



National Aeronautics and Space Administration



NASA Earth Science Division Overview:

Michael H. Freilich October, 2017

OUTLINE

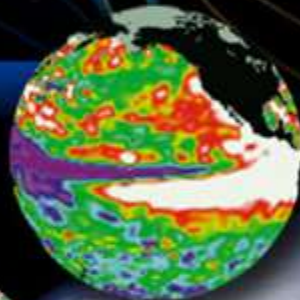


- ESD overview and Non-Flight summary
- Budget Status
- Flight Program including Venture Class
- Innovation including Small-Sat Constellation
- Satellite Needs Working Group results

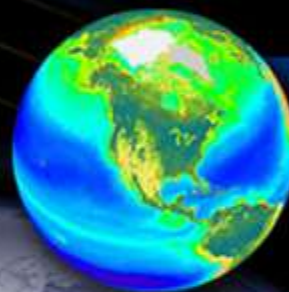
Earth System Science



Climate Variability
and Change



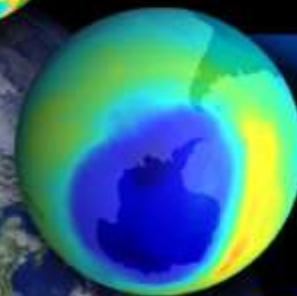
Carbon Cycle
and Ecosystems



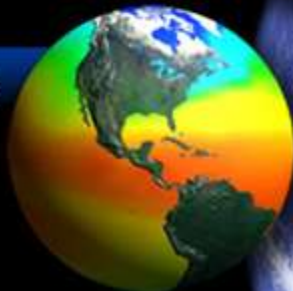
Earth Surface
and Interior



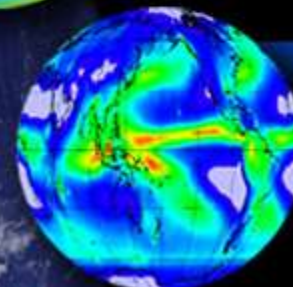
Atmospheric
Composition



Weather



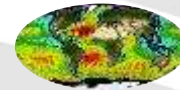
Water &
Energy
Cycle





Flight (incl. Data Systems)

Develops, launches, and operates NASA's fleet of Earth-observing satellites, instruments, and aircraft. Manages data systems to make data and information products freely and openly available.



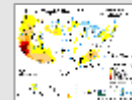
Research & Analysis

Supports integrative research that advances knowledge of the Earth as a system, and capabilities to conduct research. Six focus areas plus field campaigns, modeling, and scientific computing.



Technology

Tests and demonstrates scientific technologies for future satellite and airborne missions:
Instruments, Information Systems, Components, InSpace Validation (cubesats).



Applied Sciences

Develops, tests, and supports innovative and uses of Earth observations and scientific knowledge by private and public sectors to inform their planning, decisions, and actions.

Earth Science Research



Focus Areas

Carbon cycle and Ecosystems

Climate Variability and Change

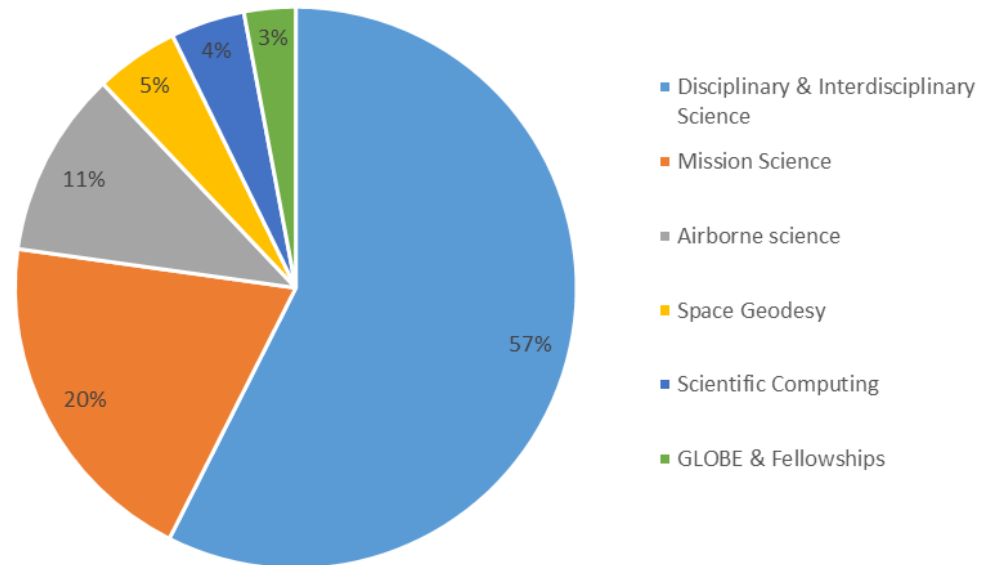
Atmospheric Composition

Global Water and Energy Cycle

Earth Surface and Interior

Weather

FY17 Research Budget by Category



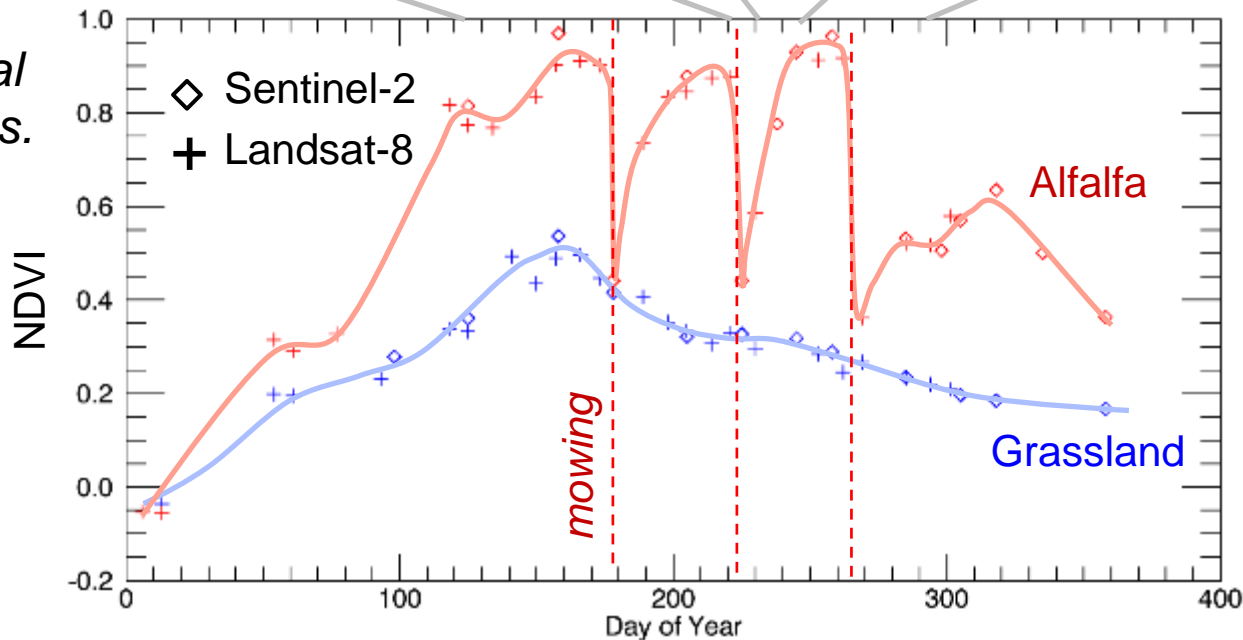
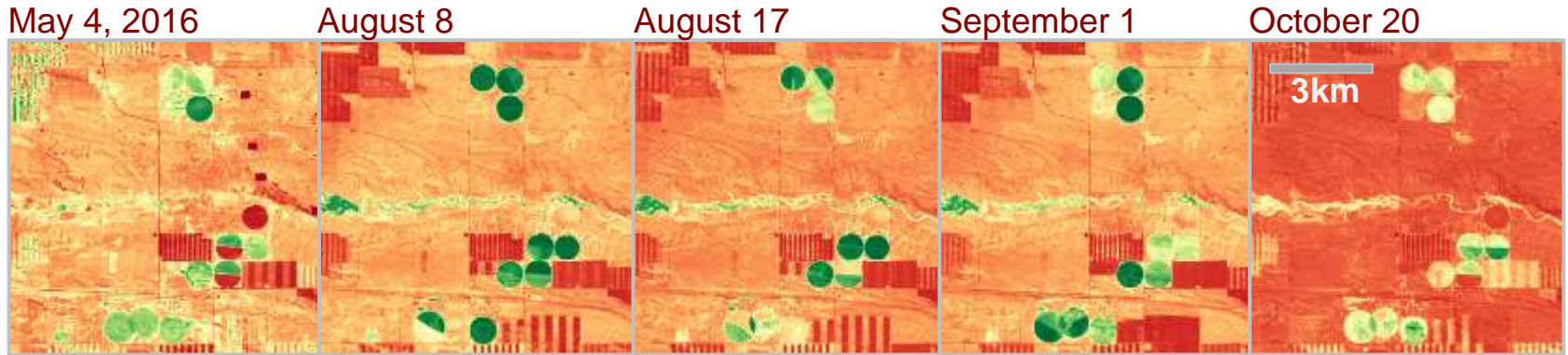
>2,100 current awards (valued at \$384M) to Centers, other agencies, private entities, universities, etc.

>1,100 (\$144M) of these are grants/coop. agreements issued through HQ Grants Office

HLS: Harmonized Landsat/Sentinel-2 Products

<https://hls.gsfc.nasa.gov>

Laramie County, WY



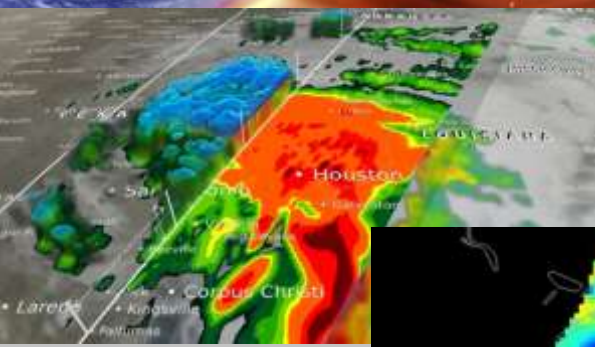
High temporal density of obs. allows individual mowing events to be detected within alfalfa fields.

Seasonal phenology:
Natural Grassland (blue line)
Irrigated Alfalfa (red line)

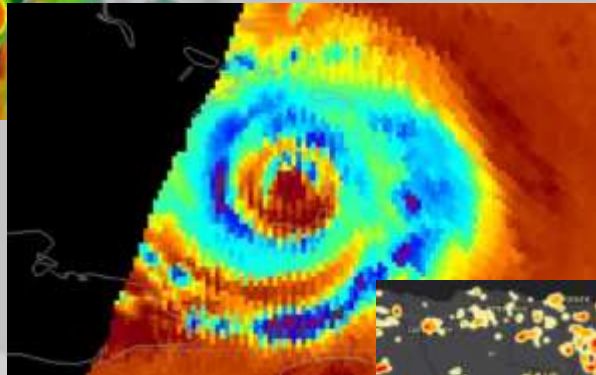


Health & Air Quality Applications
Ecological Forecasting Applications
Water Resources Applications
Disaster Applications & Response Teams
Capacity Building program:
• SERVIR (joint with USAID),
• ARSET Training, DEVELOP
Early Adopters & Applications Support to
Mission Planning
Socioeconomic Impact Methodologies
Food Security Consortium
Western Water Applications Office
GEO Work Programme
Sustainable Development Goals

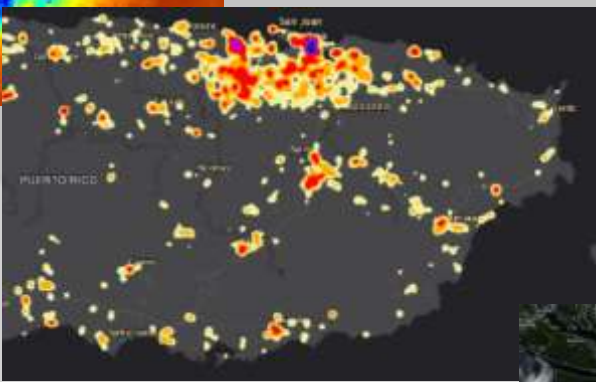
- SERVIR hubs and SERVIR Applied Sciences Teams
- Western Water Applications Office
- Food Security and Agriculture Consortium
- VALUABLES Consortium (techniques to quantify socio-economic benefit from Applications)
- Disaster Response Support and increased preparation-based approaches
- Funds ESD-led *International Space Apps Challenge*



Harvey strikes Texas
August 25



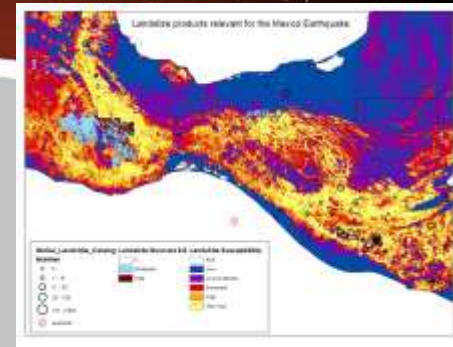
Irma strikes the Keys
September 10



Maria strikes Puerto Rico
September 20



Raboso (M7.1) Earthquake
September 19

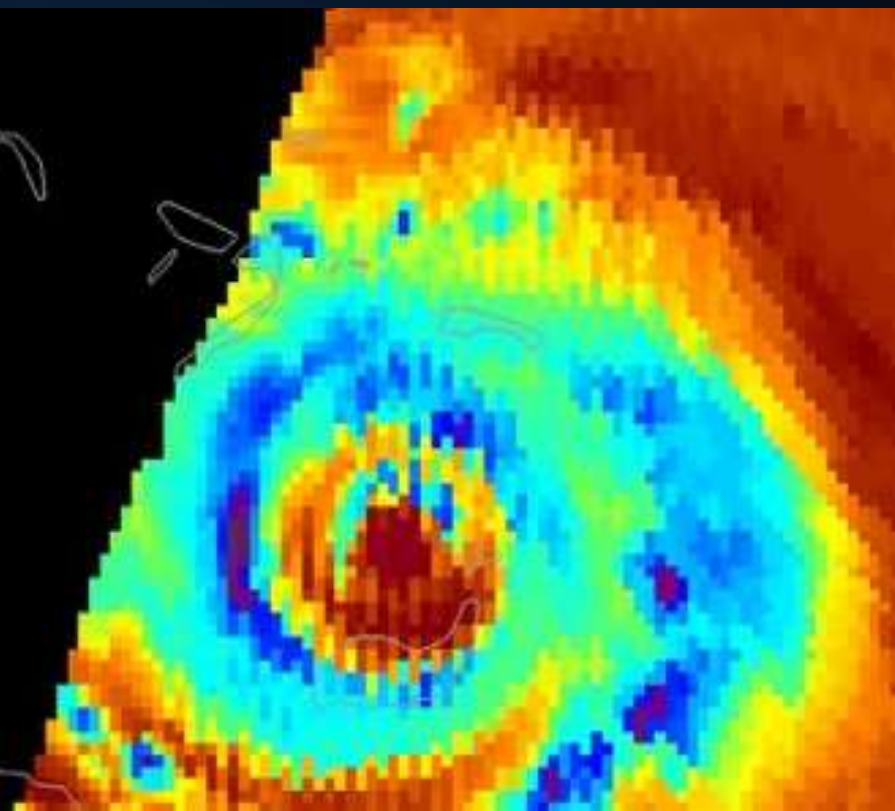


Chiapas (M8.1) Earthquake
September 7



Western Wildfire Season from VIIRS
and MODIS

GPM Measurements Influence Hurricane Forecasts



Hurricane Irma Discussion Number 37
NWS National Hurricane Center Miami FL AL112017
500 AM EDT Fri Sep 08 2017

Microwave images and data from an Air Force Reserve Hurricane Hunter aircraft indicate that Irma is currently undergoing an eyewall replacement cycle. A recent GMI overpass showed an 50 nmi wide outer eyewall, with the inner eyewall weakening. The Hurricane Hunter aircraft reported peak 700-mb winds of 147 kt in the outer eyewall near 0500 UTC, and maximum SFMR winds were in the 125-130 kt range. Based on these data, the initial intensity is reduced to 135 kt.

GPM Constellation



Advanced Technology Initiatives (ATI)



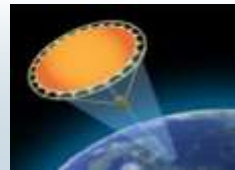
Advanced Component Technologies (ACT) - development of critical components and subsystems for instruments and platforms

Future solicitations/selections planned in FY 2020 and FY 2023



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

Future solicitations/selections planned in FY 2018 and FY 2021



Instrument Incubator Program (IIP) - robust new instrument developments and measurement techniques

Future solicitations/selections planned in FY 2019 and FY 2022



Advanced Information Systems Technology (AIST) - innovative advances in on-orbit and ground technologies to generate, manage, and exploit data in the 5-20 year horizon

Future solicitations/selections planned in FY 2018, FY 2020 and FY 2022

InVEST/Venture Tech Launch Schedule

| Project | NET Launch Date [Deploy Date Estimate CY] | Vehicle | Status | Mission |
|-------------------|--|--------------------------------------|--------------------------|--|
| RAVAN | November 11 th , 2016 | Atlas-V (NRO) | Launched | WorldView-4 / Digital Globe 600 km sun-synch |
| IceCube | April 18 th , 2017 [May 16 th , 2017] | NASA ISS (OA-7) Atlas-V | Launched/Deployed | ELaNa-17 400 km at 51.6 deg. inclination |
| HARP | January 26 th , 2018 | NASA ISS (SpX-14) Falcon-9 | Manifest | ELaNa-21 400 km at 51.6 deg. inclination |
| MiRaTA | November 10 th , 2017 | Delta-II (JPSS-1) | Manifest | ELaNa-14 440 x 811 km sun-synch |
| TEMPEST-D | March 14 th , 2018 [NET April 2018] | NASA ISS (OA-9) Cygnus/Antares II | Manifest | ELaNa-23 400 km at 51.5 deg. inclination |
| RainCube | March 14 th , 2018 [NET April 2018] | NASA ISS (OA-9) Cygnus/Antares II | Manifest | ELaNa-23 400 km at 51.5 deg. inclination |
| CubeRRT | March 14 th , 2018 [NET April 2018] | NASA ISS (OA-9) Cygnus/Antares II | Manifest | ELaNa-23 400 km at 51.5 deg. inclination |
| CIRiS-BATC | August 1 st , 2018 | TBD | In Work | ELaNa-?? TBD |
| CSIM-FD | 2018 | Falcon-9 | Manifest | SSO-A 575 km - 10:30am LTDN desired |
| CIRAS-JPL | TBD | TBD | TBD | TBD |

NASA/ESD Funding/Appropriation Timeline



- FY18 (1 Oct 2017 – 30 Sept 2018) funding at **FY16** level through 8 December 2017
- President's FY18-22 detailed budget proposal released **23 May 2017**
 - Proposes **FY18 ESD funding at \$1.754B**
 - Proposes **termination** of analysis activities for **DSCOVER** EO instruments **EPIC, NISTAR**
 - Proposes **termination** of development activities for **OCO-3, PACE, CLARREO-PF, RBI**
 - Proposes **termination** of Carbon Monitoring System science activities (R&A)
 - Proposes **reduction** of ESD **research** activities for FY18
- **CONGRESS** must pass an appropriation for the rest of FY18, and it must be signed by the **President**, by **8 Dec 2018** (or short-term *continuing resolutions* must be passed and signed)
 - Actual passed/signed appropriation is informed by – **but possibly modified from** – the President's detailed budget proposal
 - House Appropriations Committee identified a budget of \$1.70B for ESD
 - Senate Approps. budgeted \$1.92B, restored DSCOVER, OCO-3, PACE, CLARREO-PF, called for RBI schedule and cost study, and was silent on the Carbon Monitoring System
- **Decadal Survey report expected by 31 December 2017**
 - If the DS follows the Statement of Work, NASA will conduct roadmapping activities for 12-18 months to translate science/application priorities into a portfolio of specific, realistic, launch-ordered missions
 - With 15 – 20 missions/instruments now in development for launch before 2023, Decadal budget wedge does not open up until FY21

FY18-22 President's Budget Request: ESD



| Budget Authority (in \$ millions) | Actual | Enacted | Request | Notional | | | |
|--|---------------|-----------|---------------|---------------|---------------|---------------|---------------|
| | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 |
| Earth Science Research | 477.7 | -- | 406.7 | 435.1 | 441.1 | 459.7 | 477.8 |
| Earth Systematic Missions | 914.6 | -- | 778.0 | 787.1 | 755.0 | 708.7 | 680.4 |
| Earth System Science Pathfinder | 233.6 | -- | 264.5 | 243.8 | 256.0 | 271.5 | 268.3 |
| Earth Science Multi-Mission Operations | 192.4 | -- | 196.5 | 194.1 | 200.7 | 208.6 | 218.6 |
| Earth Science Technology | 60.7 | -- | 60.4 | 59.7 | 63.6 | 65.9 | 67.8 |
| Applied Sciences | 47.6 | -- | 47.9 | 49.3 | 52.8 | 54.7 | 56.3 |
| Total Budget | 1926.6 | -- | 1754.1 | 1769.1 | 1769.1 | 1769.1 | 1769.1 |

- Maintains a robust program of competed Venture-class missions
- Supports formulation and development of ICESat-2, GRACE-FO, SWOT, NISAR, Landsat 9, Sentinel-6, TSIS-1, TEMPO, GEDI, MAIA, ECOSTRESS, OMPS-L, TROPICS, and GeoCarb.
- Multi-Decadal Sustainable Land Imaging (SLI) program provides Land Imaging Technology and System Innovation.
- Supports initiatives to use smaller, less expensive satellites and public-private partnerships to advance science in a cost-effective manner, including cubesats and small satellite constellations.
- Operates 18 additional missions, and Airborne Science
- NASA will receive a new Earth Science Decadal Survey in December 2017
- **Proposes termination** of Carbon Monitoring System and proposes reductions in funding for Earth science research grants.
- **Proposes termination** of five Earth Science **missions—PACE, RBI, OCO-3, DSCOVR Earth-viewing instruments, and CLARREO Pathfinder.**
- Proposed terminations reflect budget priorities and the need to adjust the Agency's budget to match the nation's current fiscal position.

Earth Science Missions

FY17 Program of Record

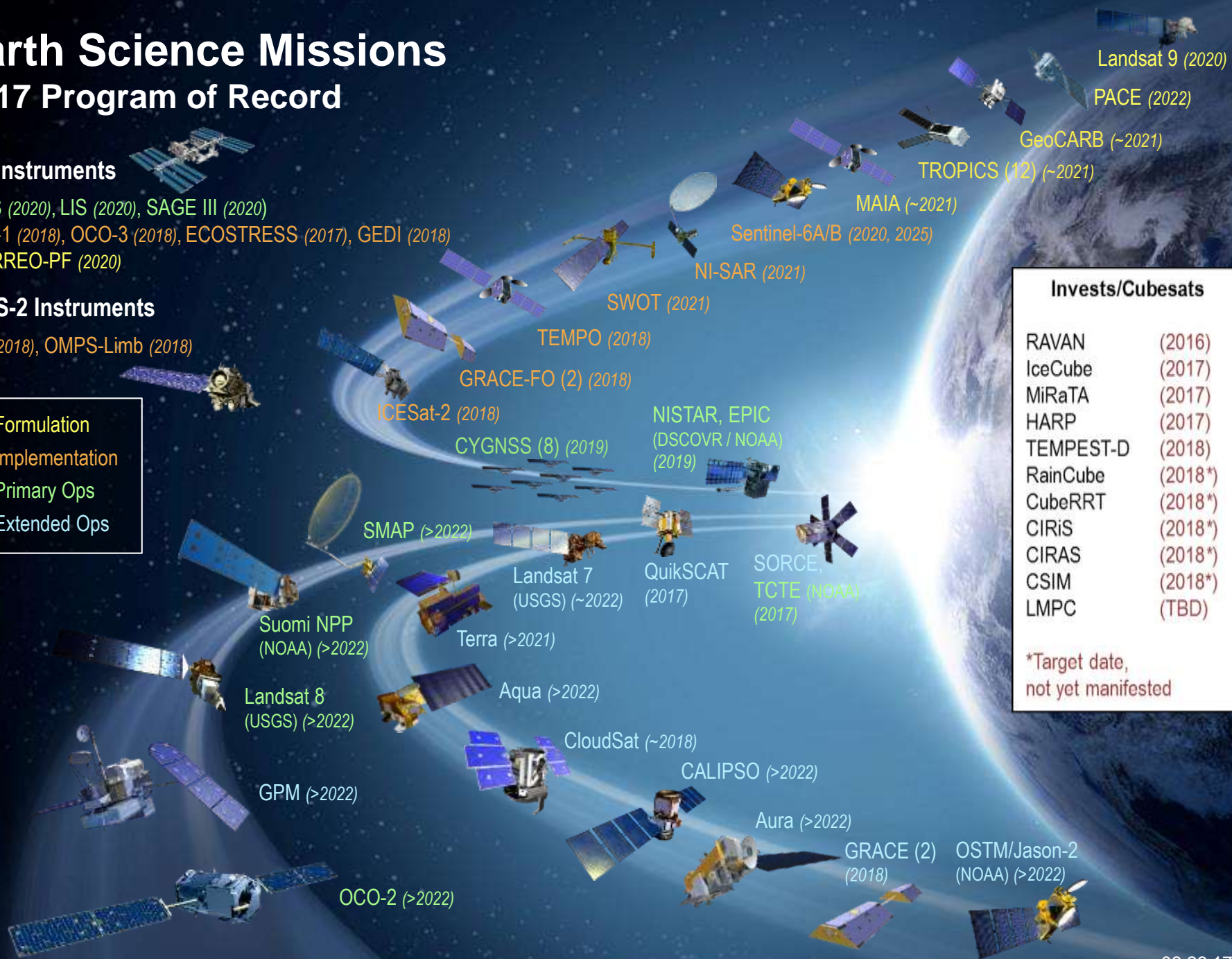
ISS Instruments

CATS (2020), LIS (2020), SAGE III (2020)
 TSIS-1 (2018), OCO-3 (2018), ECOSTRESS (2017), GEDI (2018)
 CLARREO-PF (2020)

JPSS-2 Instruments

RBI (2018), OMPS-Limb (2018)

| | |
|---|----------------|
| ■ | Formulation |
| ■ | Implementation |
| ■ | Primary Ops |
| ■ | Extended Ops |



| Invests/Cubesats | |
|------------------|---------|
| RAVAN | (2016) |
| IceCube | (2017) |
| MiRaTA | (2017) |
| HARP | (2017) |
| TEMPEST-D | (2018) |
| RainCube | (2018*) |
| CubeRRR | (2018*) |
| CIRiS | (2018*) |
| CIRAS | (2018*) |
| CSIM | (2018*) |
| LMPC | (TBD) |

*Target date, not yet manifested

Earth Science Missions

President's Budget Request (May 2017)

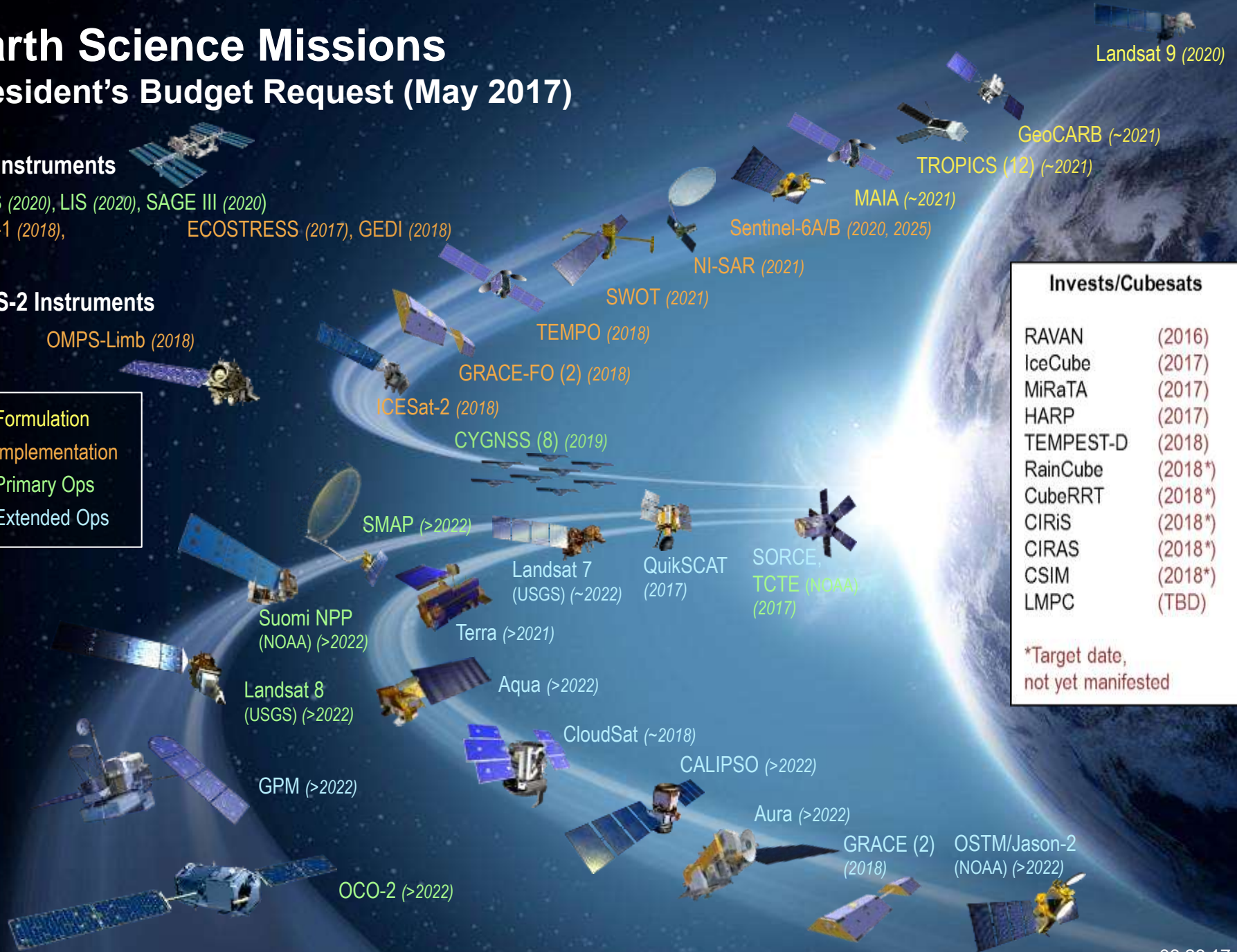
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JPSS-2 Instruments

OMPS-Limb (2018)

| | |
|---|----------------|
| ■ | Formulation |
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| ■ | Primary Ops |
| ■ | Extended Ops |



Landsat 9 (2020)

GeoCARB (~2021)

TROPICS (12) (~2021)

MAIA (~2021)

Sentinel-6A/B (2020, 2025)

NI-SAR (2021)

SWOT (2021)

TEMPO (2018)

GRACE-FO (2) (2018)

ICESat-2 (2018)

CYGNSS (8) (2019)

SMAP (>2022)

Landsat 7 (USGS) (~2022)

QuikSCAT (2017)

SORCE, TCTE (NOAA) (2017)

Suomi NPP (NOAA) (>2022)

Terra (>2021)

Landsat 8 (USGS) (>2022)

Aqua (>2022)

CloudSat (~2018)

CALIPSO (>2022)

GPM (>2022)

Aura (>2022)

GRACE (2) (2018)

OSTM/Jason-2 (NOAA) (>2022)

OCO-2 (>2022)

| Invests/Cubesats | |
|------------------|---------|
| RAVAN | (2016) |
| IceCube | (2017) |
| MiRaTA | (2017) |
| HARP | (2017) |
| TEMPEST-D | (2018) |
| RainCube | (2018*) |
| CubeRRR | (2018*) |
| CIRiS | (2018*) |
| CIRAS | (2018*) |
| CSIM | (2018*) |
| LMPC | (TBD) |

*Target date, not yet manifested

Earth Venture Overview



EVS
Sustained Sub-Orbital Investigations
(~4 years)

EVM Complete,
self-contained,
small missions
(~4 years)

EVI
Full function, facility-class instruments
Missions of Opportunity (MoO)
(~18 months)

| Mission | Mission Type | Release Date | Selection Date | Major Milestone |
|-------------------------|--|--------------|----------------|--------------------------|
| EV-1, aka EVS-1 | 5 Suborbital Airborne Campaigns | 2009 | 2010 | N/A |
| EVM-1, CYGNSS | Smallsat constellation | 2011 | 2012 | Launched December 2016 |
| EVI-1, TEMPO | Geosynchronous hosted payload | 2011 | 2012 | Delivery NLT 2017 |
| EVI-2, ECOSTRESS & GEDI | Class C & Class D ISS-hosted Instruments | 2013 | 2014 | Delivery NLT 2019 |
| EVS-2 | 6 Suborbital Airborne Campaigns | 2013 | 2014 | N/A |
| EVI-3, MAIA & TROPICS | Class C LEO Instrument & Class D Cubesat Constellation | 2015 | 2016 | Delivery NLT 2021 |
| EVM-2, geoCARB | Geostationary hosted payload | 2015 | 2016 | Launch ~2021 |
| EVI-4 | Instrument Only | 2016 | 2017 | Delivery NLT 2021 |
| EVS-3 | Suborbital Airborne Campaigns | 2017 | 2018 | N/A |
| EVI-5 | Instrument Only | 2018 | 2019 | Delivery NLT 2023 |
| EVM-3 | Full Orbital | 2019 | 2020 | Launch ~2025 |
| EVI-6 | Instrument Only | 2019 | 2020 | Delivery NLT 2024 |

Open solicitation - In Review

Completed solicitation

NASA Earth Venture Suborbital-2 Investigations



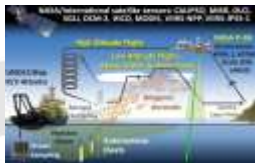
ACT-America (*Atmospheric Carbon and Transport – America*): Quantify the sources of regional carbon dioxide, methane, and other gases, and document how weather systems transport these gases



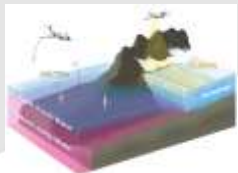
ATom (*Atmospheric Tomography Experiment*): Study the impact of human-produced air pollution on certain greenhouse gases



CORAL (*COral Reef Airborne Laboratory*): Provide critical data and new models to analyze the status of coral reefs and predict their future



NAAMES (*North Atlantic Aerosols and Marine Ecosystems Study*): Improve predictions of how ocean ecosystems would change with ocean warming



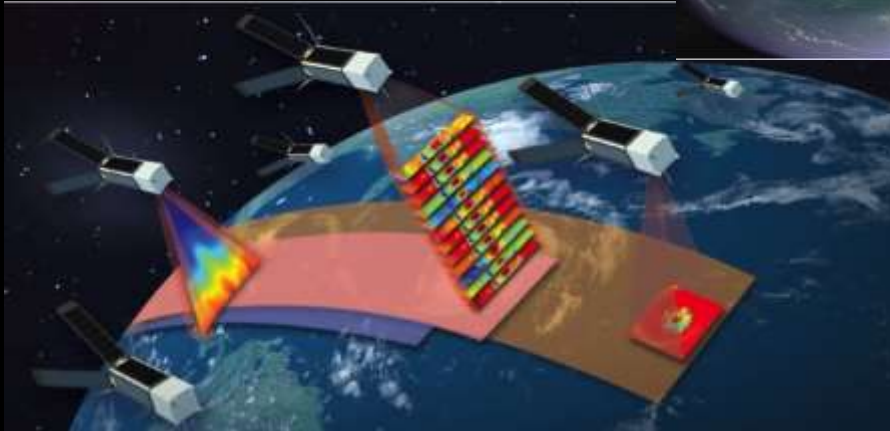
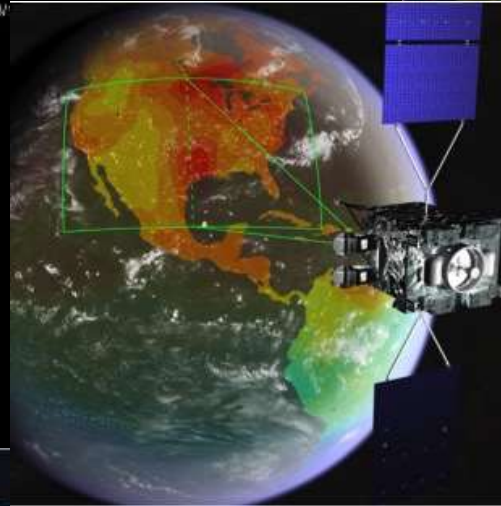
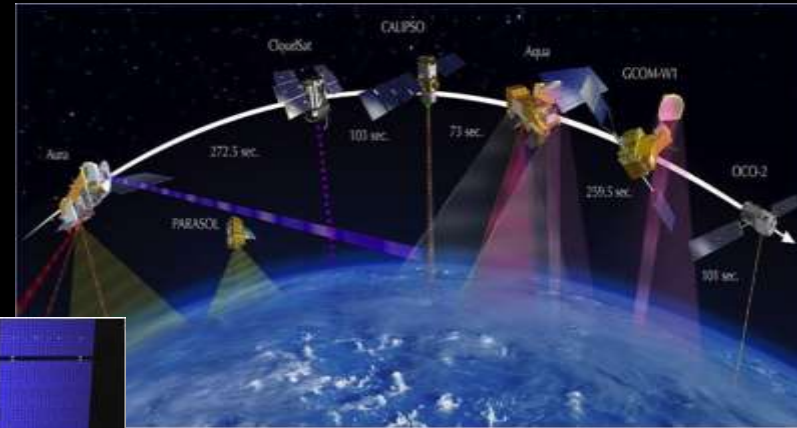
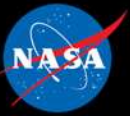
OMG (*Oceans Melting Greenland*): Investigate the role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting



ORACLES (*ObseRvations of Aerosols Above CLouds and Their IntEractionS*): Probe how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic

Eight NASA Centers;
Five US government agencies;
32 educational institutions;
Two non-profit institutions;
Three industry partners

NASA Observing System *INNOVATIONS*



CubeSats, SmallSats, and Constellations



- Small Satellite Solutions
 - Venture-class Launch Services (RocketLabs USA, Virgin Galactic – NASA launches by April 2018, available for TROPICS)
 - CYGNSS homogeneous **SmallSat constellation** – launched December 2016
 - TROPICS homogeneous **CubeSat constellation** – first science CubeSat
 - InVEST CubeSat-based technology demonstrations (RAVAN, ICECube launched; at least 7 more manifested for launch by end of 2018)
- SmallSat and Commercial Partnership
 - SmallSat constellation data buy program (\$20M/year FY 2018-2023 if appropriated, pilot starting in FY 2018)
- Hosted Payload solutions
 - TEMPO (instrument on NASA-arranged geo comsat)
 - MAIA (instrument on NASA-arranged LEO satellite – likely commercial)
 - GeoCarb (instrument on PI-arranged geo comsat)
 - Extensive use of ISS (ISERV, CATS, RapidScat, SAGE-III, LIS, ECOSTRESS, GEDI, TSIS-1, ...)
- Miniaturized Science Payload Development
 - CSIM/TSIM development/test to replace TSIS-2 (2023 launch)
 - SLI-T instrument development for Landsat-10, future SLI consideration (6 projects selected)
- Heterogeneous, International Constellations (e.g., A-Train)

Selected Private Sector Activities



- Private-Sector Bilateral Partnerships [started 2016]
 - Microsoft; Google; Mercy Corps; Conservation International
 - Space Act Agreements
- Early Adopter Program for ESD Flight Missions
 - Presently 72 organizations – domestic and international – for SMAP, ICESat-2 alone
 - SWOT, PACE, ECOSTRESS, TEMPO, NISAR, TROPICS in development
 - Pre-launch activities funded by participating organizations (not NASA)
 - ESD and missions manage overall program
- Data System
 - Commercial Cloud utilization pilots/prototypes for EOSDIS and DAACs
 - Space Act Agreements with Amazon Web Services, Google, Microsoft
 - Coordinated with OCIO (NASA-compliant General Application Platform) for security/monitoring/accounting
 - Examining/testing hosting of core DAAC functions and processing
 - Common Cross-DAAC Development Strategy for Applications/Interfaces
 - Developing/Testing NASA-compliant Open-Source software development approaches

Small-Satellites and Constellations



- NASA/ESD objectives include encouraging/enabling efficient approaches to advancing Earth System Science and applications development for societal benefit – ***including use – where they make sense – of measurements and information products derived from government-funded, and/or private sector-developed, small-satellite constellations***
- As an interested consumer, NASA is willing to purchase Earth-relevant data and information products derived from small-satellite constellations developed by the private sector *in order to evaluate their value to the ESD research mission*
- ESD has responsibilities and international arrangements which drive us to an open data exchange policy; however we are keenly aware of intellectual property rights. Near-term ***evaluation*** pilot activities will likely be confined to NASA-funded, non-real-time research
- Initial RFI was released in 2016, with good response; full solicitation (contract vehicle under evaluation) likely in Q1 FY18

Satellite Needs Working Group Activity Summary

- Satellite Needs Activity Objective: ***Identify, communicate to NASA, and NASA respond to USG agency requests for specific “new” satellite-based Earth observation data/information products***
- NASA received 187 product requests from 17 Federal government departments and agencies (*99 product requests from DOE alone*)
 - ESD assembled 36 SMEs who worked from November 2016 to May 2017, analyzing/clarifying the requests and determining the feasibility of generating and providing the desired information products
- Process kindled focused **NASA** discussions on creative ways to meet the needs/requests
- Process served as a tool to spread awareness to other agencies about NASA’s existing products
- Process highlighted the high degree of overlap between existing/planned NASA products, and other agencies’ data product needs

Needs/Desired Data Products Summary



| Agency | Submitted Need Count | Data Products requested | Existing | Phase C+ | Formulation | Decadal | Commercial | New Development | Airborne |
|--|----------------------|-------------------------|----------|----------|-------------|---------|------------|-----------------|----------|
| Agriculture Research Service (ARS) | 2 | 3 | 2 | 1 | | | | | |
| Bureau of Land Management (BLM) | 3 | 11 | 4 | 4 | | | | | 3 |
| Bureau of Reclamation (BR) | 1 | 5 | 4 | 1 | | | | | |
| Environmental Protection Agency (EPA) | 5 | 13 | 10 | 1 | 1 | 1 | | | |
| Farm Service Agency (FSA) | 1 | 1 | 1 | | | | | | |
| Federal Emergency Management Agency (FEMA) | 1 | 2 | 1 | 1 | | | | | |
| Foreign Agricultural Service (FAS) | 3 | 5 | 4 | 1 | | | | | |
| Forest Service (USFS) | 3 | 4 | 4 | | | | | | |
| National Agriculture Statistics Service (NASS) | 1 | 1 | 1 | | | | | | |
| National Oceanic and Atmospheric Administration (NOAA) | 8 | 10 | 7 | | 1 | | | 2 | |
| National Science Foundation (NSF) | 1 | 1 | | | 1 | | | | |
| Natural Resources Conservation Service (NRCS) | 2 | 2 | | | | 1 | | | 1 |
| Department of Energy (DOE) | 13 | 99 | 56 | 6 | 2 | 9 | 1 | 11 | 16 |
| Risk Management Agency (RMA) | 2 | 2 | 1 | | | 1 | | | |
| U.S. Agency for International Development (USAID) | 9 | 3 | | 3 | | | | | |
| U.S. Fish and Wildlife Service (USFWS) | 5 | 6 | | 2 | | | 2 | 2 | |
| U.S. Geological Survey (USGS) | 17 | 19 | 6 | 3 | | 4 | 5 | | 1 |

NASA Assessment Summary



- **46** product needs could be **nearly fully met with measurements from existing on-orbit systems**
 - 23 requested products could be provided at 100% and 23 at 90% or better
- **25** product requests could be substantially met (at the 70% – 90% level) with (1) presently on-orbit and in-development missions, and (2) by combining measurements from multiple similar missions – particularly Landsat 7/8 and Sentinel-2A/B
- **33** requests for agricultural information products could be **substantially satisfied by the planned September 2022 launch of the NASA-ISRO Synthetic Aperture Radar (NISAR) mission** coupled with a modification/addition of an additional ground station to increase its bandwidth and/or modifications to the collection mode
- **9** desired products for soil moisture could be **substantially provided by modifying the planned NASA-ISRO Synthetic Aperture Radar (NISAR) split-spectrum measurement acquisition strategy** – including increasing the mission’s download bandwidth – and generating previously unplanned soil moisture products

None of the remaining 108 submitted needs can be met at the estimated 70% level by NASA and/or partner missions presently in development for launch before the 2025 timeframe

NASA Assessment Summary



- Requested data products **most easily** provided included: fire detection, vegetation and land cover, land disturbance and use, land surface temperature, land classification, vegetation continuous fields, evapotranspiration, precipitation, surface albedo, snow cover, surface deformation, sea ice, water storage and solar induced fluorescence (SIF) at moderate spatial (100s of meters or coarser) and temporal (days or less frequent) resolutions
- **More difficult** data products to provide included: all of the above (when higher temporal, spatial, or spectral resolution was needed), SAR products, and detailed cloud products (fraction, reflectance, emissivity, phase, distribution, etc.)
- Product requests **impossible to meet** before 2025 or later included: fine resolution hyperspectral imagery (presently unfunded HypSIRI mission); animal telemetry; fire front locations (unfunded Firesat); global, vertically resolved cloud properties, motions, and distributions; snow depth; vegetation structure change; and global vertical wind profiles

Agencies Requesting Possible Near-Term Products



- Cloud retrievals from Landsat: **DOE, EPA, NOAA, NSF, RMA, USAID, USDA, USFWS**
- NISAR Soil Moisture Products*: **ARS, BLM, BR, DOE, FEMA, NRCS, USAID, USDA, USFWS, USGS**
- Historical Airborne Products: **DOE, EPA, FEMA, NOAA, USDA, USFWS, USGS**
- Polar Geospatial and NGA Availability: **USAID, USDA, USGS**
- Harmonized Landsat/Sentinel-2 (archive/distro): **BLM, FEMA, USDA, USFWS, USGS**

* Requires NISAR Quad-Pol 40 MHz hardware/download/conops augmentation



BACKUP



Flight Validation Highlights: InVEST-12,15

| PI Name | Org | Status | InVEST-12 Project Title | Start Date | End Date | Comments |
|----------|----------------|--------|---|------------|----------|---|
| Swartz | JHU-APL | | RAVAN Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) | 08/16/13 | 08/20/18 | Launched 11/11/16 , Continues to regularly acquire radiometer and calibration data. Updated payload firmware s/w to mitigate SD card failure. Held annual review August 16th, 2017 |
| Wu | GSFC | | IceCube: Spaceflight Val. of an 883- GHz Submm Wave Radiometer for Ice Cloud Remote Sensing | 04/14/14 | 09/30/17 | Launched 4/18/17 to ISS, OA-7, ELaNA-17 , deployed from ISS May 16 th , 2017. Routinely acquiring data during daylight. |
| Martins* | UMBC | | HARP HyperAngular Rainbow Polarimeter HARP-CubeSat | 08/12/16 | 09/30/17 | Re-manifested on Sp-X-14 ISS resupply launch, with November 1 st 2017 delivery Jan. 26 th , 2018 launch on ELaNa-21. Required augmentation to recover from battery test failure. |
| Cahoy | MIT | | MiRaTA The Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat | 12/11/13 | 03/01/18 | Delivered payload in PPOD on 6/26/17. Testing ground ops with EM. Launch – NET , Nov. 10th, 2017 on ELaNa-14 (JPSS-1). |
| Fields | Aerospace Corp | | LMPC (Linear Mode Photon Counting) A CubeSat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat) | 08/1/13 | 09/30/17 | Unable to meet the schedule for July delivery and did not meet the Sept. launch date – officially off the manifest. Made incremental progress under another program that can be applied to LMPC – resolved DAQ issues, have an improved detector assembly. Detector was radiation tested 8/2017 and is now TRL-6 |

* Project status presented in this EPR

| PI Name | Org | Status | InVEST-15 Project Title | Start Date | End Date | Comments |
|----------|------|----------|---|------------|----------|---|
| Peral | JPL | CSLI #2 | RainCube: A Precipitation Profiling Radar in a CubeSat | 11/16/15 | 11/15/18 | Instrument successfully completed bus fit-check, Tyvak Sept. 11th, 2017. Annual Review Oct 10th, 2017. Manifest on OA-9, ELaNA-23 ISS launch March 14 th , 2018. Delivery NET February 1 st , 2018, |
| Johnson | OSU | CSLI #10 | CubeRRT: CubeSat Radiometer Radio Frequency Interference Tech Validation | 01/04/16 | 01/03/19 | Interim review held June 7th, 2017. FM payload delivery to BCT on target for 9/30/17 delivery. Manifest on OA-9, ELaNA-23 ISS launch March 14 th , 2018. Delivery NET February 1 st , 2018 |
| Osterman | BATC | CSLI #11 | CIRiS: Compact Infrared Radiometer in Space | 01/11/16 | 01/10/19 | Interim review held July 14 th , 2017. LSP should be securing launch soon may be ISS or VCLS |
| Pagano | JPL | CSLI #5 | CIRAS: CubeSat Infrared Atmospheric Sounder | 05/01/16 | 05/31/19 | Significant (x2) extra funding required to deliver flyable unit |

2017 Senior Review – April-June 2017



The Senior Review makes recommendations on the continuation of on-orbit missions that are beyond their baseline design lives (2yr/4yr recommendations); most missions are generally recommended for continuation

Missions Included:

Thirteen missions evaluated: Aqua, Aura, CALIPSO, **ISS-CATS**, CloudSat, **DSCOVR Earth Science Instruments**, **GPM**, **OCO-2**, QuikSCAT, **SMAP**, **SORCE**, **TCTE**, and Terra. (Blue: New to the Senior Review)

Missions NOT included

EO-1: Not included based on 2015 SR findings; terminated in March 2017.

GRACE: GRACE is projected to re-enter due to orbital decay in approximately March 2018. Note: GRACE partners have agreed to operate GRACE in dual-satellite mode through December 2017.

Suomi-NPP: NOAA has stated that they will continue operating Suomi-NPP until JPSS-2 is on-orbit. No proposal for extension is required.

OSTM: Although OSTM has been extended through the Senior Review process in the past, it is operated by NOAA for operational purposes, and NOAA has stated that they will continue operating OSTM until it fails (similar to the Suomi NPP commitment). Therefore, NASA Sr. Review did not evaluate in 2017.

Landsat-7 and Landat-8: operated by USGS, no NASA MO&DA funding

CYGNSS, SAGE-III, ISS-LIS: in prime mission



Constellations ... Hosted ... Sat Size ... Temporal



CYGNSS

Cyclone Global Navigation Satellite System

8-microsat constellation
Launched 15.Dec.2016



TROPICS

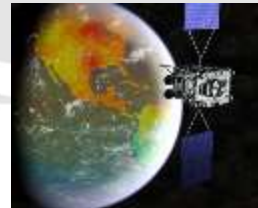
Time-Resolved Obs. of Precipitation structure and storm Intensity with a Constellation of Smallsats
6, 3U CubeSats; ~2021



TEMPO

Tropospheric Emissions: Monitoring Pollution

Hosted payload; ~2018
Geostationary platform

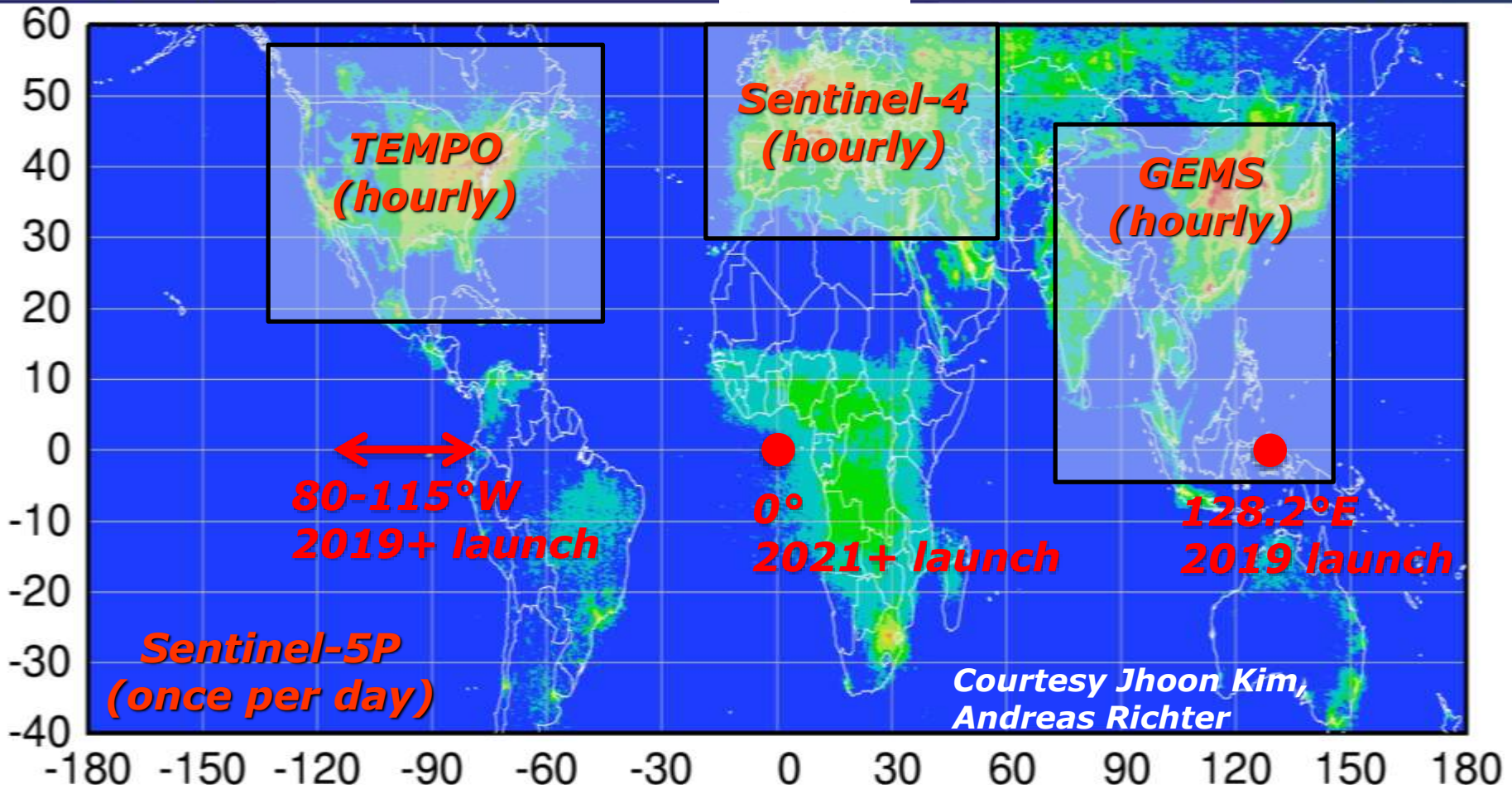


GeoCARB

Geostationary Carbon Observatory

Hosted payload; ~2021
SES Commercial Comm. Satellite

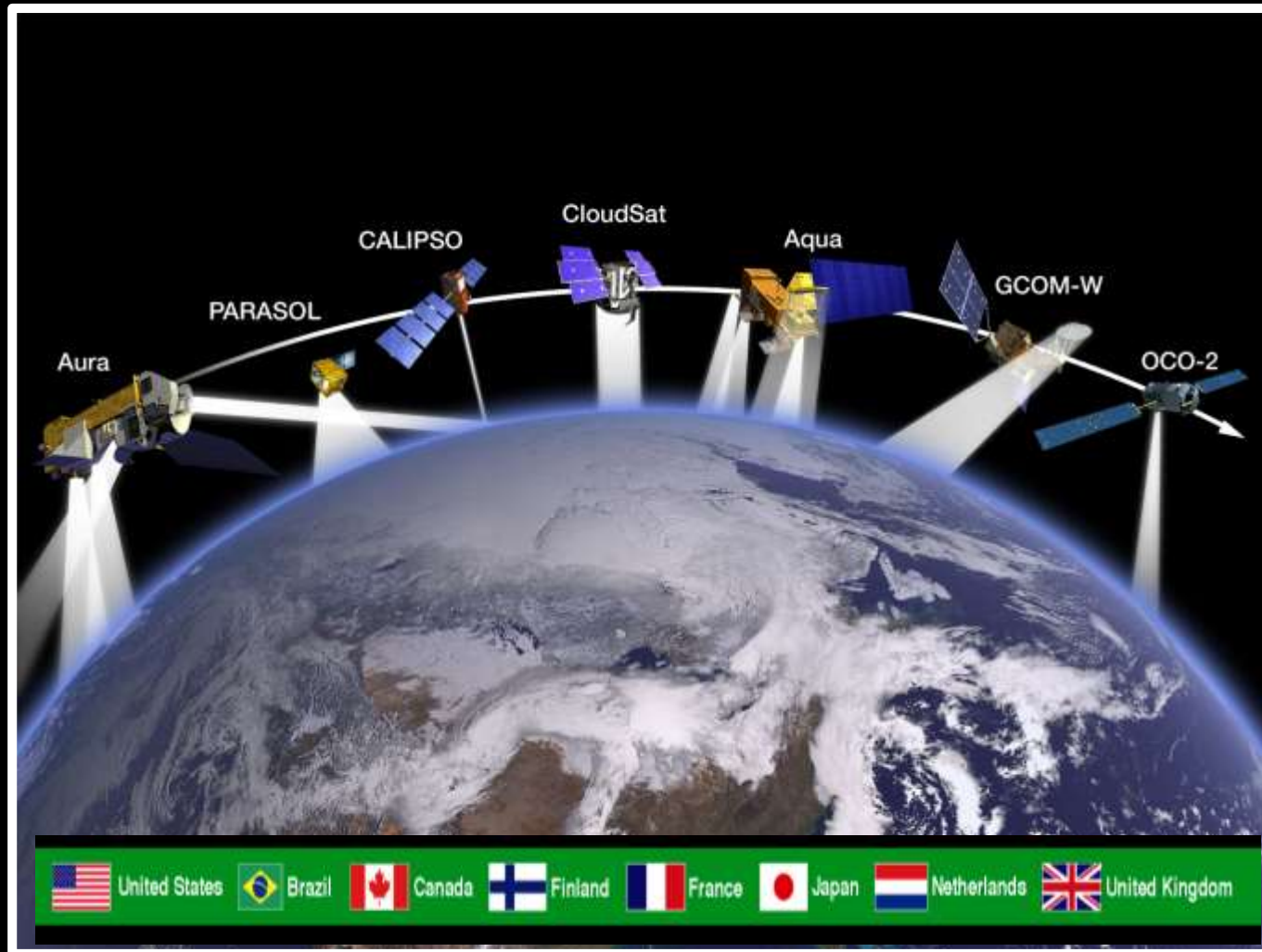
Global pollution monitoring constellation: Tropospheric chemistry missions funded for launch 2016-2021



Policy-relevant science and environmental services enabled by common observations

- Improved emissions, at common confidence levels, over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, e.g., observations to support United Nations Convention on Long Range Transboundary Air Pollution

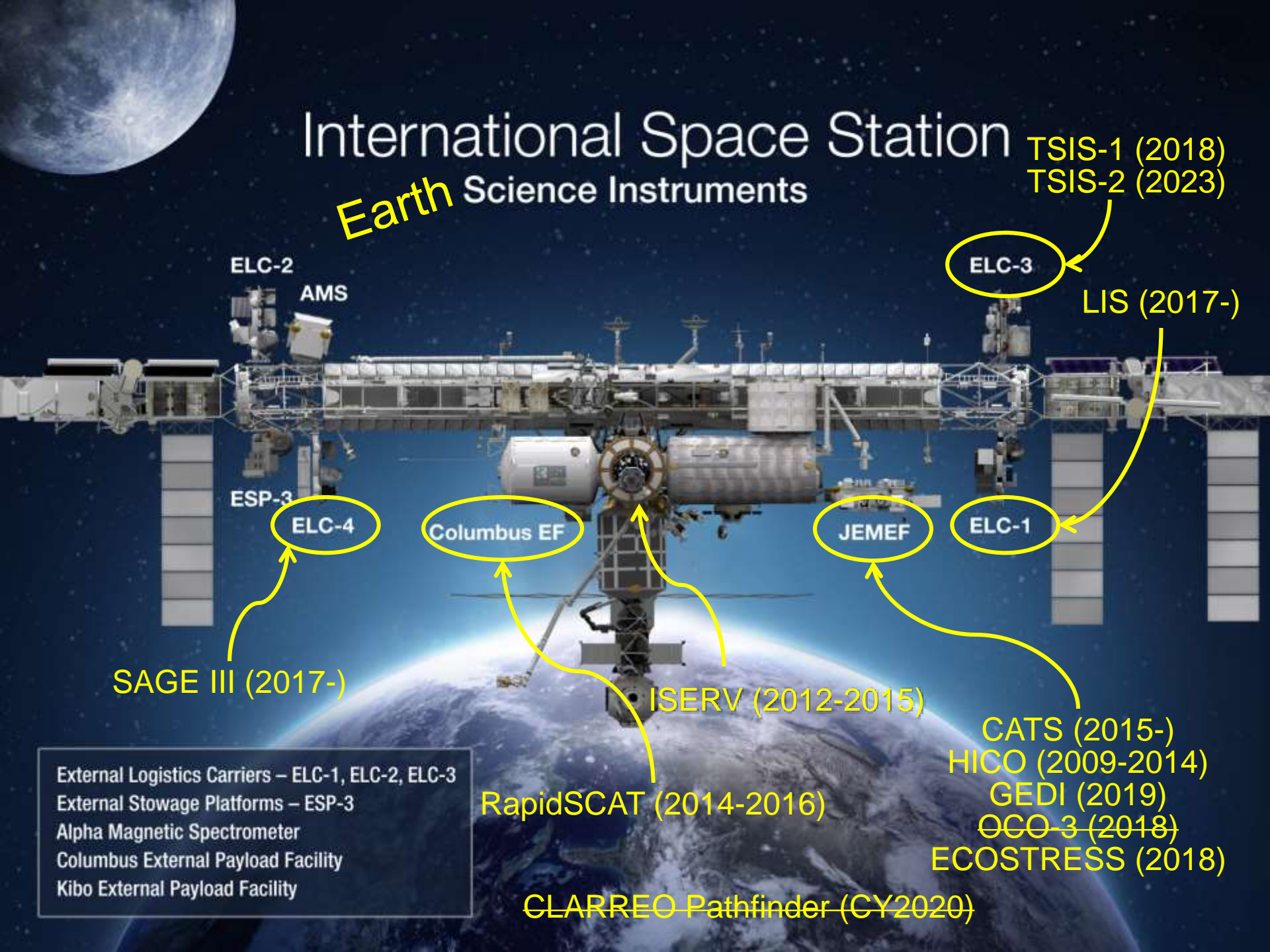
International A-Train



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

International Space Station

Earth Science Instruments



TSIS-1 (2018)
TSIS-2 (2023)

ELC-3

LIS (2017-)

ELC-2

AMS

ESP-3

ELC-4

Columbus EF

JEMEF

ELC-1

SAGE III (2017-)

ISERV (2012-2015)

CATS (2015-)

HICO (2009-2014)

GEDI (2019)

OCO-3 (2018)

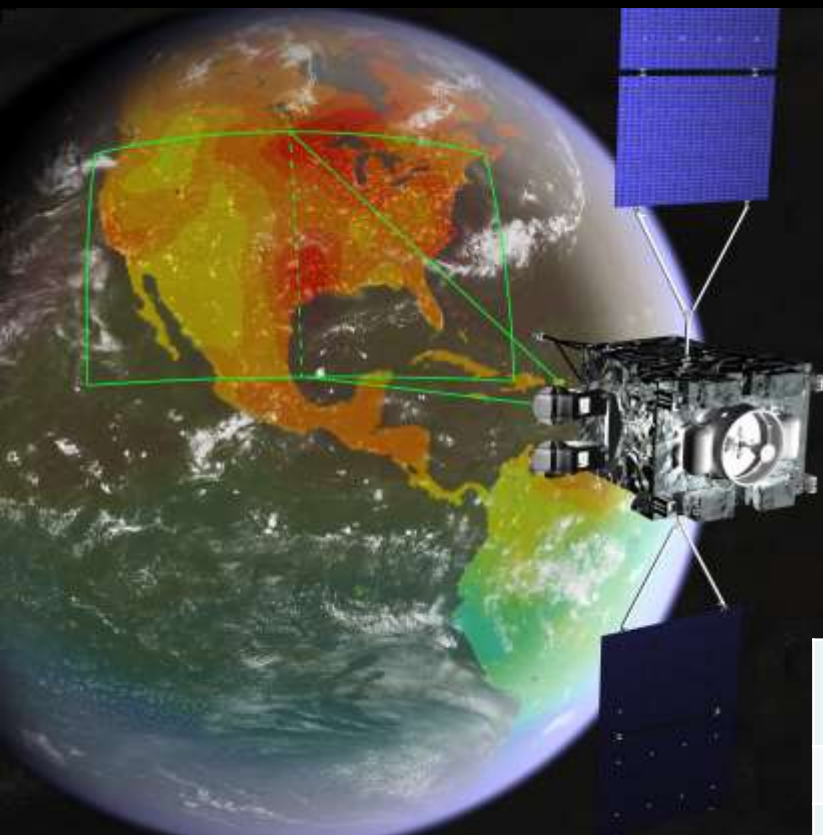
ECOSTRESS (2018)

RapidSCAT (2014-2016)

CLARREO Pathfinder (CY2020)

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

The **GeoCarb** Mission: Measuring Carbon Trace Gases and Vegetation Health from Space



Principal Investigator

Berrien Moore, Univ. of Oklahoma

Technology Development

Lockheed Martin Advanced Tech. Center

Host S/C & Mission Ops

SES Government Solutions

| | |
|-----------------|---|
| Instrument | Single slit, 4-Channel IR Scanning Littrow Spectrometer |
| Bands | 0.76m, 1.61m, 2.06m and 2.32m |
| Gases | O ₂ , CO ₂ , CO, CH ₄ & Solar Induced Fluorescence |
| Mass | 138 kg (CBE) |
| Dimensions | 1.3 m x 1.14 m x 1.3 m |
| Power | 128W (CBE) |
| Data Rate | 10 Mbps |
| Daily Soundings | ~10,000,000 soundings per day; CONUS > once/day 5-10 km spatial resolution |