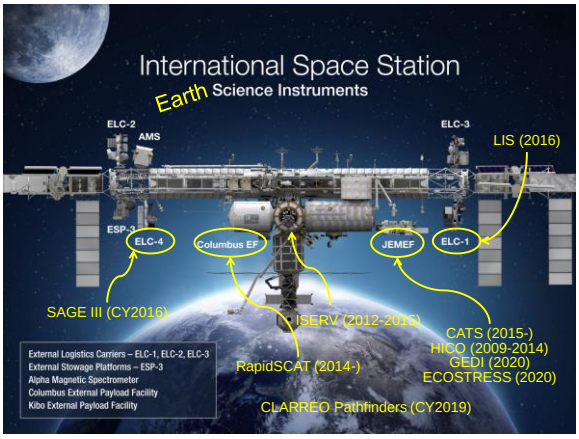
OCO-2 Solar Induced Chlorophyll Fluorescence – Nov-Dec, 2014



RapidScat Observations of Super Typhoon Hagupit – 12/6/14



CATS Image over Africa – 2/11/15



OVERALL SUMMARY (2 of 2)

- Earth Science Research

	FY15	FY16	FY17	FY18	FY19	FY20
FY16	**399**	**432**	**417**	**425**	**418**	**414**
FY15		424	400	390	392	---

  - ✧ Includes funding to improve understanding of coupled North Atlantic-Arctic system
  - ✧ Includes additional funding for research to understand linkages between oceans and climate
  - ✧ Funds CDI, BEDI/GCIS, CRT/Citizen Science
- Applied Sciences

	FY15	FY16	FY17	FY18	FY19	FY20
FY16	**40.4**	**47.6**	**48.7**	**48.4**	**47.6**	**48.8**
FY15		38.0	38.7	39.8	39.8	---

  - ✧ Will be used to accelerate ramp-up of Water and Food Security initiatives
- Earth Science Technology Office

	FY15	FY16	FY17	FY18	FY19	FY20
FY16	**59.7**	**60.7**	**62.1**	**61.5**	**61.2**	**62.7**
FY15		54.5	55.6	55.5	55.6	---

✧Increase for the InVEST program (~ $5M/year additional)

8

Long-term Measurement Mandate Missions

- Precision Altimetry following the launch of Jason-3
  - FY16-20 budget supports NASA contributions to Jason-CS
    - – LV, radiometer, laser retroreflector; etc. NASA funding for mission ops and data analysis; 2020 launch
  - Continued development of SWOT (2020 launch)
- Solar Irradiance
  - TSIS-2 and beyond transferred to NASA in FY14
  - FY16-20 budget supports completion of TSIS-1 and flight on ISS, LRD August 2017
    - – Recognizes NOAA FY15 appropriation for TSIS-1
- Earth Radiation Balance (RBI instrument)
  - RBI continues to be developed by NASA for flight on JPSS-2

9

SLI in FY16 President's Budget Submit

A multi-component program, with the essential investments in technology and observational innovation to ensure a world class, sustainable, and responsible land imaging program through 2035:

1. TIR-FF (Class D Thermal Infrared Free Flyer) to launch ASAP (no later than 2019) and to fly in constellation with a reflective band imager like OLI on L-8
   - Low-cost mitigation against an early loss of the Landsat 8 Class C TIRS, while demonstrating feasibility of constellation flying for land imaging
2. Landsat 9 (Class B upgraded rebuild of Landsat 8) to launch in 2023
   - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B
3. Land Imaging Technology and Systems Innovation
   - Hardware, operations and data management/processing investments to reduce risk in next generation missions.
4. Landsat 10
   - Mission definition to be informed by the Technology investments, leading to key mission configuration/architecture decisions by the end of the decade

NASA Budget for Sustainable Land Imaging	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020
	$30,000	$64,100	$78,900	$134,600	$174,400	$179,900	$147,300

10

Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) Mission

Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) is an ocean color, aerosol, and cloud mission identified in the 2010 report "Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space Science".

Science Objectives

- **Primary:** Understand and quantify global biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change: **ocean color sensor**
- **Secondary:** Understand and resolve/quantify the role of aerosols and clouds in physical climate (the largest uncertainty): **polarimeter**
- Extend key Earth system data records on global ocean ecology, biogeochemistry, clouds, and aerosols (expanded ocean color sensor similar to MODIS)

Risk	• 8705.4 Payload Risk Class C
Launch	• 2022/2023, budget and profile driven
Orbit	• 97° inclination; ~650 km altitude; sun synchronous
Duration	• 3 years
Payload	• Ocean color instrument; potential for a polarimeter
LCC	• **$805M Cost Cap**

11

Venture Class Solicitation Schedule

Mission	Mission Type	Solicitation Release	Proposal Selection	Major Milestone	Total Funding*
EVI-3	Instrument Only	Q2 FY2015	Q2 FY2016	Delivery NLT 2020	$130M
EVI-4	Instrument Only	Q4 FY2016	Q4 FY2017	Delivery NLT 2021	$150M
EVI-5	Instrument Only	Q2 FY2018	Q2 FY2019	Delivery NLT 2023	$182M
EVI-6	Instrument Only	Q4 FY2019	Q4 FY2020	Delivery NLT 2024	$155M
EVI-7	Instrument Only	Q2 FY2021	Q2 FY2022	Delivery NLT 2025	$185M
EVM-2	Full Orbital	Q3 FY2015	Q3 FY2016	Launch ~2021	$165M
EVM-3	Full Orbital	Q3 FY2019	Q3 FY2020	Launch ~2025	$179M
EVS-2	**Suborbital**	**Q4 FY2013**	**Q1 FY2015**	**2016-2020**	**$162M**
EVS-3	Suborbital	Q4 FY2017	Q4 FY2018	2019-2023	$176M

Open solicitation

* Funding for future EVs is approximate and will be adapted depending on previous selections.

12

Earth Venture Suborbital-2 (EV-2) Investigations

Atmospheric Tomography Experiment (ATom) – Harvard University (Steve Wofsy)

This investigation will study the impact of human-produced air pollution on certain greenhouse gases. Airborne instruments will look at how atmospheric chemistry is transformed by various air pollutants and at the impact on methane and ozone which affect climate. Flights aboard NASA's DC-8 will originate from the Armstrong Flight Research Center in Palmdale, California, fly north to the western Arctic, south to the South Pacific, east to the Atlantic, north to Greenland, and return to California across central North America.

North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) – Oregon State U. (Mike Behrenfeld)

This investigation will improve predictions of how ocean ecosystems would change with ocean warming. The mission will study the annual life cycle of phytoplankton and the impact small airborne particles derived from marine organisms have on climate in the North Atlantic. The large annual phytoplankton bloom in this region may influence the Earth's energy budget. Research flights by NASA's C-130 aircraft from Wallops Flight Facility, Virginia, will be coordinated with a University-National Oceanographic Laboratory System (UNOLS) research vessel.

Atmospheric Carbon and Transport – America – Penn State University (Kenneth Davis)

This investigation will quantify the sources of regional carbon dioxide, methane and other gases, and document how weather systems transport these gases in the atmosphere. The research goal is to improve identification and predictions of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern United States. Research flights will use NASA's C-130 from Wallops and the UC-12 from Langley Research Center in Hampton, Virginia.

ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES) – ARC (Jens Redemann)

ORACLES will probe how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic. Particles from this seasonal burning that are lofted into the mid-troposphere and transported westward over the southeast Atlantic interact with permanent stratocumulus "climate radiators," which are critical to the regional and global climate system. NASA aircraft, including a Wallops P-3 and an Armstrong ER-2, will be used to conduct the investigation flying out of Walvis Bay, Namibia.

Oceans Melting Greenland (OMG) – JPL (Josh Willis)

The objective of OMG is to investigate the role of warmer saltier Atlantic subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater. Measurements of the ocean bottom as well as seawater properties around Greenland will be taken from ships and the air using several aircraft including a NASA S-3 from Glenn Research Center in Cleveland, Ohio, and Gulfstream III from Armstrong.

13

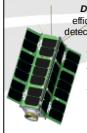
Technology Program: In-Space Technology Validation of ES Technologies (InVEST)

The need to space-validate new technologies is critical to reduce risk for future Earth science measurements. The In-Space Validation of Earth Science Technologies (InVEST) program is intended to fill the gap. The first InVEST solicitation in 2012 sought small instruments and subsystems that advance technology to enable relevant measurements and targeted the CubeSat platform.

The ***Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat*** will validate multiple subsystem technologies and demonstrate new miniature microwave radiometers operating near 52-58, 175-191, and 206-208 GHz that could dramatically enhance the capabilities of future temperature and humidity measurements. - K. Cahoy, MIT; **Launch NET 2016**

The ***Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN)*** project will demonstrate a bolometer radiometer that is compact, low cost, and absolutely accurate to NIST traceable standards. RAVAN could lead to affordable CubeSat constellations that, in sufficient numbers, might measure Earth's radiative diurnal cycle and absolute energy imbalance to climate accuracies (globally at 0.3 W/m2) for the first time. - W. Swartz, JHU/APL; **Launch NET 2016**

The objective of the ***CubeSat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat)*** is to demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 1 to 2 microns. - R. Fields, Aerospace Corporation; **Launch NET 2016**



The ***HyperAngular Rainbow Polarimeter HARP-CubeSat*** will validate a technology required by the Aerosol-Cloud-Ecosystem (ACE) mission concept and prove the capabilities of a highly-accurate, wide-FOV, hyperangle, imaging polarimeter for characterizing aerosol and cloud properties.
- J. V. Martins, UMBC; **Launch NET 2016**

IceCube is a three unit (3U) CubeSat under development to validate a 874-GHz radiometer receiver for future use in ice cloud measurement missions. This submillimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer such as that called for by the Aerosol-Cloud-Ecosystem (ACE) mission concept.
- D. Wu, NASA Goddard Space Flight Center; **Launch NET 2016**

Your Planet is Changing
Earth Right Now
We're on it!

GPM

OCO-2

RapidScat

CATS

SMAP