

NASA Report on the Status of Current and Future Earth Satellite Systems

Presented to CGMS-46 Plenary Session, Agenda Item D.10

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Report prepared based on inputs from numerous colleagues at NASA HQ, NASA Centers (JPL, GSFC) and broader research community

Earth Science Missions

As of 13-May-18

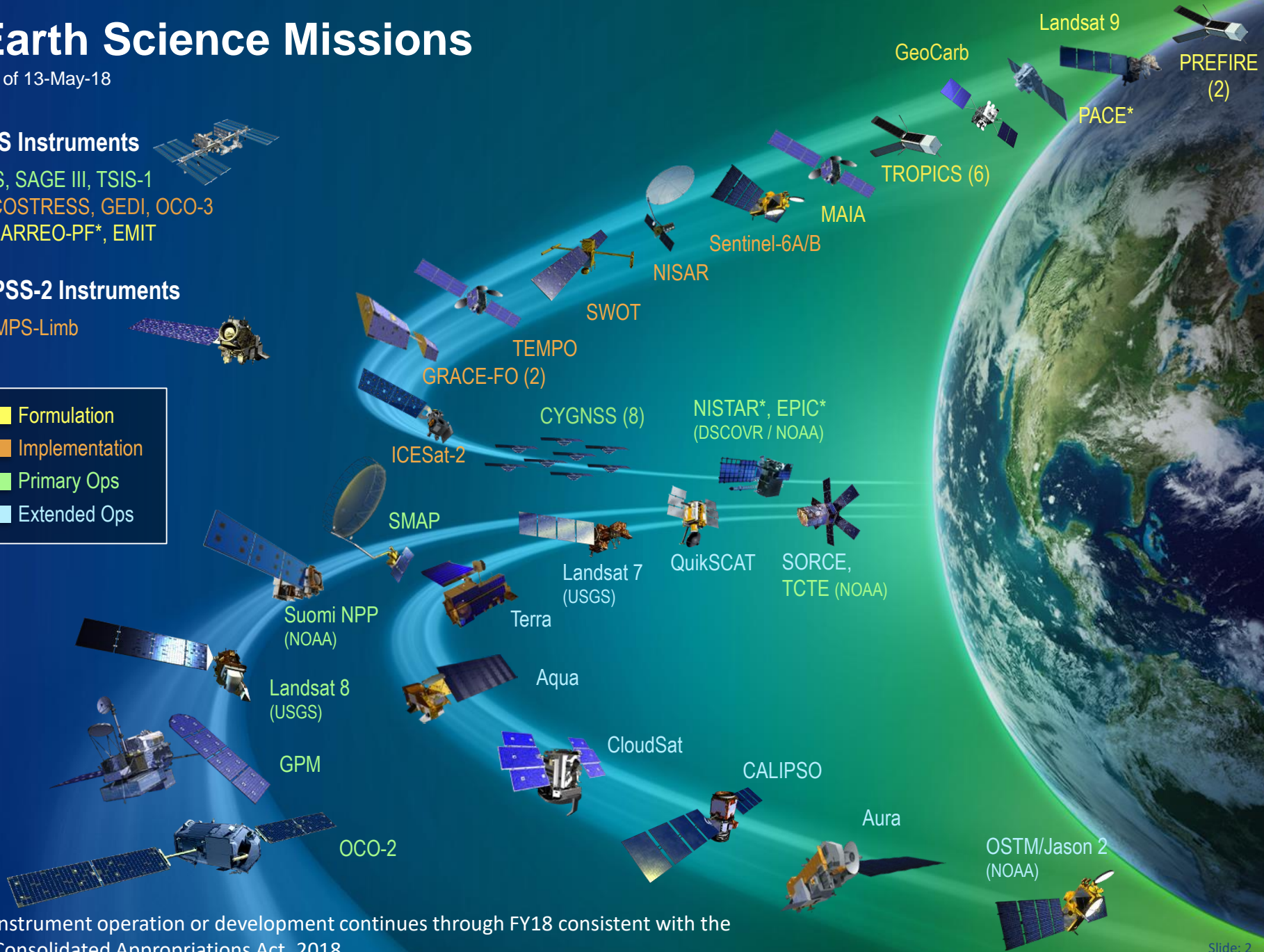
ISS Instruments

LIS, SAGE III, TSIS-1
ECOSTRESS, GEDI, OCO-3
CLARREO-PF*, EMIT

JPSS-2 Instruments

OMPS-Limb

- Formulation
- Implementation
- Primary Ops
- Extended Ops



* Instrument operation or development continues through FY18 consistent with the Consolidated Appropriations Act, 2018.

Overview of NASA's current and future satellite systems

Mission	Launch (CY)	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
QuickScat	1999																										
Landsat-7	1999																										
Terra	1999																										
Aqua	2002																										
SORCE	2003																										
Aura	2004																										
CALIPSO	2006																										
CloudSat	2006																										
Jason-2	2008																										
Suomi-NPP	2011																										
Landsat-8	2013																										
TCTE	2013																										
GPM Core	2014																										
OCO-2	2014																										
SMAP	2015																										
DSCOVR*	2015																										
CYGNSS	2016																										
SAGE-III-ISS	2017																										
LIS-ISS	2017																										
TSIS-1-ISS	2017																										
GRACE-FO	2018																										
ECOSTRESS-ISS	2018																										
ICESat-2	2018																										
CSIM	2018																										
GEDI-ISS	2018																										
OCO-3-ISS*	2019																										
TROPICS	2020																										
Landsat-9	2020																										
Sentinel-6A	2020																										

Current Missions – 21 total
 (as of 31 May 2018)

End dates may reflect NASA "Senior Review" approved dates, but these missions will likely operate longer.

By 2020, 5 missions and 3 instruments launched

Typical NASA missions are planned for 3 to 5 years but have operated much longer.

Future missions and instruments with launches > 2020
 (not shown in the figure)

TEMPO, SWOT, NISAR, CLARREO PF-ISS, PACE*, GeoCarb, MAIA, TSIS-2, EMIT, PREFIRE*

* Instrument operation or development continues through FY18 consistent with the Consolidated Appropriations Act, 2018.

Current **NASA** Satellites ... **Recent News**

- NASA is currently supporting operations of **21 Earth Science missions**.
- Four new missions have launched since CGMS-45:
 - **TSIS-1** launched on 15 Dec 2017, will measure total and spectral solar irradiance.
 - **RainCube** and **TEMPEST-D** launched on 21 May 2018 as technology demonstrations.
 - **GRACE-FO** launched on 22 May 2018, will continue measurements of the Earth's gravity field begun by the GRACE mission.
- The **GRACE** mission ended operations on 12 Oct 2017, due to a battery cell failure on the GRACE-2 satellite. GRACE-2 re-entered the Earth's atmosphere in December 2017 and the GRACE-1 satellite re-entered in March 2018.
- The **CATS** instrument on the ISS experienced an abrupt loss of power on 30 Oct 2017, which ended science operations for the mission.
- The **TES** instrument on the **Aura** mission was decommissioned on 31 Jan 2018.
- After more than 19 years in orbit, the **QuikSCAT** mission is scheduled to be decommissioned by 30 Sept 2018.
- Several new missions are scheduled for launch later this year:
 - **ECOSTRESS**
 - **ICESat-2**
 - **GEDI**
 - **CSIM-FD**

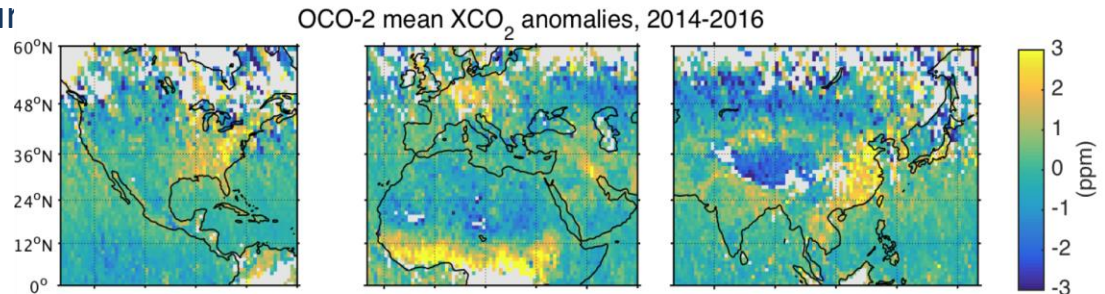
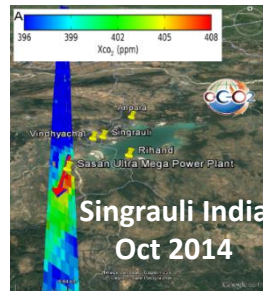
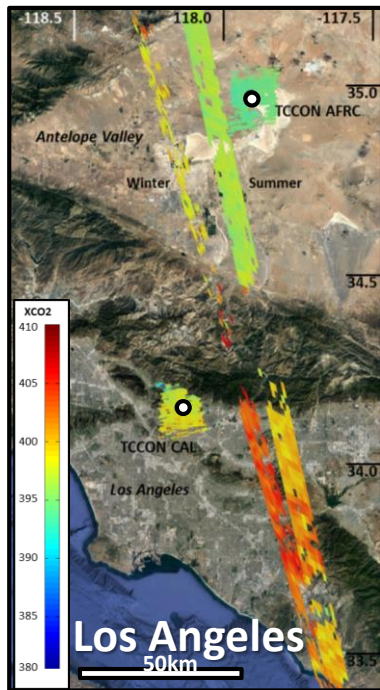
Current **NASA** Satellites ... Ongoing Activities

- NASA's missions were conceived as research missions, but have supported **operational and near-real-time applications** due to their recognized value, longevity, sustained calibration and validation, and data quality.
- Continued operation of the missions is determined through a science review process, called the "**Senior Review**", which considers operational use but primarily uses science for defining factor for continuation. Continued operations (up to 3 more years) was approved for all NASA missions at the end of 2017. The next Senior Review is scheduled for 2020.
- **Direct Broadcast** is currently available for three NASA missions including: Aqua, Terra, and Suomi-NPP. More information can be found at NASA's Direct Readout Laboratory (DRL) website: <http://directreadout.sci.gsfc.nasa.gov>
- NASA also provides access to **Near Real-Time (NRT)** products from the MODIS (on Terra and Aqua), OMI and MLS (on Aura), and AIRS (on Aqua) instruments in less than 2.5 hours from observation from the Land and Atmosphere Near real-time Capability for EOS (LANCE) data system at <http://earthdata.nasa.gov/lance>

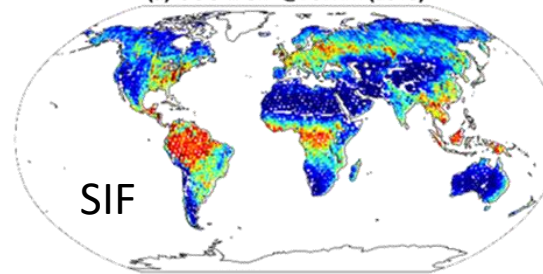
Measurement Continuity and Transition to Follow-on Missions

Orbiting Carbon Observatory-2 (OCO-2)

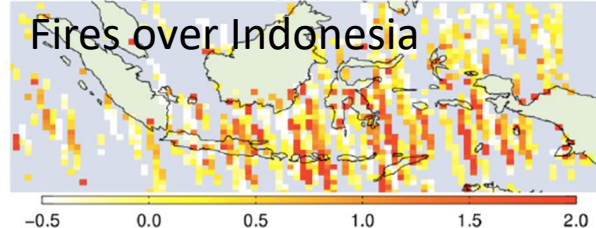
- OCO-2 acquires space-based measurements of carbon dioxide (CO_2), with unprecedented precision and accuracy.
- OCO-2 X_{CO_2} and solar induced chlorophyll fluorescence (SIF) are being used to study the response of the carbon cycle to the intense 2015-2016 El Niño as well as anthropogenic emissions of CO_2 from fossil fuel combustion and biomass bur



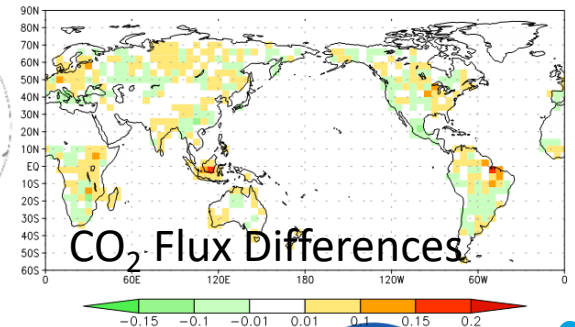
(a) OCO-2 SIF @757nm (2015)



(c) OCO-2 X_{CO_2} enhancements [ppm]



2015 - 2011 (GtC/yr)



GRACE Follow-On spacecraft launched onboard a SpaceX Falcon 9 on 22 May 2018



Above: lifted off on a SpaceX Falcon 9 rocket from Space Launch Complex 4E at Vandenberg Air Force Base in California at 12:47 pm PT from Vandenberg Air Force Base, sharing their ride into space with five Iridium NEXT communications satellites.

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission is a partnership between NASA and the German Research Centre for Geosciences (GFZ). GRACE-FO is a successor to the original GRACE mission, which orbited Earth from 2002-2017. GRACE-FO will carry on the extremely successful work of its predecessor while testing a new technology designed to dramatically improve the already remarkable precision of its measurement system. Ground stations have acquired signals from both GRACE-FO spacecraft. Initial telemetry shows the satellites are performing as expected. The GRACE-FO satellites are at an altitude of about 305 miles (490 kilometers), traveling about 16,800 mph (7.5 kilometers per second). They are in a near-polar orbit, circling Earth once every 90 minutes.

The GRACE-FO satellites will spend their first few days in space moving to the separation distance needed to perform their mission. When they reach this distance, the mission begins an 85-day, in-orbit checkout phase. Mission managers will evaluate the instruments and satellite systems and perform calibration and alignment procedures. Then the satellites will begin gathering and processing science data. The first science data are expected to be released in about seven months.

<https://www.nasa.gov/gracefo>

Right: the twin GRACE-FO spacecraft stack mounted on top of the 5 Iridium NEXT satellites



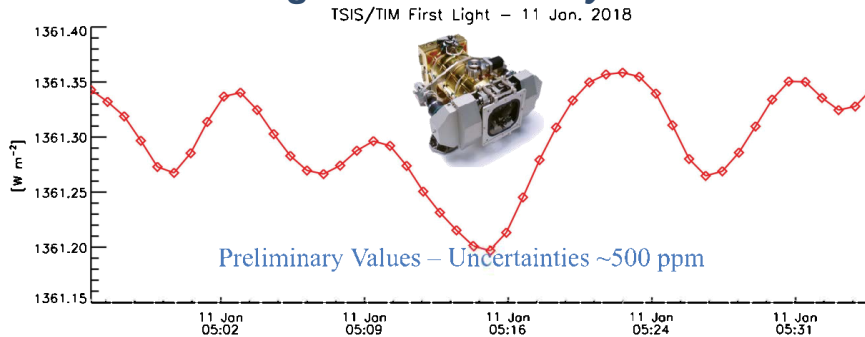
Measurement Continuity and Transition to Follow-on Missions

Total and Spectral Solar Irradiance Sensor on the ISS (TSIS-1)

- Launched on 15 December 2017
- Provides two measurements critical for understanding solar influences on Earth's climate:

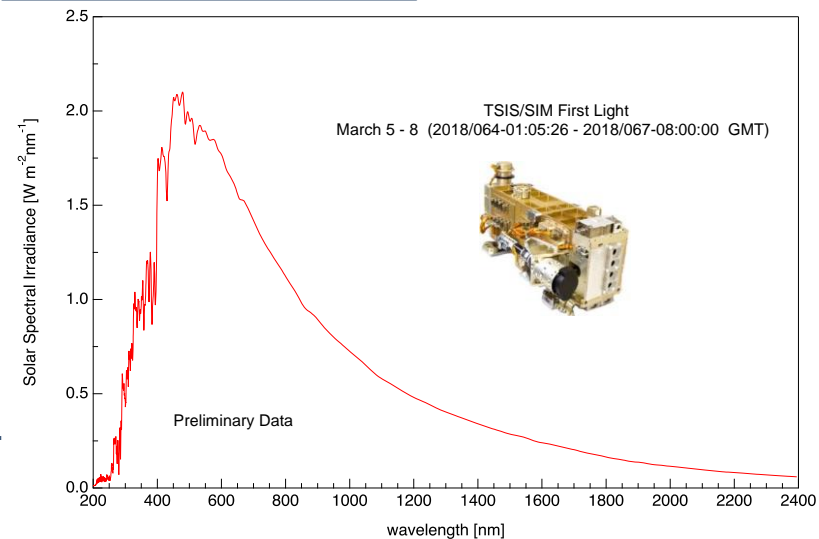
Total solar irradiance (TSI)

- Earth's predominant energy source.
- Total Irradiance Monitor (TIM) will **continue a 40-year long uninterrupted measurement record of TSI.**
- *TSIS TIM operating flawlessly – first light on 11 January 2018.*



Solar spectral irradiance (SSI)

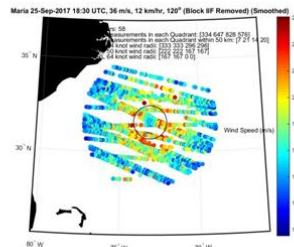
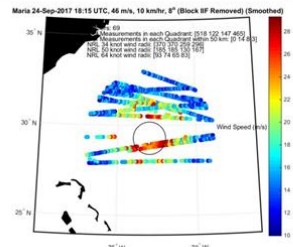
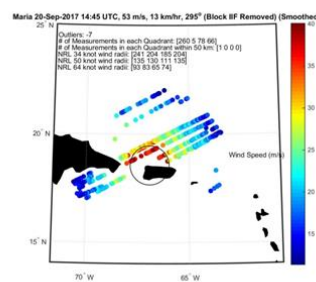
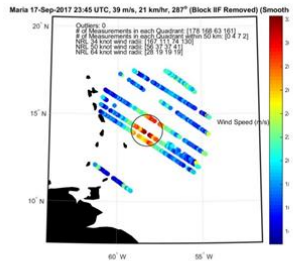
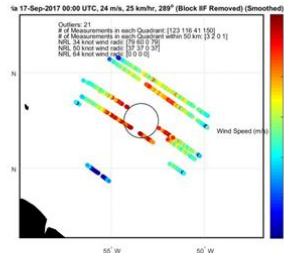
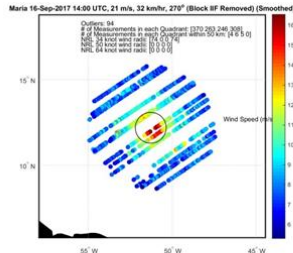
- Measured by the Spectral Irradiance Monitor (SIM).
- Identifies the regions of atmosphere that are affected by solar variability and the mechanisms of response.
- *TSIS SIM operating flawlessly – first light on 5 March 2018.*



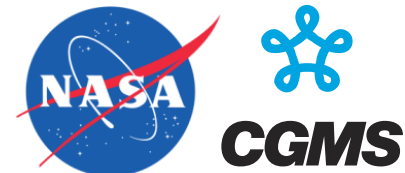
Cyclone Global Navigation Satellite System (CYGNSS) Mission

Wind speed during Hurricane Maria Overpasses

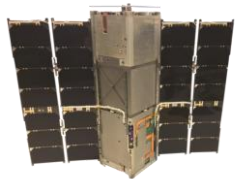
- 16 Sep @ 14:00, 17 Sep @ 00:00 UTC
- 17 Sep @ 23:45, 20 Sep @ 14:45 UTC
- 24 Sep @ 18:15, 25 Sep @ 18:30 UTC



- 15 Dec 2016 at 08:37 EST: Launch
- Mar 2017: begin “Science Mode” with continuous data taking; Initial Cal/Val
- May 2017: Provisional release of wind speed data products to NASA PO.DAAC
- Aug – Oct 2017: Atlantic Hurricane Overpasses; High wind Cal/Val
- Nov 2017: Public (non-provisional) release of wind speed data products to NASA PO.DAAC



Successful Launch and Operations for ESTO 3U CubeSats



RAVAN launched on 11 November 2016 and began taking data on 25 January 2017. It is still in orbit and continues to collect data to better refine and quantify the instrument performance.



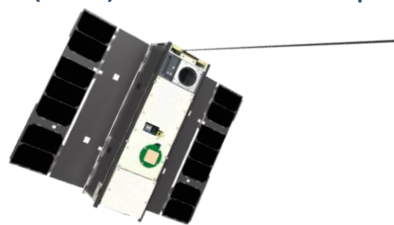
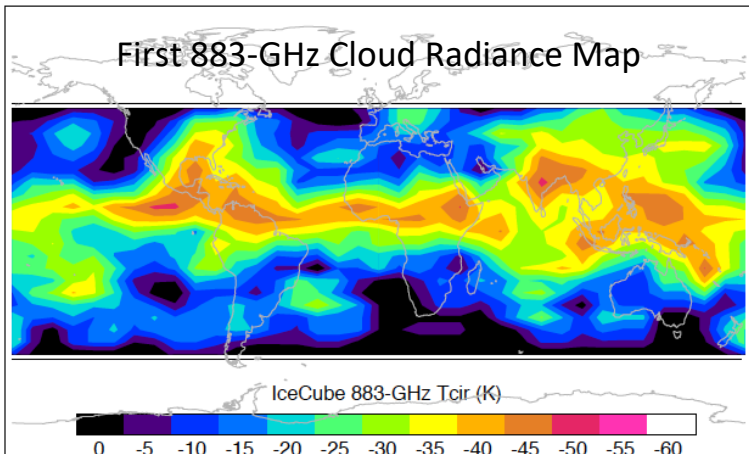
IceCube

Launched on 18 April 2017 on Orbital ATK's seventh commercial resupply services mission to the ISS and was deployed on 16 May 2017.

Data collected by IceCube produced the **first global ice-cloud map** using a commercially available 883-GHz radiometer.

Successfully demonstrated and still in orbit, this submillimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer, such as that called for by the **Aerosol-Cloud-Ecosystem (ACE)** mission concept.

IceCube Cloud-Induced Radiance (Tcir)
During 20170620 to 20170702

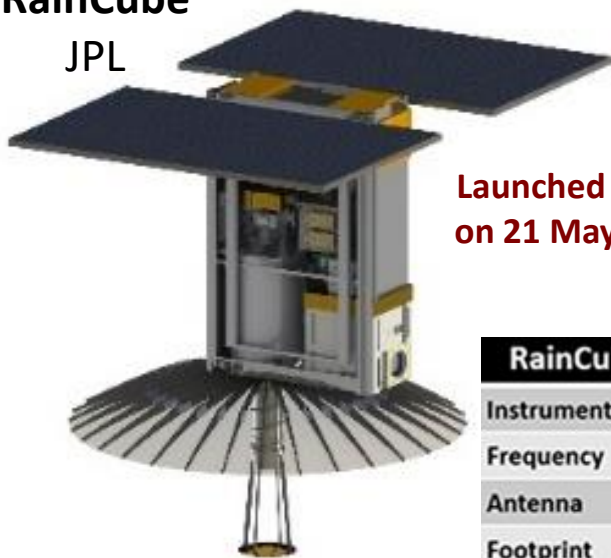


IceCube is a 3U CubeSat weighing 10 pounds, complete with three-axis attitude control, deployable solar areas and a deployable UHF communications antenna. (Image credits: NASA)

Successful Launch for ESTO-managed 6U CubeSats

RainCube

JPL



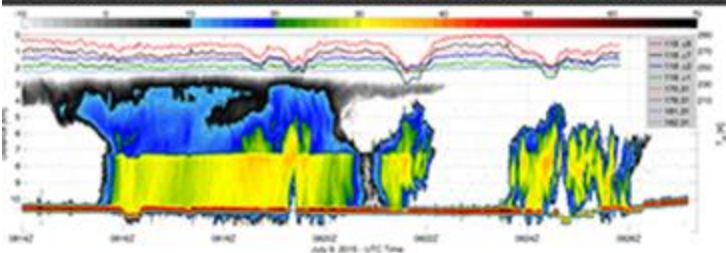
Launched to ISS
on 21 May 2018

RainCube	Value
Instrument	Ka-Band Radar
Frequency	35.75 GHz
Antenna	0.5m deployable
Footprint	<10 km
Vert. resolution	<250 m
Sensitivity	20 dBZ

Precipitation Radar

Validate a new architecture for Ka-band radars on CubeSat platform and an ultra-compact deployable Ka-band antenna

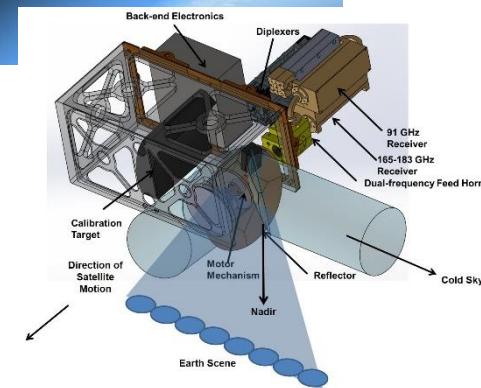
Radar data from 2015 airborne demonstration



TEMPEST-D

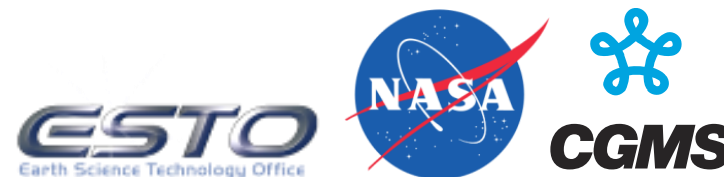
CSU

Launched to ISS
on 21 May 2018



5 Frequency mm-Wave Radiometer

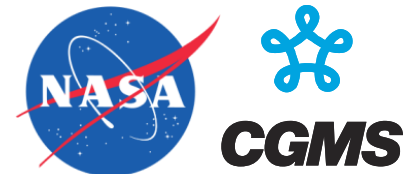
Technology demonstrator measuring the transition of clouds to precipitation



Future **NASA** Satellites

- NASA's plans include the launch of **2 missions and 2 instruments** later this year.
 - The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (**ECOSTRESS**) is an Earth Venture Instrument scheduled for launch in June 2018 that will identify critical thresholds of water use and water stress in key climate-sensitive biomes.
 - The Ice, Cloud and land Elevation Satellite 2 (**ICESat-2**) mission is scheduled for launch in September 2018, and will measure the elevations of ice sheets, glaciers, sea ice and vegetation canopy.
 - The Global Ecosystem Dynamics Investigation (**GEDI**) instrument is scheduled to launch to the ISS in November 2018, and will characterize forest canopy height, canopy vertical structure, and surface elevation.
 - The Compact Solar Spectral Irradiance Monitor Flight Demonstration (**CSIM-FD**) is scheduled to launch no earlier than late 2018, and will validate science-quality solar spectral irradiance (SSI) measurements utilizing a 6U CubeSat platform, allowing direct data comparisons to TSIS and Source from a much smaller platform.

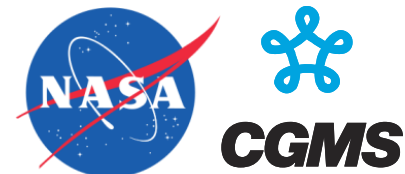
* Development continues through FY18 consistent with the Consolidated Appropriations Act, 2018.



Future **NASA** Satellites (cont'd)

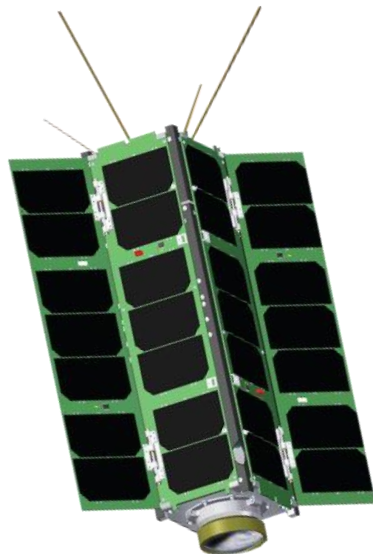
- NASA is formulating and/or developing **14 more future missions and instruments**:
 - Orbiting Ocean Observatory 3 (**OCO-3**) instrument on ISS
 - Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (**TROPICS**) mission
 - Land Remote-Sensing Satellite 9 (**Landsat-9**) mission
 - **Sentinel-6A** mission
 - Tropospheric Emissions: Monitoring of Pollution (**TEMPO**) instrument on a GEO host mission
 - Surface Water Ocean Topography (**SWOT**) mission
 - NASA ISRO-Synthetic Aperture Radar (**NI-SAR**) mission
 - CLARREO Pathfinder (**CLARREO PF**) instrument on ISS
 - Pre-Aerosols, Carbon and Ecosystems (**PACE**) mission
 - Geostationary Carbon Observatory (**GeoCarb**) instrument on a GEO host mission
 - Multi-Angle Imager for Aerosols (**MAIA**) mission
 - Total Solar Irradiance Spectral Solar Irradiance 2 (**TSIS-2**) mission
 - Earth Surface Mineral Dust Source Investigation (**EMIT**) instrument on ISS
 - Polar Radiant Energy in the Far Infrared Experiment (**PREFIRE**) mission

* Development continues through FY18 consistent with the Consolidated Appropriations Act, 2018.



NASA ESTO 3U CubeSats

**ISS Launch NET
Autumn 2018**



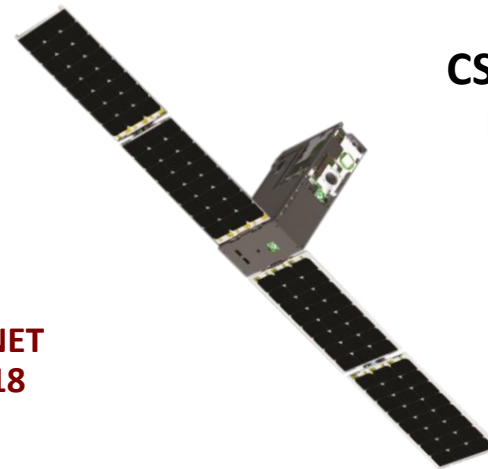
**HARP
UMBC**

Wide FOV Rainbow Polarimeter

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

NASA ESTO-managed 6U CubeSats

**Launch NET
late 2018**



**CSIM-FD
LASP**

Solar Spectral Irradiance Monitor

Demonstration of a compact SSI monitor with high calibration accuracy and improved performance stability

Decadal Survey

- Released in early 2018: *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*
- More details are presented in CGMS-46-NASA-WP-06, *Joint NASA-NOAA Briefing on the 2017 Decadal Survey*



Commercial Data Buy

NASA has begun an activity to **purchase and analyze commercial satellite data** from private sector entities that have satellites in orbit providing data.

Request for Information (RFI) was released in 2017 for satellite providers with data from three or more satellites.

- NASA is in the process of looking to purchase data (with associated metadata) from companies whose responses met the requirements of the RFI, but procurements are not yet in place.
- NASA is also looking to provide added support to evaluate the ability of purchased data to meet NASA's research and/or applied sciences goals.
- The evaluation process is expected to take approximately one year, culminating in a detailed assessment that will be used to guide NASA's future plans for data purchases.

Competed Research and Suborbital Investigations

- **The Science of Terra, Aqua, and Suomi NPP** program selected 67 proposals for a total of \$44.6M/three years.
- Suomi NPP EOS continuity algorithm work began in 2013 and continued in 2017 (see below).
- Terra and Aqua standard data products were transitioned to the Senior Review during the 2009-2013-2017 period competitions.

Land	Ocean	Atmosphere (MODIS)	Atmosphere (OMI/MLS)	Atmosphere (Sounder Profiles)
Surface Reflectance	Sea Surface Temperature	Aerosol Product	Total Column Ozone	Atmospheric Temperature
Snow Cover	Aerosol Angstrom Exponent	Cloud Product	Ozone Concentration	Atmospheric Moisture
Land Surface Phenology and Vegetation Indices	Aerosol Optical Thickness	Cloud Mask	Aerosol Concentration	Surface Temperature
Fire and Thermal Anomalies	Subsurface Chlorophyll a Concentration		NO ₂ Total Column	Cloud Properties
Sea Ice Cover and Ice Surface Temperature	Diffuse attenuation at 490 nm		Sulfur Dioxide Total Column	
BRDF/Albedo	Photosynthetically Available Radiation		Aerosols Total Column	
Incident downward shortwave radiation and PAR	Particulate Organic Carbon			
	Remote Sensing Reflectance			

Competed Research and Suborbital Investigations

- NASA is soliciting proposals for **U.S. Participating Investigator (USPI)** investigations that contribute and facilitate access to foreign space agencies' assets; focus on development phase.
- The proposer's role in the foreign space mission or science/engineering team can include, but is not limited to:
 - instrument design, modeling, and simulation of the instrument's operation and measurement performance
 - calibration of the instrument
 - mission planning, mission operations, data processing, data analysis, and data archiving.
- Must contribute product development, especially as may be carried out in Observing System Simulation Experiments
- Missions to launch during or after 2020 are encouraged.

USPI-18 Schedule

- Maximum 5-year awards
- Proposals due by 12 July 2018
- Awards expected by Autumn 2018

ACKNOWLEDGMENTS

Contributions to this report were made by the following:

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