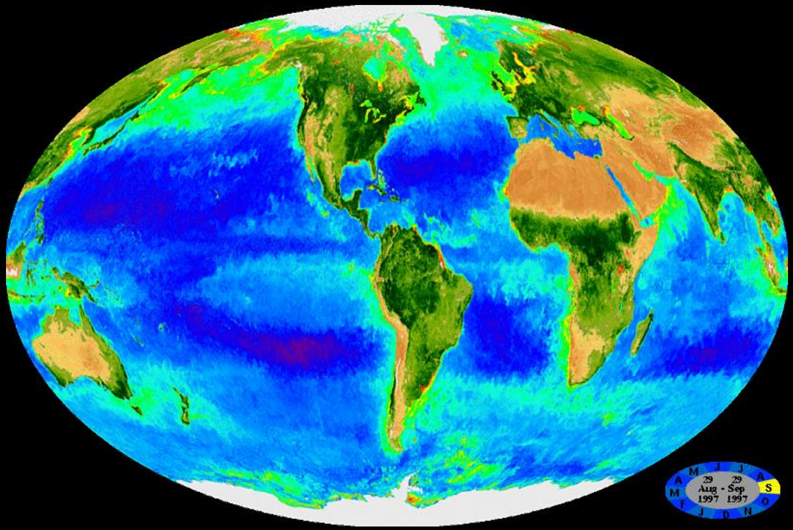
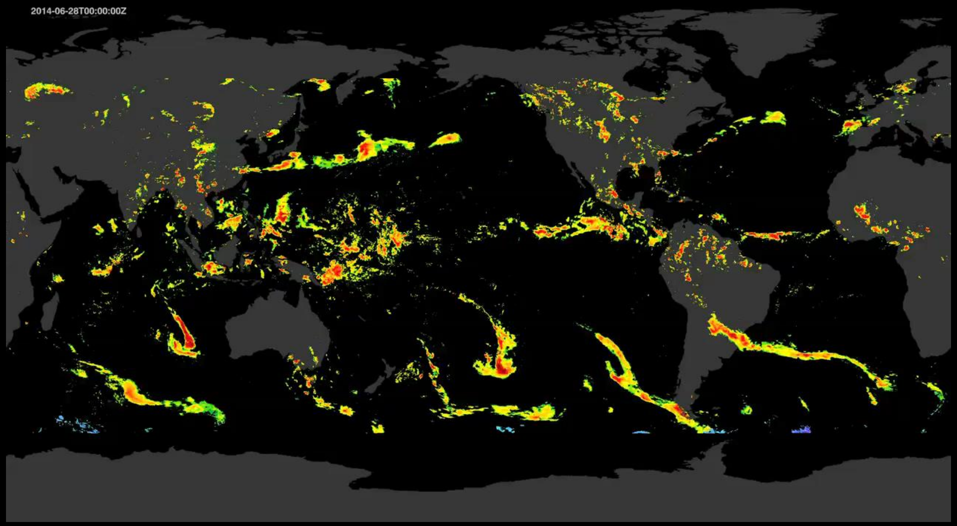
NASA Earth Science Division: Status, Plans, Accomplishments

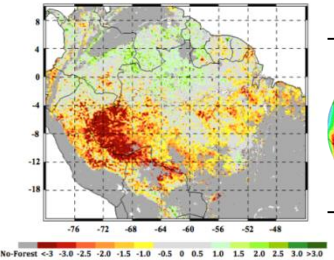
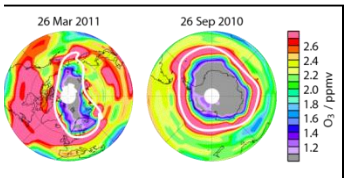
ch, 27 July 2015

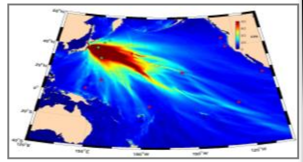
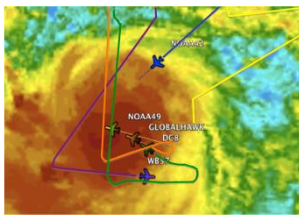


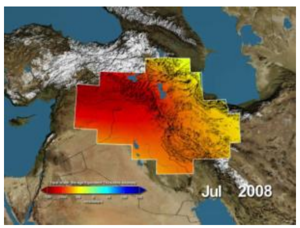


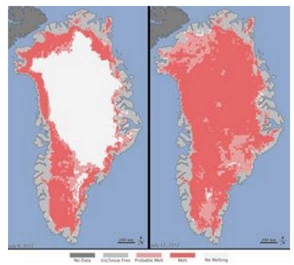
NASA's Earth Science Division

Research

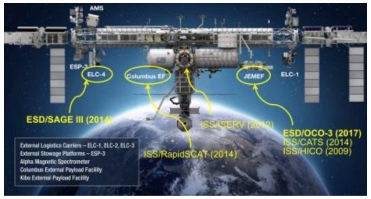



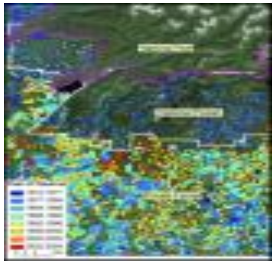
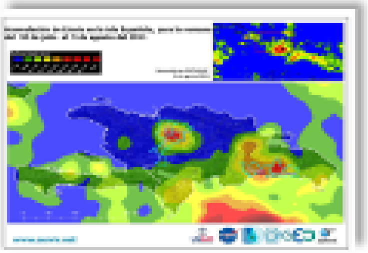
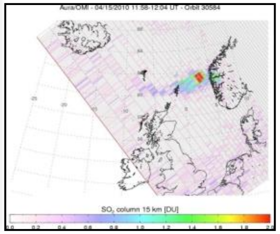
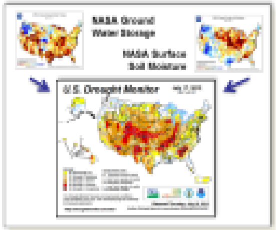


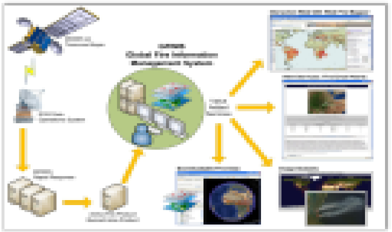
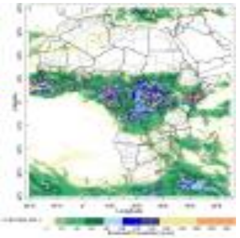


Flight

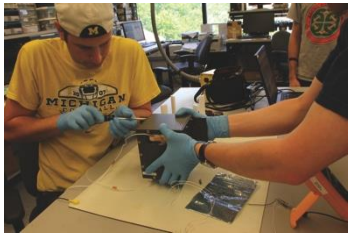
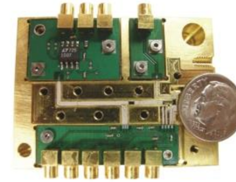


Applied Sciences

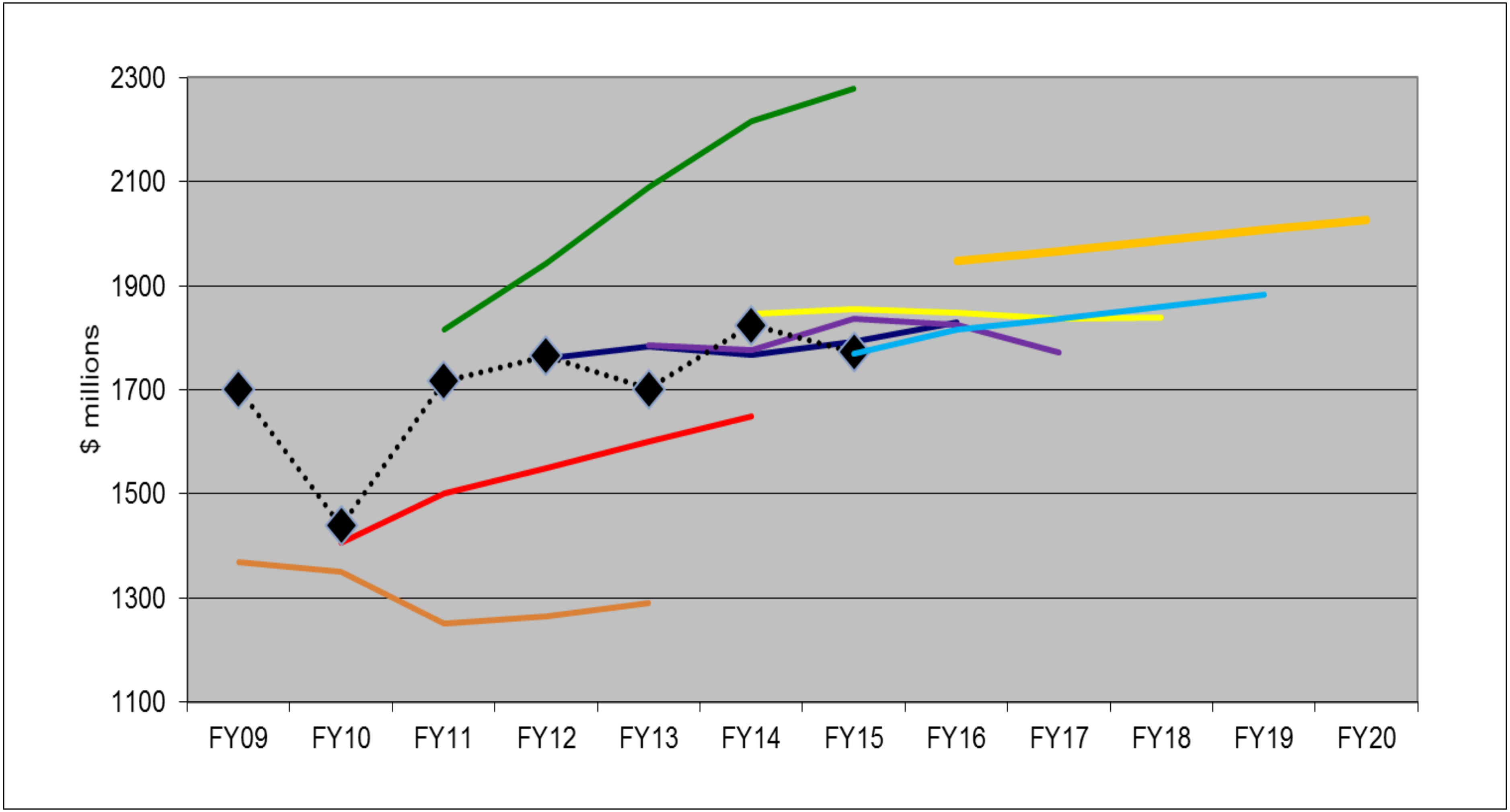



Technology

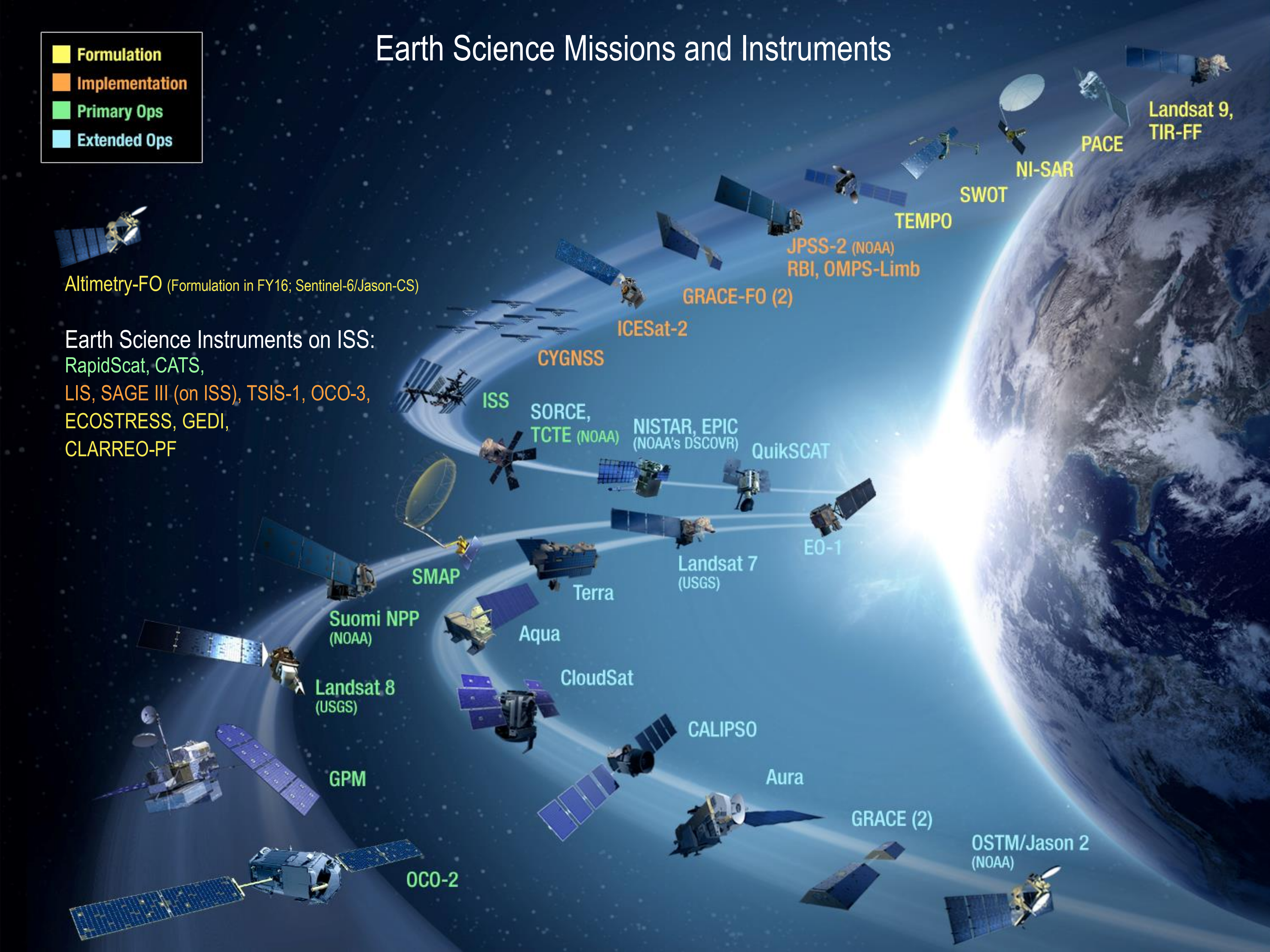


Earth Science Budget:
FY16 Request/FY15 Appropriation



Earth Science Division Budget Evolution

- FY14 ESD Appropriated Budget: $1.825B
- FY15 ESD Appropriated Budget: $1.773B
- **FY16 President's Budget Request: $1.947B**
- FY16 House Authorization Comm.: $1.450B ($1.198B seq.)
- FY16 House Appropriations Mark-up: $1.683B
- FY16 Senate Appropriations Mark-up: $1.932B


Earth Science Missions and Instruments
Formulation
Implementation
Primary Ops
Extended Ops
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
Landsat 9, TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA's DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
Terra
SMAP
Suomi NPP
(NOAA)
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

RECENT CHANGES TO ON-ORBIT CONSTELLATION

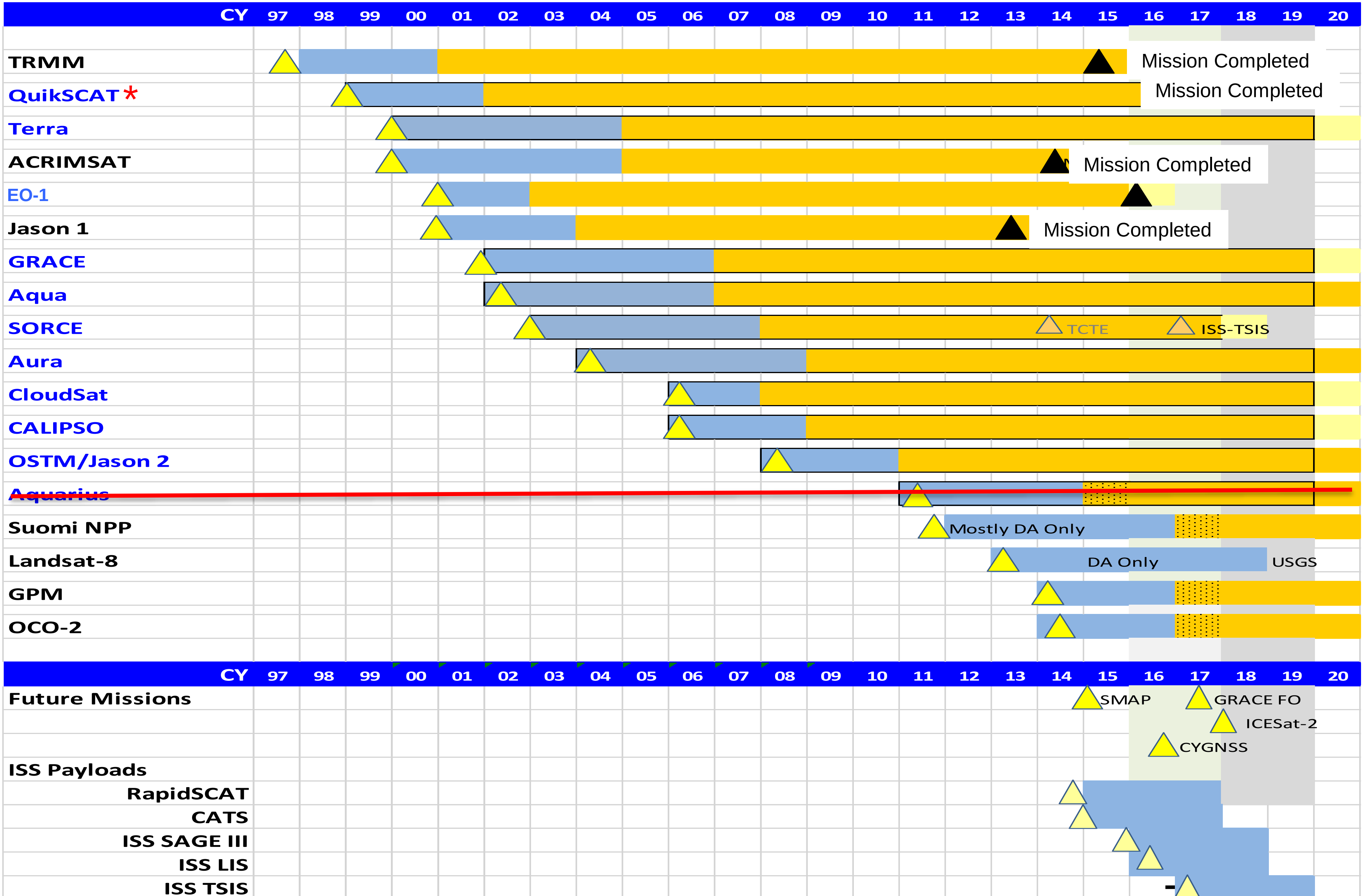
- TRMM (Tropical Rainfall Measuring Mission) Re-enters (Tropical Precipitation)
  - Launched 27 November 1997
  - Joint with Japanese Space Agency (now JAXA)
  - "Passivated" 15 April 2015
  - Re-entered 16 June 2015 UTC (Indian Ocean)

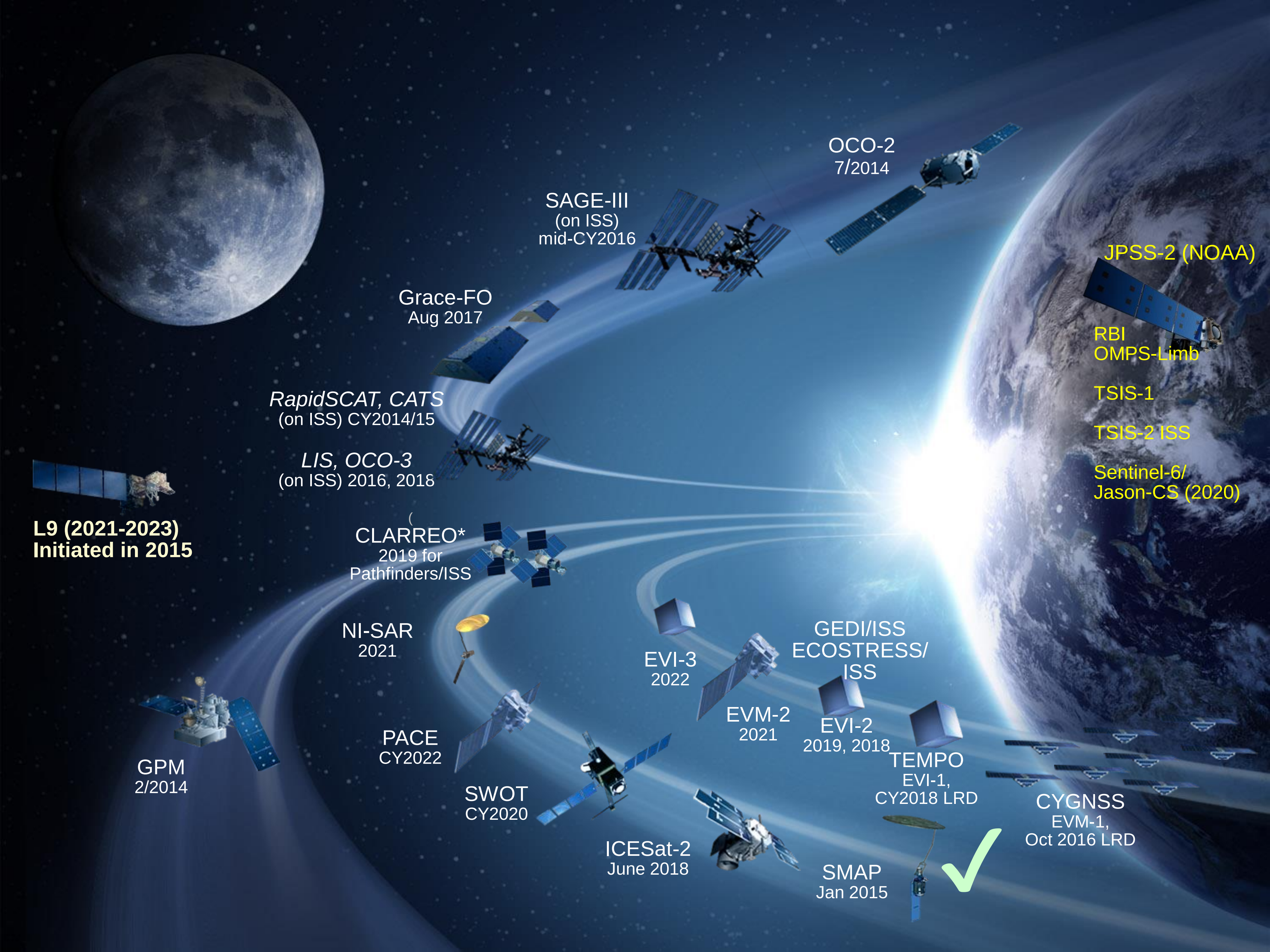
- Aquarius/SAC-D Satellite Bus Failure (Sea-surface Salinity)
  - Launched 10 June 2011
  - Joint with Argentine Space Agency (CONAE)
  - Satellite bus failure 7 June 2015 (DC-DC converter, redundant unit failed

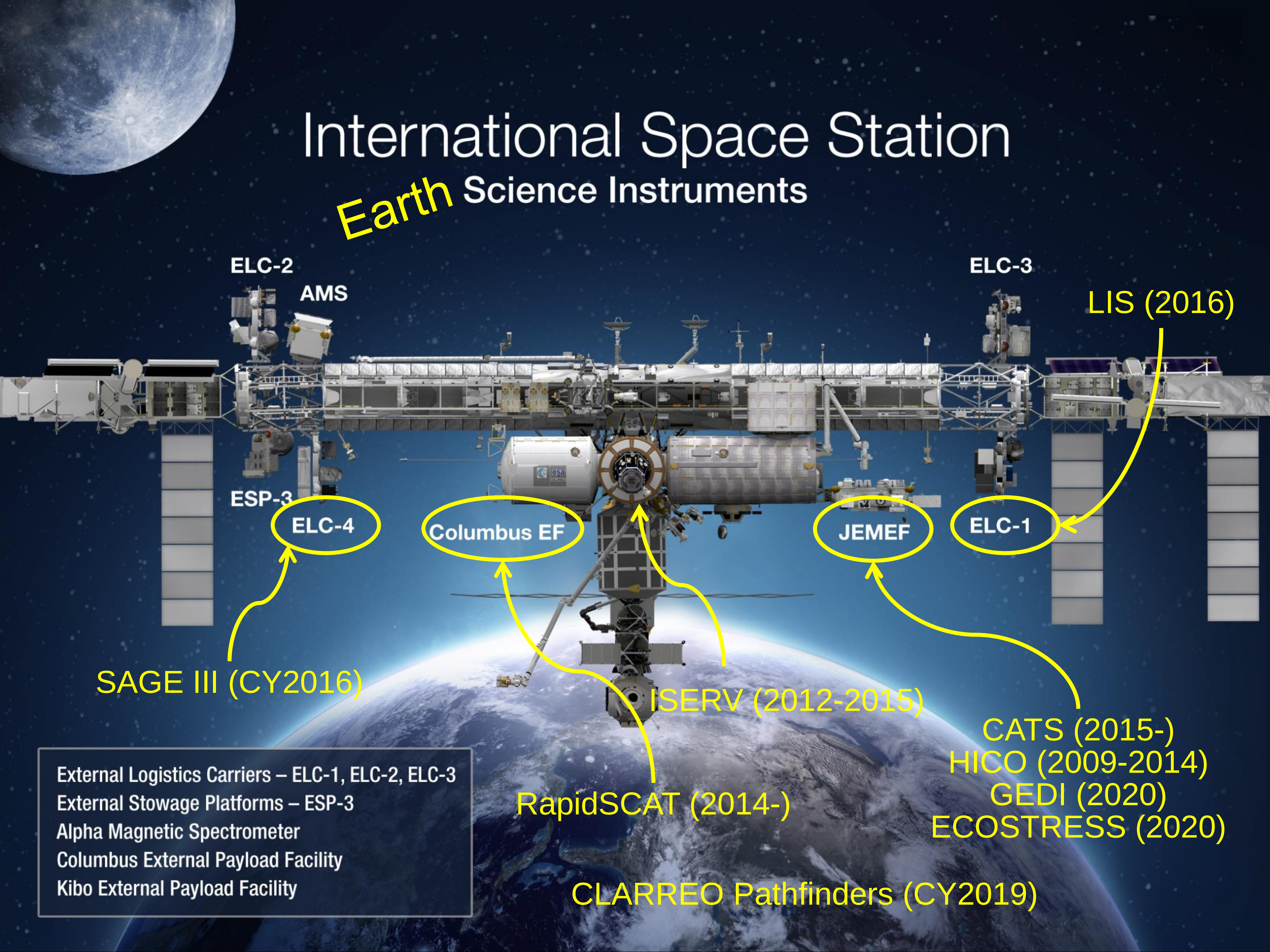
- Soil Moisture Active/Passive (Soil Moisture and Freeze-Thaw state)
  - Launched 31 January 2015
  - First systematic Tier-1 Decadal Survey mission to be launched
  - Active Radar has not operated since 7 July 2015; diagnostic activities continue
  - Satellite bus, rotating 6m antenna, and microwave radiometer are functioning well, science mode operations continue

ED 2015 Senior Review Mission Set

Prime
Extension
Phase F

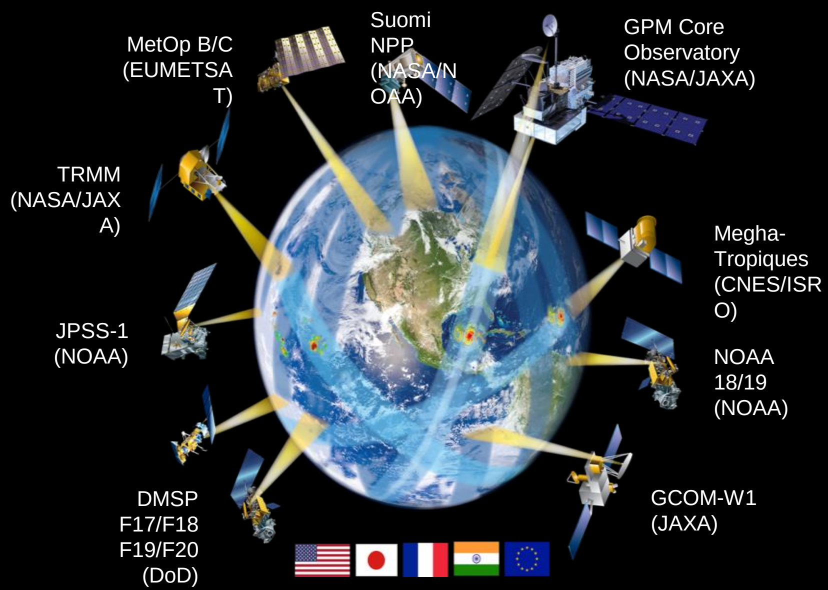


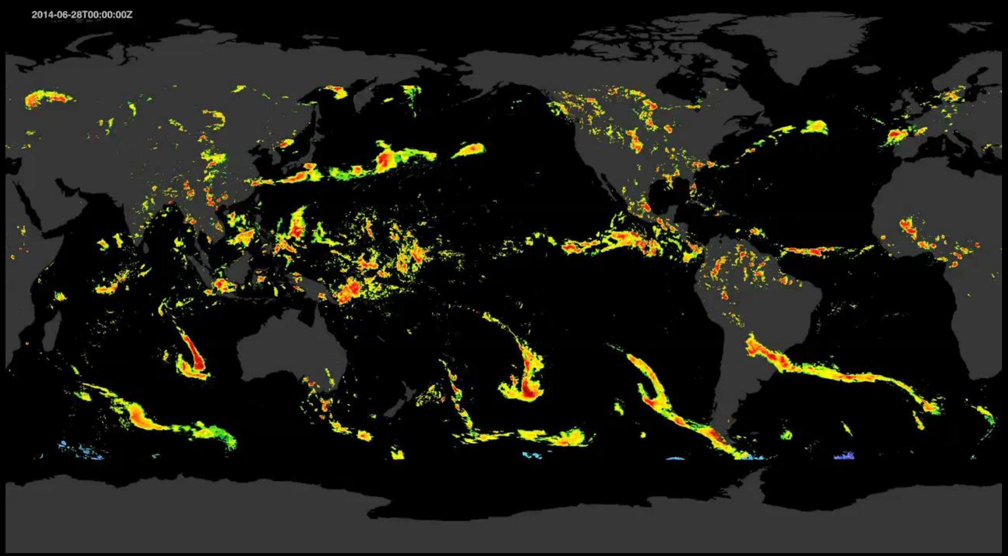

OCO-2
7/2014
SAGE-III
(on ISS)
mid-CY2016
JPSS-2 (NOAA)
Grace-FO
Aug 2017
RBI
OMPS-Limb
TSIS-1
TSIS-2 ISS
Sentinel-6/
Jason-CS (2020)
RapidSCAT, CATS
(on ISS) CY2014/15
LIS, OCO-3
(on ISS) 2016, 2018
L9 (2021-2023)
Initiated in 2015
CLARREO*
2019 for
Pathfinders/ISS
NI-SAR
2021
EVI-3
2022
GEDI/ISS
ECOSTRESS/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

Global Precipitation Measurement Mission

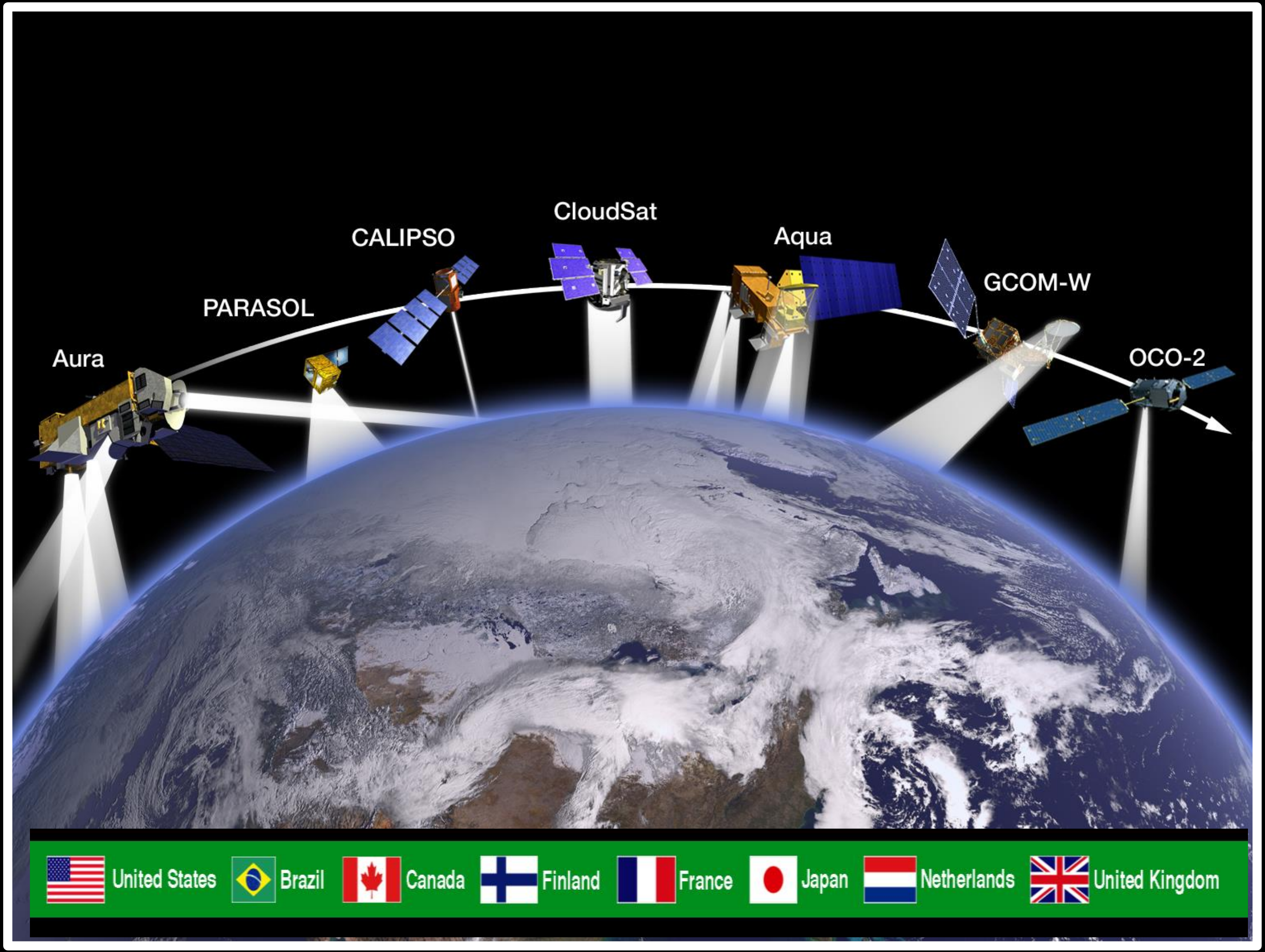
GPM Constellation Status





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

International A-Train



Formation flying and data exchange allow creation of "virtual observatories" with greater capability than any single satellite

Venture Class Selections/Solicitations

			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

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, ECOSTRESS (2019, 2018 Inst. Del.)
EVS-2: AtoM, NAAMS, OMG, ORACLES, ACT-America

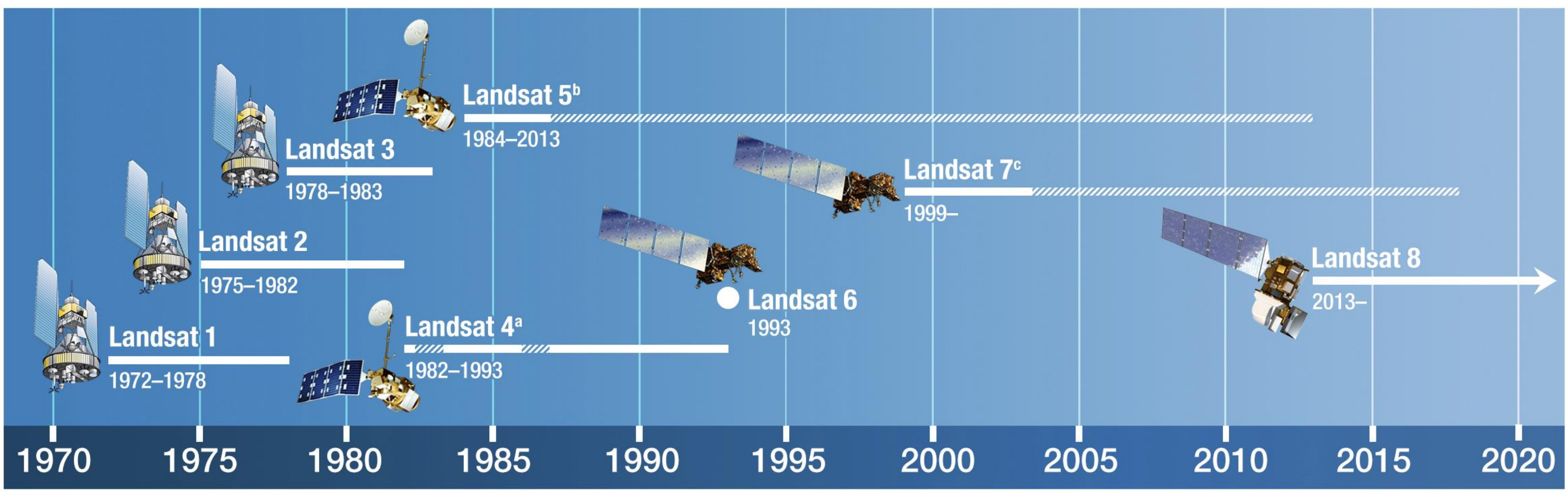
Open solicitation

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 products finalized 9 July 2015
  - 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
- Earth Radiation Balance (RBI instrument)
  - RBI being developed by NASA for flight on JPSS-2 (~April 2019 instrument delivery date)
  - Stop Work/Cure notice in effect at contractor

Sustainable Land Imaging 2016 - 2035

FY14, FY15 President's NASA budgets called for design and initiation of an affordable, ***sustained,*** Land Imaging Satellite System (with USGS) to extend the Landsat data record for decades – not just the "next mission"



[a]Limited data due to transmitter failure soon after launch. Only 45,172 Landsat 4 Thematic Mapper scenes from 1982–1993 available for science users—~10 scenes/day (vs 725 scenes/day from L8)

[b]Data coverage limited to Continental US (CONUS) and International Ground Station sites after a transmitter failure in 1987; Multispectral Scanner turned off in August 1995

[c]Degraded Performance due to Scan Line Corrector failure in May 2003

Landsat On-Orbit Status

- Landsat 7
  - Launched in 1999
  - Scan Line Corrector instrument hardware failure in 2003 resulted in a loss of 22% of each Landsat 7 scene
  - Collecting ~475 scenes per day; ~22% of pixels missing per scene (faulty scan-line corrector)
  - L7 collection strategy modified to concentrate on continental coverage (L8 capturing islands and reefs)
  - Expected to be decommissioned in 2020 (potential extension by an additional 24 months beyond 2020 if science is still valuable from data acquired earlier than 0930 MLT)
- Landsat 8
  - Launched in February 2013
  - Operational Land Imager (OLI; the 30m resolution, multi-spectral instrument) operating superbly
  - Thermal Infrared Sensor (TIRS) experiencing a stray light problem in one of two channels; also now operating on redundant hardware
  - Currently collecting 725 scenes/day (exceeding the requirement of 400 scenes/day)
  - Fuel could last ~20 years based on operational consumption to date

Sentinel-2 – European Multi-Spectral Land Imaging

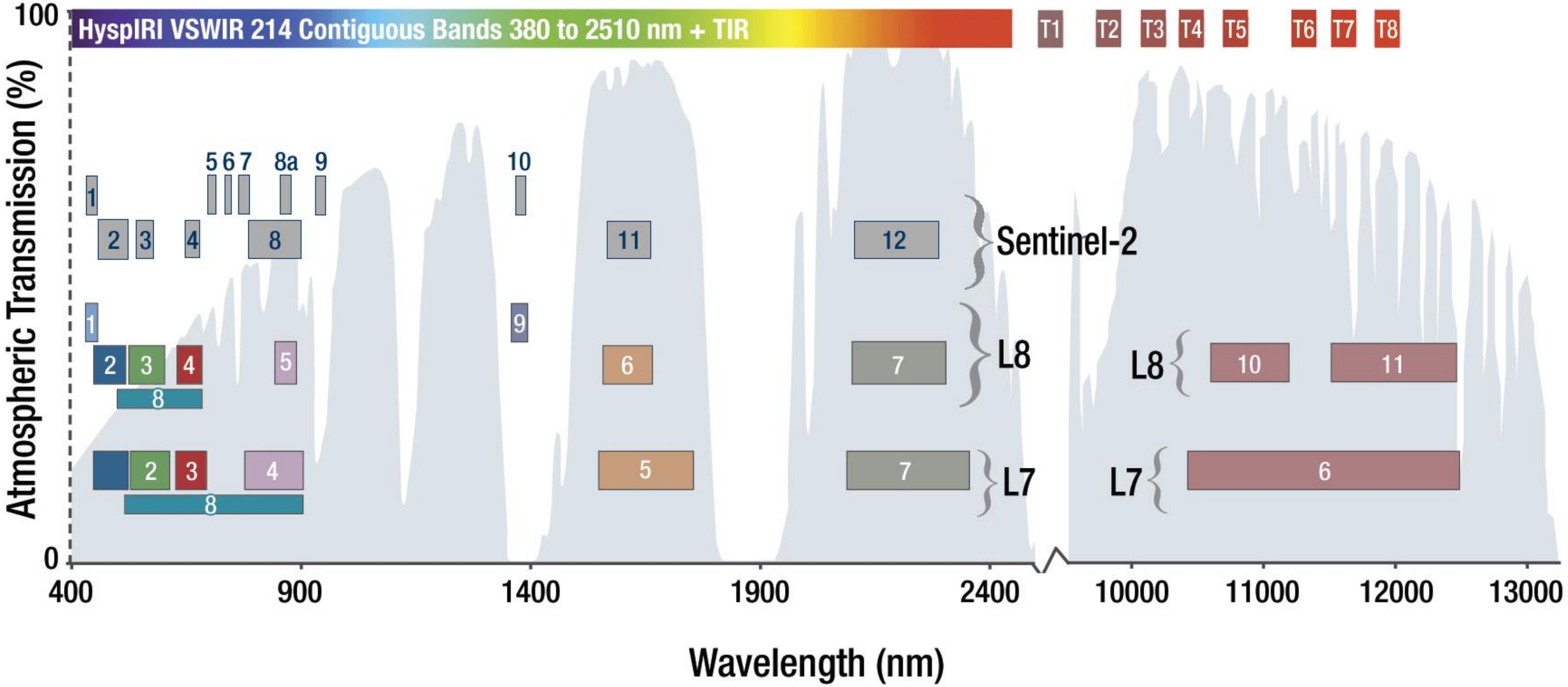
- Sentinel-2A launched successfully 23 June 2015
  - 13 spectral bands (Landsat-8 bands plus…) – ***NO THERMAL INFRARED***
  - 10 m resolution, 280 km swath – 10-day, single-satellite repeat
  - First imagery and processed products received 27 June 2015
  - Sentinel-2B on schedule for mid-2016 launch – 5-day system repeat

Northwest Sardinia

So. France, No. Italy

- Open data availability agreement w/EU agreed: NASA, NOAA, USGS; State Dept. signs
- NASA has solicited and selected research investigations for multi-system data fusion products

Land Imaging Sensor Spectral Ranges/Bands



Sentinel-2 and other planned international missions do not acquire Thermal IR measurements

SLI in FY16 President's Budget Submit

- A 3+1 part program to ensure a world class, sustainable, and responsible land imaging program through 2035:

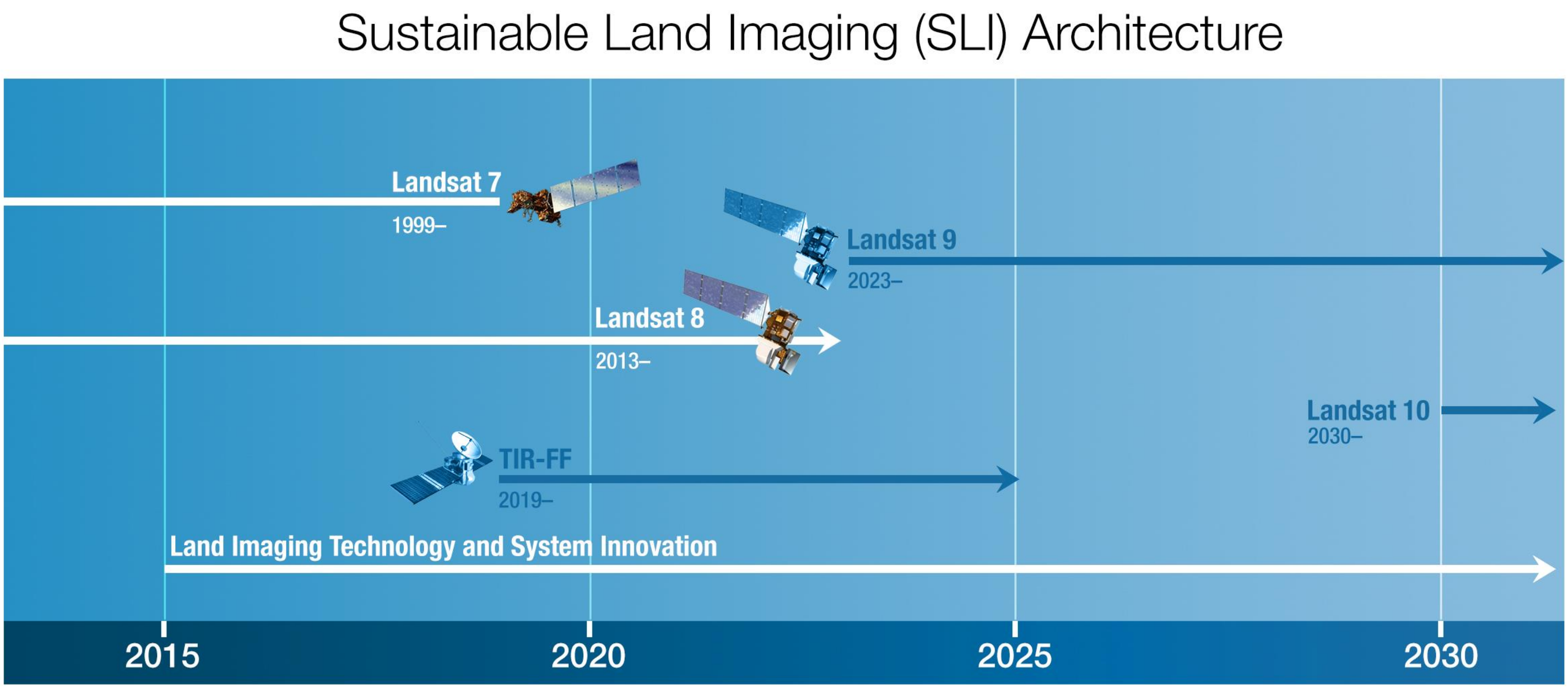
1. **Class D Thermal Infrared Free Flyer** (TIR-FF) to launch ASAP (NLT 2019) and to fly in constellation with a reflective band imager
   - Low cost mitigation against an early loss of the Landsat 8 Class C TIRS, while demonstrating feasibility of constellation flying

2. **Landsat 9** (fully Class-B rebuild of Landsat 8) to launch NLT 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**, Class B full spectrum, to launch ~2030
   - Mission architecture to be informed by the technology investments (2015-), leading to definition ~2020

Landsat Future – FY16 Budget Submit



SLI: Congressional Action/Status

- FY15 ***Appropriation*** allocated $64.1M for initiation of Landsat-9
  - Called for Landsat-9 as a lower cost Landsat-8 “copy,” 2020 launch date
  - “*The* [Conference] *does not concur with various administration efforts to develop alternative ‘‘out of the box’’ approaches to this data collection — whether they are dependent on commercial or international partners.*”

- NASA request to initiate both TIR-FF (2019 LRD) and Landsat-9 (2023 LRD) in FY15, consistent with President’s FY16 budget submit, was denied by both House and Senate – directed focus on Landsat-9 (Tech. Dev. activities underway)

- FY16 Appropriations Mark-Up: House
  - Rejected President’s budget proposal to develop TIR-FF beginning in FY16
  - $32.9M in FY16 (added to significant carryover from FY15) for L-9 development for launch in **2023**

- FY16 Appropriations Mark-Up: Senate
  - Rejected President’s budget proposal to develop TIR-FF beginning in FY16, directs no launch of TIR-FF prior to launch of Landsat-9
  - $100M in FY16 (added to significant carryover from FY15) for L-9 development for launch in **2020**

SLI: NASA Present Status, FY15

- Landsat-9 Project has been initiated with $60M in FY15 funds
  - Directed to NASA's Goddard Space Flight Center (GSFC)
  - Project Office established and substantially staffed
  - OLI Instrument procurement actions in work
  - Earliest possible launch date is 2021 – sufficient FY15 funding level

- Technology studies underway
  - Detector component development
  - Overall instrument size reduction using advanced technologies

- NASA has solicited, selected, and initiated science investigations focused on construction of multi-system fusion data sets ("Multi-Source Land Imaging Science")
  - "…[W]e solicit for efficient use and seamless combination with Landsat, of satellite sensor data from international Landsat-type moderate resolution (~30 m ground resolution), multispectral sources on continental to global scales. A primary focus is on developing algorithms and prototyping products for combined use of data from Landsat and Sentinel-2 toward global land monitoring. However, we also welcome proposals combining Landsat with other sources of moderate resolution data, such as IRS and/or CBERS…"
  - 7 investigations selected
  - $1.3M/year total, 3-year studies

DSCOVR EPIC First-Light Release – 20 July

Tweets | Tweets & replies | Photos & videos

President Obama @POTUS · 2m

Just got this new blue marble photo from @NASA. A beautiful reminder that we need to protect the only planet we have.

872 · 1.3K · View photo

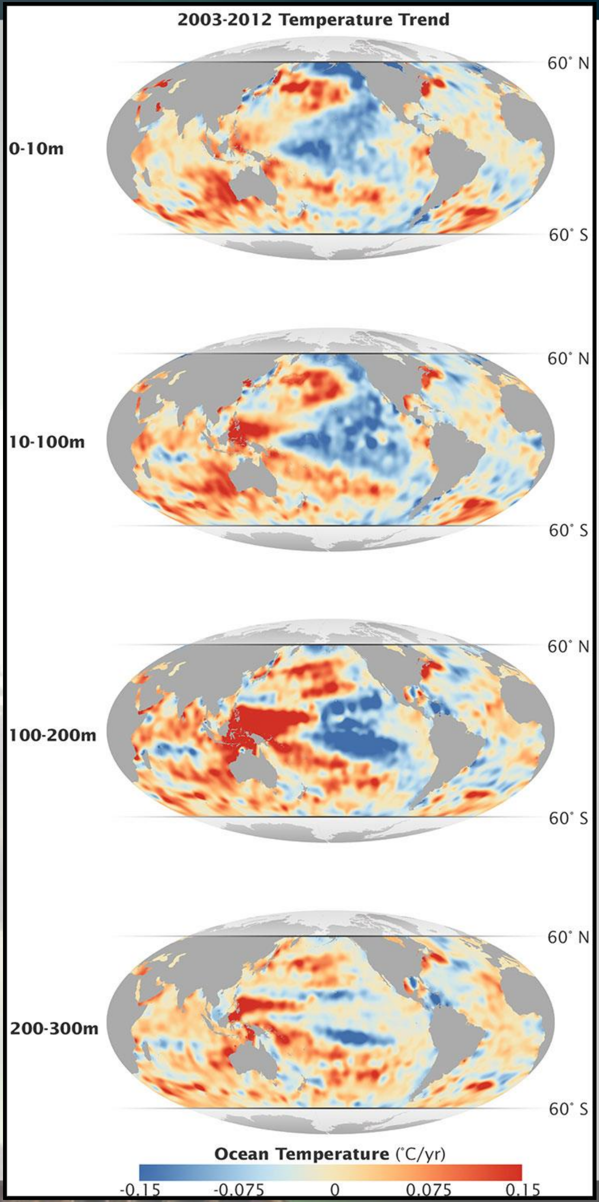
DSCOVR EPIC First-Light Release – 20 July

Recent hiatus caused by decadal shift in Indo-Pacific heating

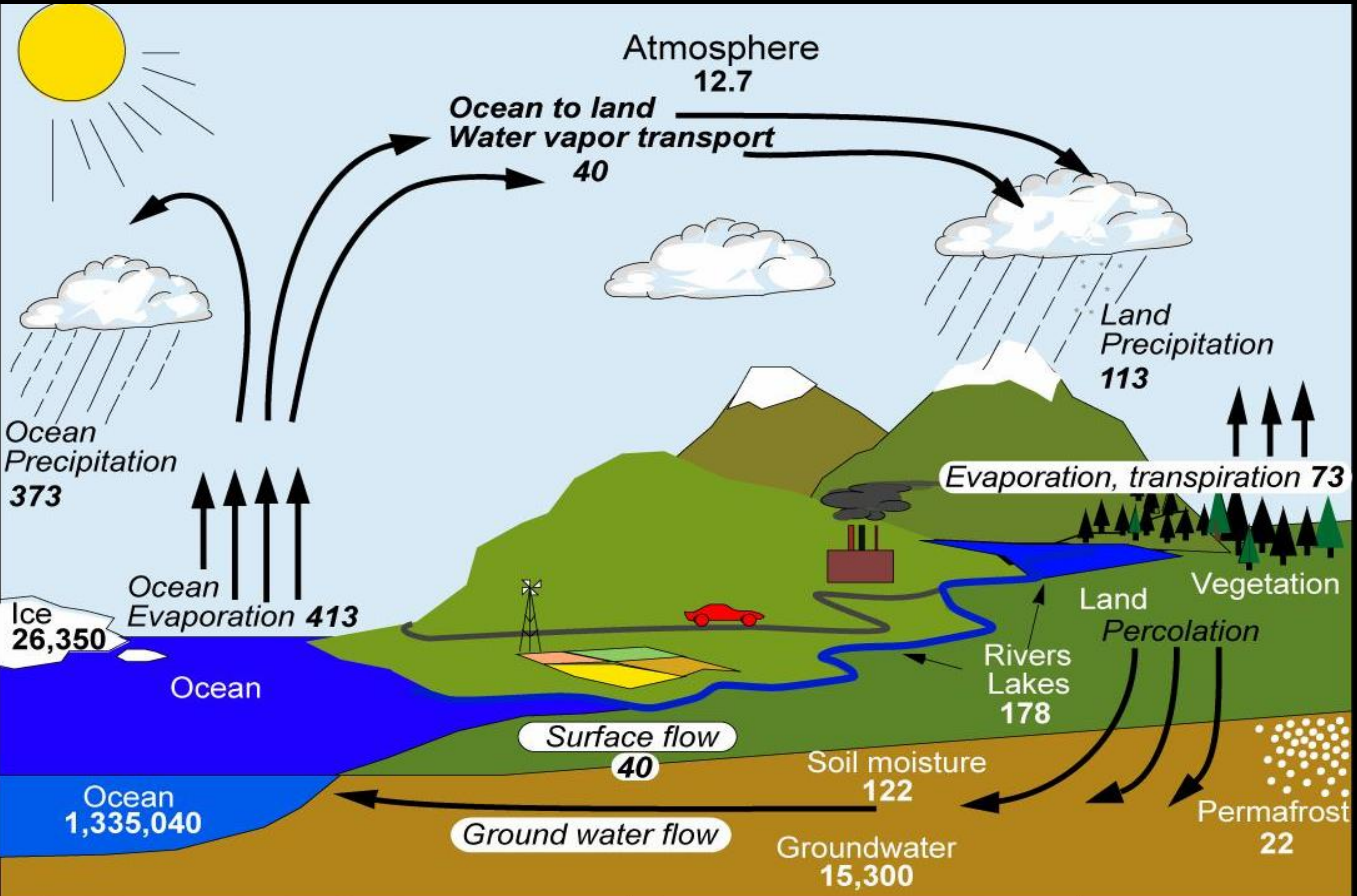
Veronica Nieves, Josh K. Willis, and William C. Patzert | Science | JULY 2015 | doi: 10.1126/science.aaa4521

A new NASA study finds that cooling in the top 100 m layer of the Pacific Ocean was mainly compensated by warming in the 100 to 300 m layer of the Indian and Pacific Oceans in the last decade since 2003. Recent modeling studies have proposed different scenarios to explain the slowdown in surface temperature in the most recent decade. This study's examination of observational data over the last two decades shows some significant differences compared to model results from reanalyses, and provides the most definitive explanation of how the heat was redistributed. These findings support the idea that the Indo-Pacific interaction in the upper-level water (0-300 m depth) regulated global surface temperature over the past two decades and can fully account for the recently observed hiatus. Furthermore, as previously shown for interannual fluctuations, the decade long hiatus that began in 2003 is the result of a redistribution of heat within the ocean, rather than a change in the net warming rate.

Left: An Argo float, foreground. The new study included direct measurements of ocean temperatures from the global array of 3,500 Argo floats and other sensors.
Right: Temperature trend data from the global ocean (2003-2012) at four depths shows the most rapidly warming water at depths of about 330-660 feet (100-200m) in the western Pacific and Indian Oceans.



Hydrologic Cycle – "Schematic"



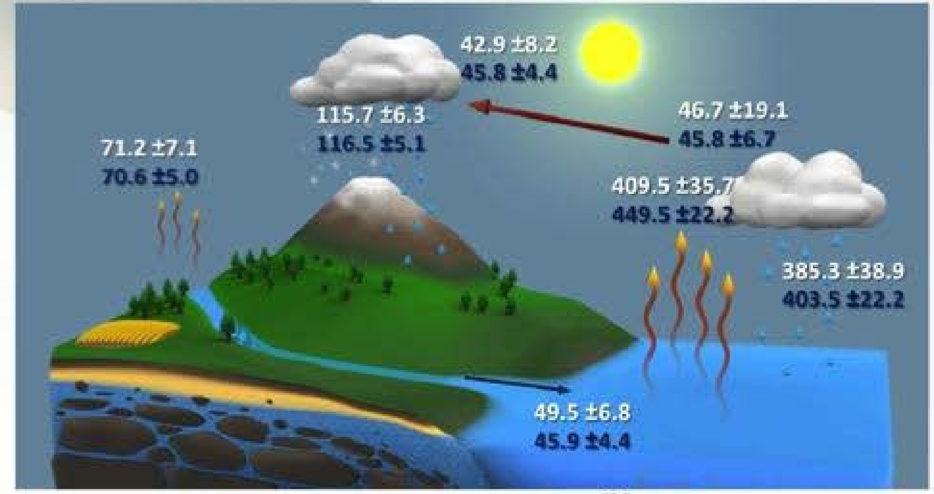
Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

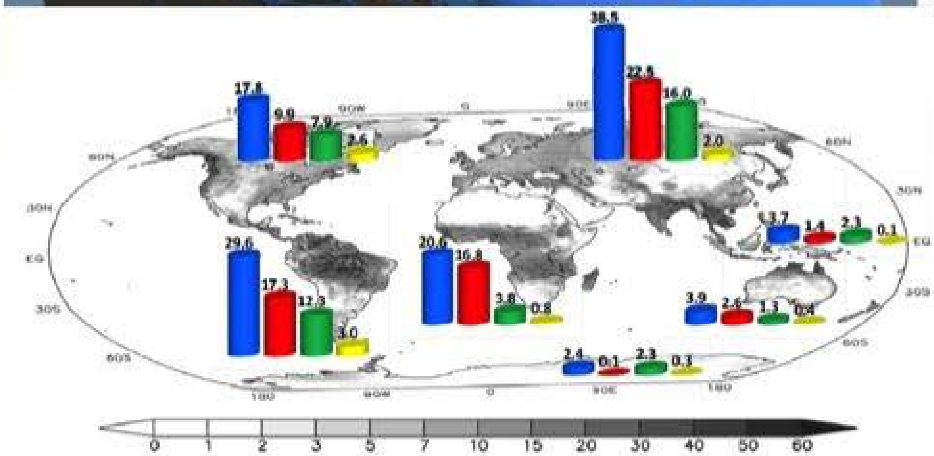
The Observed State of the Water Cycle in the Early 21st Century

M. Rodell, H.K. Beaudoing, T.S. L'Ecuyer, W.S. Olson, J.S. Famiglietti, P.R. Houser, R. Adler, M.G. Bosilovich, C.A. Clayson, D. Chambers, E. Clark, E.J. Fetzer, X. Gao, G. Gu, K. Hilburn, G.J. Huffman, D.P. Lettenmaier, W.T. Liu, F.R. Robertson, C.A. Schlosser, J. Sheffield, and E.F. Wood | Journal of Climate | JULY 2015 | doi: 10.1175/JCLI-D-14-00555.1x

A new NASA study quantifies mean annual and monthly fluxes of Earth's water cycle over continents and ocean basins during the first decade of the millennium. The researchers combined data from 10 sources that made use of observations from more than 25 satellites to describe different aspects of the water cycle: precipitation and evaporation over land and oceans, atmospheric water vapor and its movement, river runoff, and water storage including groundwater, soil moisture, and snowpack. To the extent possible, the flux estimates are based on satellite measurements first and data-integrating models second. A careful accounting of uncertainty in the estimates is included. It is applied within a routine that enforces multiple water and energy budget constraints simultaneously in a variational framework, in order to produce objectively-determined, optimized flux estimates. In the majority of cases, the observed annual, surface and atmospheric water budgets over the continents and oceans close with much less than 10% residual.

A robust, global inventory of current hydrologic flux rates is essential to the assessment and prediction of climate change. This study attempts to quantify the current state of the water and energy cycles, which is an important first step towards the NASA Energy and Water Cycle Study (NEWS) program goal of evaluating water and energy cycle consequences of climate change.





Top Right: Mean annual fluxes (1,000 km³/yr) of the global water cycle, and associated uncertainties, during the first decade of the millennium. White numbers are based on observational products and data integrating models. Blue numbers are estimates that have been optimized by forcing water and energy budget closure and taking into account uncertainty in the original estimates. ***Bottom Right:*** Optimized annual mean fluxes for North America (including Greenland), South America, Africa, Eurasia, the Islands of Australasia and Indonesia, mainland Australia, and Antarctica: precipitation (blue), evapotranspiration (red), runoff (green), and annual amplitude of terrestrial water storage (yellow), in 1,000 km³/yr. The background image shows GRACE-based amplitude (maximum minus minimum) of the annual cycle of terrestrial water storage (cm).