National Aeronautics and Space Administration

Earth Science

Accomplishments and Plans, Challenges and Opportunities

M. H. Freilich

29 October 2013

LDCM First-Light
OLI False-Color
Fort Collins area

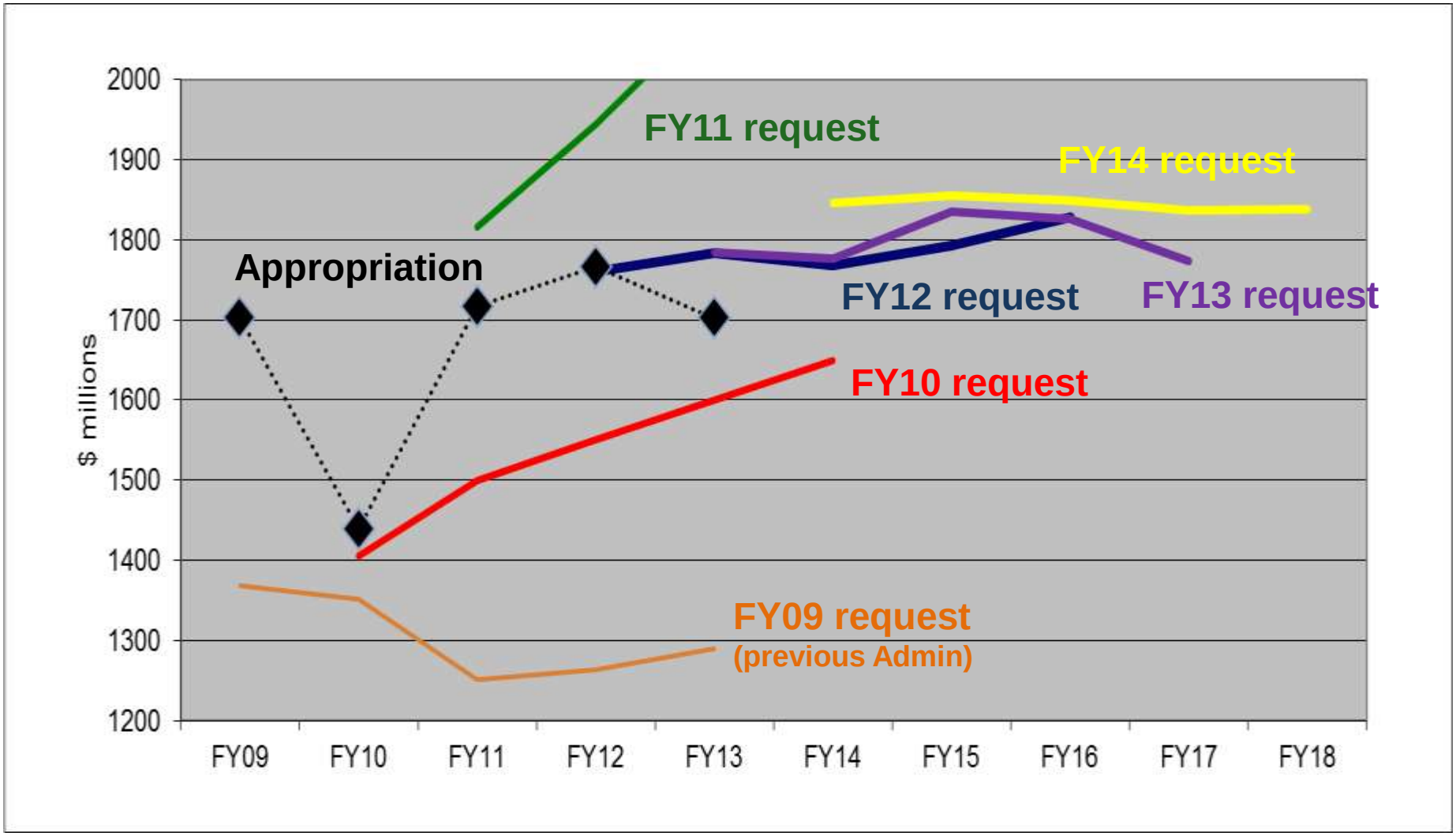
OUTLINE

- Brief Budget Overview
- On-orbit constellation overview
- Upcoming Launches – mission development
- Venture Class status/plans/schedule
- Airborne Program highlights
- SI-OP-ERB (ex-NOAA sustained measurements)
- Sustained Land Imaging
- [[Next Earth Decadal Survey]]

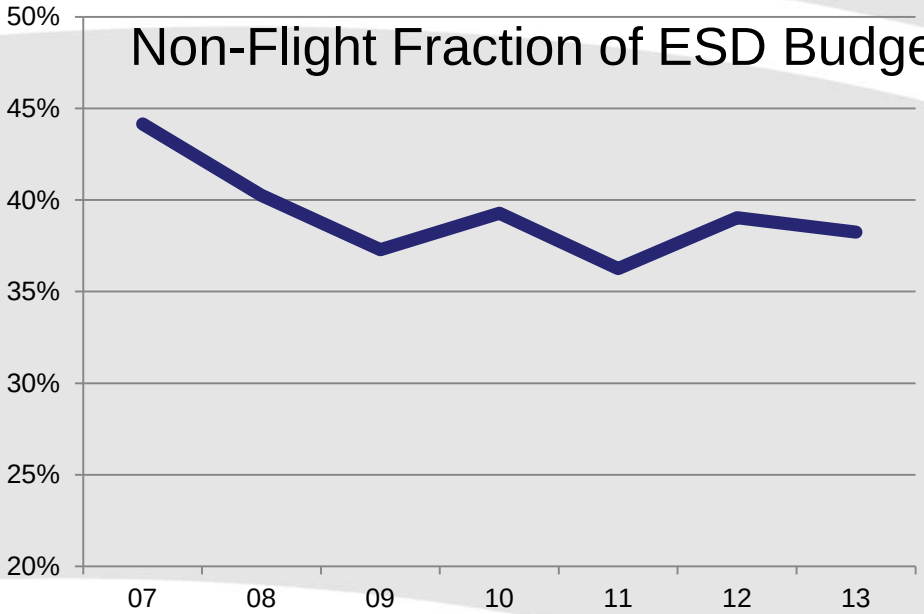
Overall NASA ESD Strategy/Scope

- Provide an executable, balanced, program that:
  - advances Earth System Science and 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
- Support Flight, Research, Applied Sciences, Technology Development**,** and E/PO elements
- Operate and provide core data products for on-orbit missions in prime and extended phases (informed by the 2013 Senior Review recommendations and mission status)
- Complete and launch GPM (2/14), OCO-2 (7/14), SMAP (11/14), and SAGE-III/ISS (3/15)
- Execute the full Venture Class program (Suborbital, Small-Mission, Instrument), including implementation and launch of CYGNSS (LRD 2017) and TEMPO (LRD 2018) and on-schedule solicitations for all 3 strands
- Continue development and launch selected top-priority Decadal Survey and Continuity missions: ICESat-2 (12/2016 [TBR]), OCO-3-ISS (2017), GRACE-FO (2017), and SWOT (2020)
- Lead NASA-USGS study and begin implementation of a multi-decadal, spaceborne, global Sustained Land Imaging system to follow Landsat-8, executable within Administration-defined cost constraints
- Develop and implement plans for measurements of solar irradiance, ozone profiles, and Earth radiation budget (“SI-OP-ERB”; ex-NOAA “Climate Sensors”) in the JPSS-2 (~2021) timeframe
- Provide significant support to National Climate Assessment, USGCRP, and international (CEOS) coordination activities

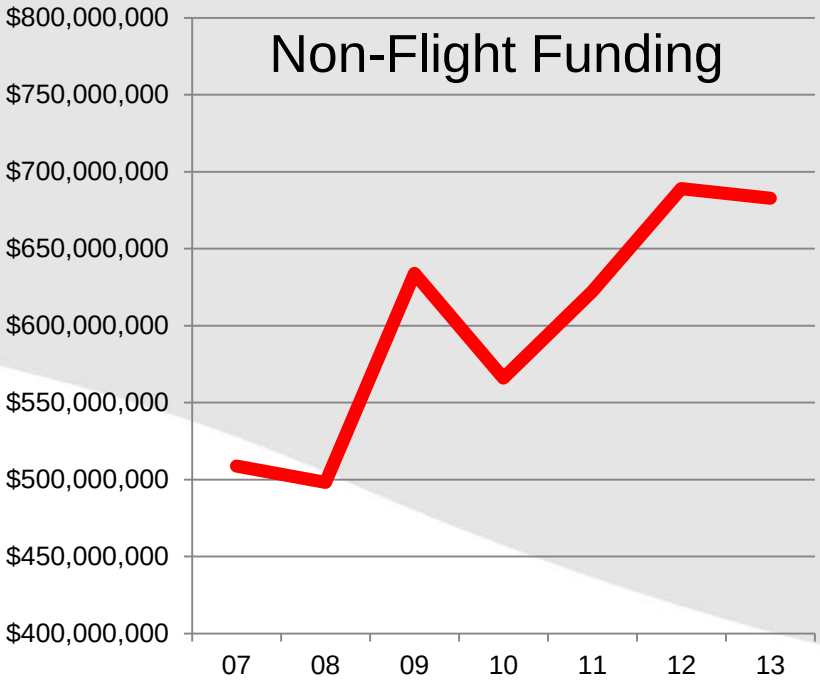
Earth Science Budget – FY14 Request



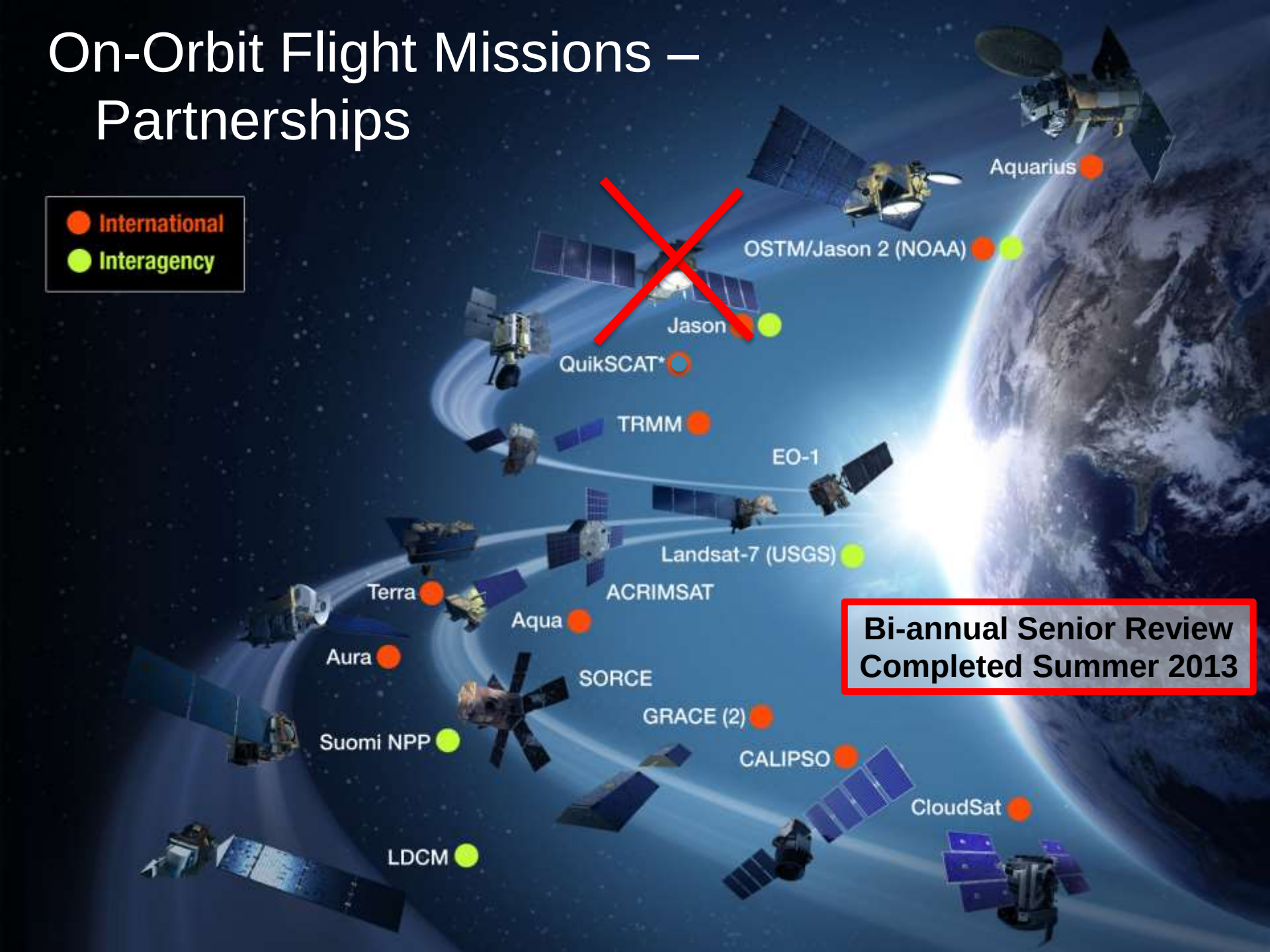
Non-Flight Budgets: 2007-2013



- R & A
- Applied Sciences
- Technology
- Competed Science Teams

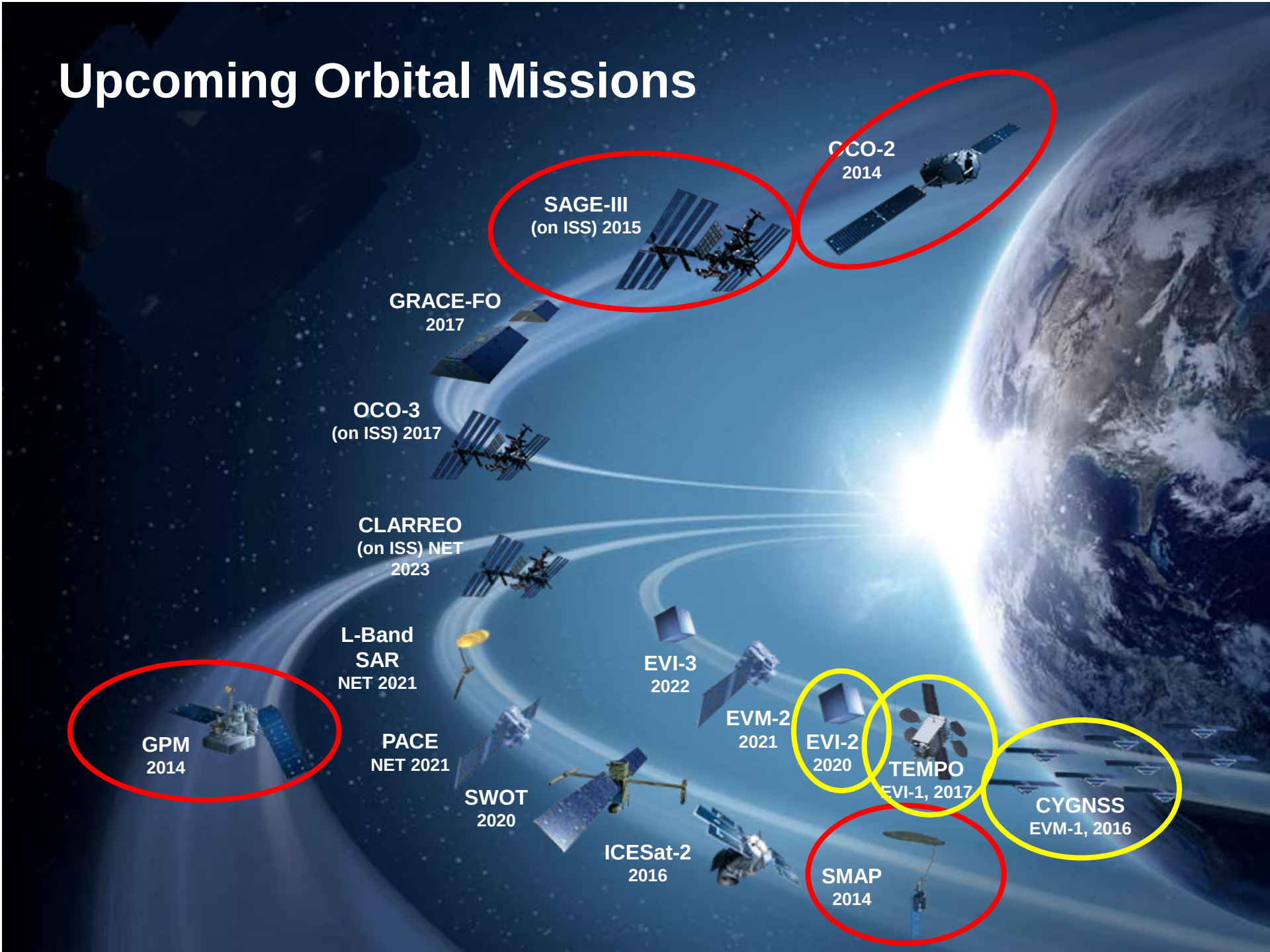


On-Orbit Flight Missions – Partnerships



Bi-annual Senior Review Completed Summer 2013

Upcoming Orbital Missions

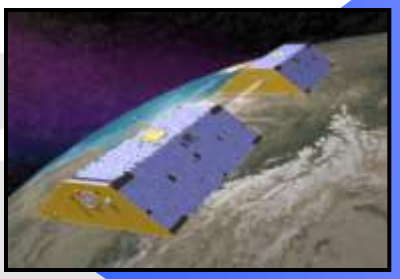


Near-Term Formulation & Development Missions

GPM
28 Feb 2014
w/ JAXA; Precip
H-IIA

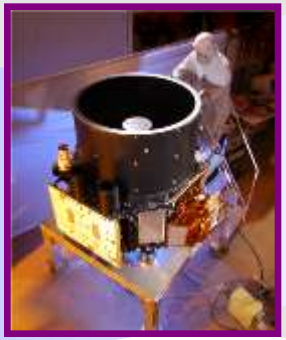
OCO-2
1 July 2014
Global CO_2
Delta II

SMAP
5 Nov 2014
w/CSA
Soil Moist., Frz/Thaw
Delta II



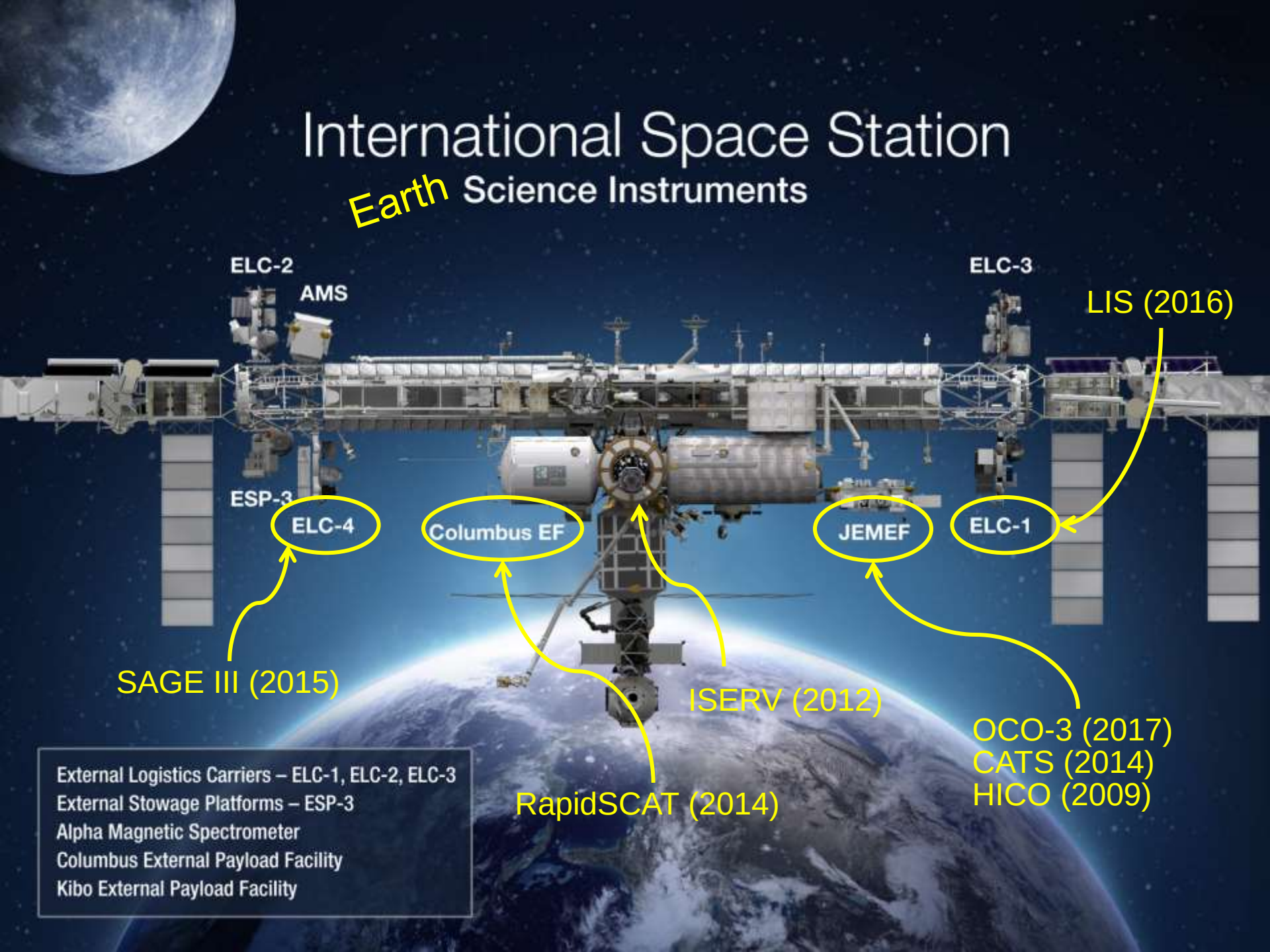
GRACE FO
Aug 2017
w/Germany; Global Mass & Water Variation
German-supplied Dnepr LV

CYGNSS
2016-2017
Tropical Cyclone Generation, Air-sea Interaction in Extreme Conditions



ICESat-2
Dec 2016 (TBR)
Ice Dynamics
Delta II

SAGE III
Mar 2015
Ozone & Trace Gases
Falcon-9


International Space Station
Earth Science Instruments
ELC-2
AMS
ELC-3
LIS (2016)
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (2015)
ISERV (2012)
OCO-3 (2017)
CATS (2014)
HICO (2009)
RapidSCAT (2014)
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

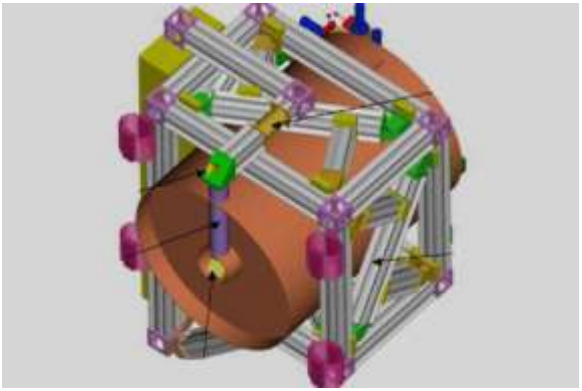
Venture-Class

- 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 UPDATE/STATUS

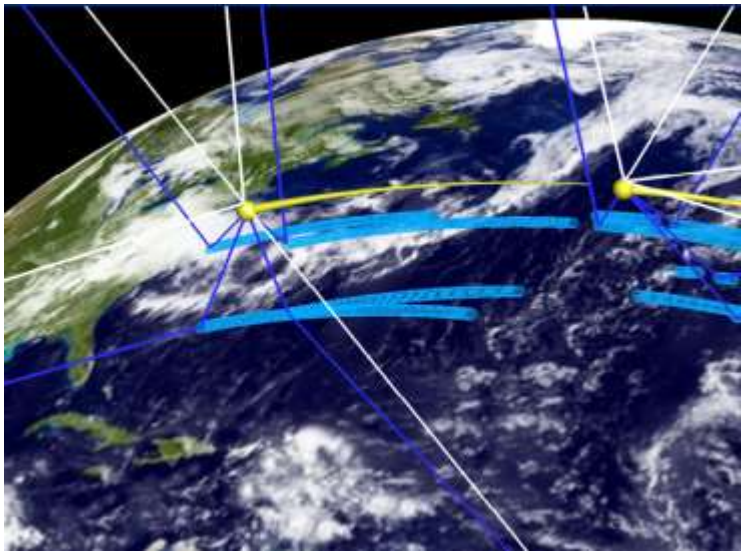
- EV-S ("EV-1" - Suborbital, Airborne; solicited every 4 years)
  - All 5 investigations have completed at least 1 sustained field campaign
  - All EV-1 investigations are flying during 2013
  - ***Second EV-S solicitation released 6/2013, proposals due 1/10/2014***

- EV-M ("EV-2" - Small-sat; solicited every 4 years)
  - **CYGNSS successful KDP-B in 7/2013, planned LRD 10/2016-4/2017**
  - **FY14 budget proposal includes EV-M/2 solicitation on-schedule in 6/2015**

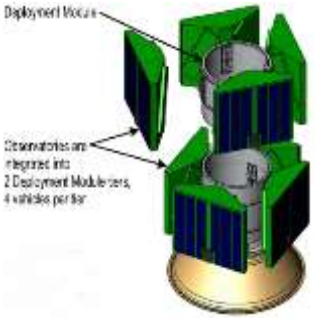
- EV-I (Instrument; solicited every 18 months)
  - **TEMPO selected for GEO hosted payload opportunity (early FY18 launch)**
  - ESD making excellent progress on formal host selection/negotiation
  - ***Second "EV-I/2" solicitation released 7/2013, proposals due 11/25/2013***
  - **FY14 budget proposal includes EV-Instrument/3 and subsequent solicitations on-schedule**

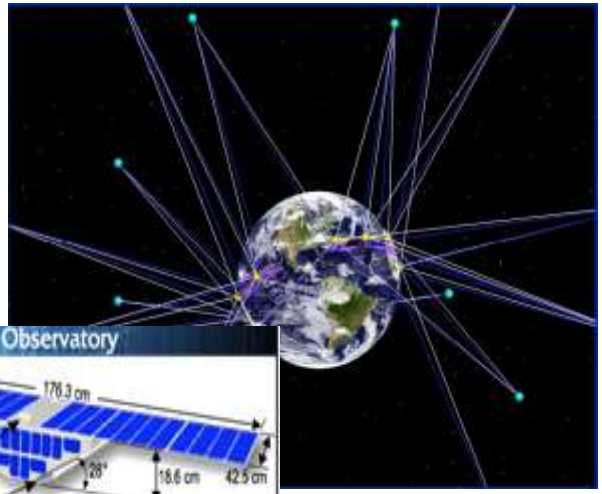
Earth Venture Mission-1 Selection
CYGNSS (CYclone Global Navigation Satellite System)

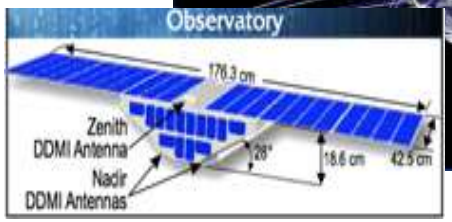
- ***CYGNSS is a pathfinder to using small satellite constellations***
- 8 microsatellite (18 kg each) dense sampling constellation
- GPS reflectometry to measure ocean surface winds in hurricane eyewalls and core in all precipitating conditions
- To improve understanding of hurricane development and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



PI: Chris Ruf, University of Michigan
Instrument Development: Surrey Satellite Technology US
Spacecraft: SwRI
Project Management: SwRI
RY$: 102.8M + NASA Provided Launch Vehicle
Orbit requirements: ***Low Earth Orbit***
35^{o} inclination, 500 km altitude

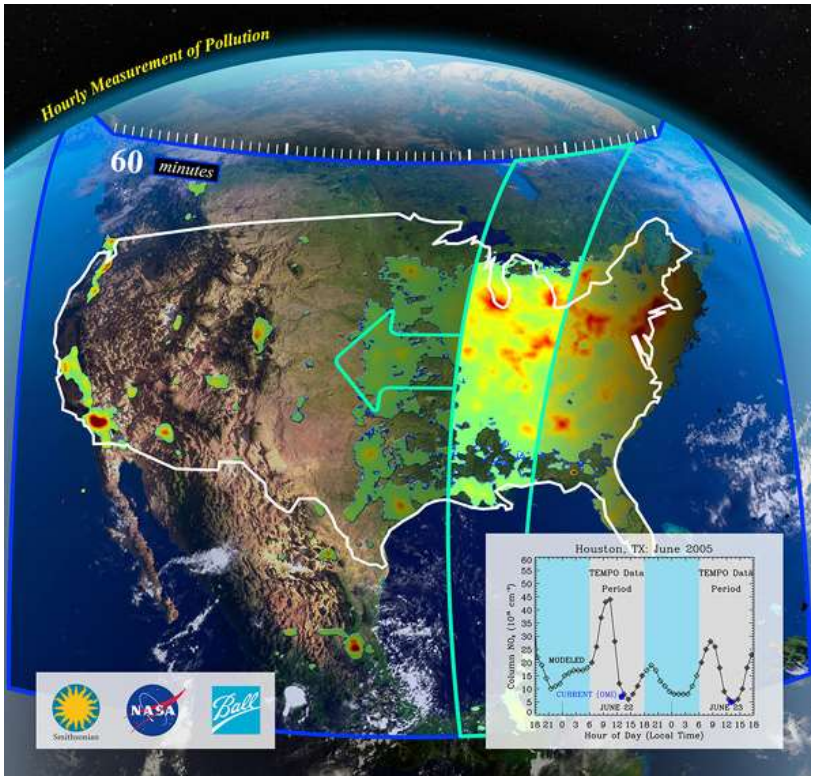






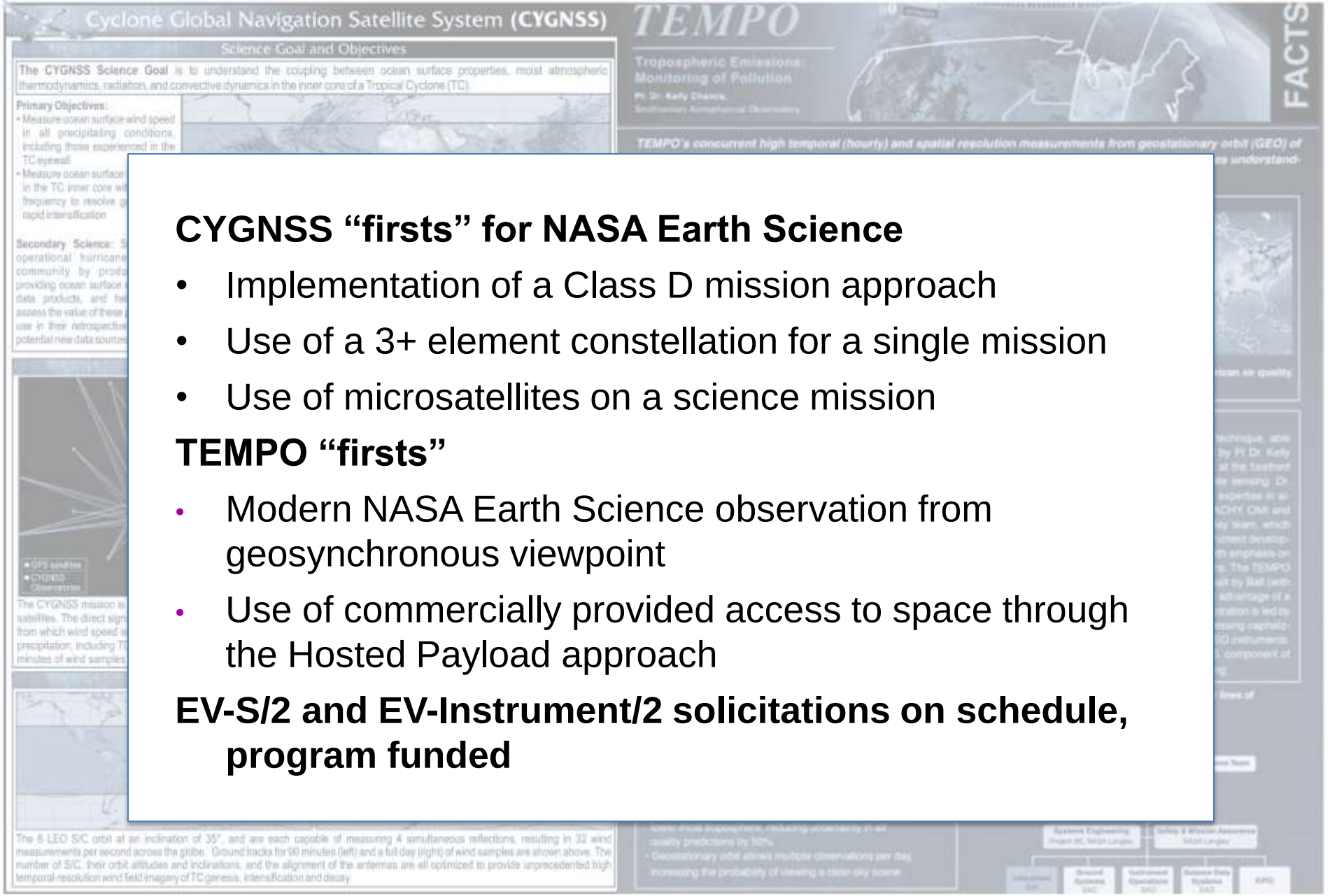
Earth Venture Instrument-1 Selection
Tropospheric Emissions: Monitoring of Pollution

- ***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
RY$: 93.2M
Orbit requirements: ***Geostationary Orbit.*** Hosted on a commercial communication satellite

Venture Class Advances



CYGNSS "firsts" for NASA Earth Science

- Implementation of a Class D mission approach
- Use of a 3+ element constellation for a single mission
- Use of microsatellites on a science mission

TEMPO "firsts"

- Modern NASA Earth Science observation from geosynchronous viewpoint
- Use of commercially provided access to space through the Hosted Payload approach

EV-S/2 and EV-Instrument/2 solicitations on schedule, program funded

ESD: FY13-16 Key Milestones

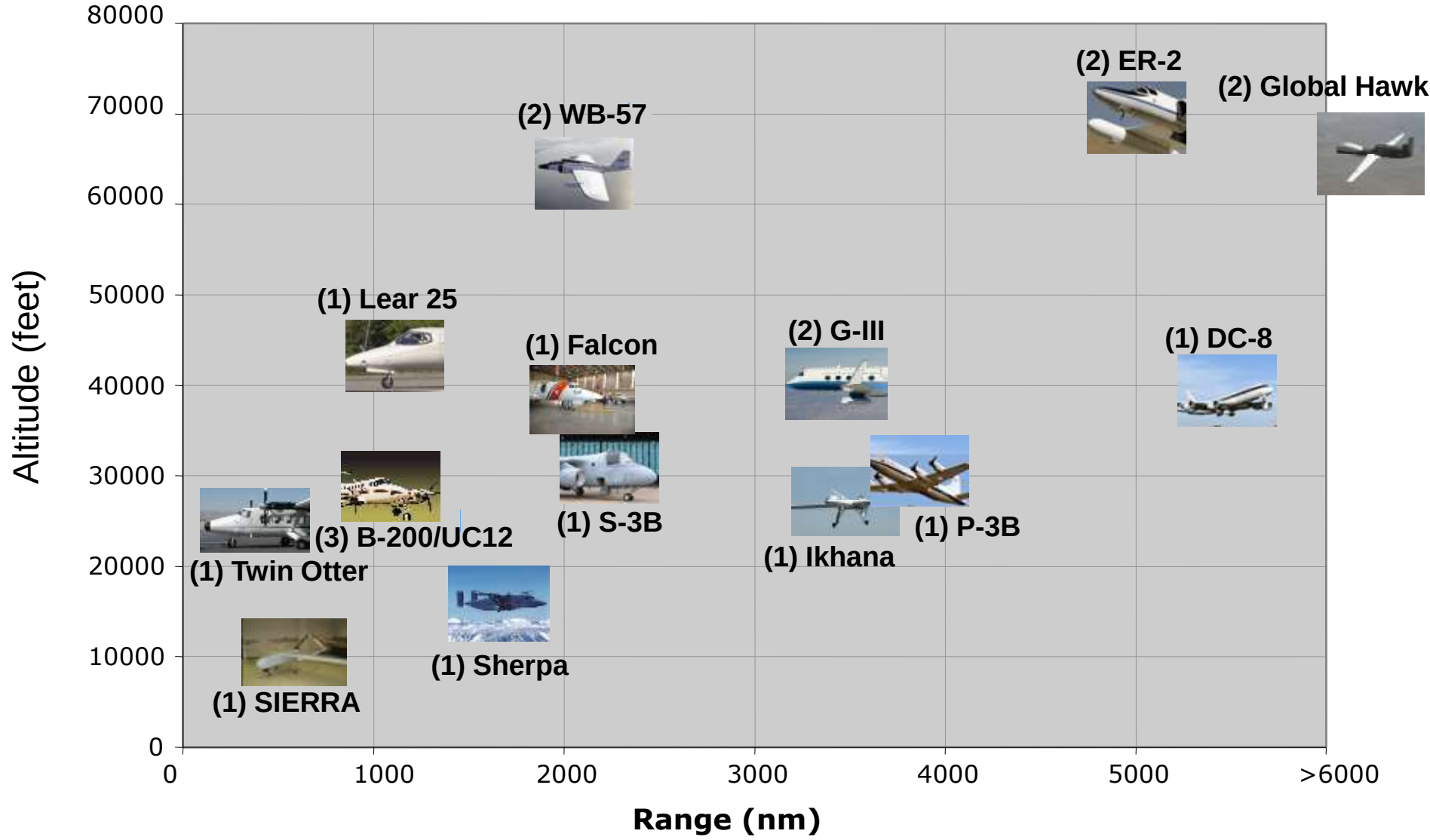
Key Decision Points

FY	Mo./Yr.	Mission	KDP	FY	Mo./Yr.	Mission	KDP
13	November 2012	SWOT	KDP-A	14	**July 2014**	**OCO-2**	**KDP-E**
		OCO-3	KDP-B	15	**October 2014**	**SMAP**	**KDP-E**
	January 2013	OCO-2	KDP-D		November 2014	TEMPO	KDP-C
	February 2013	**LDCM**	**KDP-E**		**March 2015**	**SAGE-III**	**KDP-E**
	May 2013	SMAP	KDP-D		June 2015	ICESAT-2	KDP-D
	July 2013	CYGNSS	KDP-B		July 2015	GRACE-FO	KDP-D
	August 2013	OCO-3	KDP-B	16	December 2015	OCO-3	KDP-D
14	January 2014	TEMPO	KDP-B		March 2016	SWOT	KDP-C
	February 2014	**GPM**	**KDP-E**		**June 2016**	**ICESAT-2**	**KDP-E**
		CYGNSS	KDP-C				
		GRACE-FO	KDP-C				
	May 2014	SAGE-III	KDP-D				
		SWOT	KDP-B				
		OCO-3	KDP-C				

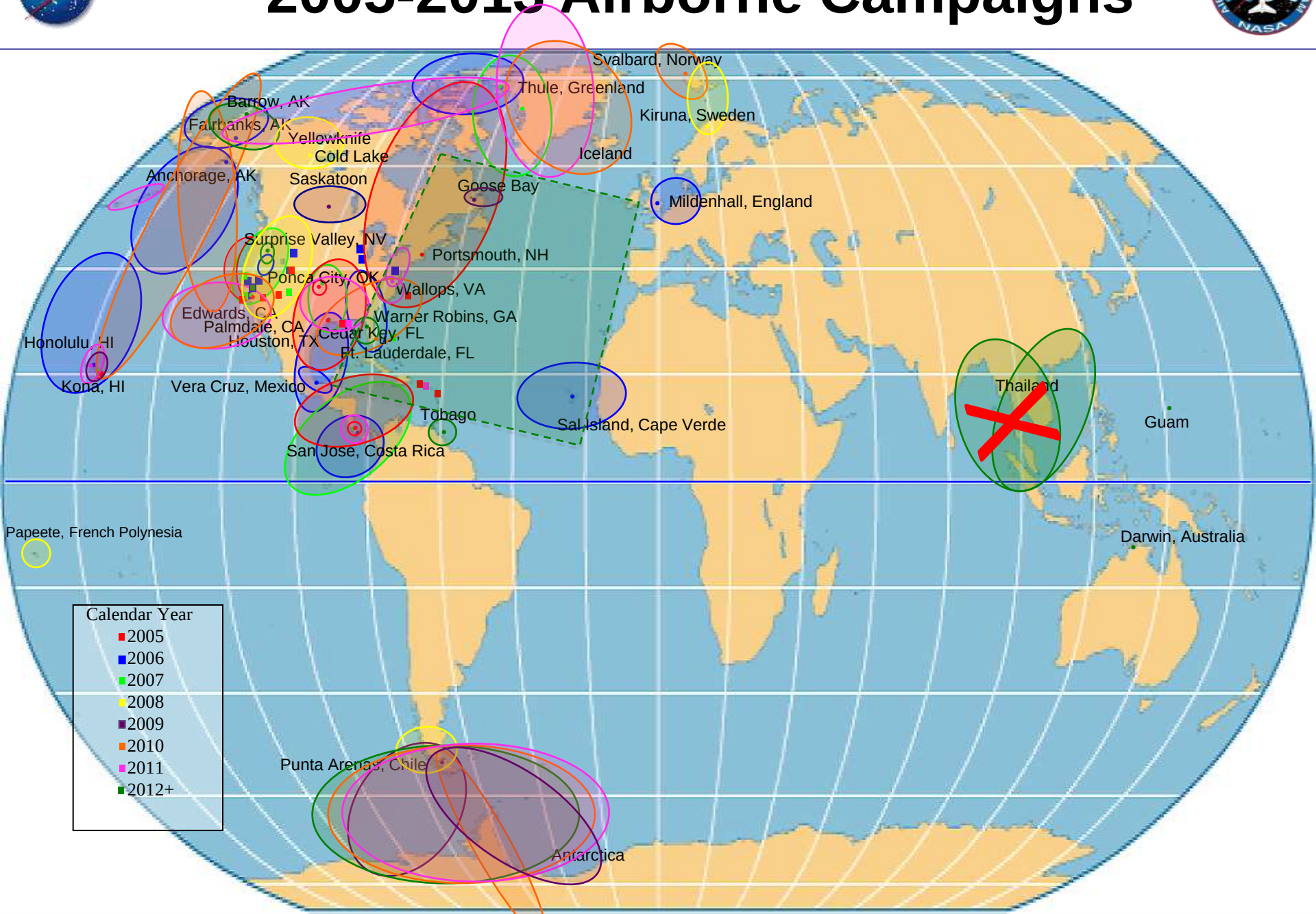
NASA ESD Launch Schedule/Status

• GPM	On Schedule for 2/15/2014 Launch
• OCO-2	On Schedule for 7/1-7/2014 Launch
• SMAP	On Schedule for 11/05/2014 Launch
• SAGE-III/ISS	On Schedule for 3/2015 Launch
• ICESAT-2	Confirmed for launch 12/2016 (TBR)
• CYGNSS (EVM)	Formulation for launch late 2016/17
• GRACE-FO	Formulation for launch 8/2017
• OCO-3/ISS	Formulation for launch 2017
• TEMPO (EVI)	Formulation for launch 2018
• SWOT	Formulation for launch 2020
• *PACE*	*Acquisition Strategy under evaluation, launch NET 2021*
• *L-Band SAR w/ISRO*	*TAA signed, launch NET 2021*

NASA Airborne Science Aircraft



2005-2013 Airborne Campaigns



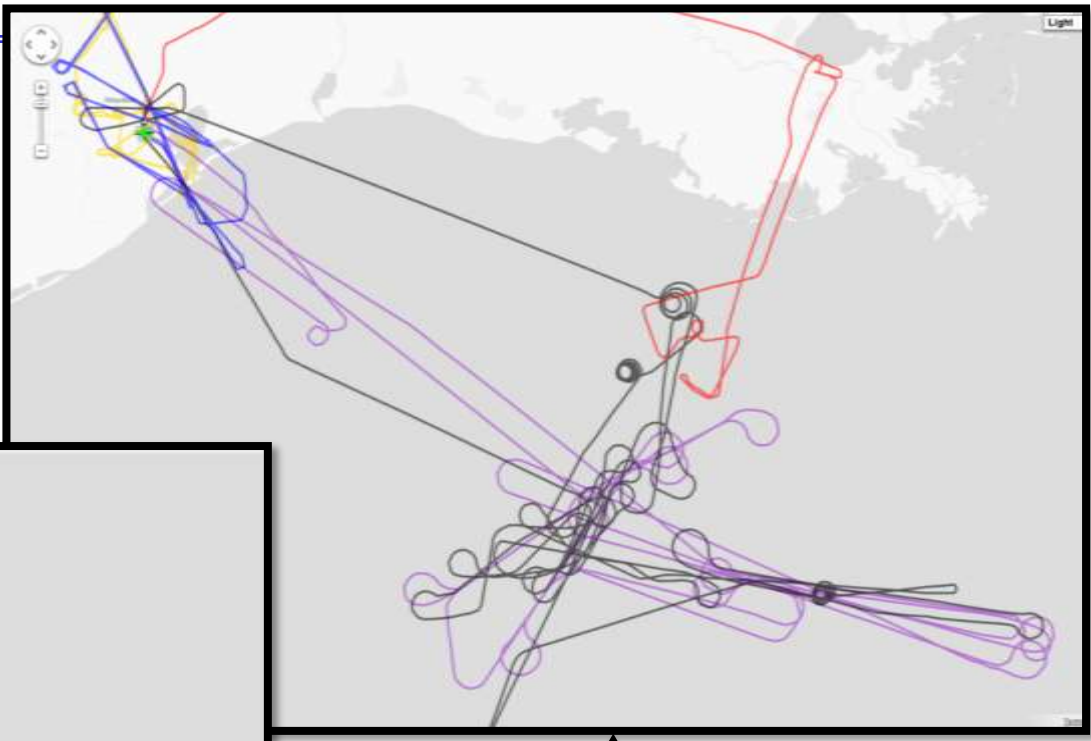
Airborne Science Program
September 4, 2013: Record Setting Day

6 NASA affiliated science aircraft flying missions at the same time

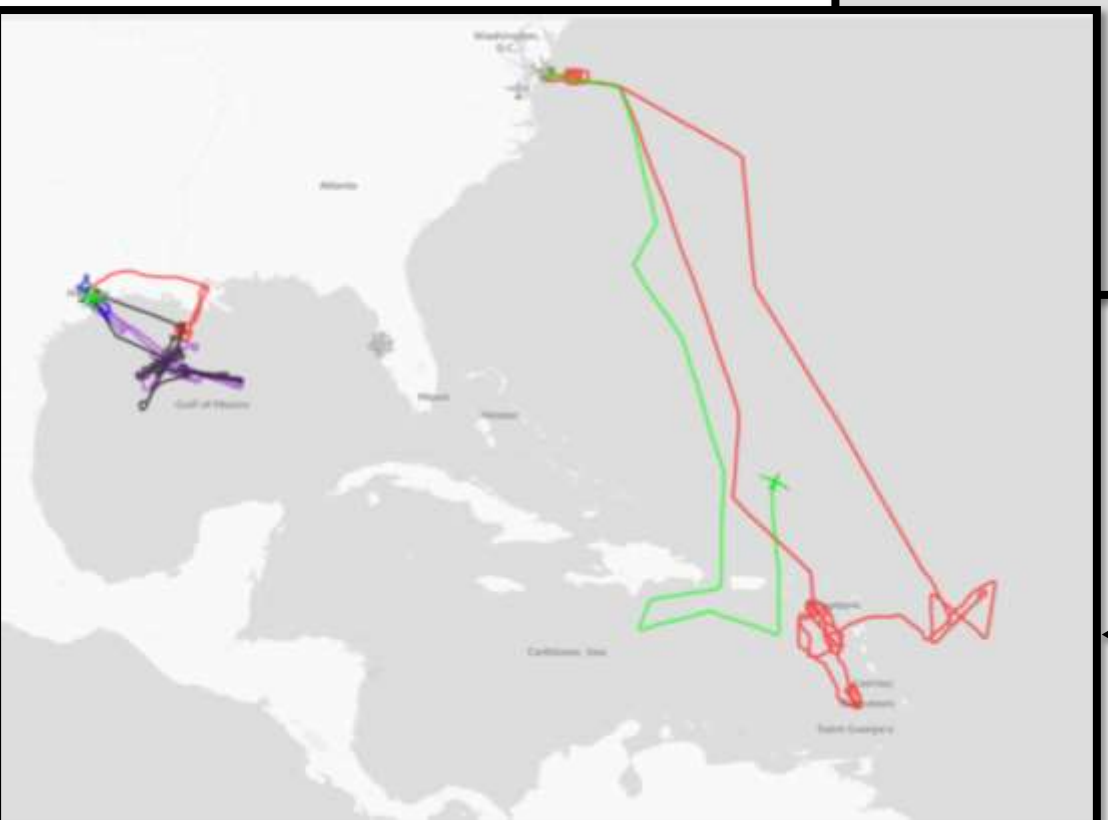
- **SEAC4RS: DC-8, ER-2 and SPEC Lear**
- **DISCOVER-AQ: P-3B and UC-12**
- **HS3: GH**

1st back-to-back GH science flights

7 science aircraft flew that day



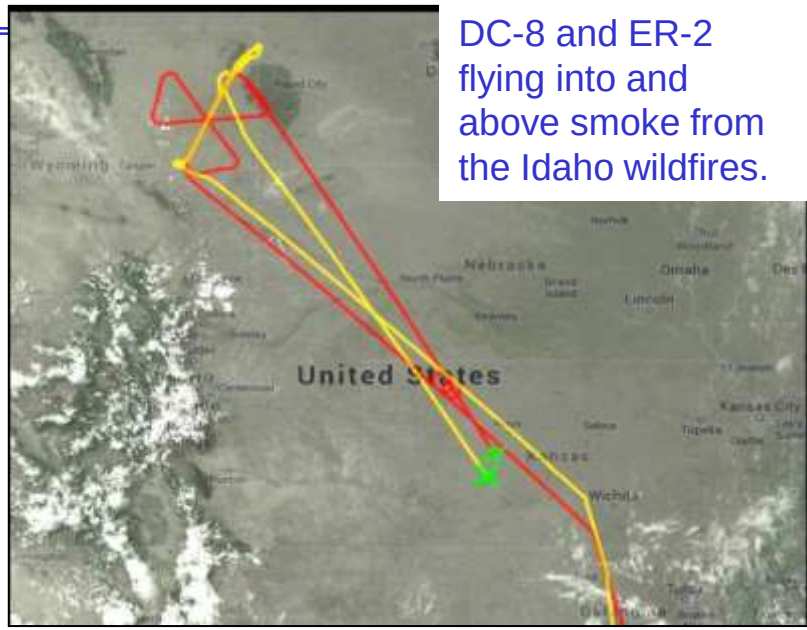
SEAC4RS and DISCOVER-AQ flight track enlargement



Sep 4th flight tracks

SEAC^{4}RS

- **Atmospheric composition and air quality mission**
- **Campaign includes DC-8, ER-2 and SPEC Lear Jet**
- **All aircraft based at JSC's Ellington Field facilities**
- **Flight activity from August 8th to October 1st**
- **360 flight hours planned and completed**
  - DC-8 & ER-2: 150 each; Lear Jet: 60
- **~190 total people deployed**
  - ~56 from ASP over mission 7 week duration
- **Coordinated flights with HS3**
  - NASA GH & WB-57, NOAA P-3 & AF C-130
- **Close collaboration with DISCOVER-AQ**
  - P-3B, UC-12 and HU-25 on ESTO IIP mission



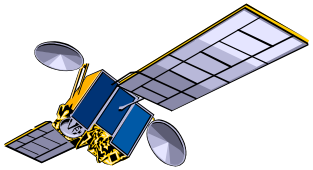
DC-8 and ER-2 flying into and above smoke from the Idaho wildfires.

The DC-8 carries 32 instruments (largest payload to date) to study trace gases, black carbon, cloud particles & formaldehyde that contribute to pollution.

ER-2 – just prior to taxi

SEAC^{4}RS Experimental Approach

Satellites/Instruments: MLS, TES, CALIPSO, CloudSat, MODIS, MISR, OMI, MOPITT, AIRS



Aircraft:
ER-2 (150 hrs & 14+ sensors), DC-8 (150 hrs & 26 sensors, Lear (60 hrs & 7 sensors)

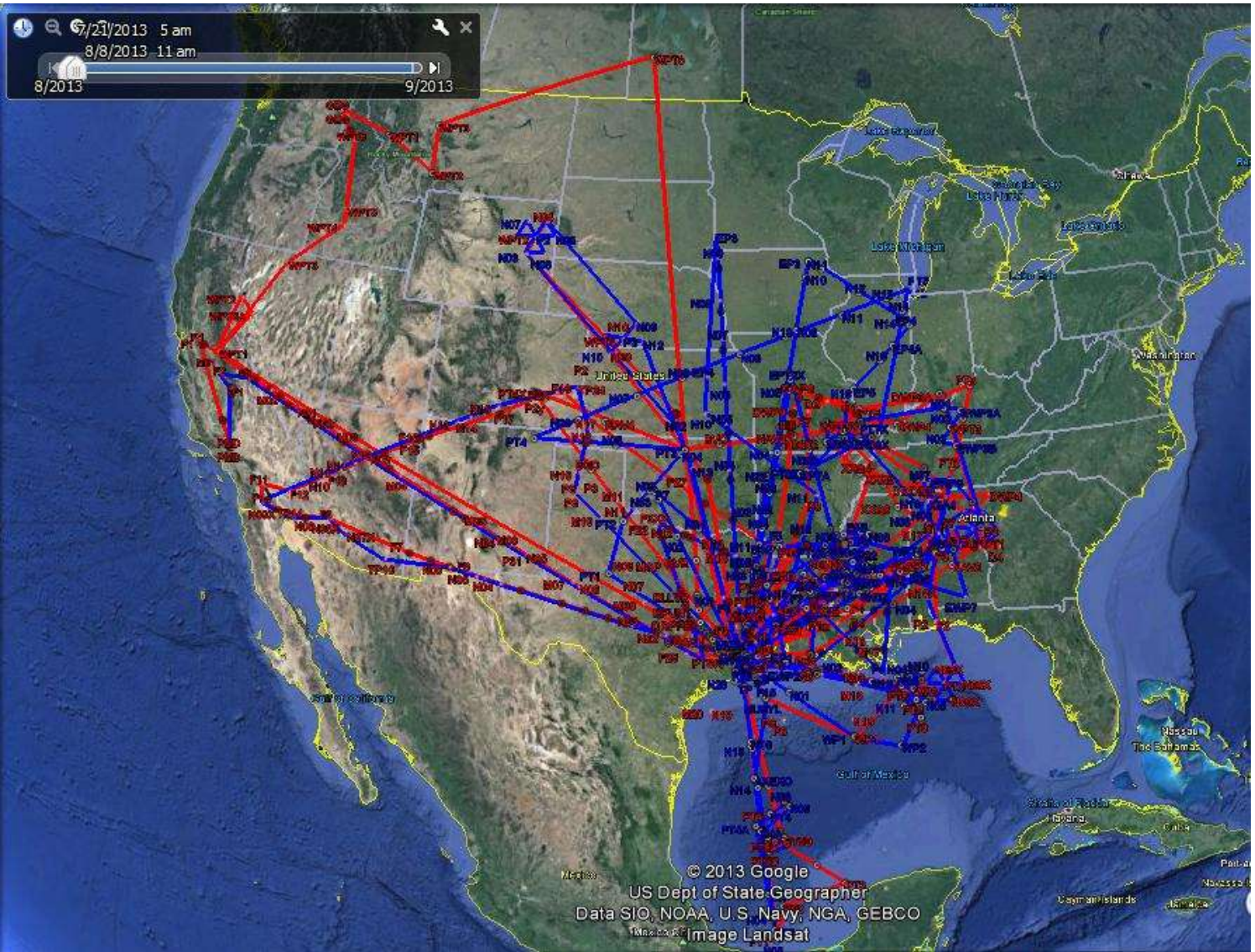
Ground-Based Networks:
AERONET, MPLNET, SHADOZ, Met & Water Vapor Sondes, HSR Lidar, Cloud Radars

Models:
CTMs, GCMs, ESMs

Calibration and Validation
Retrieval development
Correlative information
Small scale structure and processes

Model error evaluation
Data assimilation
Diagnostic studies

Where Have We Been in SEAC^{4}RS as of September 15, 2013



Successfully Sampled:

- Fires
  - Idaho fires
  - Rim fire
  - Agricultural burning
- North American Monsoon
- SE US gas phase chemistry
- Continental convection
- Marine convection
- Tropical storm
- Urban pollution plumes

NASA's "SI-OP-ERB" Activities - Background

The responsibility for ***sustained*** measurements of **S**olar **I**rradiance, **O**zone **P**rofiles, and **E**arth **R**adiation **B**alance beginning in the 2021 ("JPSS-2") timeframe was transferred ***from*** NOAA ***to*** NASA/ESD in the FY14 President's Budget Request.

Additional funding ($40M, FY14) was provided to ESD for this new scope in FY14; no funds were added in FY15 and beyond.

NASA's new "SI-OP-ERB" Activity

Solar Irradiance: To continue the total and spectrally resolved solar irradiance measurements begun in the 1980's

- SORCE and ACRIMSAT are currently operating but well past their expected lifetimes and suffering battery problems;TCTE instrument (a SORCE EM unit refurbished for flight) will launch November, 2013.
- TSIS-1, a repeat of the SORCE TSIS instrument is nearing completion, to fly on NOAA's Free Flyer-1

- Task is to continue the solar measurements with new builds of the proven TSIS instrument
  - Approach is to procure new TSIS instruments to be launched as hosted payloads when needed (first launch date dependent on TSIS-1 and FF-1 schedule)

Ozone Profiles: To continue the ozone profile measurements

- The OMPS-Limb instrument has been developed to "bolt-on" to OMPS-Nadir and is currently flying on Suomi-NPP. There is no OMPS-Limb on JPSS-1.

- Task is to re-establish the limb profiling measurement for JPSS-2 and beyond
  - Baseline plan is OMPS-Limb#2 would fly together with OMPS Nadir on JPSS-2 (~2021) with accommodation costs covered by NOAA/JPSS-2. ***Combined OMPS Limb/Nadir flights post-JPSS-2 are TBD.***

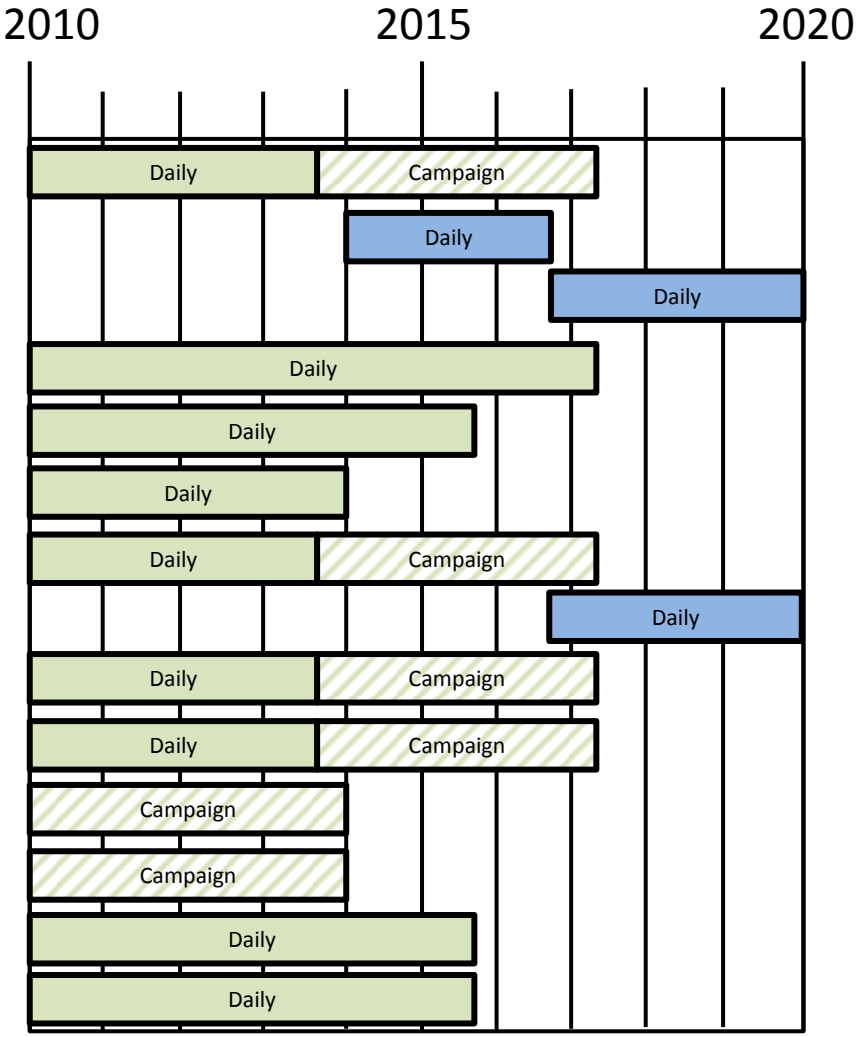
Earth Radiation Budget: To continue the established data record started with ERBS satellite launched in 1984 and continued with the CERES suite of instruments

- We are currently operating 2 CERES on Terra, 2 on Aqua, and 1 on Suomi-NPP; CERES FM6 is being completed to fly on JPSS-1 in FY2017 (NOAA)

- Task is to develop the next generation Radiation Budget Instrument (RBI) to fly post-JPSS-1
  - Baseline plan is RBI#1 would fly as hosted payload on JPSS-2 around 2021 with accommodation costs covered by NOAA/JPSS-2. ***Approach for flights of later RBI instruments is TBD.***

Status of Solar Irradiance Measurements

Instrument / Wavelength Range	Status
SORCE TIM / TSI	Campaign Mode
TCTE TIM / TSI	Launch: 11/2013
TSIS TIM / TSI	Launch: 2016
ACRIMSAT / TSI	Daily Measurements
SOHO VIRGO / TSI	Daily Measurements
PICARD PREMOS / TSI	Daily Measurements
SORCE SIM / 240-2400 nm	Campaign Mode
TSIS SIM / 200-2400 nm	Launch: 2016
SORCE SOLSTICE/ 115-310 nm	Campaign Mode
SORCE XPS / 0-40 nm	Campaign Mode
ISS SOLSPEC / 200-3000 nm	Campaign Mode
ISS SOLACES / 17-120 nm	Campaign Mode
TIMED SEE / 0-190 nm	Daily Measurements
SDO EVE / 0-122 nm	Daily Measurements



Measurement Key	
Current Daily	Campaign
Future Measurements	

High Priority Goals / *Concerns*:

1) **SORCE mission overlap with TCTE TIM and TSIS**
2) *Current SSI gaps in 190-2400 nm (campaign = 2-6 per year)*
3) *SORCE, ACRIMSAT, SOHO, and TIMED are extended missions*

Status of Ozone Profile Measurements

- Stratospheric Ozone profile measurements (3 km vertical resolution) are presently being acquired from the OMPS-Limb instrument on S-NPP (launched in 2011)

- OMPS-Limb and OMPS-Nadir are flown as a single entity (OMPS-Limb “bolts-on” to OMPS-Nadir)

- No Ozone profile measurements are planned from JPSS-1

Status of Earth Radiation Budget Measurements

- NASA Earth Radiation Budget measurements are obtained from the Clouds and the Earth's Radiant Energy System (CERES) instruments.
- There are currently 5 CERES instruments flying on 3 satellites: Terra (1999), Aqua (2003) and SNPP (2011). A CERES instrument will fly on JPSS-1 in 2016. The Radiation Budget Instrument (RBI) will fly on JPSS-2 in 2021.
- The CERES science team is producing a global, long-term, integrated climate data record (CDR) for detecting decadal changes in the Earth's radiation budget (ERB) from the surface to the top-of-atmosphere (TOA) together with the associated cloud and aerosol properties at climate accuracy.
- Data product generation involves a high level of data fusion: Over 90% of the CERES data product volume involves two or more instruments (including polar-orbiting imagers and geostationary sensors).
- Data Product Temporal Coverage: 03/2000 – Present.
- Instrument Status:
  - CERES/Terra: FM1 and FM2 Nominal.
  - CERES/Aqua: FM3 Nominal. FM4 shortwave channel anomaly in 2005.
  - CERES/SNPP: FM5 Nominal.
- Data Processing/Archival/Distribution (ASDC) Status: Nominal.
- Current Version of Data Products: Edition 3.

SI-OP-ERB Approach

Solar Irradiance: One TSIS instrument developed as rebuild of existing TSIS-1

- TSIS-2 delivery in FY19, budgeted cost includes accommodations in FY20-21

Ozone Profiles: One OMPS-Limb instrument developed as rebuild of existing OMPS-Limb

- OMPS-Limb delivery in FY18;
- OMPS-Limb integral with OMPS-Nadir **on JPSS-2** (accommodations costs covered by NOAA/JPSS)

Earth Radiation Budget: One RBI instrument developed (new design)

- RBI delivery in FY20
- RBI launch in late CY2021 ***on JPSS-2*** (accommodations costs covered by NOAA/JPSS)

Ongoing SI-OP-ERB Procurement Activities

Solar Irradiance:

- No procurement activities planned or needed in FY14 for TSIS
  - Hosted payload flight options studies will be initiated in FY14
- ***NASA ESD will begin negotiations with TSIS manufacturer LASP to prepare for the purchase of a follow-on unit, with development to start in FY2015***
  - ***Hosted payload procurement studies would continue***

Ozone Profiles:

- Sole source proposal for OMPS-Limb and Nadir has been received (from BATC) and is being reviewed
- ***Baseline is full OMPS – Nadir and Limb***
- In October(?) 2013, the JPSS Program is releasing the RFP for an RSDO bus for JPSS-2; baseline is to accommodate full OMPS (Nadir and Limb)
- ***NASA ESD plans to issue authorization in November (assuming the technical evaluation is positive) to procure the full OMPS (Nadir and Limb)***
  - ***Detailed planning for the procurement of follow-on unit(s) would follow***

Earth Radiation Budget:

- Request for Proposals for a single RBI was released in June 2013 by LaRC under guidance from the JPSS Program
- Proposals received 4 September 2013; ongoing SEB October 2013 – February 2014
- Selection decision expected before 4 April 2014
- ***Depending on the outcome of guidance related to the FY2014 budget, NASA ESD will either***
  - ***Proceed with the procurement of a single RBI instrument, or***
  - ***Authorize development of a series of RBI instruments to reduce the overall measurement cost and risk***

Land Imaging in FY 2014 President's Budget

In FY14 ***NASA will initiate*** *the definition of a sustained, space-based, global land imaging capability for the nation, ensuring continuity following LDCM. Near-term activities* ***led by NASA****, in cooperation with USGS, will focus on studies to define the scope, measurement approaches, cost, and risk of a viable long-term land imaging system that will achieve national objectives. Evaluations and design activities* ***will include consideration of stand-alone new instruments and satellites, as well as potential international partnerships****. It is expected that* ***NASA will support*** *the overall system design, flight system implementation, and launch of future missions, while* ***USGS will continue to fund ground system development****, post-launch operations, and data processing, archiving, and distribution.*

- President's FY2014 Budget release for NASA

Sustained Land Imaging

- FY14 President's budget proposal calls for NASA to lead the architecture design and space component implementation of a **sustained system** for moderate-resolution, global land imaging – with USGS

FY14	FY15	FY16	FY17	FY18	FY19
20	64.1	66.1	116.7	116.7	118.9

- NASA role:
  - System architecture study lead
  - Design, implement, launch, on-orbit commissioning of USG spaceborne segment (if any)
- USGS role:
  - Represent user communities in system architecture study
  - Post-commissioning operations, downlink, ground data processing, data distribution, archiving
- System characteristics:
  - 20-year lifetime, 2018-2038
  - Consistent with and continue 41-year Landsat data set
  - Products consistent with Landsat-7 and LDCM/Landsat-8 bands and data products
- Study guidance from OMB
  - ***Cost is a constraint:*** $120M/year ***NASA*** average cost (and near-flat budget) over system lifetime
  - Examine international and private sector partnerships
  - Specifically examine infusion of hyperspectral technology
  - Balance initial capability, gap risk/continuity, technology infusion over system lifetime, cost
  - Study results due August 2014

Architecture Study Approach

- NASA and USGS have established the Land Imaging Architecture Study Team (AST) within the NASA Earth Systematic Missions Program Office. The AST:
  - Includes representatives from NASA Centers, USGS, JPL, Aerospace, others
  - Conducts independent analyses and architecture feasibility studies
- NASA released an RFI September 18 with inputs due on 1 November
  - — Responses will be used as an input to the study
- NASA and USGS will hold a Community Workshop to communicate architecture options and to elicit feedback
- The AST will refine architecture options and present them to NASA and USGS for final review and evaluation
- The study activity will result in recommendations and an implementation plan for a Sustainable Land Imaging System (combined space and ground system) to be provided to the Executive Office of the President by August 15, 2014

National Aeronautics and Space Administration
Goddard Space Flight Center

Search
Flight Projects | Sciences and Exploration

Sustainable Land Imaging Architecture Study Industry & Partner Day ..... September 18, 2013

- Overview
- → Watch Event (starting 1:30 p.m. EDT on September 18)
- → REGISTER NOW
- Landsat @ GSFC
- Landsat @ USGS

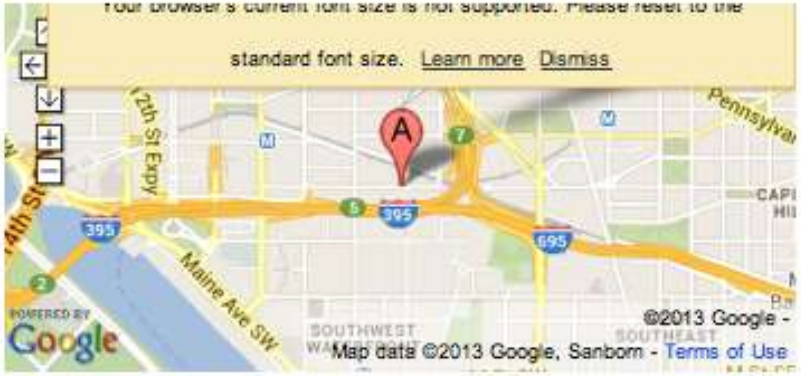
Time: 1:00 - 4:30 p.m. EDT

Date: Wednesday, September 18, 2013

Location: **NASA Headquarters James E. Webb Auditorium**
300 E Street, SW, Washington, D.C. [get directions].

Capacity Note: Onsite-attendance will be limited by seating capacity.

→ Register now



View Larger Map

On September 18, NASA will host an event in which leadership from NASA and the United States Geological Survey (USGS) will provide details about NASA's Sustainable Land Imaging Architecture Study to design and implement a spaceborne system to provide global, continuous Landsat-quality multispectral and thermal infrared measurements for at least the next 25 years. To spur innovation and increase efficiencies, the study will identify and evaluate a range of solutions including large and small dedicated spacecraft, formation flying, hosted instruments, and integration of other land imaging data sets, as available, as well as possible international and private sector collaborations. The study will include careful consideration of the current and future planned ground system capabilities provided by the established USGS Earth Resources Observation and Science (EROS) Center. The study must recognize that lowering the system's cost to the nation is an important goal, and that implementing a system that stays within the allocated budget is an essential programmatic requirement for the U.S. government. We will describe our upcoming planning timeline and identify opportunities and processes for providing input into our planning. Following this public forum, NASA will also a Request for Information (RFI) to seek new ideas for mission elements and describe the process for submitting your ideas so that NASA/USGS teams may consider your innovative solutions.

Three Basic Study Tenets for the Program

- Sustainability
  - The LI program should provide the data products for the long haul (at least 20 years), without extraordinary infusions of funds, within the budget guidance provided.
- Continuity
  - The LI program should continue the long term Landsat data record. This does not necessarily mean the imagery per se, but the usable products that define the utility of the data record. New products should be “compatible” with L-7, L-8 information.
- Reliability
  - The LI program should be robust and minimize data gaps insofar as possible within the programatic constraints.

Revisit Performance Results – Sentinel-2 Satellites Paired with Landsat 7/8

Max Revisit Interval Min Revisit Interval	Individual Satellite Revisit Interval			Constellation Revisit Interval			Satellites Paired with Landsat 7 and Landsat 8 Revisit Interval		
	Equator	U.S.	Europe	Equator	U.S.	Europe	Equator	U.S.	Europe
Landsat 7	16d 7d 7h			8d 3d 19h			----		
Landsat 8	16d 7d 7h						----		
Sentinel-2A	10d 4d 11h	10d 4d 17h	10d 4d 11h	5d 2d 8h	5d 2d 7h	5d 2d 5h	3d 2h 1d 12h	3d 2h 1d 11h	3d 2h 1d 10h
Sentinel-2B	10d 4d 11h	10d 4d 17h	10d 4d 11h						
Sentinel-2A	10d 4d 11h	10d 4d 17h	10d 4d 11h	----			4d 11h 2d 4h	4d 11h 2d 3h	

Sustained Architecture Study Schedule

October – December 2013
- Receive RFI Inputs
- Perform initial system and specialty trade studies, led by the Architecture Study Team
- Conduct Landsat Data User's Workshop

January – March 2014
- Reduce multiple system architecture approaches to highest value options
- Conduct Community Workshop to solicit community feedback

April – June 2014
- Refine final system architectures, including cost estimations and end-to-end data production and management approach
- Produce final report and implementation plan

July – August 2014
- Communicate through NASA and USGS and USG stakeholders

ESD Orbital Flight Portfolio – 2012-2022

- **LDCM** (2/11/2013) – "Landsat-8" including thermal IR, w/USGS ✓ ✓ ✓
- **GPM** (2/2014) – Global Precipitation mapping, w/JAXA
- **OCO-2** (7/2014) – Atmospheric CO2 monitoring, recovery mission
- **SMAP** (10/2014) – Soil Moisture and Freeze/Thaw cycling, w/CSA (minor)
- **SAGE-III/ISS** (3/2015) – Ozone, Temp, Humidity profiles, w/HEOMD, ESA
- **ICESat-2** (2017 [TBR]) – Precision Ice Topography, Ecosystem monitoring
- ***CYGNSS [EV-Mission/1]*** *(late 2016)*
- **GRACE-FO** (8/2017) – Gravity/Ice Mass/Ground Water, w/GFZ & DLR
- ***OCO-3/ISS*** *(Fall 2017)* – CO2 continuity, from ISS, OCO-2 spares
- ***TEMPO [EV-Instrument/1]*** *(2018)*
- **SWOT** (2020) – Wide-swath ocean altimetry, land water, w/CNES
- ***PACE*** *(2020)* – Ocean Color, possibly Aerosols
- ***EV-Instrument/2 Venture-Class*** *(NLT 2020)*
- ***L-band SAR*** *(NET 2021)* – Solid Earth, Cryosphere, Ecosystems, w/ISRO
- ***CLARREO*** *(2022?)* – Precise global radiation balance, possibly w/UK
- ***EV-Mission/2*** *(NLT 2022)*
- ***EV-Instrument/3*** *(NLT 2022)*
- Significant studies ongoing for all other Tier-2 Decadal Survey missions

Near-Term Flight Program Developments

- LDCM/Landsat-8 successfully completed commissioning and transfer to USGS for operations (May, 2013)
- Senior Review recommends continuation of on-orbit missions
- Jason-1 mission terminated 1 July 2013 – final data transmitter failed
- CYGNSS successfully passed KDP-B (July 2013)
- SAGE-III replan (new LRD 3/2015) to accommodate ESA delay in pointing platform delivery
- Venture-class future solicitations (for EVS-2 and EVI-2) released on schedule June, July 2013
- L-band (+S-Band) SAR mission TAA recently signed by ISRO

Earth Observations from the ISS: NASA/ESD Status and Plans

- On-orbit instruments funded by non-ESD sources, ESD funding for analysis
  - HICO (Hyperspectral Imager for the Coastal Ocean)
    - Launched September, 2009 on HTV; mounted on JEM-EF
  - ISERV (Digital Camera and Telescope)
    - Launched July, 2012 on HTV-3; mounted internally on WORF

- Planned instruments funded by NASA/HEOMD, ESD funding for analysis
  - CATS (Cloud-Aerosol Transport System for ISS)
    - LIDAR, summer 2013, HTV, JEM-EF
  - Rapid-Scat (Ku-band scatterometer)
    - Launch early CY2014, Falcon/Dragon
  - *Lightning Imaging Sensor (under consideration)*
  - *Hyperspectral Follow-on to HICO (under consideration)*

- Approved instruments funded by ESD
  - SAGE-III (Stratospheric Aerosol and Gas Expt)
    - In Phase-C; 8/2014 Launch on Falcon/Dragon; ESA provides hexapod pointing p'form
  - *OCO-3 (Orbiting Carbon Observatory-3 instrument only)*
    - *Phase-A November 2012; Launch Fall, 2017*

Major Partnerships

Intra-NASA

OIIR, OSI, HEO (ISS and LSP), ARMD, STMD

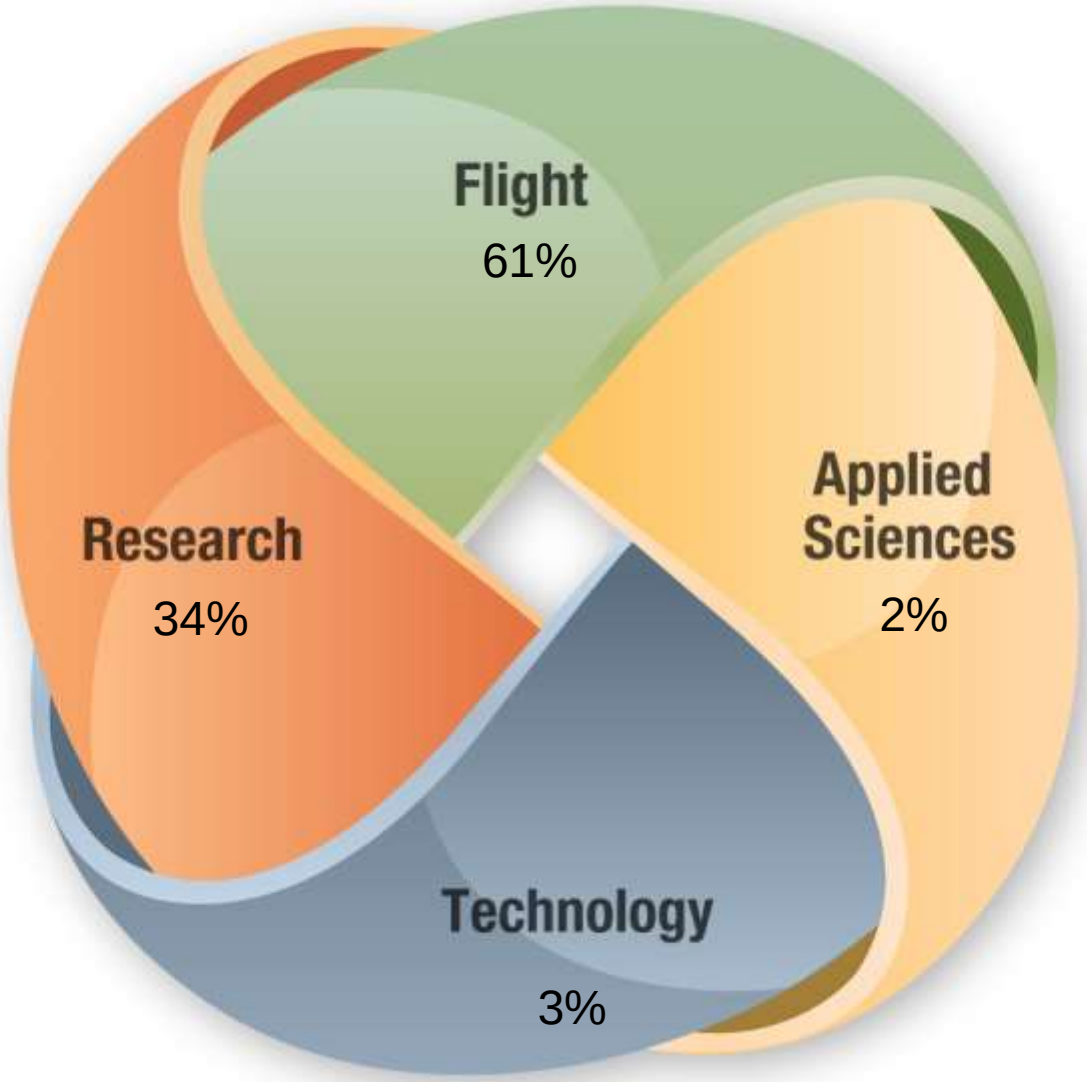
International

- Collaborations: JAXA, CNES, CSA, DLR/GFZ, ESA, ISRO, CONAE
- Coordination: CEOS, GEO, CGMS, disciplinary coordination groups

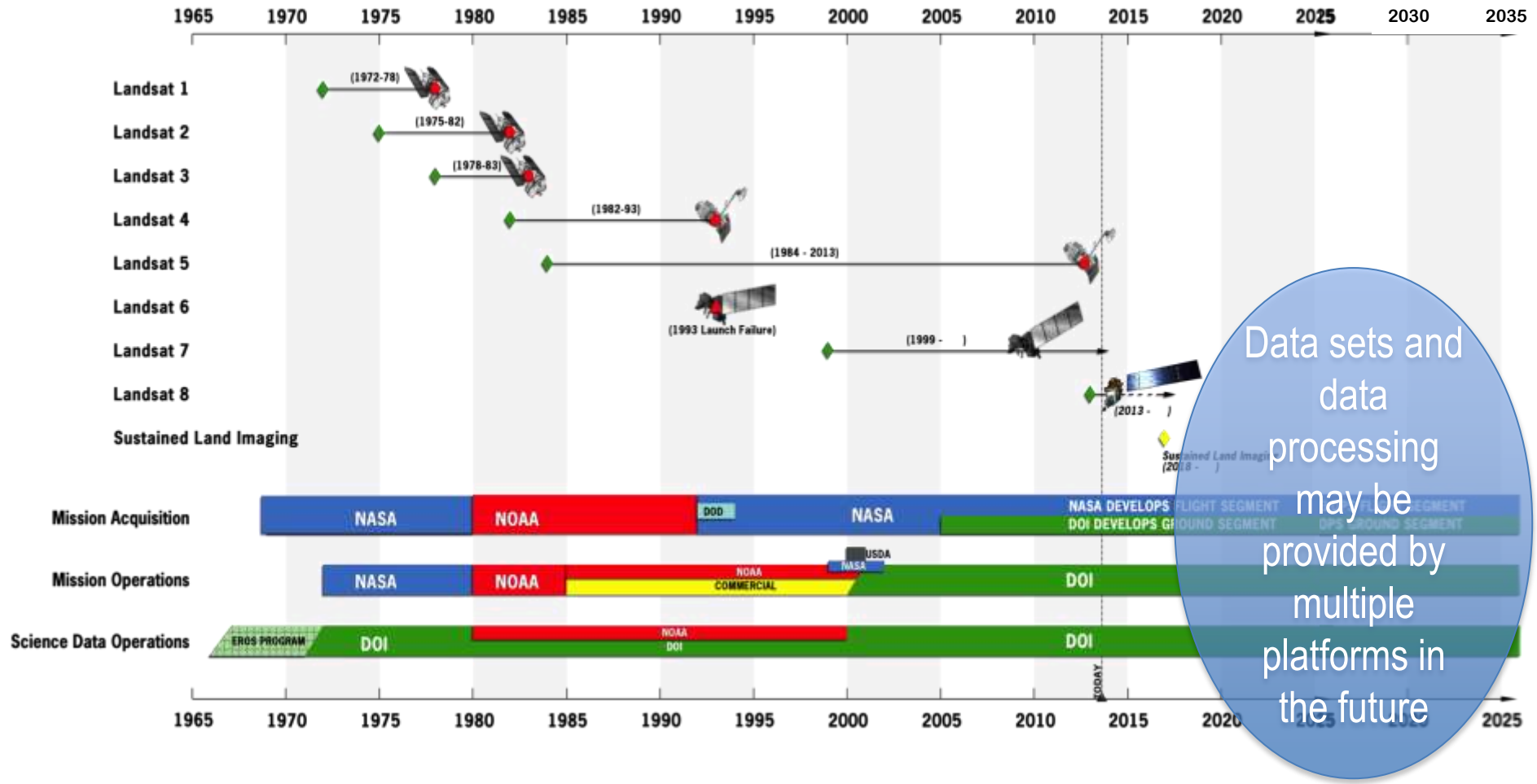
Interagency

- Collaborations: NOAA, USGS, NSF, ONR, DoS, DoE
- Coordination: USGCRP, SGCR, IARPC, SOST, USGEO, WestFAST, FAA

Earth Science Division



USGS/NASA Landsat Partnership Since 1966



Historical US Landsat "Program"

- **Historical Landsat Program Objectives:**
  - Acquire, archive, and distribute multispectral imagery affording global, synoptic, and repetitive coverage of the Earth's land surfaces at a scale where natural and human-induced changes can be detected, differentiated, characterized, and monitored over time.

Relative NASA & USGS Roles

- **NASA:**
  - Develops sensors, satellites, and launches land imaging space systems and performs Earth-system measurements and research using land-image data

- **USGS:**
  - Documents user land imaging requirements, develops ground systems for land imaging space systems, operates US land imaging satellites, and collects, processes, archives and disseminates land-image data

Earth Science Division Overview

- **Overarching goal:** To advance knowledge of the Earth as a system to meet the challenges of environmental change, and to improve life on our planet. This is accomplished through spaceborne data acquisition; scientific and application research and analysis; and predictive modeling
- Major activities:
  - **Building and operating Earth observing satellite missions**, many with international and interagency partners
    - Presently operating 17 NASA on-orbit research missions: TRMM, Landsat 7, QuikScat, Terra, ACRIMSAT, EO-1, Jason 1/2, GRACE, Aqua, SORCE, Aura, Cloudsat, CALIPSO, Aquarius, Suomi-NPP, LDCM
  - **Making high-quality data products available** to the broad science community
  - **Conducting and sponsoring cutting-edge research**
    - ***Field campaigns*** to complement satellite measurements
    - ***Analyses of non-NASA mission data***
    - ***Modeling***
  - **Applied Science** to develop and demonstrate applications delivering societal benefit and building user capacity
  - **Developing technologies** to improve Earth observation capabilities
- **Significant interagency and international interactions** are required
  - Major contributor ($ and leadership) to interagency coordination activities (e.g., US Global Change Research Program
  - Key leadership roles in international satellite coordination organizations (e.g., Committee on Earth Observation Satellites (CEOS), Group on Earth Observations (GEO), and Global Geodetic Observing Systems (GGOS))

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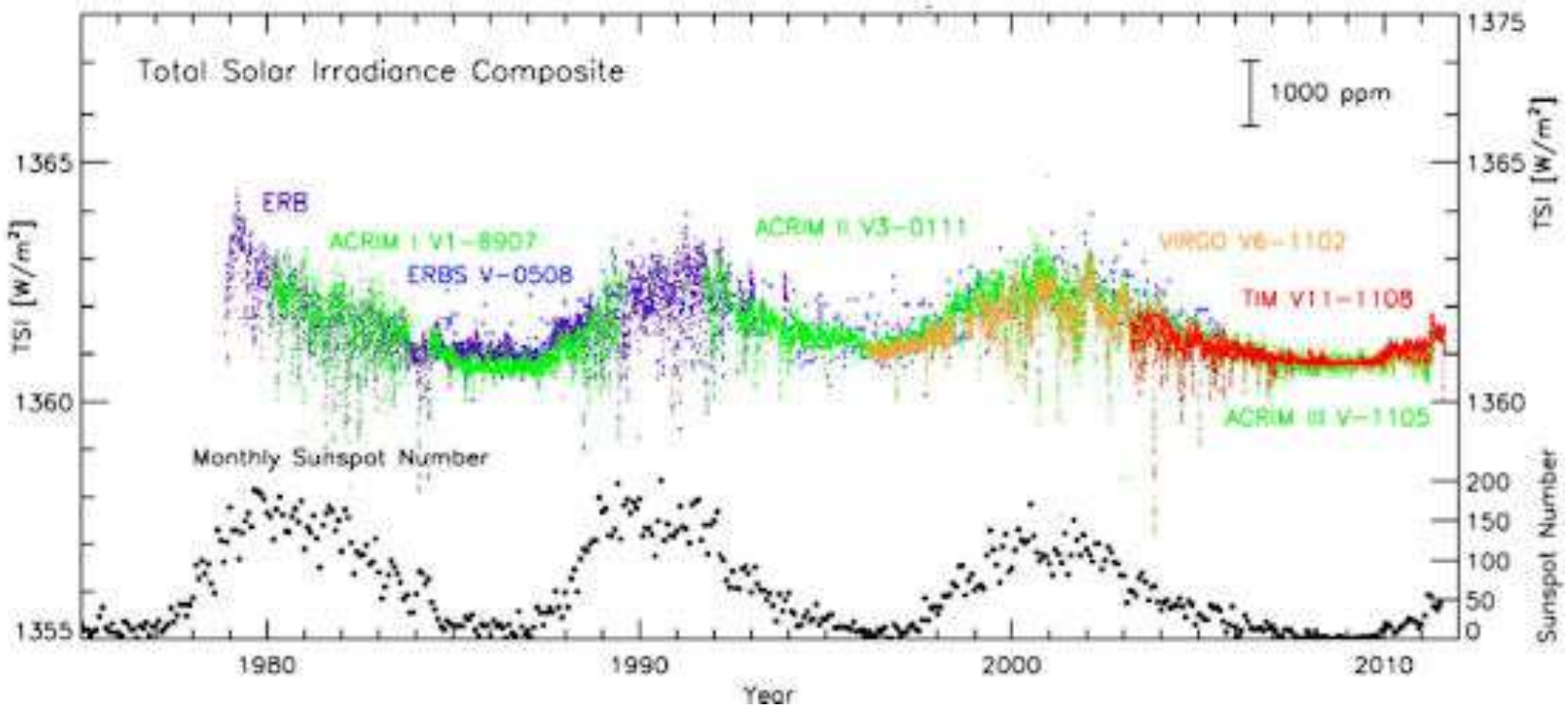
Total Solar Irradiance Multi-Decadal Composite
(Kopp et al., 2012)



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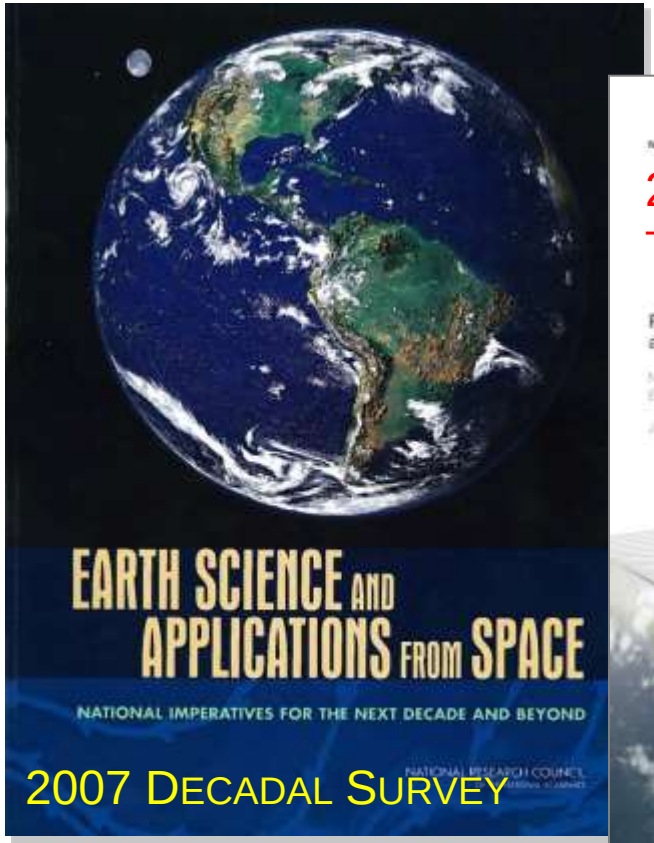
- L-band SAR mission TAA remains unsigned by ISRO

- House Appropriations text for FY14 budget deletes funding for:
  - TSIS, OMPS-Limb, Earth Radiation Budget sensor development for JPSS-2 –and-beyond timeframe
  - Sustained Land Imaging Program
  - DSCOVR-related activities
- Senate Appropriations text for FY14 budget generally follows President's request:
  - Suggests "Landsat-9" cost to be capped at $650M; Suggests limited study focusing on next mission
  - PACE mission to be developed for FY18 launch

Guiding Recommendation Documents

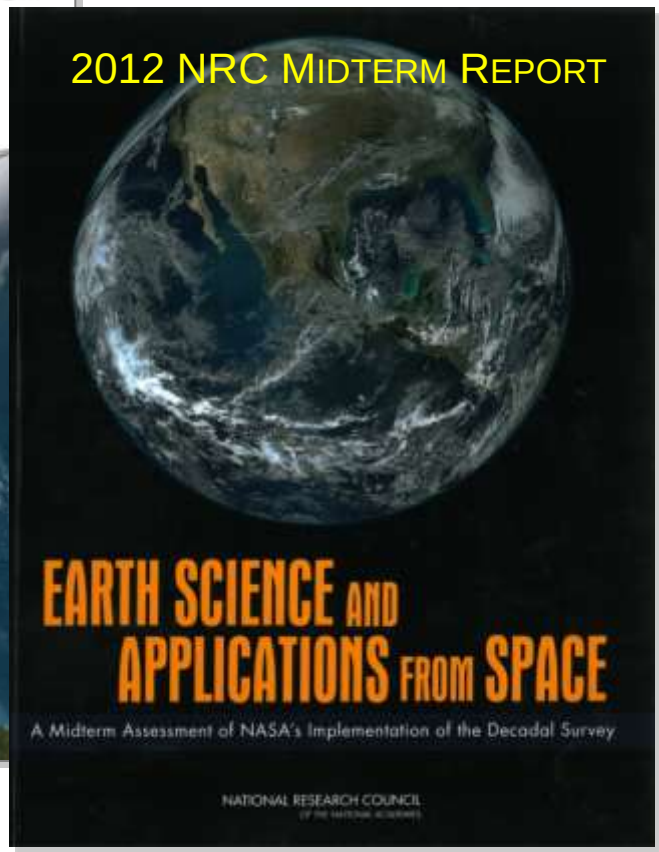


2007 DECADAL SURVEY

- Research/Applications priorities
- No realistic budget constraint
- Shopping list of missions & activities
- Assumed Legacy missions completed

2010 NASA RESPONSE TO CLIMATE PLAN

- Identified Continuity Measurements and Administration priorities
- Consistent with President's FY11 budget and realistic cost estimates
- Evaluated and endorsed by 13-agency USGCRP

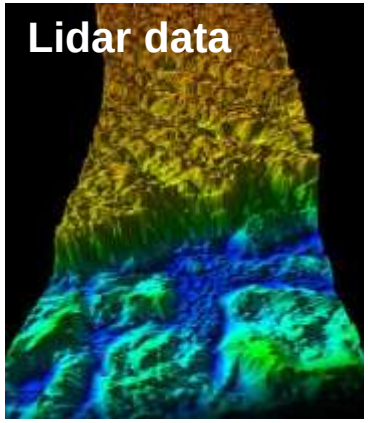


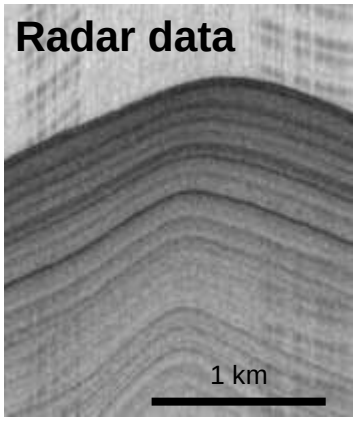
2012 NRC MIDTERM REPORT

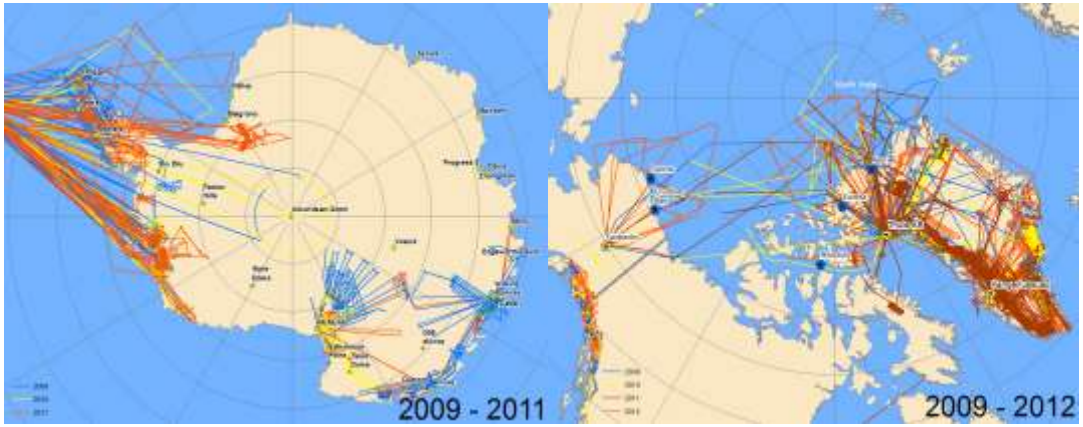
- Endorsed NASA's progress in missions and non-flight activities
- Encouraged rigorous cost control

Operation IceBridge 2009-present

- Ice surface elevation data over ice sheets, glaciers, and sea ice to bridge the gap between ICESat and ICESat-2 missions
- New measurements critical to ice sheet models: bed topography, grounding line position, ice and snow thickness
- Results: First maps of snow thickness over Arctic sea ice; fundamentally redraw of Antarctic bedmap; new insights into dynamic processes of the major ice sheets
- Science flights with multiple platforms (P-3B, DC-8, B200, HU-25, Basler BT-67, Single Otter, GV); more than 19 instruments flown
  - Total science flights: 370+
  - Total science flight hours: 1600+
  - Total science flight distance (Km): 1,200,000+



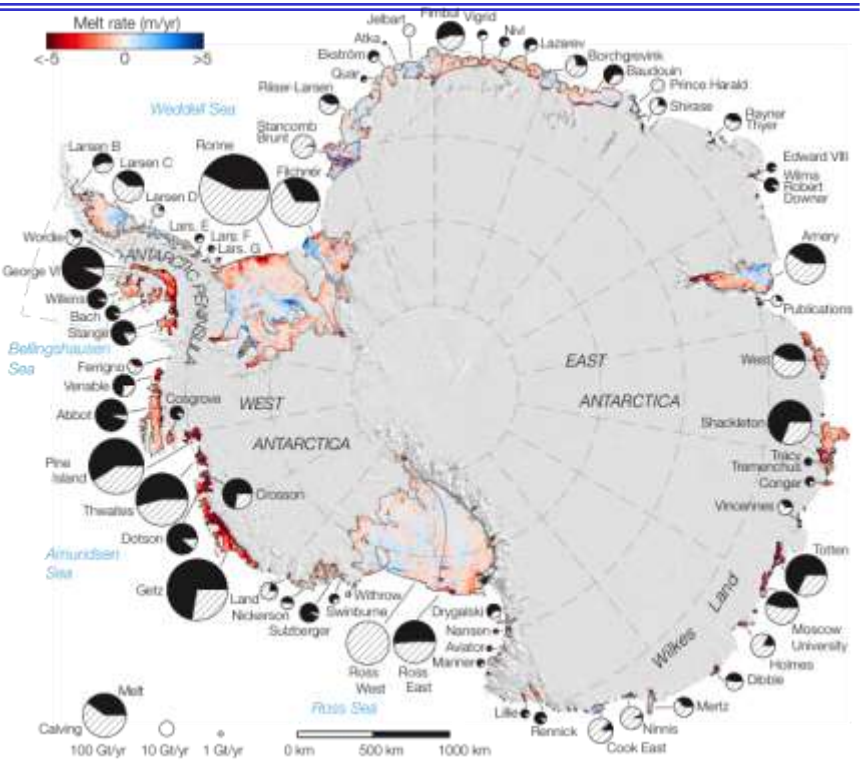




Ice Shelf Melting Around Antarctica

Rignot et al. (2013), Science, doi: 10.1126/science.1235798

- As dynamic features that control the flow of ice from the interior, understanding changes in ice shelves is critical to determining Antarctica's contribution to current and future sea level rise.
- NASA-funded scientists used ice thickness and altimetry data—from **Operation IceBridge**, ground-based radar echo sounding, and interferometric SAR (inSAR) satellite data—along with reconstructions of surface accumulation to complete a comprehensive survey of Antarctic ice shelves.
- They discovered that ***ice shelves lose the most mass to melting as opposed to calving***, which had traditionally been thought to be the far-dominant mechanism for ice removal. Overall, they estimated the basal melt rate to be 1325 +/- 235 Gt/yr, compared to an iceberg calving flux of 1089 +/- 139 Gt/yr.
- **They also found that the massive ice shelves in the Ross and Weddell seas are melting the least, with the majority of melt produced by smaller ice shelves along the Antarctic Peninsula, and West Antarctica, where warmer ocean waters consume the outflow of ice from glacier inflows within a few km of the coast.**

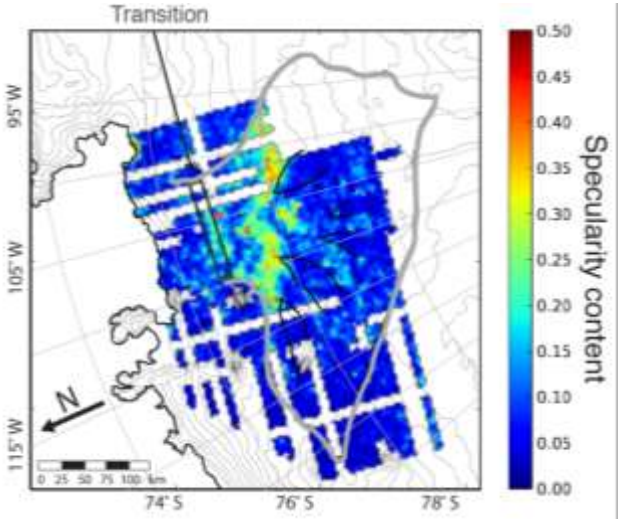


Above: Basal melt rates of Antarctic ice shelves color coded from < –5 m/year (freezing) to > +5 m/year (melting) and overlaid on a 2009 MODIS mosaic of Antarctica. Ice-shelf perimeters in 2007–2008, excluding ice rises and ice islands, are thin black lines. Each circle graph is proportional in area to the mass loss from each shelf, in gigatons (1 Gt = 1012 kg) per yr, partitioned between iceberg calving (hatch fill) and basal melting (black fill).

Evidence for a Water System Transition Beneath Thwaites Glacier, West Antarctica

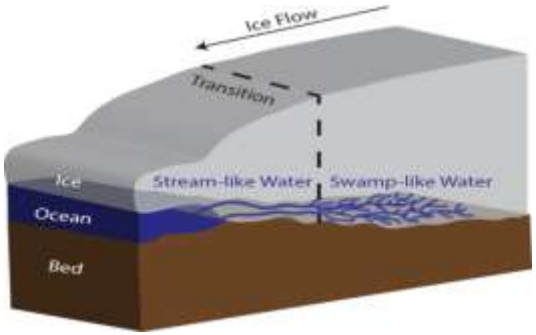
Schroeder et al. (2013), Proc. National Academy of Science, doi: 10.1073/pnas.1302828110

- Thwaites Glacier is one of the largest, most rapidly changing glaciers on Earth. It is a critical gateway to W. Antarctica's ice with great potential to raise sea level.
- Previous studies used the amplitude of ice-penetrating radar reflections to characterize subglacial water, but ice temperature complicates this approach. This new method overcomes that problem using the angular distribution of the reflections (specularity).
- They discovered that water is held in a swampy canal system—several times the size of Florida Everglades—beneath the deep interior of the ice sheet, transitioning downstream to channels.
- **The channel zone offers greater friction to flowing ice, slowing it down, and causing it to thicken. If this area is undermined by warming ocean waters or other hydrologic changes, it could lead to ice sheet collapse and rapid sea level rise.**



Left: Specularity content in the context of subglacial hydraulic potential (contour lines) and tributary boundaries (black lines) showing high specularity values in the tributaries and upper trunk. Three major subglacial pathways (light gray lines) and the distributed-to-concentrated transition (black box) are also shown.

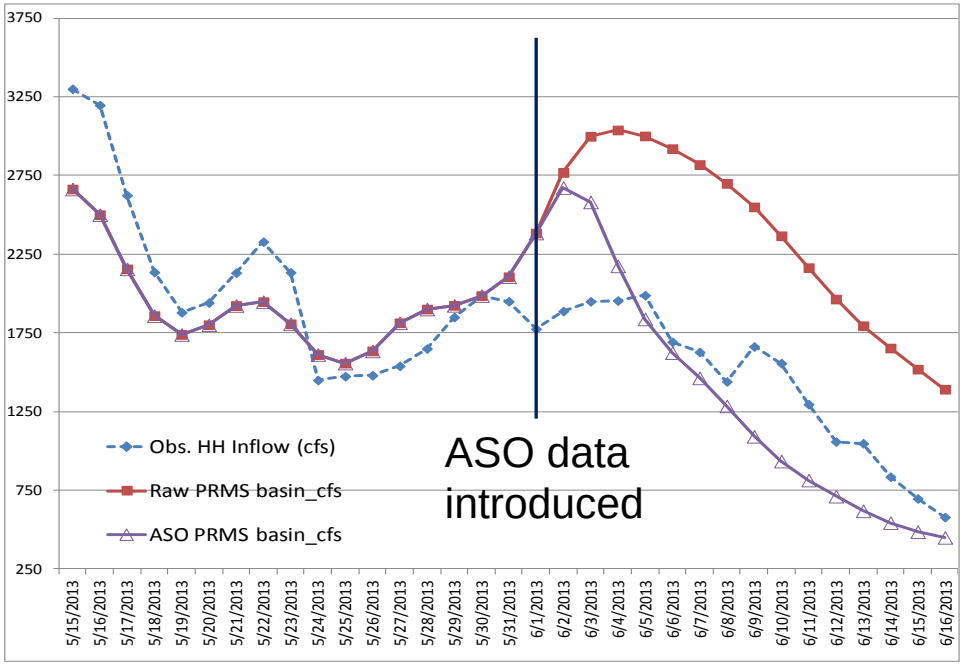
Right: Schematic representation of the Thwaites Glacier system, showing the subglacial transition from swamp-like, distributed canals to more concentrated stream-like channels, as the ice flows from the ice sheet interior to the ocean



NASA co-funded this study with NSF

Jet Propulsion Laboratory
California Institute of Technology

Improved Estimates for Water Management in California



The California Dept. of Water Resources (DWR) prediction of water inflow into the Hetch Hetchy Reservoir in thousand acre feet (shown in red) was modified on June 1, 2013 based on snow water equivalent (SWE) data from the NASA/JPL Airborne Snow Observatory. The new forecast (shown in purple) provided a factor of 2 better estimate of the actual inflow (shown in blue) and enabled water managers to optimize reservoir operations.

Tom Painter, JPL

Applied Sciences Program

- **Applications**
  - Enables identification of applications early in satellite mission lifecycle and facilitate effective ways to integrate end-user needs into satellite mission planning and throughout the mission lifecycle

- **Capacity Building**
  - Builds U.S. and developing countries' capacity, including human, scientific, technological, institutional, and resource capabilities, to enhance the ability to make decisions informed by Earth science data and models

Earth Science Technology Office

- **Advanced Technology Initiatives (ATI) / Advanced Component Technologies (ACT)**
  - Provides development of critical component and subsystem technologies for instruments and platforms, and prototype flight validations
- **Instrument Incubator Program (IIP)**
  - Provides robust new instruments and measurement techniques
- **Advanced Information Systems Technology (AIST)**
  - Provides innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products and knowledge
- **In-space Validation of Earth Science Technologies (InVEST)**
  - Pilot program provides for in space validation of Earth science technologies to will help reduce the risk of new technologies which cannot be fully tested on the ground or in airborne systems.


Jason-1
Dec 7, 2001 – Jul 1, 2013