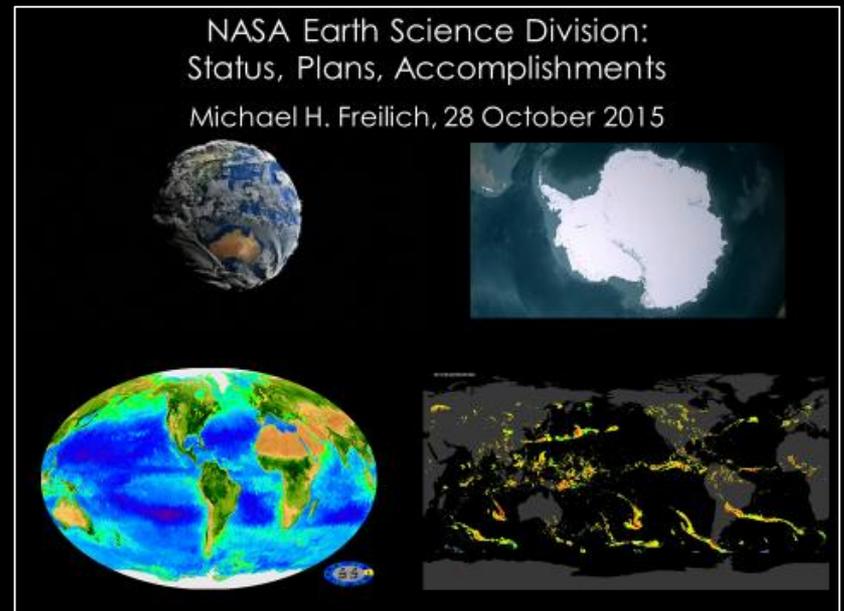


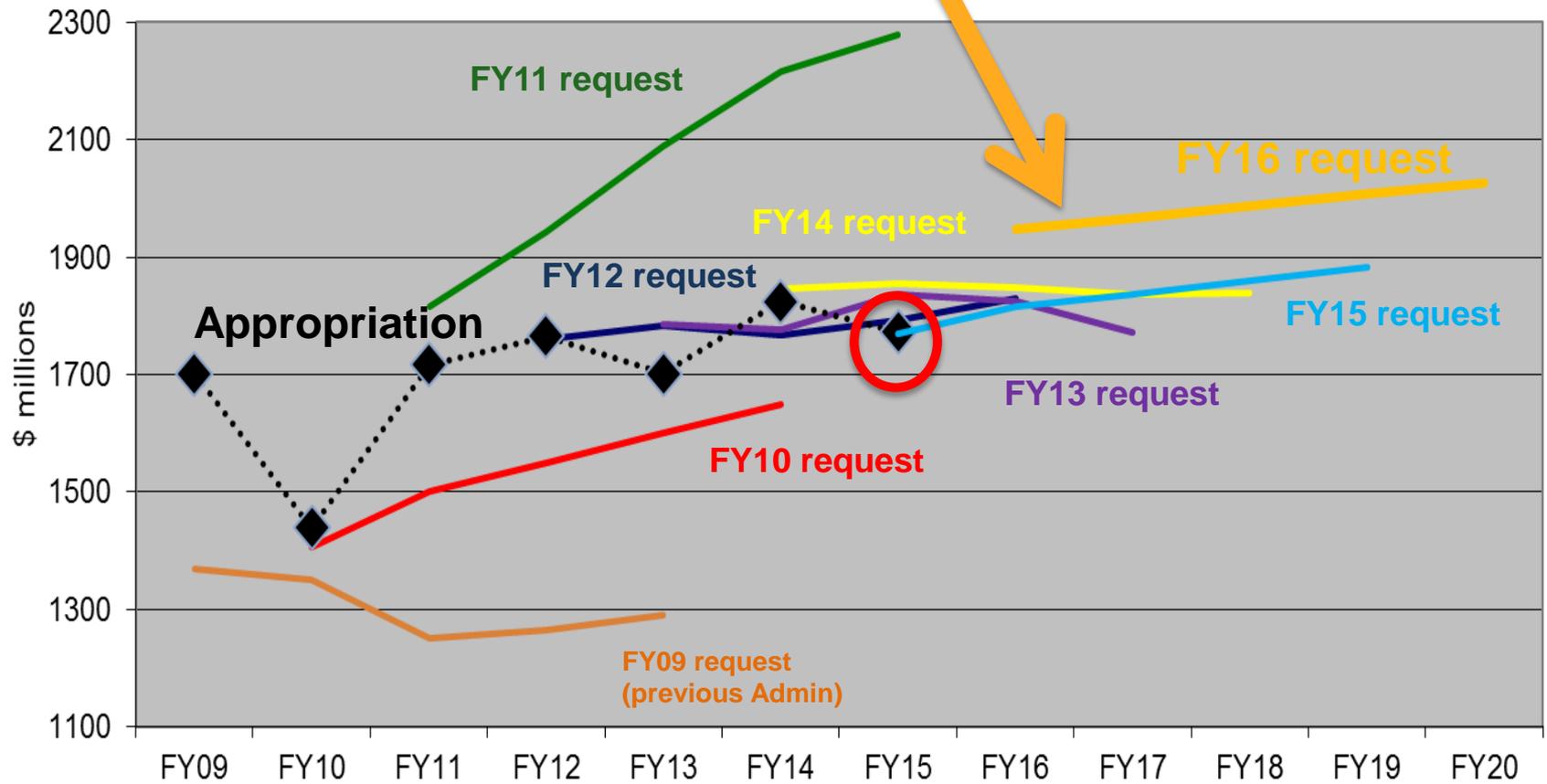
# NASA Earth Science Division Current & Future Mission Overview

2015 SORCE Sun-Climate Symposium  
Savannah, GA 10-13 November 2015



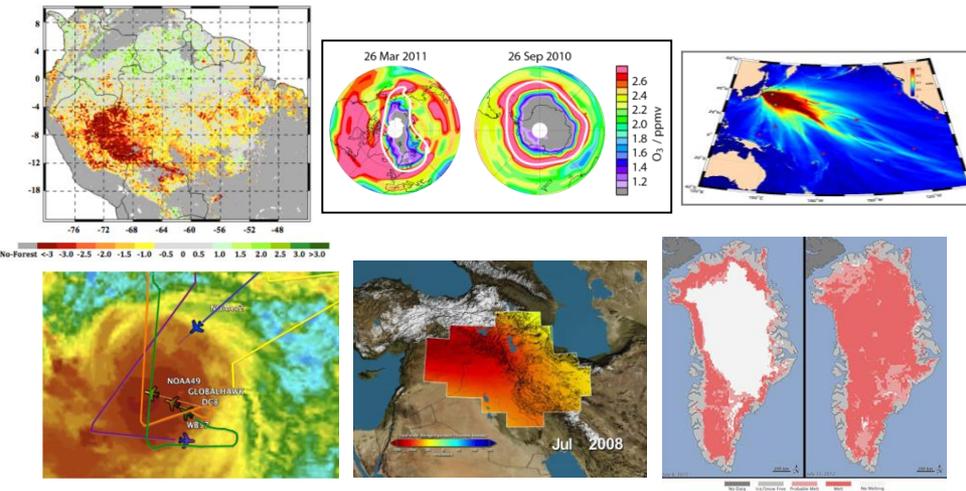
Cheryl Yuhas  
NASA Earth Science Division  
cheryl.yuhas@nasa.gov

# Earth Science Budget: FY16 Request/FY15 Appropriation

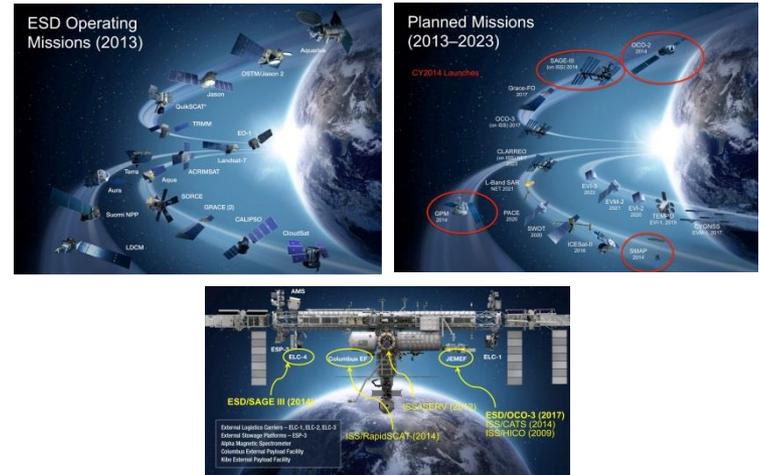


# NASA's Earth Science Division

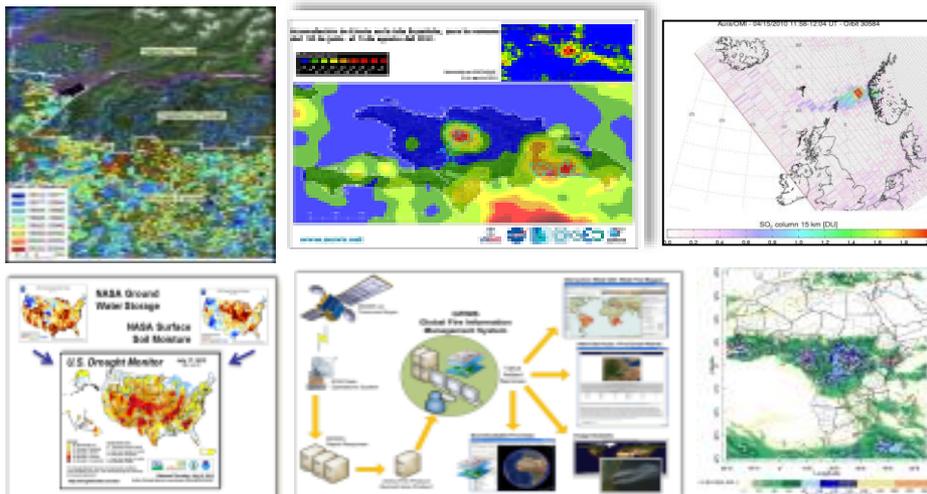
## Research



## Flight



## Applied Sciences



## Technology

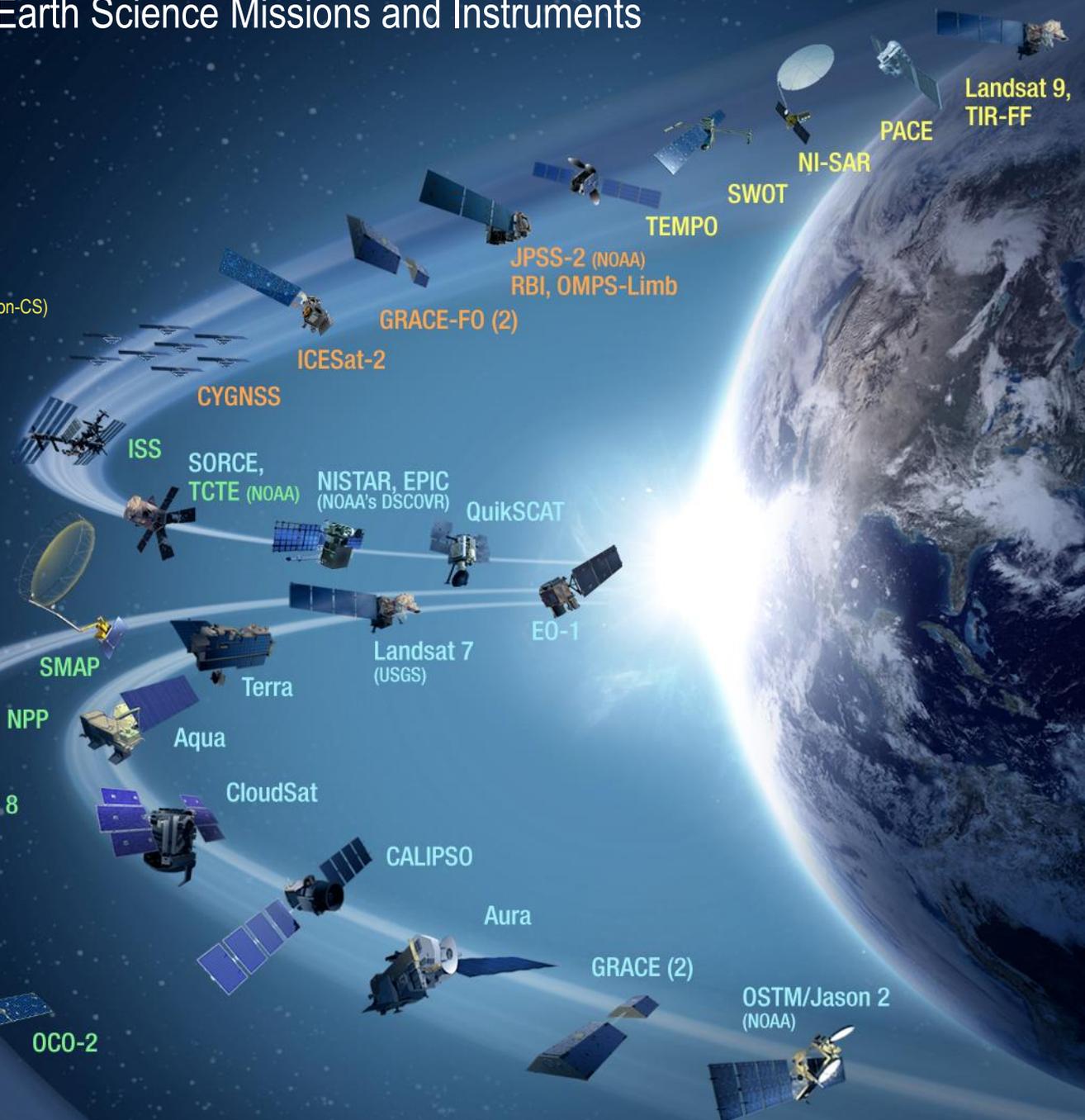


# Earth Science Missions and Instruments



Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)

Earth Science Instruments on ISS:  
RapidScat, CATS,  
LIS, SAGE III (on ISS), TSIS-1, OCO-3,  
ECOSTRESS, GEDI,  
CLARREO-PF



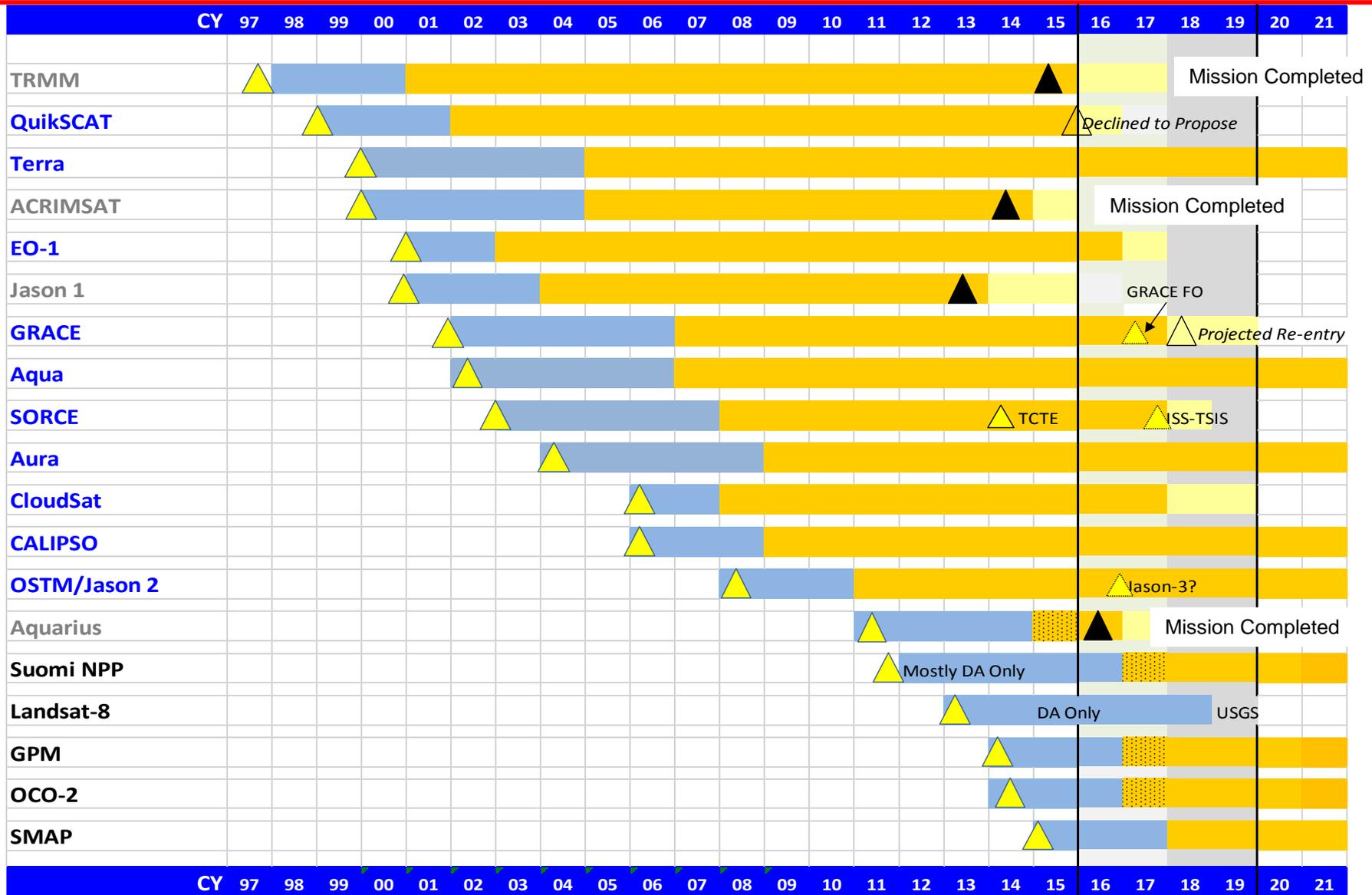
# RECENT CHANGES TO ON-ORBIT CONSTELLATION



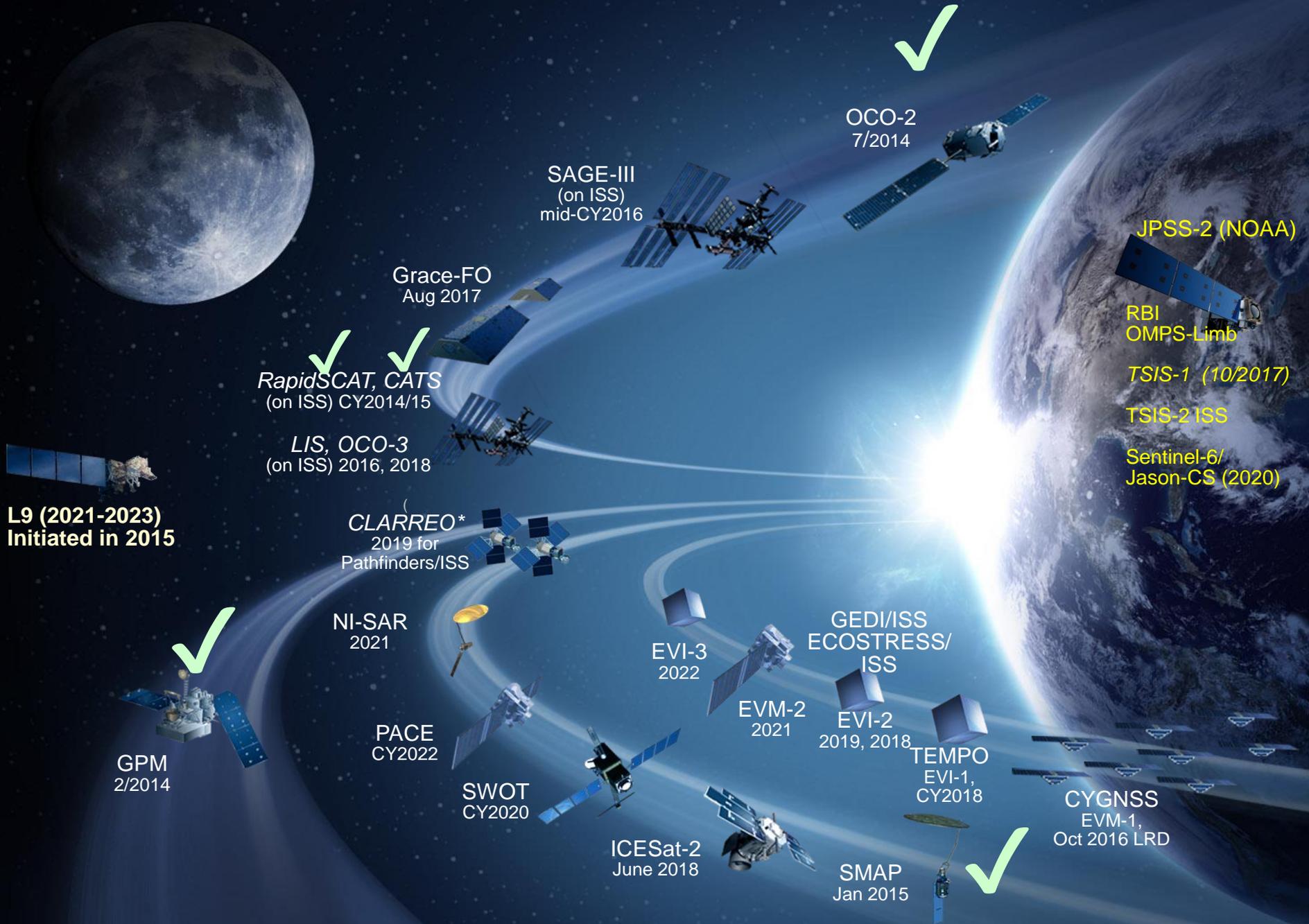
- TRMM (Tropical Rainfall Measuring Mission) Re-enters (Tropical Precipitation)
  - Launched 27 November 1997
  - Joint with Japanese Space Agency (now JAXA)
  - “Passivated” 15 April 2015
  - Re-entered 16 June 2015 UTC (Indian Ocean)
- Aquarius/SAC-D Satellite Bus Failure (Sea-surface Salinity)
  - Launched 10 June 2011
  - Joint with Argentine Space Agency (CONAE)
  - Satellite bus failure 7 June 2015 (DC-DC converter, redundant unit failed)
- Soil Moisture Active/Passive (Soil Moisture and Freeze-Thaw state)
  - Launched 31 January 2015
  - First systematic Tier-1 Decadal Survey mission to be launched
  - Active Radar failed 7 July 2015
  - Satellite bus, rotating 6m antenna, and microwave radiometer are functioning well, science mode operations continue; global soil moisture **and** sea-surface salinity products at radiometer resolution being produced routinely



# 2015 Senior Review: Funded Mission Extensions

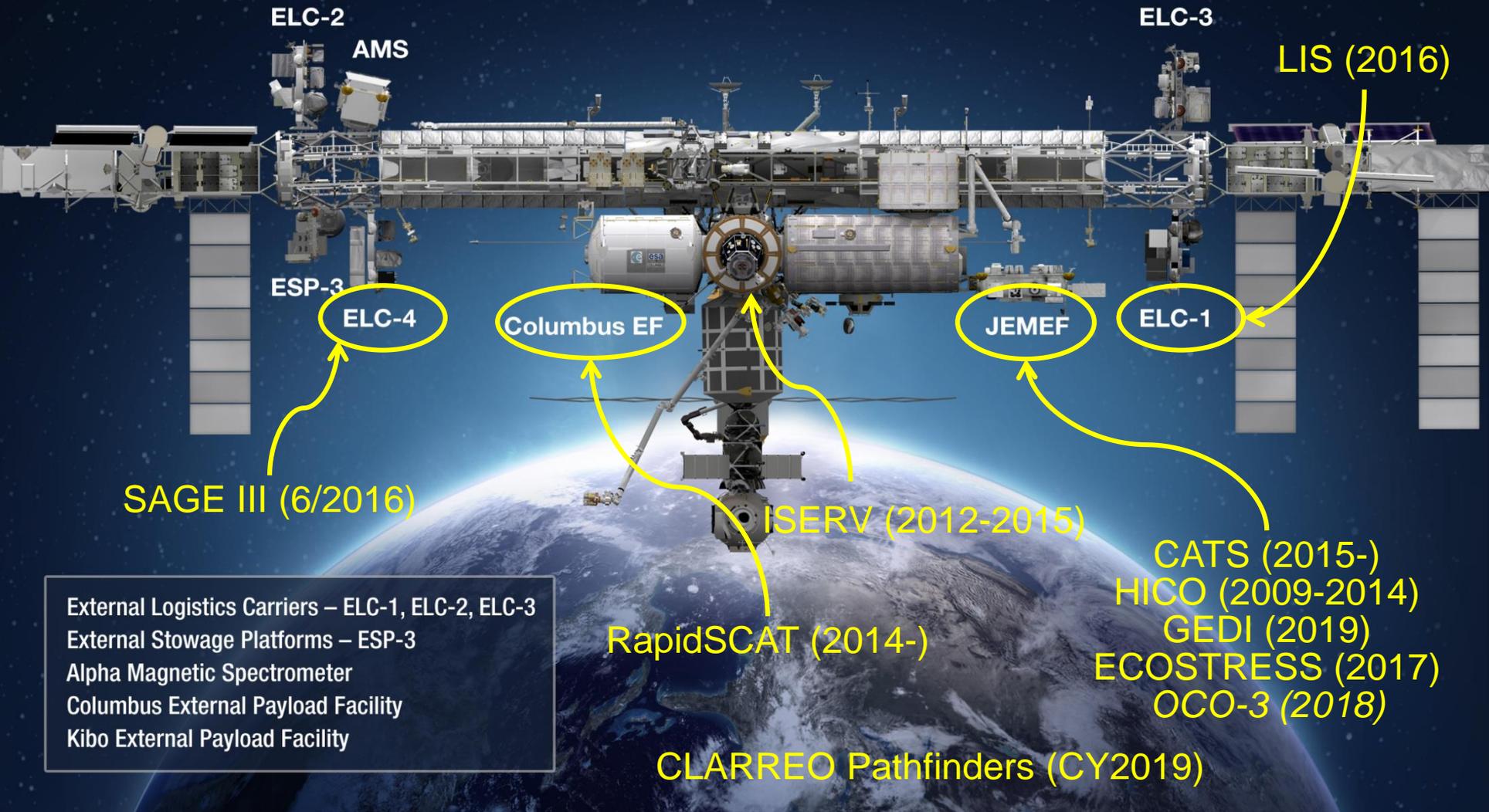


**L9 (2021-2023)  
Initiated in 2015**



# International Space Station

## Earth Science Instruments



ELC-2

AMS

ELC-3

LIS (2016)

ESP-3

ELC-4

Columbus EF

JEMEF

ELC-1

SAGE III (6/2016)

ISERV (2012-2015)

RapidSCAT (2014-)

CATS (2015-)

HICO (2009-2014)

GEDI (2019)

ECOSTRESS (2017)

OCO-3 (2018)

CLARREO Pathfinders (CY2019)

External Logistics Carriers – ELC-1, ELC-2, ELC-3

External Stowage Platforms – ESP-3

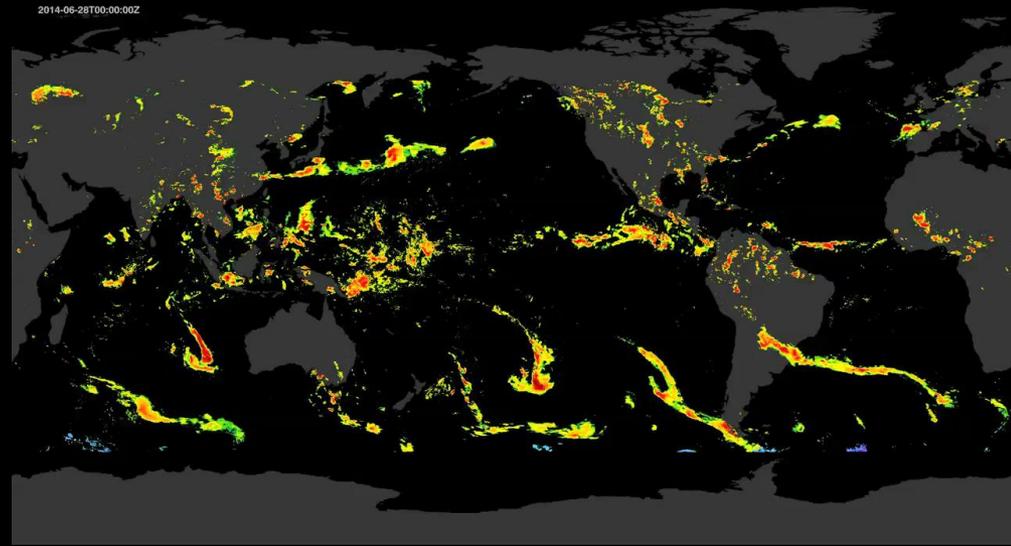
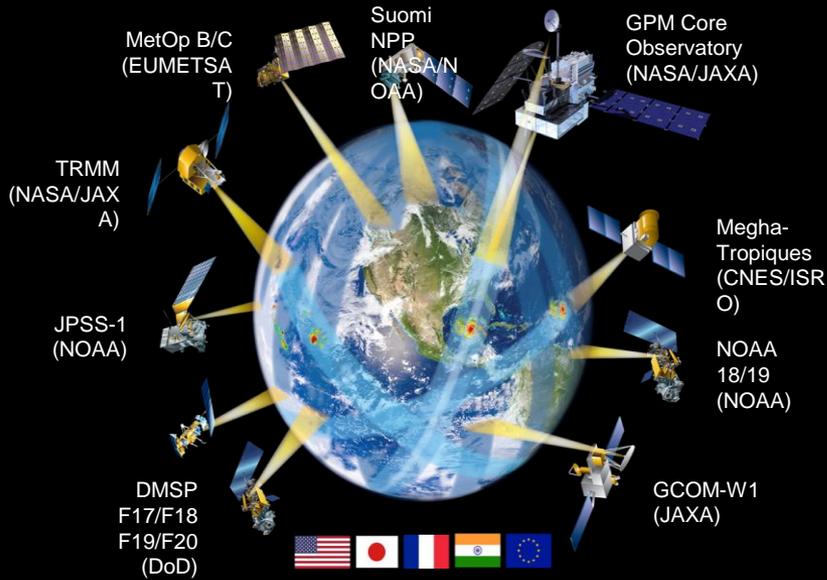
Alpha Magnetic Spectrometer

Columbus External Payload Facility

Kibo External Payload Facility

# Global Precipitation Measurement Mission

## GPM Constellation Status



Active Joint Projects (19 PI's from 13 countries)



# Venture-Class

- Science-driven, PI-led, competitively selected, cost- and schedule-constrained, regularly solicited – Venture-Class was a ***high-priority Decadal Survey Recommendation***
- Complement the systematic missions, provide flexibility to accommodate scientific advances and new implementation approaches
- ***All ongoing and planned investigations, solicitations, and selections are on track and fully funded***

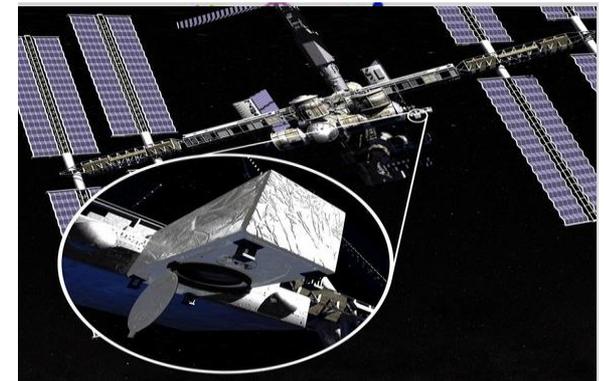
## 3 “Strands”



**Suborbital**



**Small-sat/Missions**



**Instruments**

# Venture Class Selections/Solicitations

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
<b>EVS-2</b>	<b>Suborbital</b>	<b>Q4 FY2013</b>	<b>Q1 FY2015</b>	<b>2016-2020</b>	<b>\$162M</b>
EVS-3	Suborbital	Q4 FY2017	Q4 FY2018	2019-2023	\$176M

Most recent Selection

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

EVS-1: CARVE, ATTREX, DISCOVER-AQ, AirMOSS, HS-3

EVM-1: CYGNSS (2016 LRD)

EVI-1: TEMPO (2017 Instrument Delivery)

EVI-2: GEDI (2019, 2018 del.); ECOSTRESS (10/2017, 5/2017 del.)

EVS-2: AtoM, NAAMS, OMG, ORACLES, ACT-America, CORAL

# Venture Class Launch Services (VCLS)

- Joint ESD/NASA Launch Services Program initiative
- RFP released 12 June 2015; Selections announced 14 Oct 2015
- Funded with \$10M from ESD
  - Selected launches will:
    - Accommodate 132 pounds (60 kilograms) of CubeSats on 1 or launches
    - Launch(es) must occur by April 15, 2018
- Selectees:
  - Firefly Space Systems, Inc.
  - Virgin Galactic LLC
  - Rocket Lab USA, Inc.

***Tangible and substantial ESD investment in small launch vehicles***

# Long-term Measurement Mandate Missions



- Precision Altimetry following the launch of Jason-3
  - FY16-20 budget supports NASA contributions to Sentinel-6/Jason-CS
    - LV, radiometer, laser retroreflector; etc. NASA funding for mission ops and data analysis; 2020 launch
    - US-EC agreement on exchange of **all Copernicus/Sentinel data signed 16 October 2015 – Sentinel-1 (SAR) mirror to start soon**
  - Continued development of SWOT (2020 launch)
- Solar Irradiance
  - TSIS-2 and follow-on missions 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
    - ESD can fund during Continuing Resolution
- Earth Radiation Balance (RBI instrument)
  - RBI being developed by NASA for flight on JPSS-2 (~April 2019 instrument delivery date)



# ESD Airborne Science Accomplishments



- Ongoing campaigns
  - Operation IceBridge Arctic and Antarctic
  - HypSIRI cal/val flights in CA
- Completed campaigns
  - Operation IceBridge Arctic
  - UAVSAR Mexico earthquake and deployment to Central and South America
  - UAVSAR and AirSWOT deployments to the Mississippi River delta
  - CalWater-2 CA flights
  - GPM cal/val (Polar Winds) deployment to Iceland
  - ICESat-2 cal/val deployment to Greenland
  - HypSIRI cal/val flights in CA
  - Suomi-National Polar Orbiting (SNPP) cal/val deployment to Iceland
  - PECAN deployment to KS
  - HIWC campaign in support of NASA ARMD
  - Harmful Algal Bloom flights over Great Lakes
  - NOAA operational evaluation of Global Hawk aircraft (SHOUT) mission
- Completed/ongoing airborne instrument development activities (AirSWOT, Rotating PALS, SLAP, PRISM on ER-2)
- Earth Venture Suborbital (EVS)
  - Initiated six new EVS-2 investigations (Act-America, ATOM, CORAL, NAAMES, OMG, & ORACLES)
  - OMG completed sonar survey of sea floor along Greenland coast
  - Modifying 2 C-130's and 2 G-III's for EVS-2
  - Completed almost all EVS- 1 data collection (CARVE finishes in Nov 15), investigations completing data analysis and closeout activities
- Completed Student Airborne Research Program (7<sup>th</sup> year of program) – 32 students this FY
- P-3 major maintenance (rewing) ongoing to provide another 18 years (or so) of ESD support



# ESD FY16 Airborne Science Upcoming Activities



- Upcoming deployments/campaigns
  - GPM cal/val (Olympex) campaign (Dec 15)
  - ACE mission concept development (RADEX) campaign (Dec 15)
  - SWOT cal/val (AirSWOT) deployment to the Gulf Coast (Dec 15 – Jan 16)
  - Korean air quality mission (KORUS – AQ) deployment (25 Apr – 13 Jun 16)
  - Joint NASA ESA Gabon Africa (AfriSAR) deployment (Feb or Apr/May 16)
  - ASCENDS mission development campaign (Jan – Feb 16)
  - NOAA operational evaluation of Global Hawk aircraft (SHOUT) mission (Feb – Mar 16, Aug – Nov 16)
  - HypsIRI Tropical (HI) deployment (Apr 16)
  - UAVSAR flights (variety of programs (earthquakes, levy monitoring, AfriSAR) and dates throughout FY16)
- Earth Venture Suborbital (EVS)
  - NAAMES deployment to Canada/Azores (Nov 15, Apr – May 16)
  - Complete GIII modifications for OMG (Dec 15)
  - OMG deployment to Greenland (Apr 16)
  - Complete C-130 modifications for Act-America (Dec 15)
  - Act-America deployment to Central US (Jul – Sep 16)
  - ORACLES Namibia deployment (Aug – Sep 16 dependent upon Namibian clearances)
  - Closeout all EVS-1 investigations (TBD 16)
- Student Airborne Research Program FY16 (Jun – Aug 16)
- Complete P-3 major maintenance (Apr/May 16)

# Multi-Mission Operations

- Provide science data receipt, ingest, processing, archive, and distribution to users via 12 Distributed Active Archive Centers (DAACs)
  - **New** data sets to be supported include: DSCOVN (EPIC, NISTAR), SAOCOM, ICESat-2, TEMPO, OCO-3, TSIS-1; SWOT, NI-SAR DAAC enhancements
- Includes support for Sentinel-1 (SAR) and -6 (radar altimetry) ingest, archive, and distribution of level 0/1 data products
- EOSDIS budget line includes support for Climate Data Initiative, Big Earth Data Initiative, and Global Change Information System activities

# Earth Science Research

## Focus Areas

Carbon cycle and Ecosystems

Climate Variability and Change

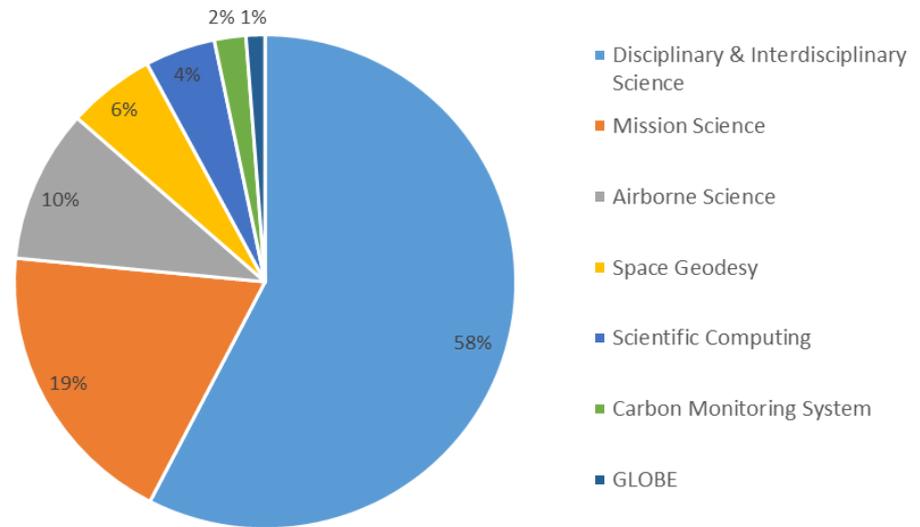
Atmospheric Composition

Global Water and Energy Cycle

Earth Surface and Interior

Weather

ESD FY15 Research Budget by Category



# Applied Sciences

Health & Air Quality Applications  
Ecological Forecasting Applications  
Water Resources Applications  
Wildfires Applications (through FY17)  
Disaster Applications  
Disaster Response Teams  
Capacity Building program  
SERVIR (joint with USAID)  
ARSET (Applied Remote Sensing Training)  
DEVELOP  
Early Adopters/Applications Support to  
Mission Planning  
Socioeconomic Impact Analyses  
Earth Science & Food Security Activity  
Western States Water Availability Activity

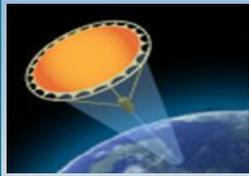
- Funds competitively selected, expanded SERVIR Applied Sciences Teams
- Initiates Snow & Water Availability Focused Activity for Western States
- Initiates Food Security Focused Activity
- Improves disaster response approach (including Center coordinators and response teams)

# Technology Program Content



The Earth Science Technology Office is a **targeted, science-driven, competed, and actively managed technology program**. The investment elements include:

Observation



## Instrument Incubator Program (IIP)

robust new instruments and measurement techniques

*17 new projects added in FY14 (total funding approximately \$71M over 3 years)*

Information



## Advanced Component Technologies (ACT)

development of critical components and subsystems for instruments and platforms

*11 new projects added in FY14 (total funding approximately \$13M over 3 years)*

Validation



## 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

*24 new projects added in FY15 (total funding approximately \$25M over 2 years)*



## 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 airborne systems

*4 new projects added in FY15 (total funding ~\$20M over 3 years)*

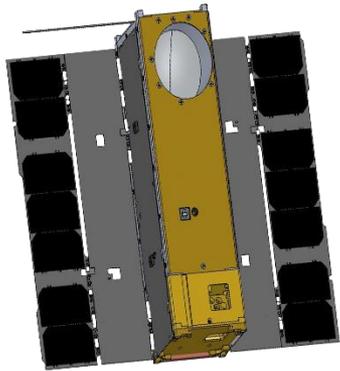
***The current portfolio of active investments supports all of the 2007 NRC Decadal Survey mission concepts. 65% directly support Tier 1 and 2 missions, ~ 15% support Tier 3 missions, and the remainder are crosscutting.***

# In-Space Validation of Earth Science Technology (InVEST)-2012



U-Class satellites advancing TRLs for Earth science measurements – all 3U

**MiRaTA**  
MIT / MIT-LL



**3 Frequency Radiometer and GPSRO**

Validation of new microwave radiometer and GPSRO technology for all-weather sounding

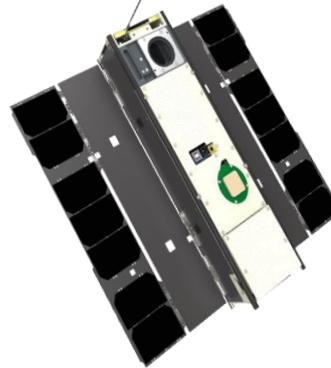
**RAVAN**  
APL/JHU



**Vertically Aligned Carbon Nanotubes (VACNTs)**

Validate VACNTs as radiometer absorbing material and calibration standard for total outgoing radiation

**ICECube**  
GSFC



**883 GHz submm-Wave radiometer**

Validation of submm radiometer for spaceborne cloud ice remote sensing

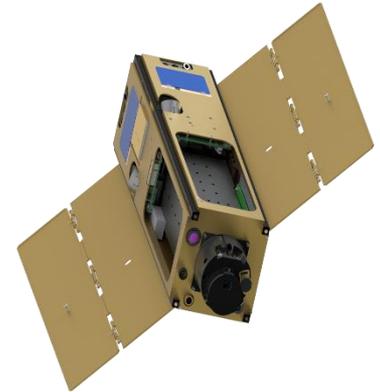
**HARP**  
UMBC



**Wide FOV Rainbow Polarimeter**

Validation of 2-4 km wide FOV hyperangular polarimeter for cloud & aerosol characterization

**LMPC**  
The Aerospace Corporation



**Photon Counting InfraRed Detector**

Validation of linear mode single photon detector at 1, 1.5, and 2 microns in space environment

*Targeting launch dates (for all) in 2016-17 timeframe primarily utilizing the CubeSat Launch Initiative*

# InVEST 2015 Program

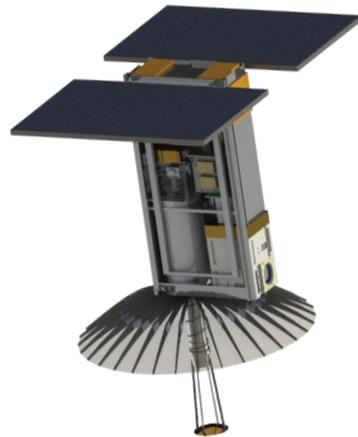


U-Class satellites advancing TRLs for Earth science measurements - **all 6U**; selected Sept. 17, 2015

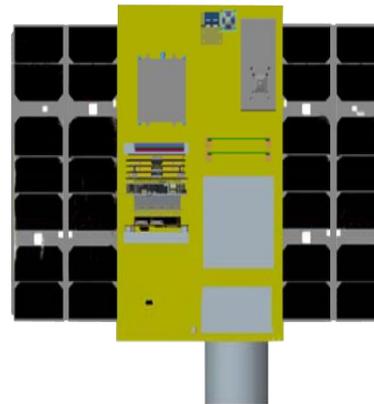
**CIRAS**  
JPL



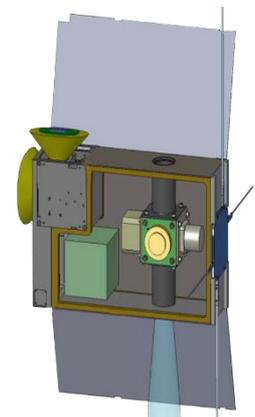
**RainCube**  
JPL



**CubeRRT**  
The Ohio State University



**CIRIS**  
Ball Aerospace



**Infrared Atmospheric  
Sounder**

Demonstrate ability to measure spectrum of upwelling infrared radiation in 4-5 micron spectral region

**Precipitation Profiling  
Radar**

Validate Ka-band (35.75 GHz) radar payload using new deployable antenna and processing technologies

**Radiometer Radio  
Frequency Interference**

Demonstrate wideband RFI mitigation technologies vital for future space-based microwave radiometers

**Infrared Radiometer**

Validation of an uncooled imaging infrared (7.5-13  $\mu\text{m}$ ) radiometer for high radiometric performance in LEO

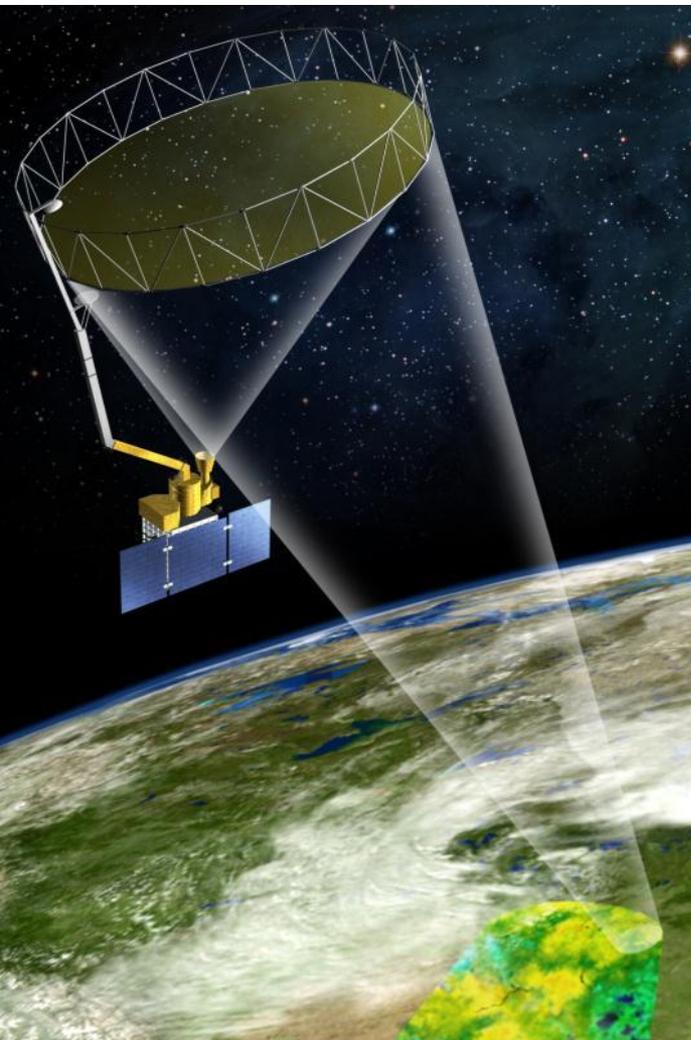
# Decadal Survey Status (1)

- 2007 Earth Science and Applications from Space is most recent Decadal Survey (Jan 2007); NRC mid-term assessment May 2012
  - “NASA responded favorably and aggressively to the decadal survey, embracing its overall recommendations for Earth observations, missions, technology investments, and priorities for the underlying science. As a consequence, the scientific and applications communities have made significant progress over the past 5 years.” (Mid-Term Report overarching Finding)
  - **All Legacy Missions launched:** OSTM (2008), OCO-1 (2009\*), Aquarius (2011), Glory (2011\*), NPP (2011), LDCM (2013), GPM (2014), *OCO-2 (2015)*
  - 31 July 2017 completion date for 2<sup>nd</sup> ESAS Decadal Survey
- Main 2007 Decadal Survey ***New Mission*** recommendations/status
  - Tier I
    - Venture Class: 3 strands, multiple solicitations in each strand, on-schedule, fully funded
      - EV-S 1: all 5 investigations completed data acquisition 2015; EV-S 2: 6 investigations selected 2015
      - EV-Instrument 1: TEMPO in Phase C for Sept 2017 instrument delivery, NLT Dec 2021 launch on host
      - EV-Mission 1 CYGNSS in Phase D for Oct 2016 launch
      - EV-Instrument 2: GEDI in Phase B for May 2018 launch to ISS;  
ECOSTRESS in Phase B (24 Sept KDP-C) for May 2017 delivery, Aug 2017 launch to ISS
      - EV-Instrument 3: Proposals in-hand, under review
    - SMAP: **Launched 31 January 2015**
    - ICESat-2: In Phase C for June 2018 [Oct 2017 MA] launch
    - NI-SAR: In Phase B for Dec 2020-Sept 2021 launch; NI-SAR is radar component of DESDynI; GEDI (EVI-2) contributes substantially to DESDynI lidar/ecosystem
    - CLARREO-Pathfinder: Proposed 2-instrument initiation in FY16 budget, flight to ISS, Sept 2019 launch

# Decadal Survey Status (2)

- Main 2007 Dec. Survey *Mission* recommendations/status (cont.)
  - Tier II, III
    - SWOT: In Phase B for Oct 2020 launch (joint with CNES)
    - GRACE-FO: In Phase D for Feb 2018 [Aug 2017 MA] launch (GFZ partner)
    - Pre-formulation: GEO-CAPE, ASCENDS, ACE, HySpIRI, [CLARREO if CLARREO-PF is not approved by Congress for FY16 start]
    - PACE: In pre-Phase A Design-to-Cost study, for development and launch by 2022; PACE substantially covers ocean color component of Decadal ACE mission
- Climate Architecture Missions (not included in Decadal Survey)
  - RBI, TSIS-1, TSIS-2, OMPS-L: Covered separately below
  - Altimeter Follow-On: **FY16** budget request included funding for NASA contribution (radiometer, GPS, Laser Retroreflectors, LV) to Jason-CS/Sentinel-6A (w/ESA/EUMETSAT/EU), 2020 LRD
  - OCO-3: **FY16** budget request restarted OCO-3 development (awaits Congressional approval)

# Soil Moisture Active/Passive (SMAP) Overview



## Primary Science Objectives

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to
  - Link terrestrial water, energy, and carbon-cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability

## Mission Implementation

<b>Partners</b>	<ul style="list-style-type: none"><li>• JPL (project &amp; payload management, science, spacecraft, radar, mission operations, science processing)</li><li>• GSFC (science, radiometer, science processing)</li></ul>
<b>Risk</b>	<ul style="list-style-type: none"><li>• 7120.5E Category 2; 8705.4 Payload Risk Class C</li></ul>
<b>Launch</b>	<ul style="list-style-type: none"><li>• January 31, 2015 on Delta 7320-10C Launch System</li></ul>
<b>Orbit</b>	<ul style="list-style-type: none"><li>• Polar Sun-synchronous; 685 km altitude</li></ul>
<b>Duration</b>	<ul style="list-style-type: none"><li>• 3 years</li></ul>
<b>Payload</b>	<ul style="list-style-type: none"><li>• L-band (non-imaging) synthetic aperture radar (JPL)</li><li>• L-band radiometer (GSFC)</li><li>• Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)</li></ul>

***NRC Earth Science Decadal Survey (2007)  
recommended SMAP as a Tier 1 mission***

<http://smap.jpl.nasa.gov/>



# SMAP Radar Failure

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- SMAP mission overview
- What has gone wrong – *Failure of the active radar instrument*
- Origin of failure – *root cause still unknown, likely low voltage power supply in the High Power Amplifier unit*
- Impact on mission objectives – *soil moisture resolution degraded to ~35 km (from 10 km)*
- Science that can be conducted with remaining instruments – *likely all planned science except for the smallest-scale applications; added sea-surface salinity retrievals and potential radiometer-only freeze/thaw*
- Lessons learned for future SMD missions – *in process*

*The SMAP mission continues to produce 35 km resolution measurements of soil moisture and sea-surface salinity with unprecedented frequent, global coverage, and high accuracy using radiometer data alone.*



# Opportunities with the SMAP Radiometer



Jet Propulsion Laboratory  
California Institute of Technology

- The SMAP radiometer has comparable spatial resolution, sensitivity and refresh-rate as the SMOS (European Space Agency) radiometer
  - The SMAP radiometer has distinct advantages with its advanced RFI detection and mitigation, thus adding more usable coverage and reduced error due to low-level RFI
  - The SMAP radiometer high temporal sampling allows resolution-enhancement in the cross-track direction
    - Resolution enhancement involves initiation of new L1\_Radiometer data product processing and assessment of resolution and noise trade-off
    - Enhanced-resolution radiometer product will have decreased SNR, *but still sufficient for soil moisture retrieval*
  - Algorithm development underway to extract freeze-thaw information from radiometer data
-

# Earth System Science Opportunities with the SMAP Radiometer-Only



Jet Propulsion Laboratory  
California Institute of Technology

1. Continued high-quality (land coverage, precision, low-level RFI mitigation) SMAP 35 km ( $\sim$ -3 dB) surface **soil moisture** product for hydrologic and climate science and applications
  2. **Sea surface salinity** (coastal and open ocean using ancillary wind data) - ongoing
  3. Landscape **freeze/thaw** classification at 35 km (advantage of deeper penetration and better representativeness using L-band instead of existing higher microwave frequencies)
  4. **Sea-ice** coverage and ice-lead thickness at 35 km regardless of illumination and clouds
  5. **Ocean surface high winds** in the presence of hurricanes and tropical storms
-