National Aeronautics and Space Administration

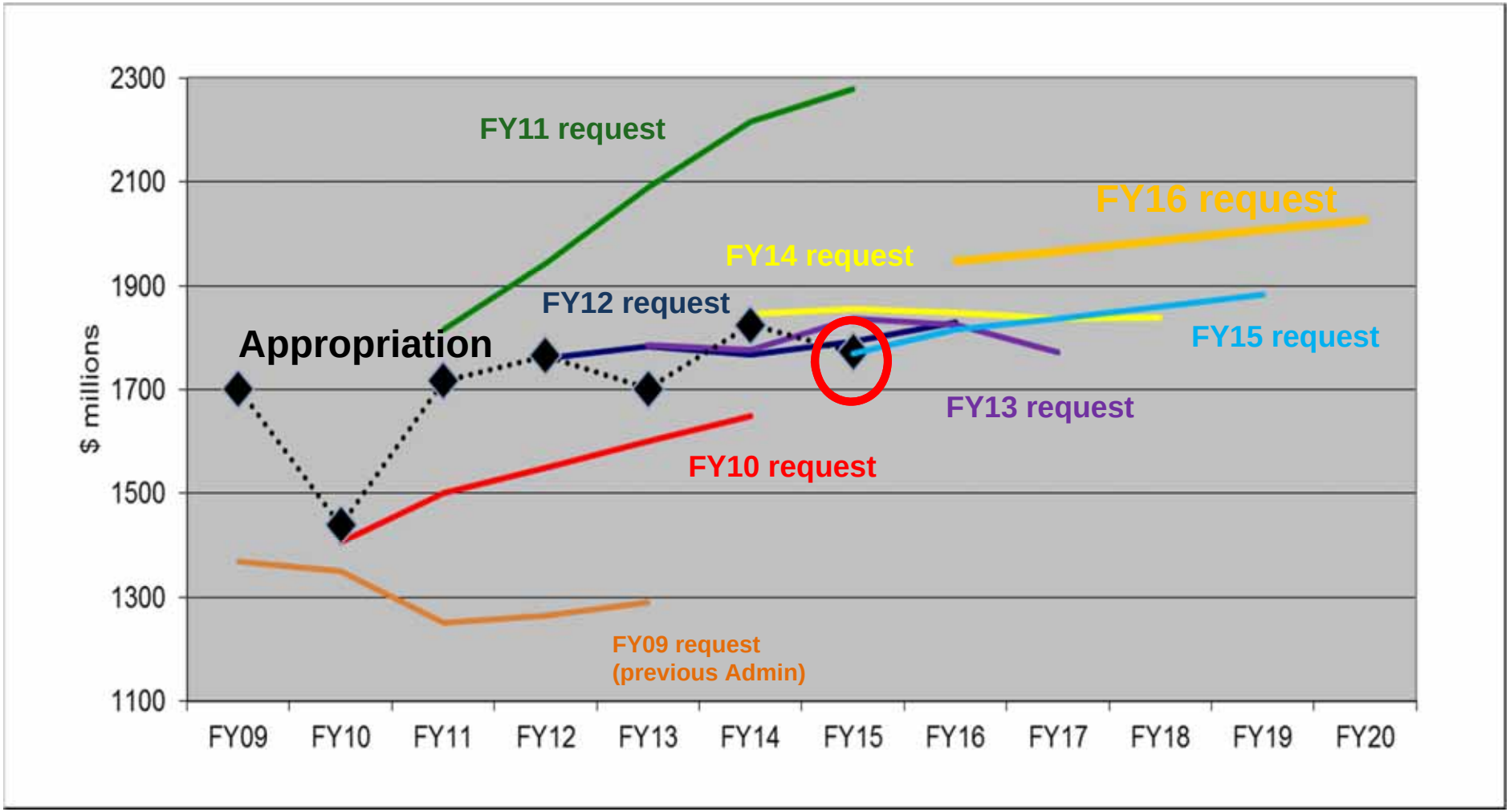
Earth Science

CESAS
September 24, 2015

OUTLINE

- Budget reminder (FY16 budget request)
- ESD program structure overview
- On-orbit constellation overview
- Mission development status/plans (incl. ISS)
- R&A, Technology, Applied Sciences overviews
- SMAP status/plan forward
- Selected science results

Earth Science Budget:
FY16 Request/Appropriation



ESD Overall Strategy

- Budget and execute a balanced program that:
  - advances Earth system science
  - delivers societal benefit through applications development
  - provides essential global spaceborne measurements supporting science and operations
  - develops and demonstrates technologies for next-generation measurements, and
  - complements and is coordinated with activities of other agencies and international partners

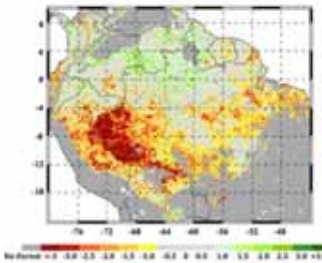
- Fund operations and core data production for on-orbit missions in prime and extended phases, in keeping with the 2015 Senior Review recommendations/decisions; expand data system to provide a US Portal for Sentinel-1 (SAR) data
- Complete top-priority missions: SMAP(2015), SAGE-III (2016), ICESat-2 (2018), GRACE-FO (2018), SWOT (10/2020), CYGNSS (2017), TEMPO (NET 2018), RBI, OMPS-Limb
- Develop (for launch beyond the FY16 budget window): ECOSTRESS (2018 inst. comp.), GEDI (2019 inst. comp.), NISAR (~2021), SLI (2019, 2023, …), PACE (2022), TSIS-1/2 (2017, ~2022)
- Continue all originally planned Venture Class solicitations/selections on schedule

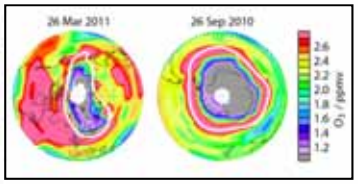
- Support for **Research, Applied Sciences, and Technology Development** elements

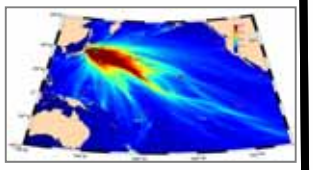
- Support National Climate Assessment, CDI, BEDI, GCIS, USGCRP, international (CEOS) coordination activities , USGEO, GEO, Carbon Monitoring System, and GLOBE

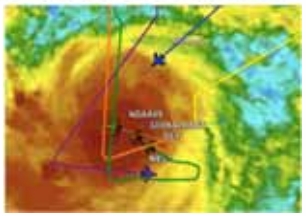
NASA's Earth Science Division

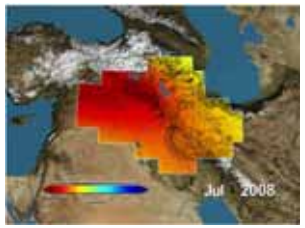
Research





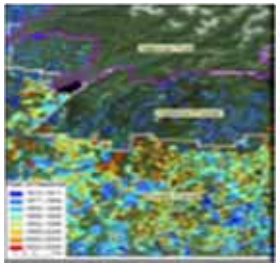


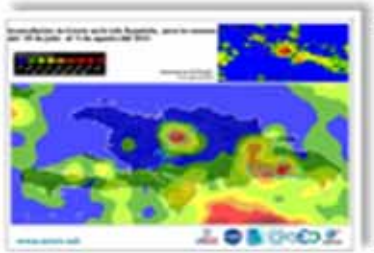


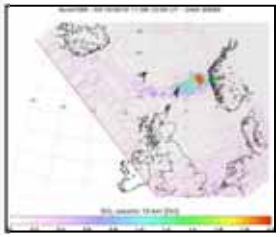


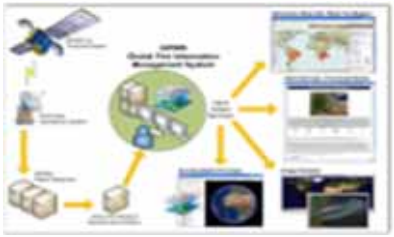
Flight

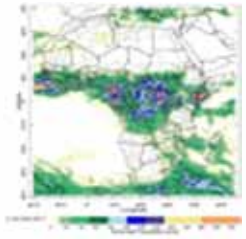
Applied Sciences





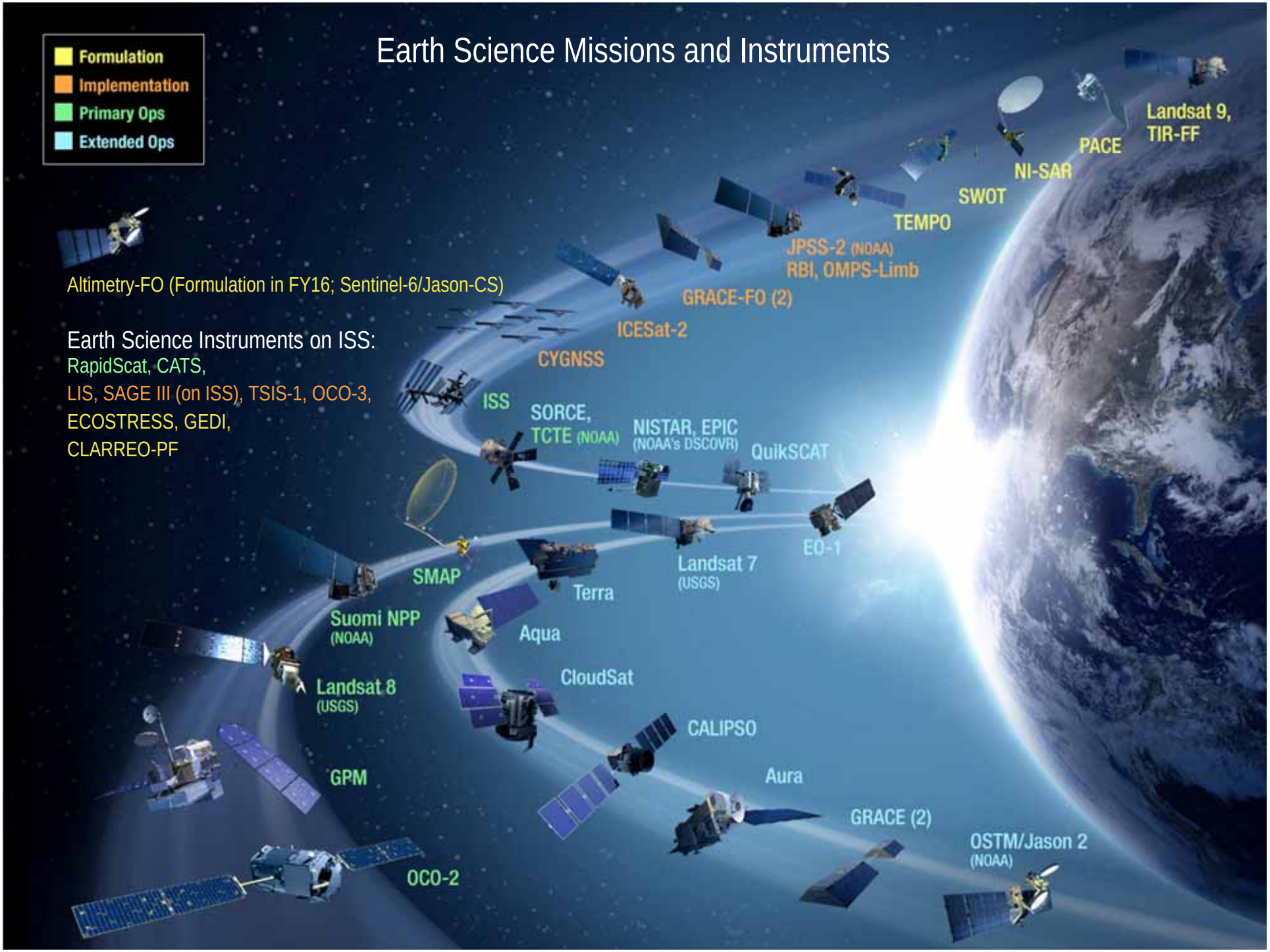


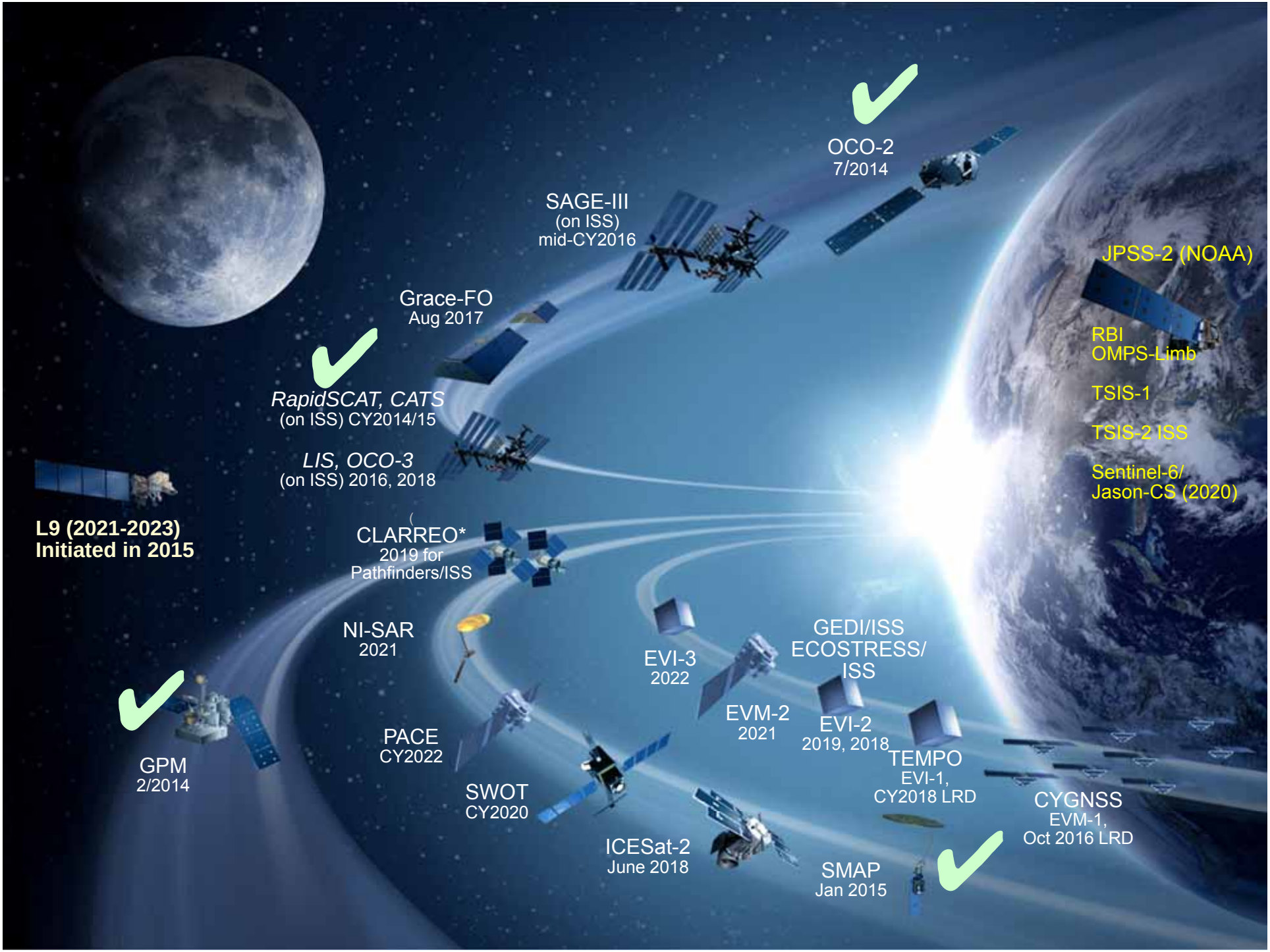


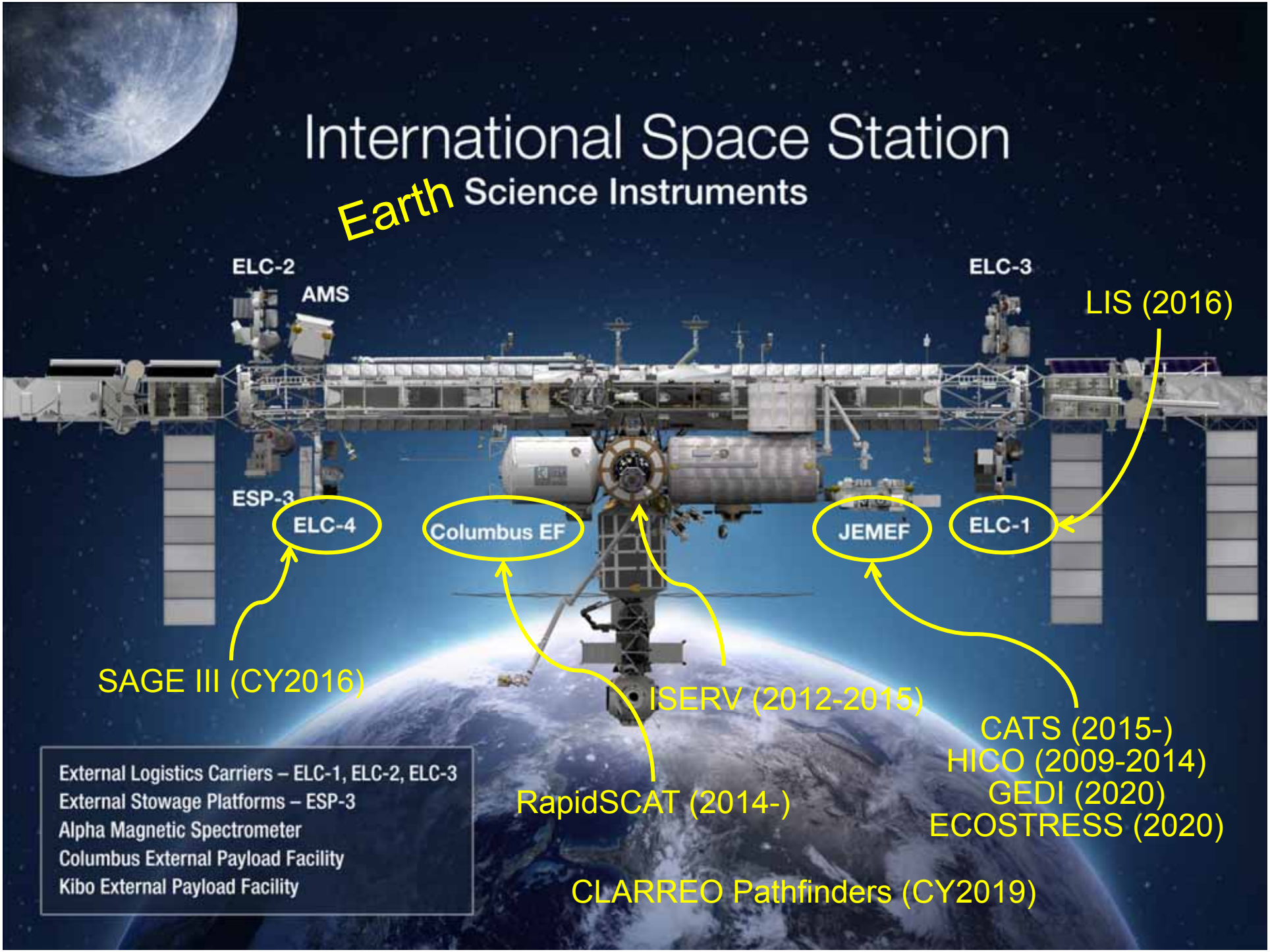


Technology

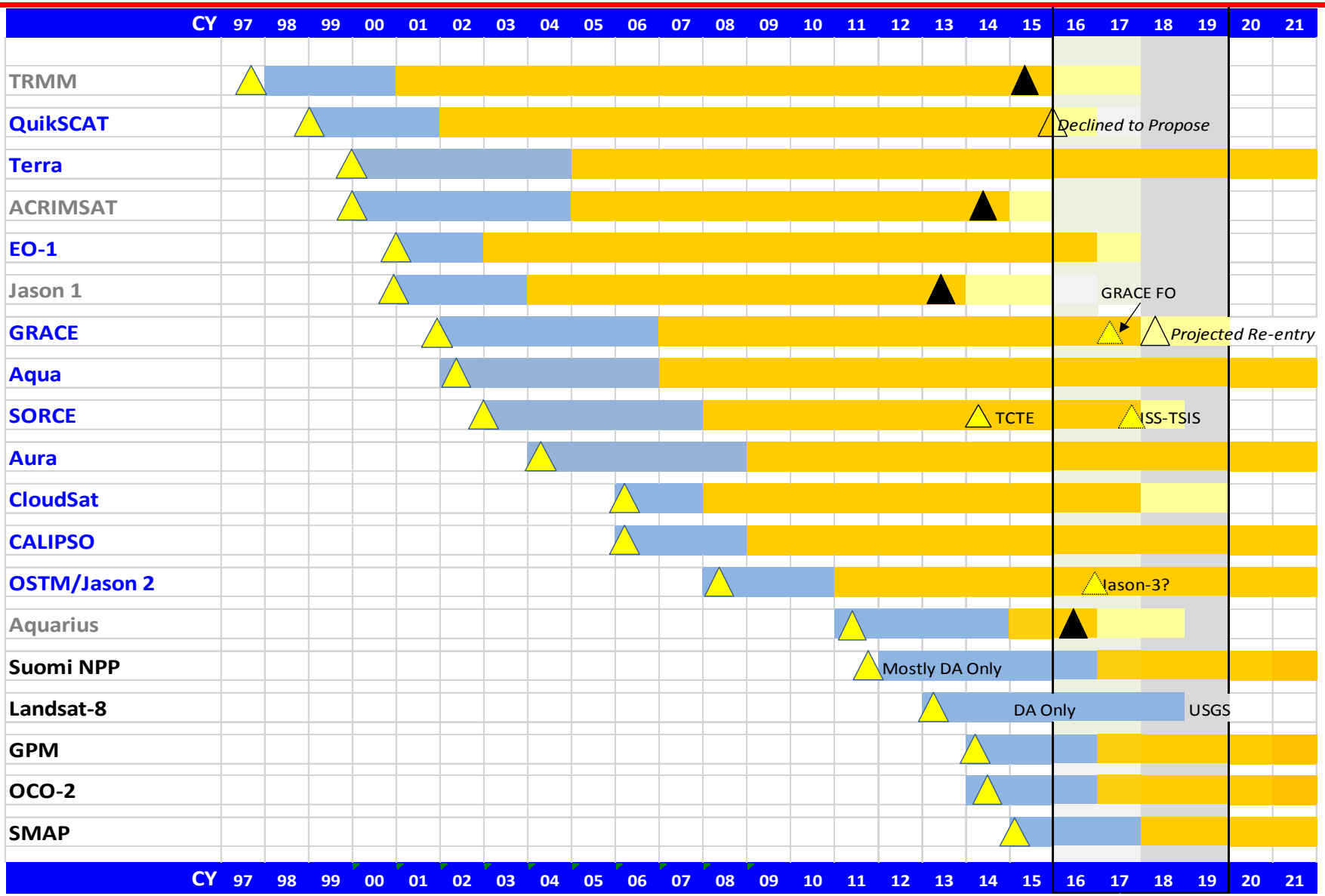
Earth Science Missions and Instruments




OCO-2
7/2014
SAGE-III
(on ISS)
mid-CY2016
Grace-FO
Aug 2017
JPSS-2 (NOAA)
RBI
OMPS-Limb
TSIS-1
TSIS-2 ISS
Sentinel-6/
Jason-CS (2020)
RapidSCAT, CATS
(on ISS) CY2014/15
LIS, OCO-3
(on ISS) 2016, 2018
L9 (2021-2023)
Initiated in 2015
CLARREO*
2019 for
Pathfinders/ISS
NI-SAR
2021
EVI-3
2022
GEDI/ISS
ECOSTRESS/
ISS
EVM-2
2021
EVI-2
2019, 2018
TEMPO
EVI-1,
CY2018 LRD
PACE
CY2022
GPM
2/2014
SWOT
CY2020
ICESat-2
June 2018
SMAP
Jan 2015
CYGNSS
EVM-1,
Oct 2016 LRD


International Space Station
Earth Science Instruments
ELC-2
AMS
ELC-3
LIS (2016)
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (CY2016)
ISERV (2012-2015)
CATS (2015-)
HICO (2009-2014)
GEDI (2020)
ECOSTRESS (2020)
RapidSCAT (2014-)
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

2015 Senior Review: Funded Mission Extensions



DSCOVR - EPIC

- **Release of Epic Images**
  - On July 22, President Obama tweeted the first publically released picture of Earth from the first Lagrange point.
  - The image showed the western hemisphere centered in the image with clouds covering the Mississippi Valley and the North East, brilliant blue waters around the Bahamas and the snow pack covering Greenland.
  - Lunar transit images tweeted by President Obama on Aug 5 (see next page).
  - The images and related news stories were carried on social media and press articles around the world.

DSCOVR – EPIC (Lunar Transit movie)

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Flight Mission Deliveries/LRDs in Baseline

Mission	Changes in the Budget	ABC LRD
SAGE III (ISS)	Budget consistent with re-baseline plan approved by SMD DPMC in June; maintains current ABC	Mar-16
CYGNSS	-	May-17
GRACE FO	Forward funded in FY15-16; JPL PRB increases accommodated by releasing HQ UFE in development and increasing Phase E budget	Feb-18
ECOSTRESS (ISS)	-	Aug-19
TEMPO	-	Nov-17** NLT 2021***
ICESat-2	-	Jun-18
GEDI (ISS)	Accommodates project-requested rephasing and small increase to cost cap for late start	May 18-20
RBI (JPSS-2)	Overguide included to restore reserves and add FTEs/WYEs	Apr-19** 2021***
OMPS-L (JPSS-2)	Budget consistent with target JPSS-2 LRD	Apr-18** 2021***
TSIS-2* (ISS - TBD)	-	Oct-20** 2022***
SWOT	-	Oct-20
NI-SAR	-	Jun-22
Landsat 9 */TIR-FF*	FY15 funds rephased to FY16	NLT 2023 (L9), 2019 (TIR-FF)
PACE*	-	2022
TSIS-1 (ISS)	Assumes Congress approves FY16 NASA funding and transfer from NOAA; Accommodated project-requested rephasing and provided 5 years of ops	Aug-17**
OCO-3	Assumes Congress approves FY16 restart	Sep-17**
CLARREO Pathfinder*	Assumes Congress approves FY16 start; Accommodates project-requested rephasing	Jun-19**/Sep-19**
JASON CS (Sentinel-6)*	Assumes Congress approves transfer from NOAA and FY16 start; Funds dual-build instrument suite	2020 (-A)/~2024 (-B)

* In Pre-Formulation ** Date Indicated is availability to platform for integration *** Date Indicated is LRD for host platform

ESM and ESSP Flight Program Overviews

- The Earth Systematic Missions (ESM) ***development*** missions include:
  - ICESat-2, SAGE III, GRACE-FO, SWOT, Landsat-9, TIRFF, RBI, TSIS-1 and -2, OMPS-Limb, NISAR, PACE, Jason CS/Sentinel-6A and -6B, CLARREO Pathfinder
- The Earth Systematic Missions (ESM) ***on-orbit**** missions include:
  - SMAP (>2021), DSCOVR (2019), S-NPP (>2021), GPM (>2021), LDCM (>2021), Terra (>2021), Aqua (>2021), Aura (>2021), OSTM (>2021), QuikScat (2015), SORCE (2017), and EO-1 (2016); also RapidScat (2017) and CATS (>2016)

- The Earth System Science Pathfinder (ESSP) ***development*** missions include:
  - OCO-3, CYGNSS, TEMPO, GEDI, ECOSTRESS
  - EVS-2 and -3 and Venture Technology selections (GrAOWL, Tempest), EVM-2 & 3, EVI-3, 4, 5, and 6
- The Earth System Science Pathfinder (ESSP) ***on-orbit*** missions include:
  - OCO-2 (>2021), GRACE (2018), CALIPSO (>2021), CloudSat (2018), Aquarius (>2021)

**On-orbit dates correspond to end-of-mission assumptions, consistent with 2015 Sr. Review*

RBI/TSIS-1/TSIS-2/OMPS-L

- **RBI**: Recovering from Stop Work/Cure Notice to instrument contractor. Main issues involve cost growth and detector technology maturation. Approaching KDP-B for delivery to JPSS-2 in April, 2019 consistent with NASA-NOAA IAA.

- **TSIS-1, -2**: TSIS-1 transferred from NOAA to NASA in FY16 PBR (pending Congressional approval). ESD intends to complete TSIS-1 instrument by August 2017, for flight to the ISS as early as Sept 2017 (consistent with original NOAA plan). Congressional approval received for NASA to spend FY15 funds on TSIS-1, clearing the way for continuous funding in the event of a CR. ESD plans to develop and deliver TSIS-2 instrument in FY2021, for flight to ISS as soon as FY2022.

- **OMPS-L**: ESD **FY16** budget request fully covers NASA funding of OMPS-L development (integrated with OMPS-Nadir) for delivery to JPSS-2 in 2021. NASA-NOAA IAA agreed and signature cycle nearly complete.

Sustainable Land Imaging (SLI) in FY16 Request

- ***Landsat-9*** development;
  - ESD initiated project and provided substantial obligation authority in FY15; however, the project's timeframe for establishing contracts does not allow significant funding to be obligated in FY15, so funds will be carried forward

- Funding requested for launch of a Thermal Infrared Free Flyer (TIRFF) mission; unsuccessfully attempted to gain Congressional approval for start in FY15; *House/Senate markups of FY16 appropriation are not supportive*

- SLI technology activities are managed by the Earth Science Technology Program, and involve focused solicitations informed by discussions with Landsat-9 and the Landsat community

- Architecture decisions for Landsat-10 will take place in the 2020 timeframe; Landsat-10 LRD ~2030

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

Pre-Aerosol, Cloud, and ocean Ecosystem (PACE) is an ocean color, aerosol, and cloud mission that follows 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

- Understand (and quantify) global biogeochemical cycling and ecosystem function in response to anthropogenic and natural environmental variability and change (ocean color sensor)
- Understand (and 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, budget and profile driven
Orbit	• 97 deg inclination; 650 km altitude; sun synchronous
Duration	• 3 year
Payload	• Ocean color instrument; potential for a polarimeter
LCC	• $805M Cost Cap

PACE Implementation Features

- ESD-imposed Cost Cap for the mission – "Design-to-Cost"
  - $805M Project LCC, launch in ~2022
    - $705M for hardware development/LV/mission ops – directed to GSFC
    - $100M for science processing and analysis
- Science Data processing
  - Conducted by the GSFC Ocean Biology Processing Group (ocean color data processing heritage)
  - Similar to the role the OBPG played on SeaWIFS
- Science team during development
  - Competed through ROSES
- Post launch science team and vicarious Cal/Val
  - Competed through ROSES
- Program management
  - Through the Earth Systematic Missions (ESM) Program at GSFC

Science Team
Competed Pre-launch
Using ROSES

Science Data Processing
Provided using interface spec

Post Launch Competed Science
Competed Using ROSES

Vicarious Calibration & Validation
Competed Using ROSES

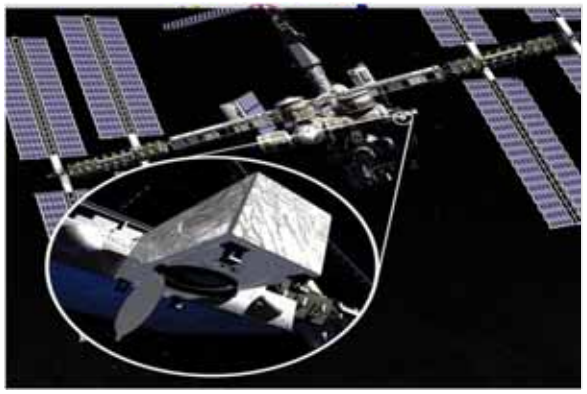
Venture-Class

- 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 Detail

- Continue long-standing cadence and scope of solicitations – no changes
- Future EVI solicitations may be targeted for science focus and/or host

Mission	Mission Type	Solicitation Release	Proposal Selection	Major Milestone
EVI-3	**Instrument Only**	**Q2 FY2015**	**Q2 FY2016**	**Delivery NLT 2020**
EVI-4	Instrument Only	Q4 FY2016	Q4 FY2017	Delivery NLT 2021
EVI-5	Instrument Only	Q2 FY2018	Q2 FY2019	Delivery NLT 2023
EVI-6	Instrument Only	Q4 FY2019	Q4 FY2020	Delivery NLT 2024
EVI-7	Instrument Only	Q2 FY2021	Q2 FY2022	Delivery NLT 2025
EVM-2	Full Orbital	Q4 FY2015	Q4 FY2016	Launch ~2021
EVM-3	Full Orbital	Q4 FY2019	Q4 FY2020	Launch ~2025
EVS-3	Suborbital	Q4 FY2017	Q4 FY2018	2019-2023
EVS-4	Suborbital	Q4 FY2021	Q4 FY2022	2023-2027
Open solicitation				

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: DSCOVR (EPIC, NISTAR), SAOCOM, ICESat-2, TEMPO, OCO-3, TSIS-1
  - SWOT and NI-SAR DAAC estimates are anticipated for future budgets
- Support for Sentinel-1 (SAR) and -6 (radar altimetry) ingest, archive, and distribution of level 0/1 data products
- EOSDIS includes Climate Data Initiative, Big Earth Data Initiative, and Global Change Information System activities

Earth Science Research

Focus Areas

Carbon cycle and Ecosystems

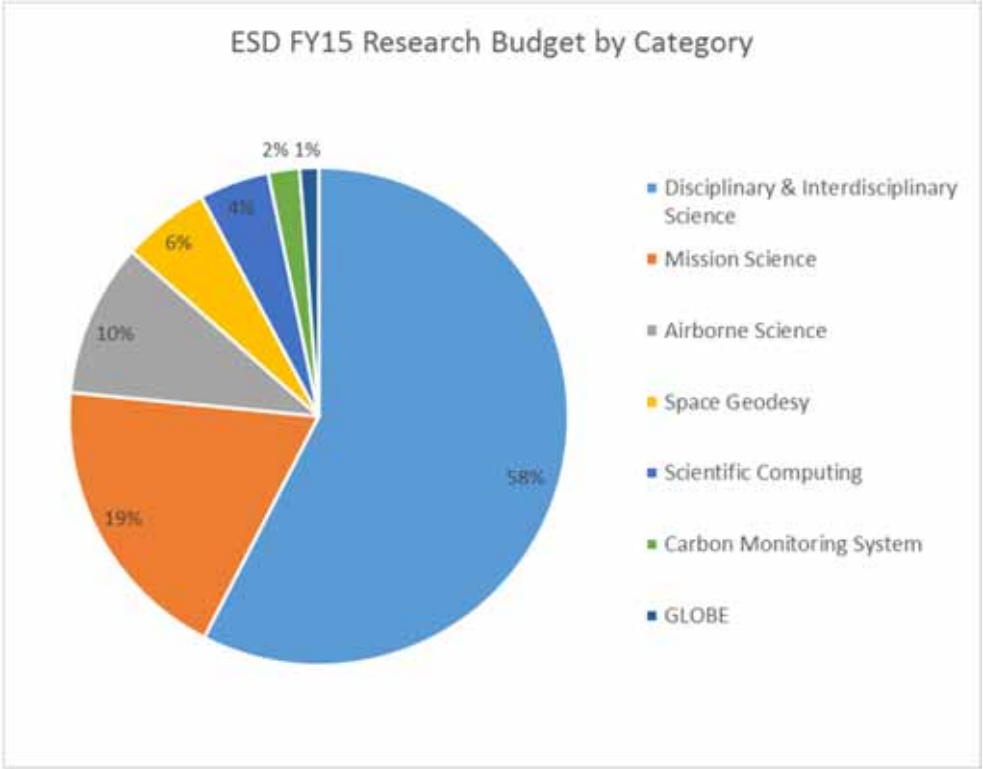
Climate Variability and Change

Atmospheric Composition

Global Water and Energy Cycle

Earth Surface and Interior

Weather



Applied Sciences

Health & Air Quality Applications
Ecological Forecasting Applications
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
Snow & Water Availability Activity

Applied Sciences Program: Project Lines

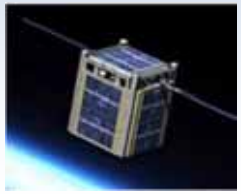
Project Lines	*Current*	*FY16+*
Applications	Ecological Forecasting	Ecological Forecasting
	Health & Air Quality	Health & Air Quality
	Water Resources	Water Resources
	Wildfires	
		Earth Science & Food Security
		Snow & Water Availability
Capacity Building	SERVIR	SERVIR
	SERVIR Applied Sciences Team	SERVIR Applied Sciences Team
	DEVELOP	DEVELOP
	ARSET Training	ARSET Training
	GOMI	
MAEA: Mission & Application Enabling Activities	Applications Activities for Missions (DPAs, workshops)	Applications Activities for Missions (DPAs, workshops)
	Community Utilities (NEX, LANCE, ESIP Fed)	Community Utilities (NEX, LANCE, ESIP Fed)
	GEO Support	GEO Support
	Climate (CASI, NCA)	Climate (CASI, NCA)
	Operating Items (AAAS Fellows, Contracts)	Operating Items (AAAS Fellows, Contracts)
	Socioeconomic Impact Analyses	Socioeconomic Impact Analyses
Disaster Support	Disaster Applications	Disaster Applications
		Disaster Response Teams

- Ends Gulf of Mexico Initiative after FY16
- Begins Snow & Water Availability Focused Activity
- Begins Food Security Focused Activity
- Establishes realistic approach to disaster response

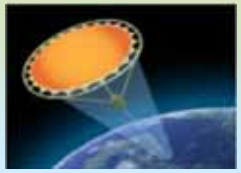
Earth Science Technology

Advanced Technology Initiatives (ATI)

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)*
Future solicitations planned in FY17 and FY20



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 - *InVEST-15 Selection Pending; 3 to 5 new projects anticipated (total funding approximately $14.6M over 3 years) Future solicitations possible in FY18 and FY21*

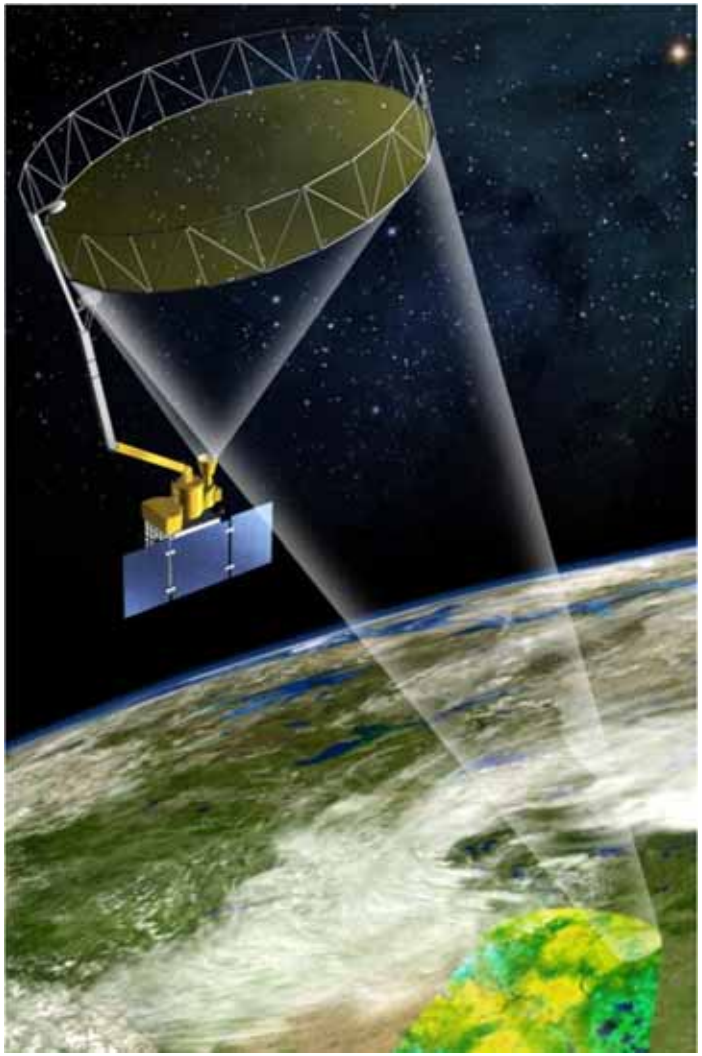


Instrument Incubator Program (IIP) - robust new instruments and measurement techniques - 1*7 new projects added in FY14 (total funding approximately $71M over 3 years)*
Future solicitations planned in FY16 and FY19

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)*
Future solicitations planned in FY16, FY18 and FY20

Soil Moisture Active/Passive (SMAP) Overview

Jet Propulsion Laboratory
California Institute of Technology



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

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

Partners	• JPL (project & payload management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• 7120.5E Category 2; 8705.4 Payload Risk Class C
Launch	• January 31, 2015 on Delta 7320-10C Launch System
Orbit	• Polar Sun-synchronous; 685 km altitude
Duration	• 3 years
Payload	• L-band (non-imaging) synthetic aperture radar (JPL) • L-band radiometer (GSFC) • Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)

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

SMAP Radar Failure High-Level Summary

- 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 (HPA) 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*

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.

Planned SMAP Science Capabilities

Jet Propulsion Laboratory
California Institute of Technology

Decadal Survey Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast Improvements	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

Key Level 1 Requirements (Derived from science objectives)

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission		Minimum Mission	
				Soil Moisture	Freeze/ Thaw	Soil Moisture	Freeze/ Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km	10 km	10 km
Refresh Rate	2–3 days	3–4 days	2–3 days[a]	3 days	2 days	3 days	3 days
Accuracy	0.04-0.06 [c]	0.04-0.06	80–70% [b]	0.04	80%	0.06	70%

[a] North of 45°N latitude

[b] Percent classification accuracy (binary freeze/thaw)

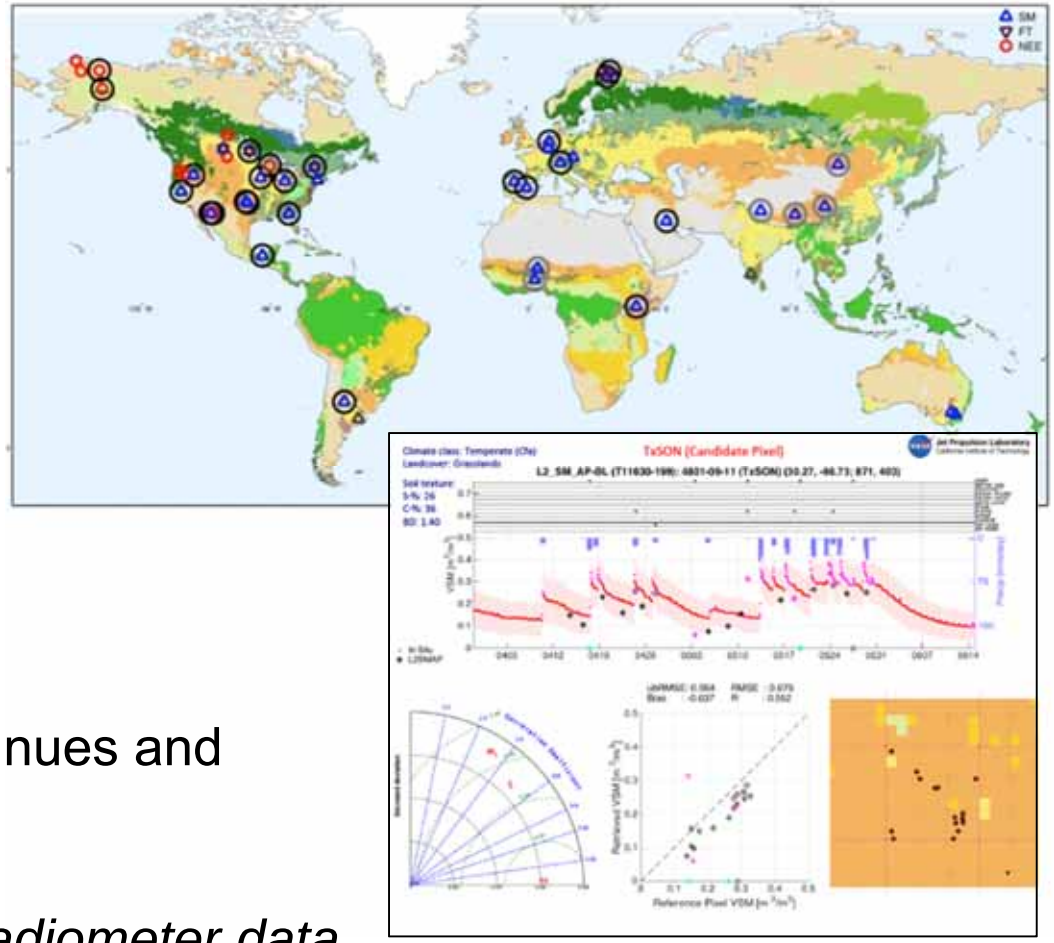
[c] Volumetric water content, 1-σ in [cm^3/cm^3] units

SMAP High-Quality Cal/Val

Jet Propulsion Laboratory
California Institute of Technology

SMAP Project advanced a unique Cal/Val model:

- Partnering with diverse community world-wide
- Advanced tools development for rigorous cal/val
- Focused and one-of-a-kind field campaigns



The SMAP cal/val activity continues and generates high science value

Existing 2 months of Radar+Radiometer data provides unique test-bed for radiometer-only products

Level 1 Key Requirements

Jet Propulsion Laboratory
California Institute of Technology

Para	Requirement Statement
4.1.1 (a)	**Baseline:** provide estimates of soil moisture in the top 5 cm of soil with an error of <0.04 cm^3/cm^3 (1σ) at 10 km resolution & 3-day average intervals over global land areas excluding regions of snow and ice, frozen ground, mountain topography, open water, urban areas, and vegetation water content >5 kg/m^2 (10 km average)
4.1.1 (b)	**Baseline:** provide estimates of surface binary freeze/thaw state in the region north of 45N latitude, which includes the boreal forest zone, with a classification accuracy of 80% at 3 km resolution and 2-day average intervals.
4.1.1 (c)	**Baseline:** collect measurements for at least three years.
4.1.1 (d)	Conduct a calibration & validation program to verify delivered data meets requirements
4.5.1 (a)	Produce the standard science data products listed in Table 1 (next slide).
4.5.1 (b)	Standard science data products listed in Table 1, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products will be delivered to the DAACs (ASF & NSIDC) as specified in Table 1.
4.5.1 (c)	Document science algorithms used to generate the standard science data products in Algorithm Theoretical Basis Documents (ATBDs).
4.5.1.1	Science Data Requirements (HDF5 format, ISO19115 Geographic Information, Data Preservation requirements
4.5.2	Organize and host a data product application workshop annually to share information on science data applications and define potential applications that can be supported with existing data requirements. Results will be provided to the Science Team and at other SMAP workshops and meetings.

Data Product Changes

- Red Data products lost
- Purple data products become Radiometer Only

Data Product	Description	Initial Delivery of Product to Data Center[4]	Validated Data Delivery to Data Center	Subsequent data Delivery to NASA Data Center [1 4] (nominal)	NASA Earth Science Data Center
Level 1	Radar sensor data Radiometer sensor data	3 months after IOC	6 months after IOC	24 hours after receipt on the ground	**ASF[2]** **NSIDC[3]**
Level 2	Soil Moisture (swaths)	6 months after IOC	12 months after IOC	48 hours after receipt on the ground	**NSIDC[3]**
Level 3	Soil Moisture (global)	6 months after IOC	12 months after IOC	72 hours after receipt on the ground	**NSIDC[3]**
Level 3	**Freeze/Thaw (>45°N)**	**6 months after IOC**	**15 months after IOC**	**72 hours after receipt on the ground**	**NSIDC[3]**

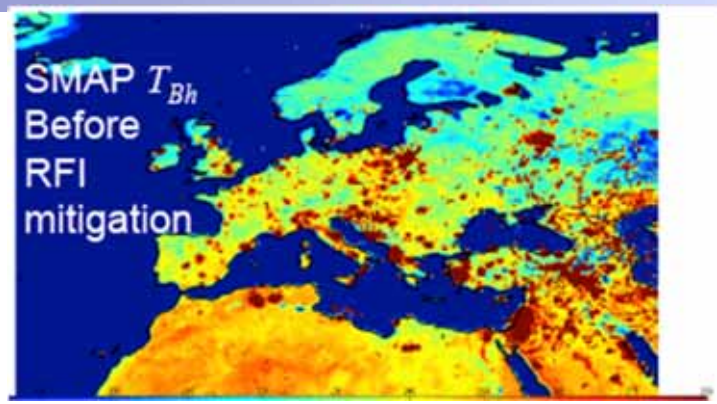
Opportunities with the SMAP Radiometer

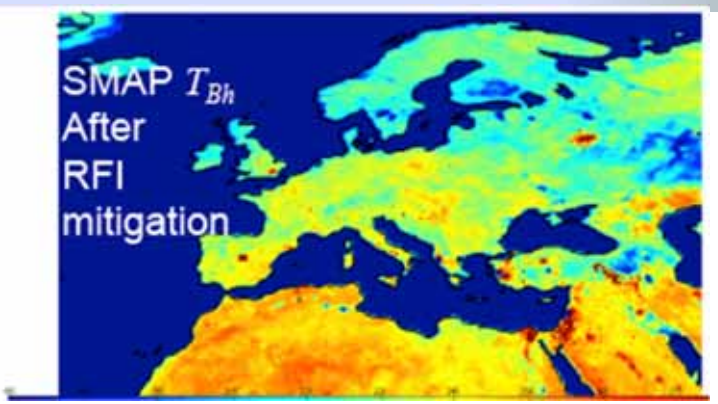
Jet Propulsion Laboratory
California Institute of Technology

- 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

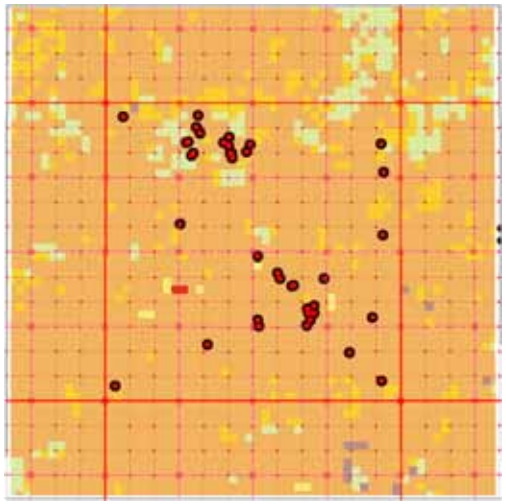
SMAP Radiometer RFI Detection & Mitigation; Soil Moisture Retrieval Capabilities

Jet Propulsion Laboratory
California Institute of Technology

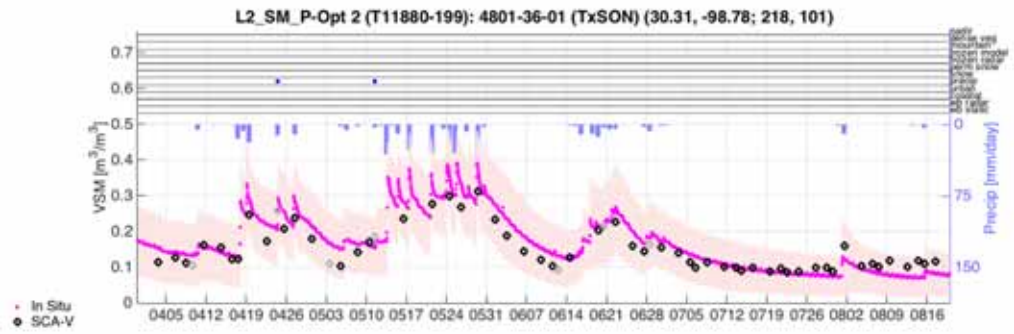


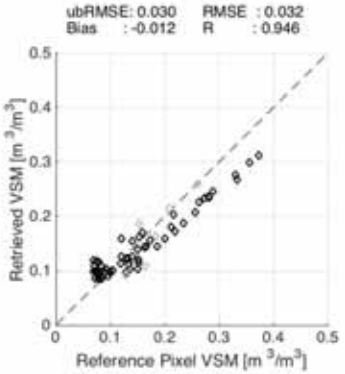


Example of radiometer-based soil moisture cal/val



Texas Soil Observation Network (TxSON)





SMAP Resolution Enhancement

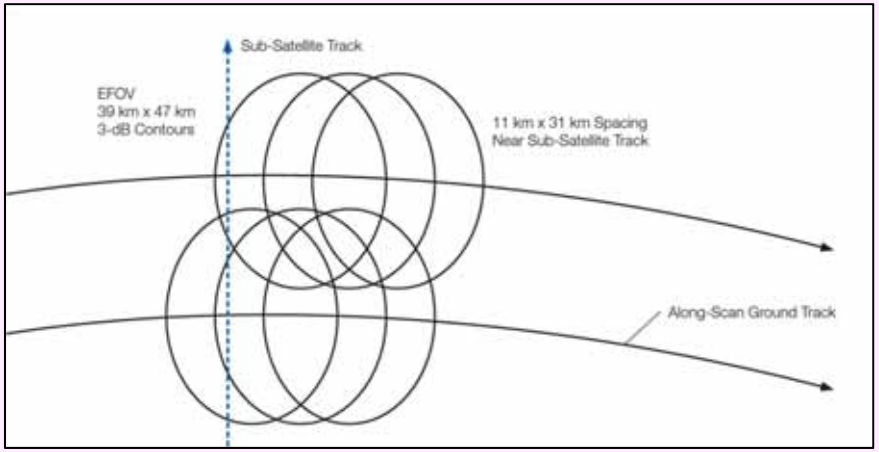
Jet Propulsion Laboratory
California Institute of Technology

Process Over-Sampled SMAP Radiometer Data

Take advantage of SMAP radiometer over-sampling to produce ~20 km resolution brightness temperature product

Global coverage every 2 – 3 days

Compares to global 10 km active-passive SMAP baseline



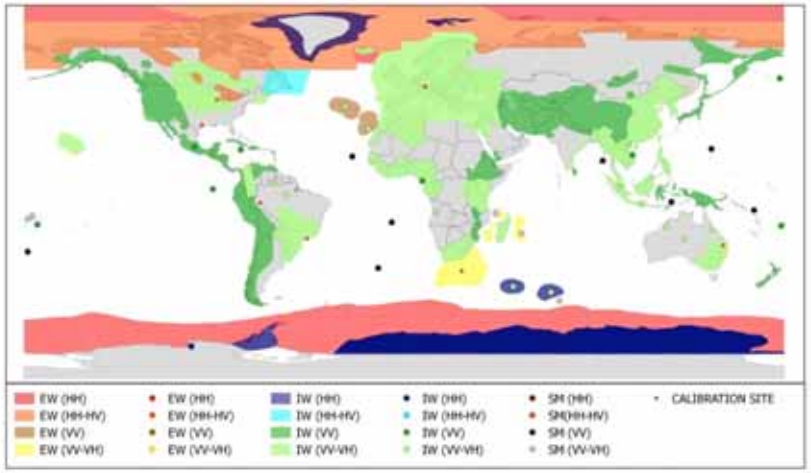
Use Multi-Platform Data

Use available radar data in SMAP's active-passive algorithm

- Better-than 10 km resolution but
- 12-day revisit
- Regional coverage

Use geostationary Satellite IR/Visible (10km resolution; 3-day revisit)

Sentinel-1 *EW* Scan-Mode (**Green**)



Summary of Ongoing Algorithm/Product Work

Jet Propulsion Laboratory
California Institute of Technology

- Continuing baseline algorithm & cal/val tasks as appropriate accounting for loss of radar
- Delivering beta and calibrated/validated data products to DAACs (L2/3/4 products by October, ahead of schedule by one month)
- Proceeding with select recovery tasks (radiometer resolution enhancement, multiplatform data use, radiometer-based landscape freeze/thaw)
- Confirm and refine approaches during Sept 29-Oct 1 SMAP Science Team meeting

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 (~-3 dB) surface **soil moisture** product for hydrologic and climate science and applications

1. **Sea surface salinity** (coastal and open ocean using ancillary wind data) - ongoing

2. Landscape **freeze/thaw** classification at 35 km (advantage of deeper penetration and better representativeness using L-band instead of existing higher microwave frequencies)

3. **Sea-ice** coverage and ice-lead thickness at 35 km regardless of illumination and clouds

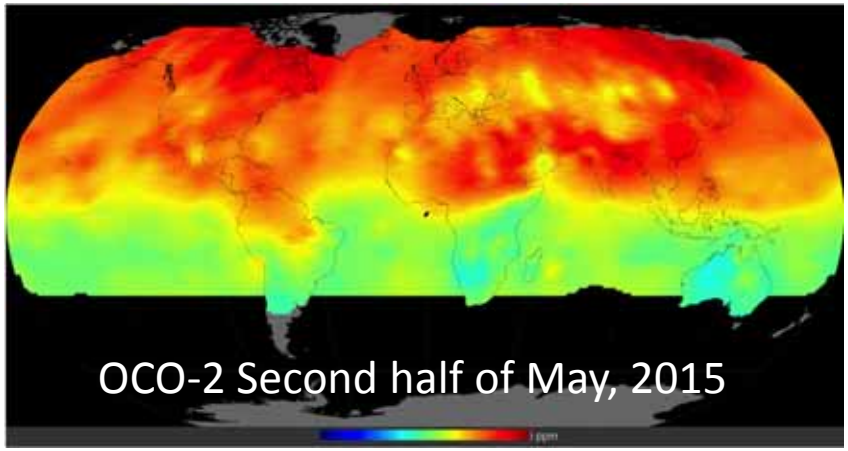
4. **Ocean surface high winds** in the presence of hurricanes and tropical storms

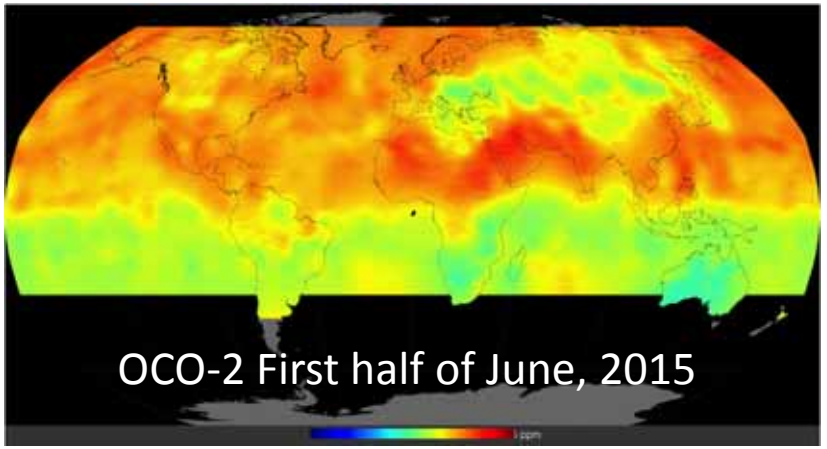
SMAP Radiometer-Only and GPM IMERG

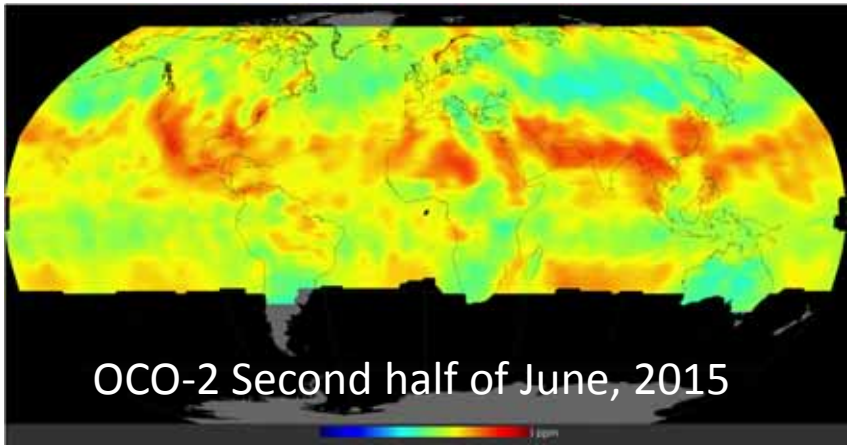
Venture Class Launch Services (VCLS)

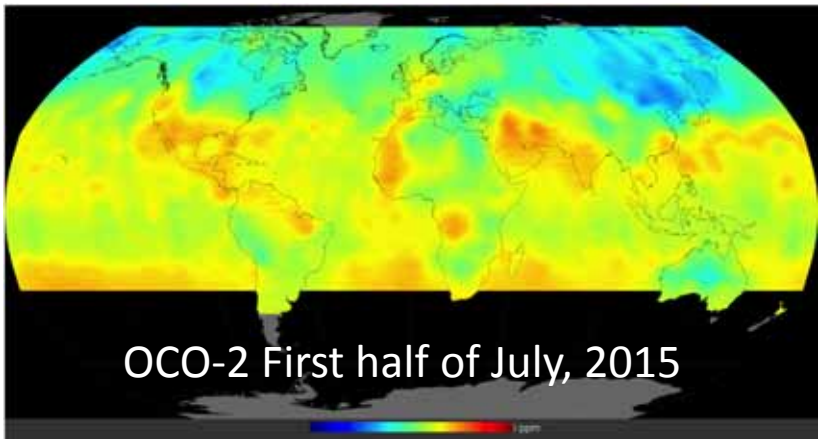
- Joint ESD/LSP Venture
  - Based on responses to RFI send out 3rd Qtr 2014
  - Responses showed 5-7 potentially viable providers.
    - Multiple responses were based on the Super Strypi
- RFP released 12 June 2015
- Proposals received and reviewed by NASA Launch Services Prog.
  - Funded with $10M from ESD Earth Venture Management line
  - Selected launches will:
    - Accommodate 132 pounds (60 kilograms) of CubeSats on a single launch or
    - Two launches carrying 66 pounds (30 kilograms) each
    - Launch must occur by April 15, 2018

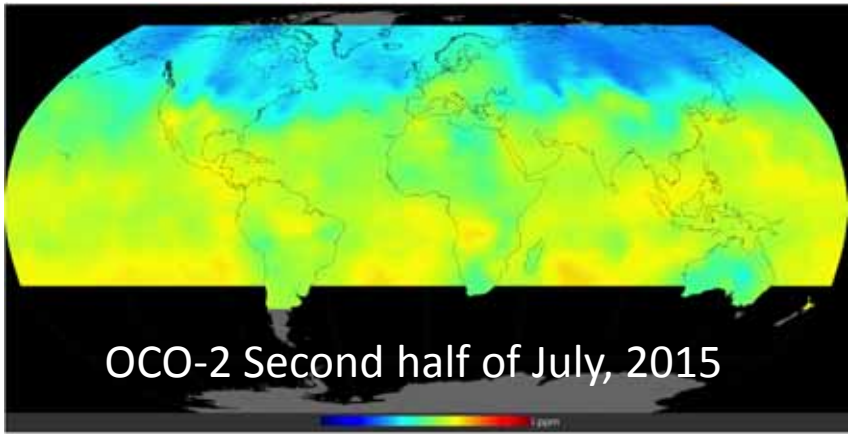
- Announcement imminent

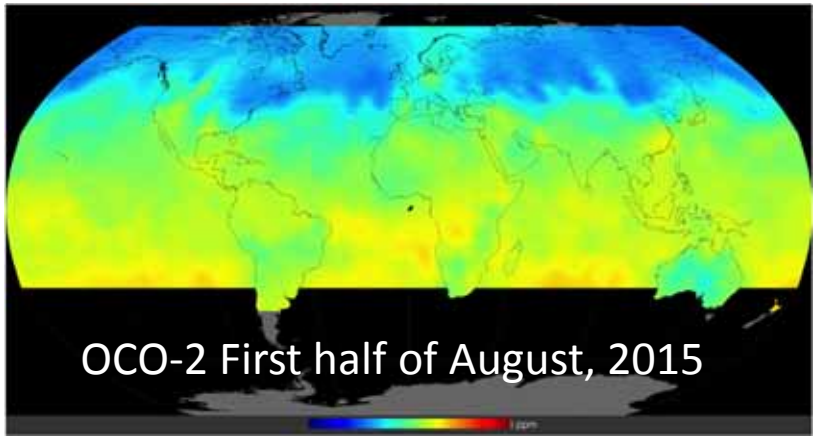

OCO-2 Second half of May, 2015


OCO-2 First half of June, 2015


OCO-2 Second half of June, 2015


OCO-2 First half of July, 2015

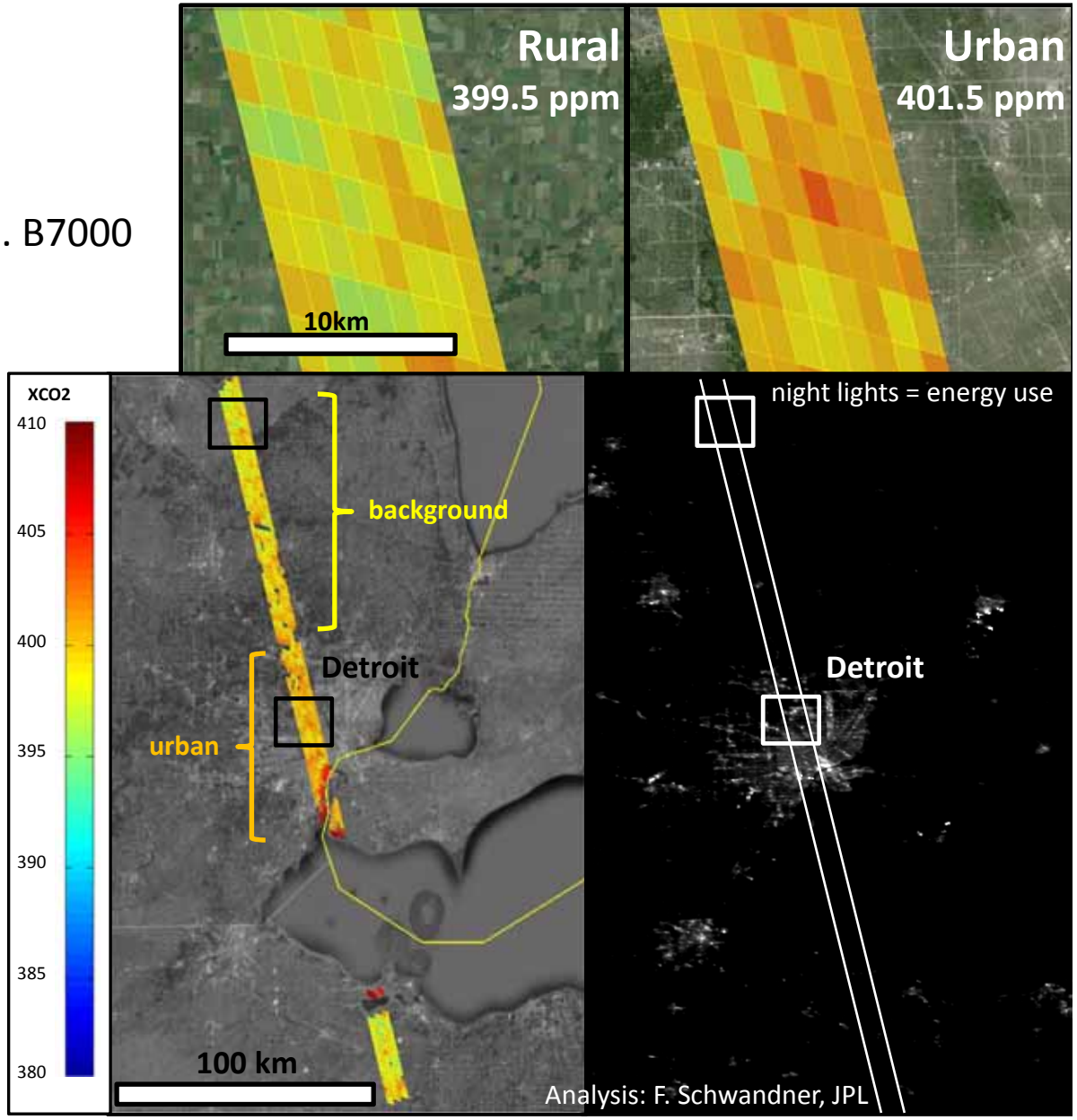

OCO-2 Second half of July, 2015


OCO-2 First half of August, 2015

OCO-2 Status: Cities

Example: Detroit MI
(2014 Detroit metro pop. 4.2 mil.)
Orbit 3866 nadir, 2015/03/24, vers. B7000

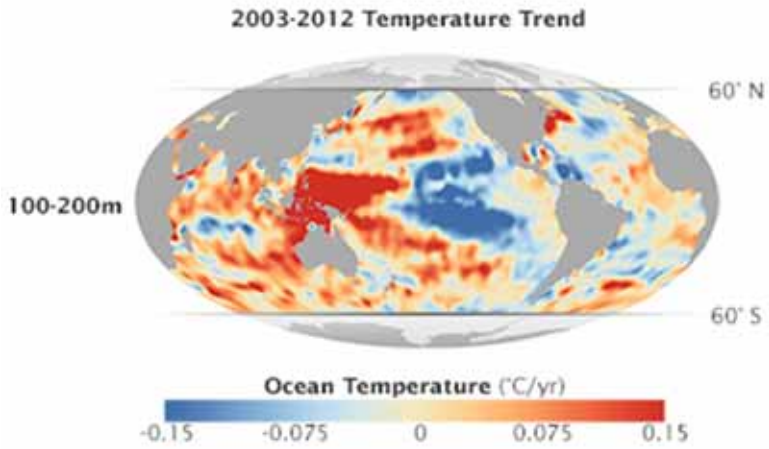
- Each vertex is a single XCO2 measurement or footprint.
- Human energy use (e.g. transport) results in elevated XCO2 over cities, relative to rural areas.
- Enhancement of ~2 ppm observed over Detroit in March 2015, consistent with enhancements seen in urban areas under relatively quiet meteorological conditions.
- "Night Lights" image (on right) illustrates the extent of urbanization and energy consumption.



Recent Hiatus Caused by Decadal Shift in Indo-Pacific Heating

Veronica Nieves, Josh K. Willis, and William C. Patzert | Science | JULY 2015 | doi: 10.1126/science.aaa4521

- **In a new study, NASA JPL researchers Veronica Nieves, Josh Willis and Bill Patzert concluded that the Indo-Pacific Oceans interaction modified global surface temperature over the past two decades, fully accounting for the recently observed 'hiatus.'**
- **Their results were based on direct ocean temperature measurements over the past two decades, including subsurface observations from a global network of about 3,500 ocean temperature probes known as Argo.**
- **Specifically, they found a subsurface layer of the Indian and Pacific oceans between 300 and 1,000 feet (100 and 300 meters) depth has been accumulating more heat than previously recognized.**



Global maps of temperature trends at four layers in the ocean show patterns of heat below the surface, during 2003-2012. The warmest water accumulated at depths of ~ 100-200 m in the western Pacific and Eastern Indian oceans, left of center. (Image credit: NASA Earth Observatory)

An Argo float, foreground. The new study included direct ocean temperature measurements from Argo floats and other ocean sensors. (Image credit: Argo program, Germany/Ifremer)


NASA

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 2nd 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)

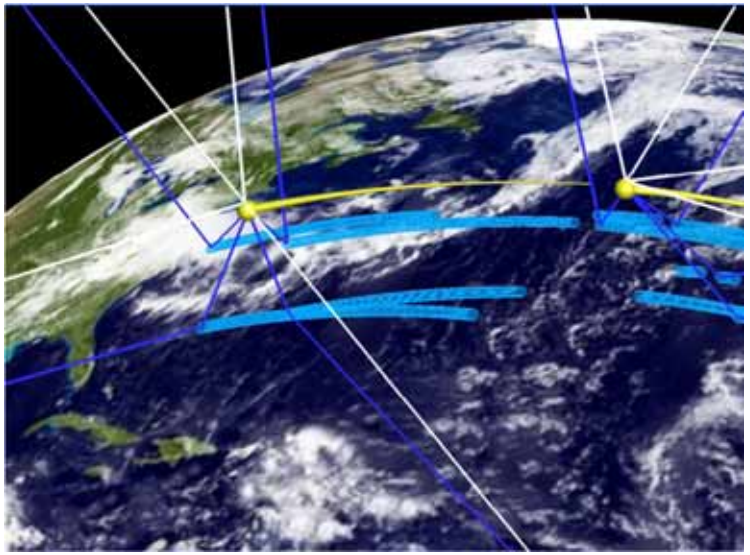
- Main 2007 Dec. Survey ***Mission*** recommendations/status (cont.)
  - Tier II, III
    - SWOT: In Phase B for Oct 2020 launch (joint with CNES)
    - *GRACE-FO*: In Phase D for Feb 2018 [Aug 2017 MA] launch (GFZ partner)
    - Pre-formulation: GEO-CAPE, ASCENDS, ACE, HySpIRI, [CLARREO if CLARREO-PF 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)

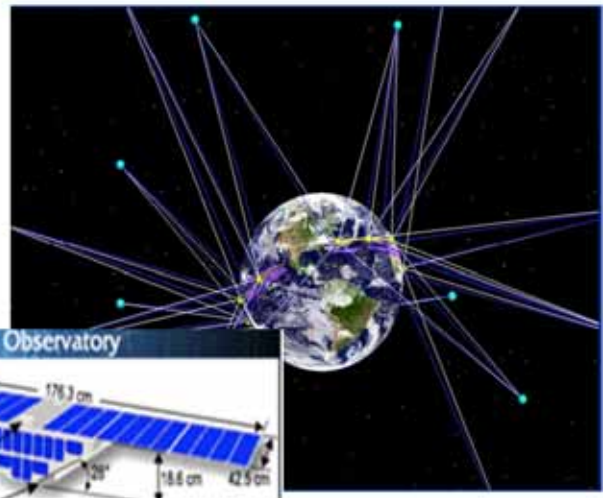
Earth Venture Mission-1 Selection

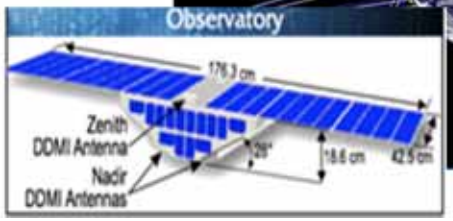
CYGNSS (CYclone Global Navigation Satellite System)

- ***CYGNSS is a pathfinder to using small satellite constellations***
- 8 microsatellite (18 kg each) dense sampling constellation
- GPS reflectometry to measure ocean surface winds in hurricane eyewalls and core in all precipitating conditions
- To improve understanding of hurricane development and intensity at landfall



PI: Chris Ruf, University of Michigan
Instrument Development: Surrey Satellite Technology US
Spacecraft: SwRI
Project Management: SwRI
KDP-C passed 2/2014
Orbit requirements: ***Low Earth Orbit***
35^{o} inclination, 500 km altitude

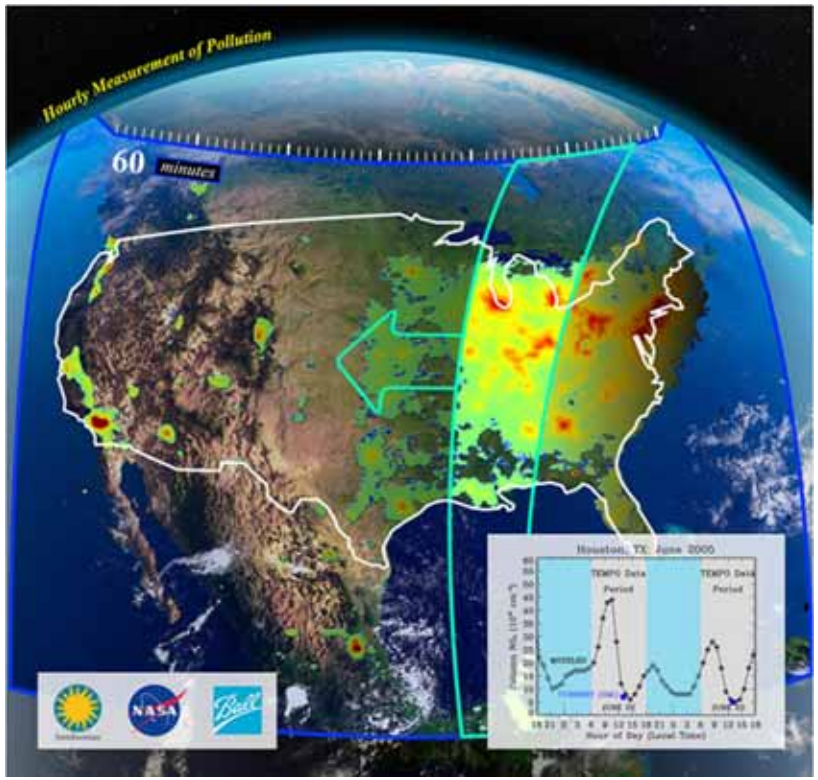




Earth Venture Instrument-1 Selection

Tropospheric Emissions: Monitoring of Pollution

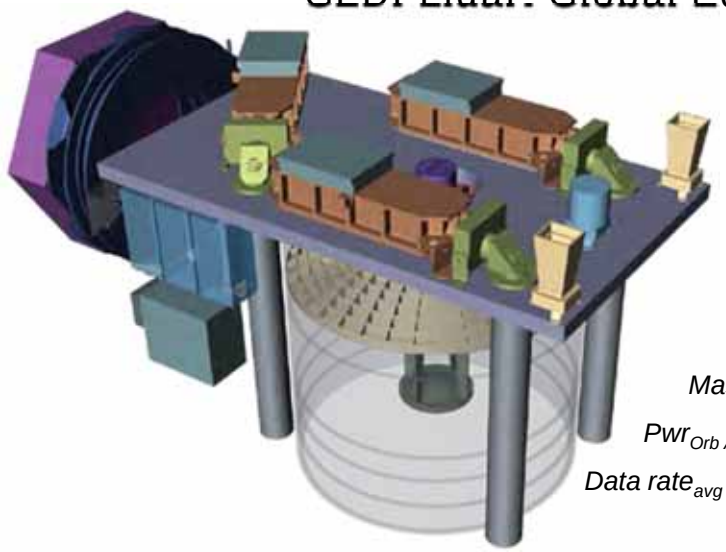
- ***TEMPO is a pathfinder to using hosted commercial payloads from GEO***
- Tropospheric pollution observations from Geostationary Orbit
  - Ozone, NO_2, SO_2, aerosols, CH_2O, others.
- Forms a global Air Quality constellation in GEO with EU/GEMS Sentinel 4 and Korean GEO observations.
- EPA and NOAA researchers are part of the science team.



PI: Kelly Chance, Smithsonian Astrophysical Observatory
Instrument Development: Ball Aerospace
Project Management: LaRC
KDP-B passed 4/2014 (KDP-C scheduled 30/9/2014)
Orbit requirements: ***Geostationary Orbit.*** Hosted on a commercial communication satellite

Mission type: Class C, ISS

GEDI Lidar: Global Ecosystem Dynamics Investigation Lidar
PI: Ralph Dubayah



Mass = 230 kg

$Pwr_{Orb\ Avg}$ = 516 W

$Data\ rate_{avg}$ = 2.1 Mbps

Mission:

GEDI will characterize the effects of changing climate and land use on ecosystem structure and dynamics, enabling improved understanding of Earth's carbon cycle and biodiversity. GEDI will provide the first global, high-resolution observations of forest vertical structure.

Goals:

GEDI will address the following questions:
- What is the above-ground carbon balance of the land surface?
- What role will land surface play in mitigating atmospheric CO2?
- How does ecosystem structure affect habitat quality and biodiversity?

GEDI measurements will quantify the following:
- Distribution of above-ground carbon at fine spatial resolution
- Changes in carbon resulting from disturbance and subsequent recovery
- Spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity
- Sequestration potential of forests over time w/changing land use, climate

Instrument: Lidar

Heritage: HOMER (laser); GLAS, CALIPSO (optics); IceSat, (detectors)

Mission & Science Team:

Principal Investigator: Ralph Dubayah, UMD
Project Manager: Kenneth Anderson, GSFC
Instrument System Engineer: Cheryl Salerno, GSFC
Deputy PI Instrument / Instrument Scientist: Bryan Blair, GSFC
Deputy PI Science: Scott Goetz, WHRC
Instrument Deputy Project Manager: Thomas Johnson, GSFC

Mission & Science Team:

University of Maryland, College Park
Goddard Space Flight Center
Woods Hole Research Center
US Forest Service
Brown University

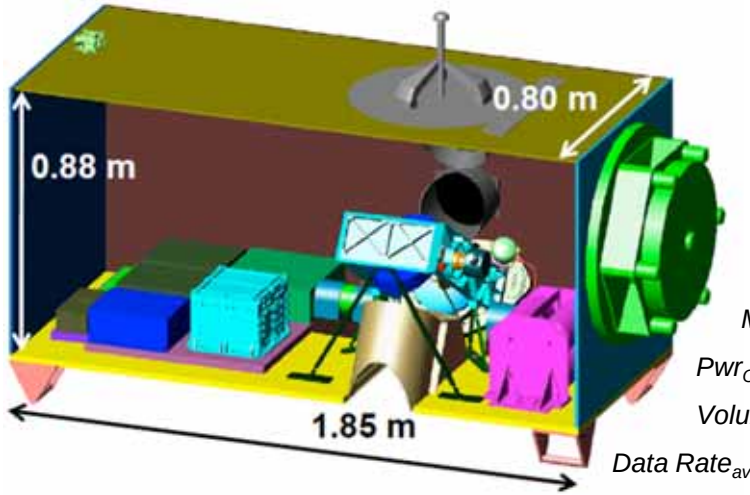
Instrument Details:

- Self-contained laser altimeter
  - 3 lasers are split into 7 beams dithered to produce 14 ground track spot beams.
  - Beams have a 25 meter footprint and are spaced 500 m cross-track and 60 m along-track to produce fine grids of forest structure.
- 70 cm diameter telescope/receiver.
  - Detector has 75% transmission and 50% quantum efficiency.
  - Si:APD detectors: Near-photon-noise limited, >500:1 dynamic range
  - IFOV matched to contain return spot beams
- GPS, IMU, Star Trackers give precise ranging, attitude and position.
- A single-axis mechanism rotates the instrument about the roll axis, providing off-nadir pointing for global coverage.
- Canopy profile accurate to 1 m
- Geolocation < 10 m for plot calibration
- Biomass error < 20% at pixel level

FY16 Cost: ~$94 M

Threshold: Acquire canopy vertical profile to estimate above-ground woody carbon density for vegetated areas at <1 km.

ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
PI: Simon Hook



Mass = 266 kg

$Pwr_{Orb\ Avg}$ = 527 W

Volume = 1.30 m^3

$Data\ Rate_{avg}$ = 2.32 Mbps

Mission:

ECOSTRESS will provide the first high spatiotemporal resolution thermal infrared measurements of Earth's surface from ISS. Measurements at varying times over the diurnal cycle will reveal answers related to water stress in plants and how selected regions will respond to future climate changes.

Goals:

- Identify critical thresholds of water use and water stress in key climate-sensitive biomes.
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Instrument: Thermal infrared radiometer

Heritage: Prototype Hyperspectral Infrared Imager (HyspIRI) Thermal Infrared Radiometer (PHyTIR; a laboratory instrument); Algorithms: ASTER, MODIS, Landsat

Mission & Science Team:

Principal Investigator: Simon Hook, JPL

Project Manager: Wes Schmitigal, JPL

Lead System Engineer: Renaud Goullioud, JPL

Major Partners:

Jet Propulsion Laboratory

Instrument Details:

- Cross-track whisk broom scanner
- Swath width: 384 km (51 °)
- Spatial resolution: 38 m x 57 m (nadir) pixels
- Five thermal IR bands between 8.3 and 12.1 microns
- Noise equivalent delta temperature: ≤ 0.1 K
- Two COTS cryocoolers for 60 K focal plane
- Typical revisit of 90% of CONUS every 4 days at varying times over diurnal cycle

FY16 Cost: ~$30M

Threshold: Same as baseline.