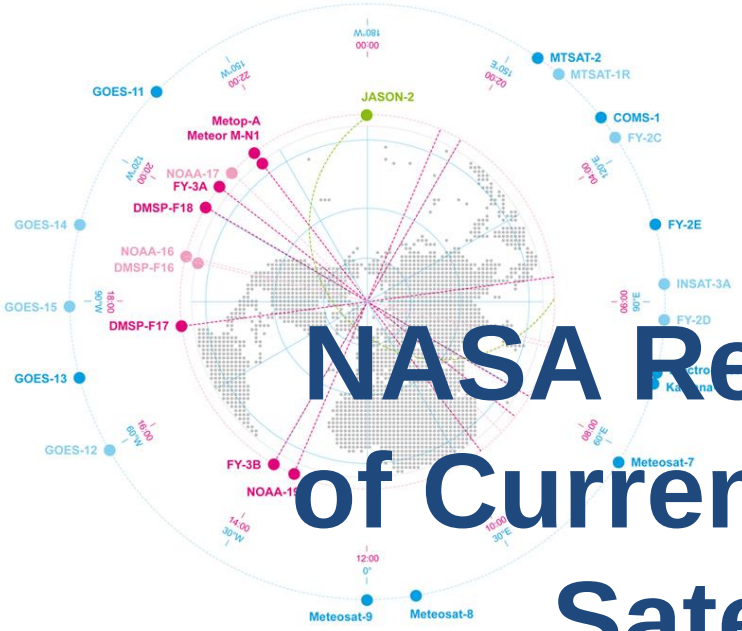


NASA Report on the Status of Current and Future Earth Satellite Systems

Presented to CGMS-47 Plenary Session, Agenda Item D.12

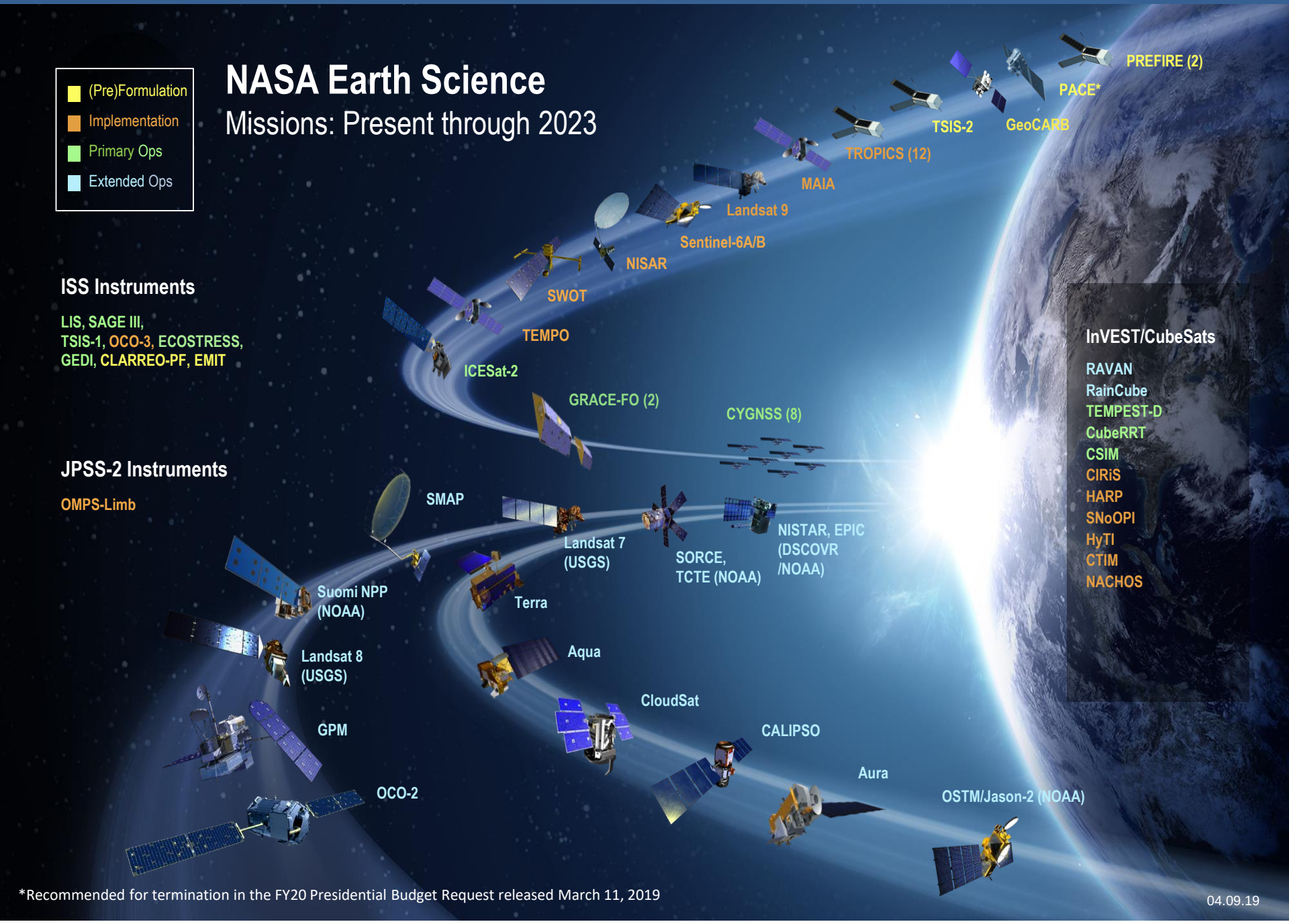
Presenter: Jack Kaye, NASA Headquarters

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

Coordination Group for Meteorological Satellites

CGMS

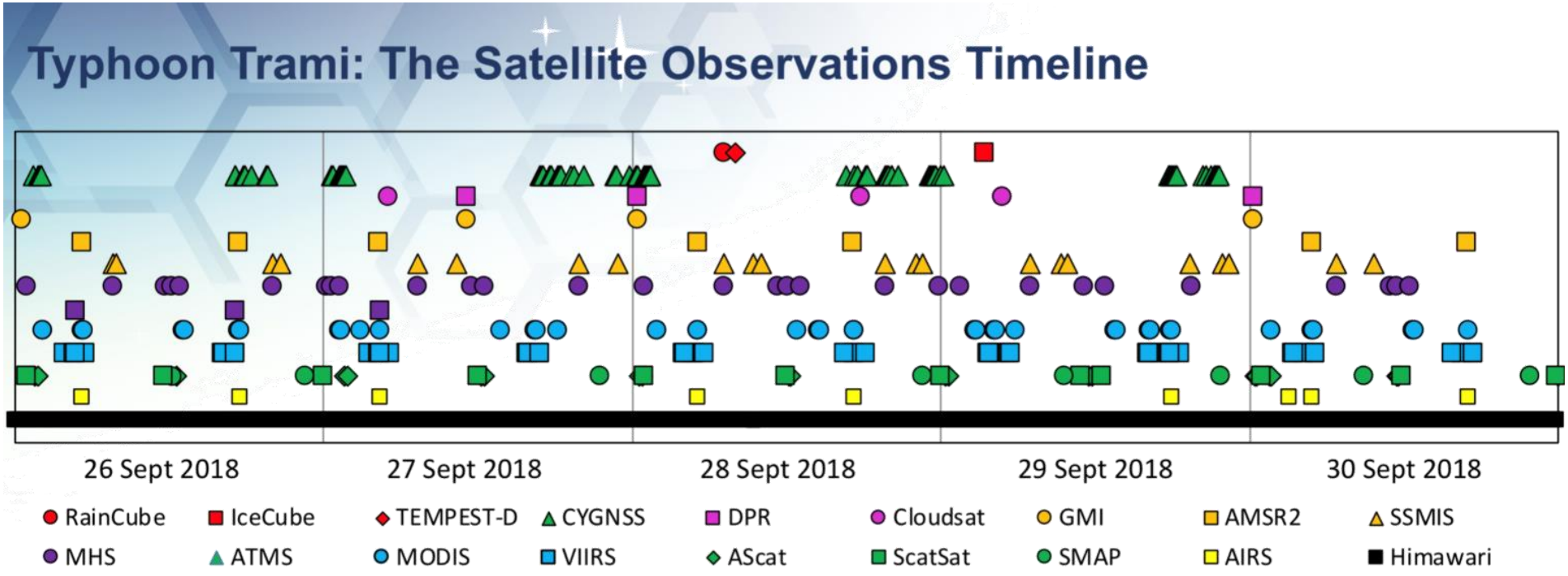
Coordination Group for Meteorological Satellites - CGMS



*Recommended for termination in the FY20 Presidential Budget Request released March 11, 2019

04.09.19

Alternate Views of Typhoon Trami



Cubesats; Smallsats+ (Winds); Radar (cloud & rain profiling); radiometers (precipitation); sounders (precipitation, T&RH profiles); Vis/IR (T, clouds, etc.); Hyperspectral (atmospheric profiles); geostationary (Vis/IR)

In 5 days:
Observations from 24 satellites
Observations from 39 sensors
Total of 773 observations

Coordination Group for Meteorological Satellites

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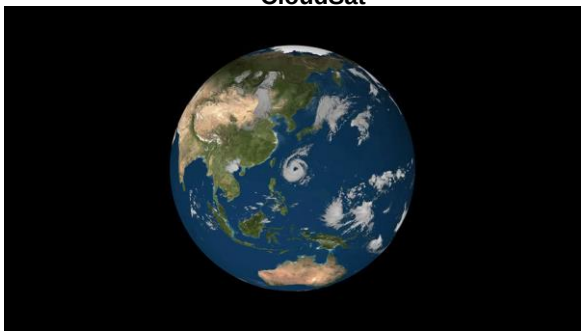
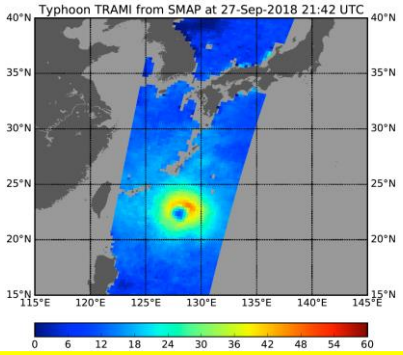
Research and Operational Satellites Observe Typhoon Trami

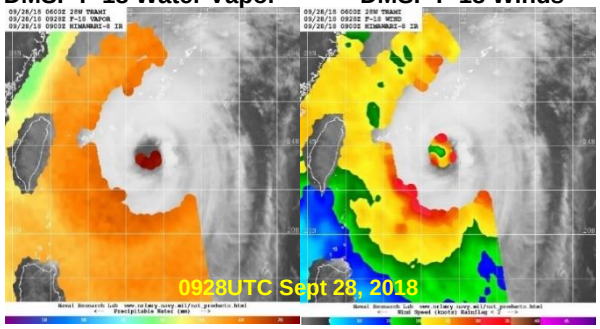
CloudSat



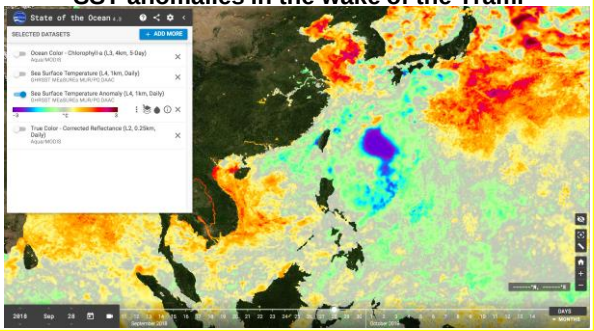
SMAP Wind Speed (max 46.7)



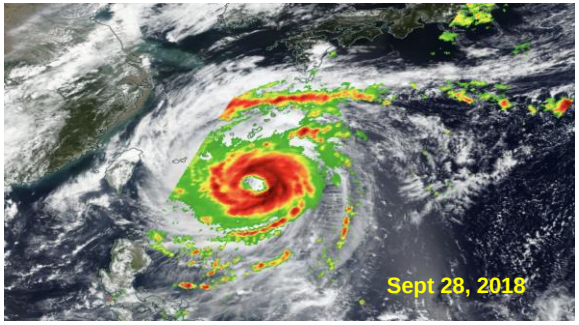
DMSP F-18 Water Vapor **DMSP F-18 Winds**



SST anomalies in the wake of the Trami



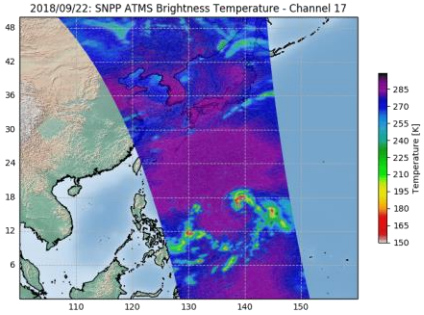
GPM Rain Rate overlaid on Suomi NPP/VIIRS



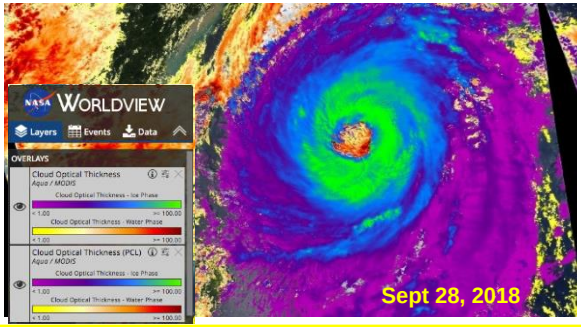
ATMS 89 GHz channel on JPSS-1 and S-NPP

High cloud top ice scattering cooling, Typhoon location fixes

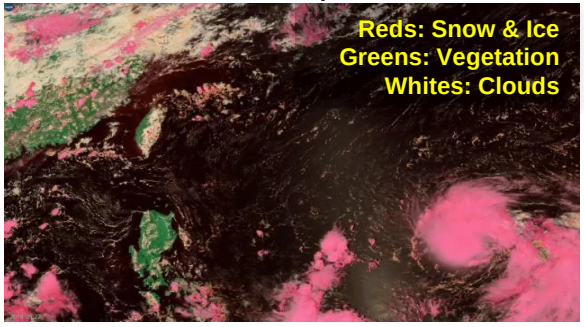
Sept 22-30, 2018

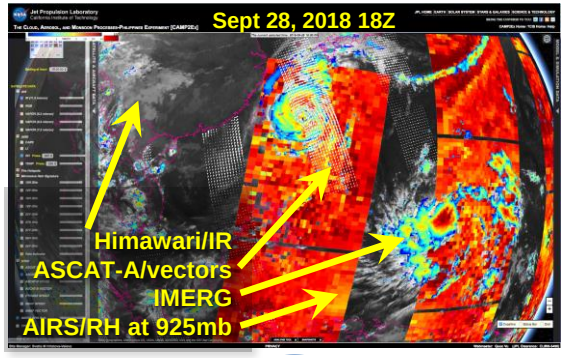


Aqua/MODIS Cloud Optical Thickness



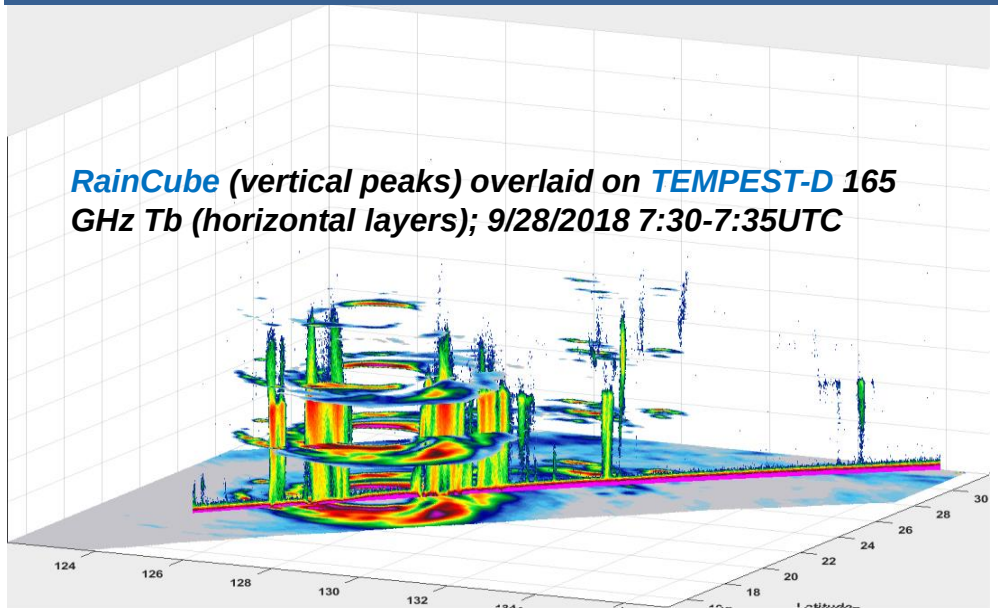
SNPP – VIIRS, Sept 22-29, 2018



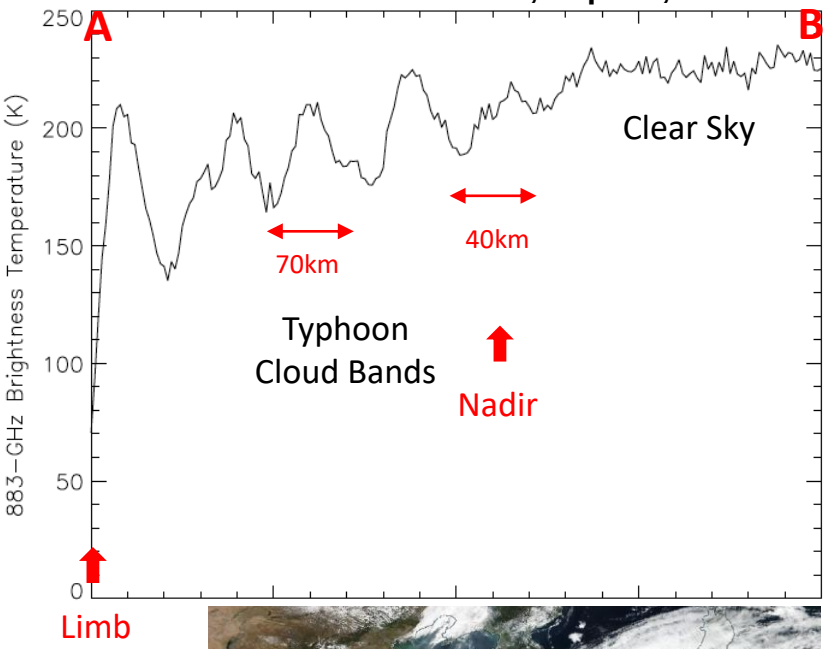


Coordination Group for Meteorological Satellites

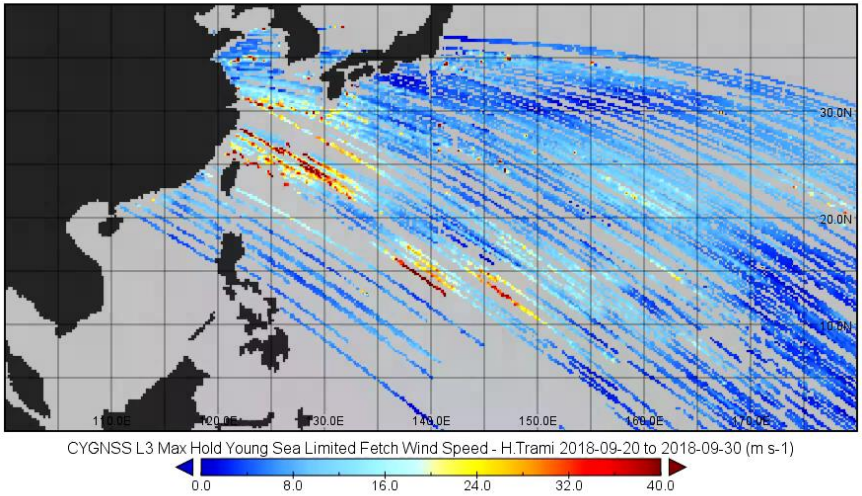
CubeSats/SmallSats Observe Typhoon Trami

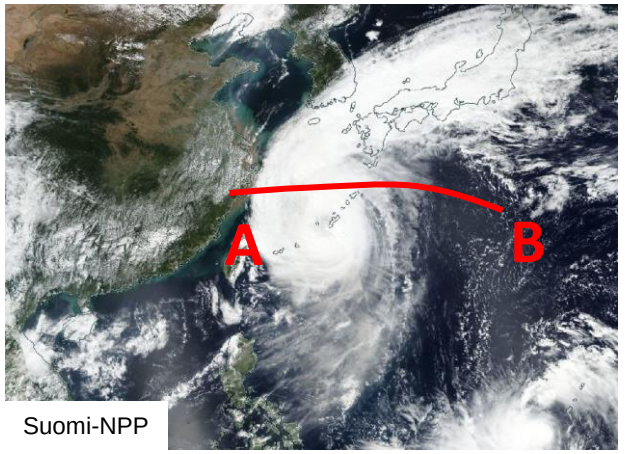


IceCube 883-GHz Radiance; Sept 29, 2018



CYGNSS L3 Max Hold Young Sea Limited Fetch Wind Speed; 2018-09-20 to 2018-09-30





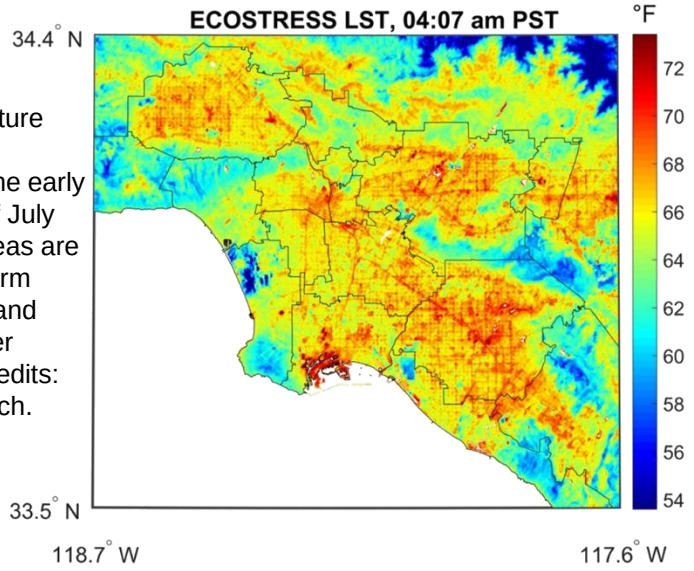
Current NASA Satellites ... Recent News

- NASA is currently supporting operations of **23 Earth Science missions**.
- Four new missions have launched since CGMS-46: **ECOSTRESS, GEDI, ICESat-2, and CSIM.**
- One new mission is scheduled for launch this year: **OCO-3**.
- **QuikSCAT** ended its long and noteworthy mission on October 2, 2018. During its more than 19 years of operation, QuikSCAT's measurements revealed new mechanisms of air-sea interactions, and had significant impact on the use of ocean wind data to improve marine forecasts, including early detection of the location, direction, structure and strength of tropical and extra-tropical cyclones.
- After 17 years in orbit, the **SORCE** mission is scheduled to be decommissioned in January 2020.

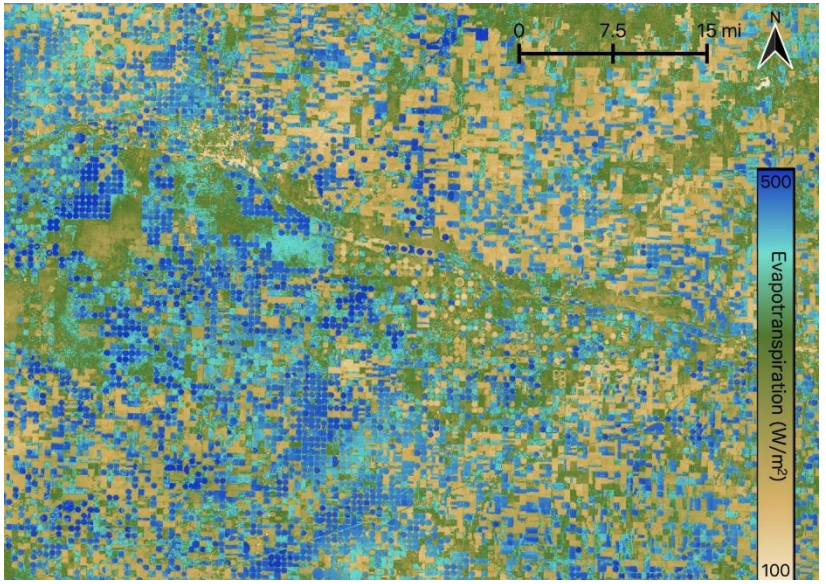
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

ECOSTRESS

- Launched on June 29, 2018 to the ISS
- Completed in orbit checkout August 20, 2018
- Acquired 16,282 scenes as of 3/5/19
- Currently acquires ~140 400 km x 400 km scenes per day
- All data freely available through the Early Adopter Program (sign up via ECOSTRESS website (https://ecostress.jpl.nasa.gov)
- ROSES call out, proposals due April 23rd



Surface temperature variations in Los Angeles, CA in the early morning hours of July 22, 2018. Hot areas are shown in red, warm areas in orange and yellow, and cooler areas in blue. Credits: NASA/JPL-Caltech.



Evapotranspiration over Garden City, Kansas USA | Center pivot irrigation dominates the landscape with circular patterns distributed across this Kansas community. Blue circles and squares indicate recently irrigated fields.

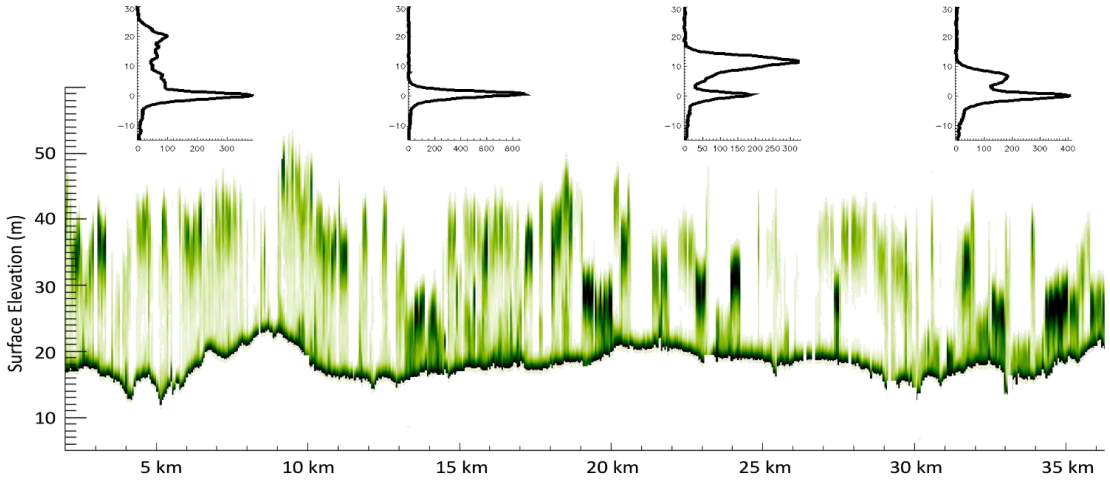
Coordination Group for Meteorological Satellites

Global Ecosystem Dynamics Investigation (GEDI)

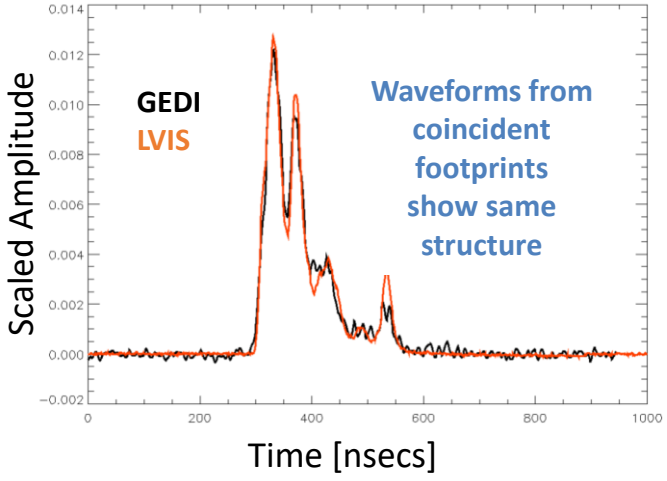
- *Launched on December 5, 2018*
- *Provides high resolution laser ranging observations of the 3D structure of the Earth which are critical for understanding:*
  - **The Carbon Balance of Earth's Forests**
  - **Future Land Mitigation of Atmospheric CO_2**
  - **The Impacts of Forest Structure on Biodiversity**

GEDI Launch on SpX CRS-16

View of GEDI on ISS JEM



GEDI – Forest Canopy Profile and Waveforms

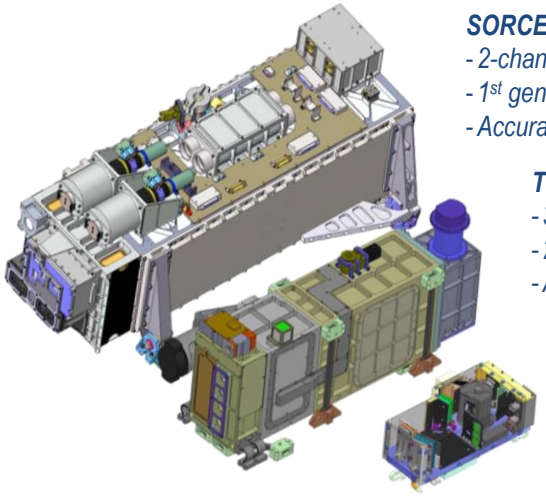


Validation with Airborne Data

Measurement Continuity and Transition to Follow-on Missions

SORCE/TSIS-1-ISS/CSIM-FD/CTIM

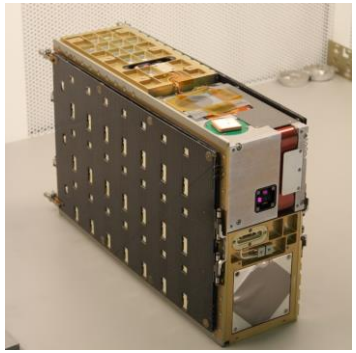
- *CSIM is an ultra-compact, solar spectral irradiance (SSI) monitor covering 200-2400 nm with the required SI-traceable accuracy and on-orbit stability to meet solar input measurement requirements for establishing benchmark climate records.*
- *Launched in December 2018, CSIM is validating performance against SSI measurements being made by the SORCE SIM and the TSIS SIM to demonstrate that climate data record SSI measurements can be maintained by a CubeSat-sized instrument.*
- *Instrument design and layout marks a significant departure from the previous SIM instruments, achieving large reductions in mass, volume, and power requirements, and enabling a flight-qualified instrument in a 6U CubeSat package.*



SORCE SIM (launched 2003)
- 2-channel instrument
- 1st generation absolute ESR detector (NiP bolometer)
- Accuracy: 2-10% wavelength dependent (no SI validation)

TSIS SIM (launched 2017)
- 3-channel instrument
- 2nd generation absolute ESR detector (NiP bolometer)
- Accuracy: 0.2% (SI-traceable validation)

CSIM (launched 2018)
- 2-channel instrument
- 3rd generation absolute ESR detector (best noise performance to date)
- Accuracy: 0.2% (SI-traceable validation)



Measurement Continuity and Transition to Follow-on Missions

SORCE/TSIS-1-ISS/CSIM-FD/CTIM

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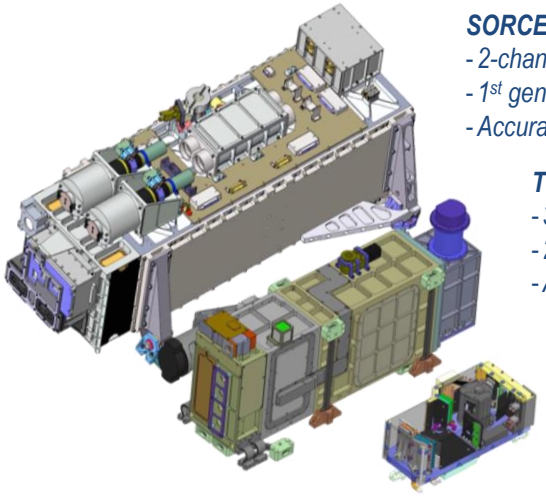

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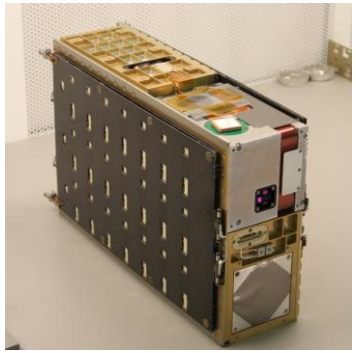

Future NASA Satellites

- NASA's plans include the launch of **9 missions and 5 instruments** in the near future.
- The Orbiting Carbon Observatory-3 (**OCO-3**) is scheduled for launch NET April 30, 2019, and from the vantage of the International Space Station, will enhance measurements of carbon dioxide being collected by OCO-2, which operates in the polar orbiting A-train.
- After OCO-3, the next four launches are currently scheduled in late 2020, including:
  - 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

Decadal Survey Response

NASA Observation System Priorities

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	x		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	x		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	x		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	x		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	x		
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		x	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		x	
Ocean Surface Winds & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.	Radar scatterometer		x	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		x	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		x	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**		x	
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		x	x
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			x
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			x

** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables

Other ESAS 2017 Targeted Observables, not Allocated to a Flight Program Element

Aquatic Biogeochemistry	Radiance Intercalibration
Magnetic Field Changes	Sea Surface Salinity
Ocean Ecosystem Structure	Soil Moisture

Coordination Group for Meteorological Satellites

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Commercial Satellite Data Buy

- NASA launched its first pilot program to purchase Earth science data from commercial small-satellite constellations for scientific evaluation
- Contracts were awarded on September 28, 2018:
  - **DigitalGlobe**, five Earth imaging satellites (GeoEye-1, WorldView-1, WorldView-2, WorldView-3, WorldView-4) capable of collecting 30-centimeter resolution imagery
  - **Planet Lab**, three satellite constellations (SkySat, Dove, RapidEye) with more than 150 satellites supplying imagery and derived global products at medium and high resolution with high repeat frequencies
  - **SPIRE**, over 60 satellites collecting radio occultation soundings, aircraft location information and ship reports
- Augmented approx. 30 current research or application investigators (e.g., land cover land use change, oceanography, atmospheric science, cryospheric science, health and air quality, natural disasters)
- Preliminary reports are to be provided by April 30, with more complete responses due in late 2019

Coordination Group for Meteorological Satellites

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Recently Selected Research and Suborbital Investigations

US Participating Investigators (USPI-18) Selections

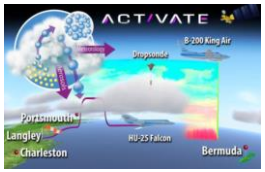
- NASA selected 6 investigations, of the 26 proposals received, that will expand scientific links with future European, Asian, and South American space missions

Name	Institution	Title	Satellite
Sinead Farrell	University of Maryland, College Park	Polar Ocean and Land-ice Assessments with Radar Altimetry (POLARA)	Polar Ice and Snow Topography (Polar IST) (Copernicus)
Robert Frouin	University Of California, San Diego	Algorithm Development (Photosynthetically Available Radiation, Atmospheric Correction) in Support of the SABIA-Mar Ocean-Color Mission	SABIA-Mar 1 (CONAE)
Thomas Painter	Jet Propulsion Laboratory	Cryosphere physical properties from the DLR EnMAP imaging spectrometer	EnMAP (DLR)
David Schimel	Jet Propulsion Laboratory	U.S. Participating Investigator for HISUI: L2 reflectance and L3 Plant Functional Trait Retrieval	HISUI (METI)
Ousmane Sy	Jet Propulsion Laboratory	EarthCARE Cloud, Convection and Precipitation Radar Products: algorithm development, product calibration and validation	EarthCARE (ESA)
Michael Twardowski	Florida Atlantic University	Adapting a new ocean color algorithm to enhance water quality and validation capabilities for the future Sentinel constellation	Sentinel-2 (Copernicus)

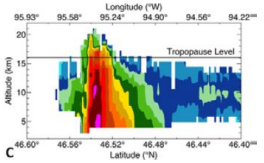
Recently Selected Research and Suborbital Investigations

Earth Venture Suborbital (EVS-3) Investigations

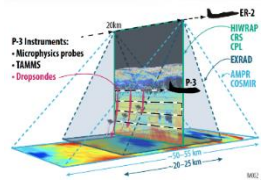
- A total of 6 NASA centers and 27 educational institutions are participating in these Earth Venture projects. The five-year investigations were selected from 30 proposals



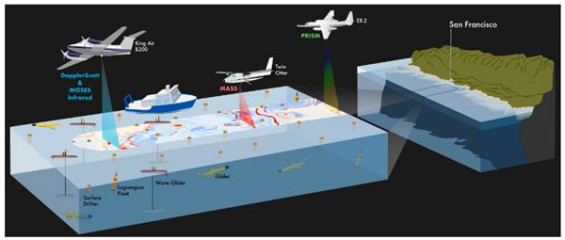
ACTIVATE - Aerosol Cloud meTeorology Interactions oVer the western ATlantic investigates how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western Atlantic Ocean



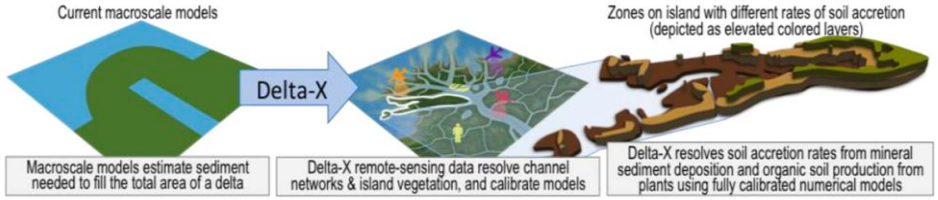
DCOTTS - Dynamics and Chemistry of the Summer Stratosphere investigates how strong summertime convective storms over North America can change the chemistry of the stratosphere



IMPACTS - Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms study the formation of snow bands in East Coast winter storms.



SMODE - Submesoscale Ocean Dynamics and Vertical Transport investigation to explore the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere



Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas

ACKNOWLEDGMENTS

Contributions to this report were made by the following:

Richard Eckman, Michael Falkowski, Garik Gutman,
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Barry Lefer, Hank Margolis, Kevin Murphy,
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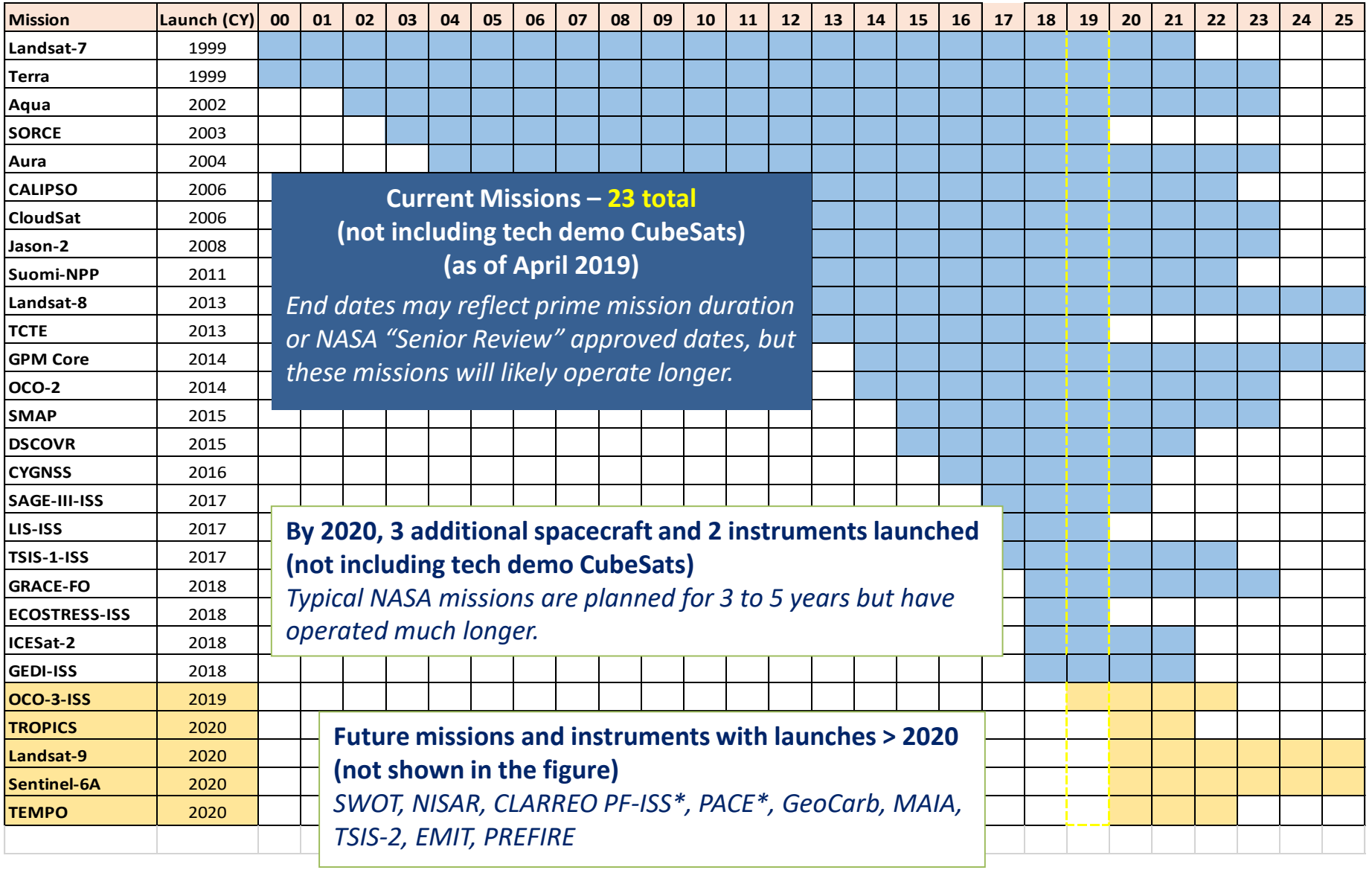
NASA Headquarters

Phillip Larkin, Pamela Millar
NASA Goddard Space Flight Center

Chris Ruf
University of Michigan

BACKUP

Overview of NASA's current and future satellite systems



Current Missions – 23 total
(not including tech demo CubeSats)
(as of April 2019)

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

By 2020, 3 additional spacecraft and 2 instruments launched (not including tech demo CubeSats)

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)

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

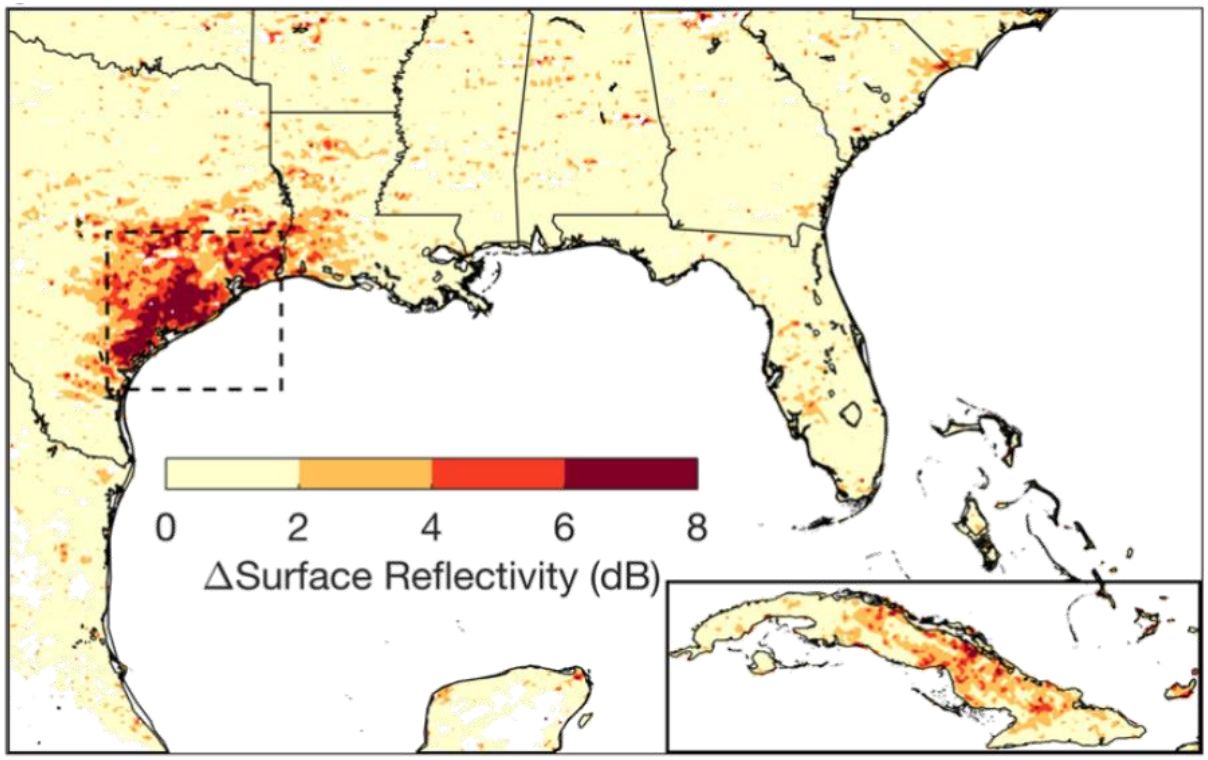
*Recommended for termination in the FY20 Presidential Budget Request released March 11, 2019

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

Cyclone Global Navigation Satellite System (CYGNSS) Mission

- *2018: Hurricane forecast data assimilation studies; New land investigations (soil moisture, flood inundation)*
- *Mar 2019: End of prime mission, extended mission begins*



- ✓ *Dec 15, 2016 at 08:37 EST: Launch*
- ✓ *Mar 2017: Phase E science operations begin*
- ✓ *Jul – Oct 2017: First Atlantic Hurricane Season; High wind Cal/Val*
- ✓ *Nov 2017: Non-provisional release of wind speed data products to NASA PO.DAAC*

Observed change in surface reflectivity after Hurricanes Harvey (southeastern U.S.) and Irma (Cuba inset)

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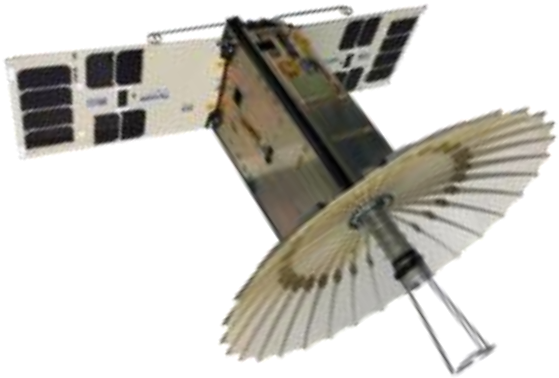
Successful Recent Launches and Ops of Additional 6U CubeSats



Radar in a CubeSat (RainCube)

Jet Propulsion Laboratory

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

Launched May 21, 2018
Deployed from ISS July 13, 2018
First Light August 27, 2018

Temporal Experiment for Storms and Tropical Systems Demonstration (TEMPEST-D)

Colorado State University

5 Frequency mm-Wave Radiometer – Technology demonstrator **measuring the transition of clouds to precipitation**

Launched May 21, 2018
Deployed from ISS July 13, 2018
First Light September 5, 2018

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Future NASA Satellites (cont'd)

- NASA is formulating and/or developing **9 more future missions and/or instruments** including:

  - Surface Water Ocean Topography (**SWOT**) mission
  - NASA ISRO-Synthetic Aperture Radar (**NI-SAR**) mission
  - CLARREO Pathfinder (**CLARREO PF***) instrument on ISS
  - Plankton, Aerosol, Cloud, ocean 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

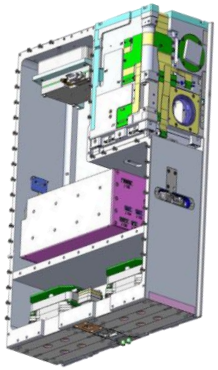
* Development continues through FY19 consistent with the Consolidated Appropriations Act 2019. Identified for termination in FY20 in the President's FY20 Budget Proposal released March 11, 2019.

CubeSats in Development for 2019-2020 Launch Readiness

HyperAngular Rainbow Polarimeter (HARP)

University of Maryland, Baltimore County

- Technology validation of a wide field of view (FOV) imaging polarimeter for characterizing aerosol and cloud properties, on a 3U CubeSat
- Launch to the International Space Station in late 2019 or early 2020
- Uses modified Philips prisms (no moving parts) to split 3 identical images into 3 independent imaging detector arrays, achieving simultaneous imagery of the 3 polarization states



Compact Total Irradiance Monitor (CTIM)

University of Colorado / LASP

- Awarded through 2017 InVEST solicitation
- Will apply new fabrication techniques using carbon-nanotube radiometers
- Validate net radiant input for Earth climate and Earth radiation balance studies from a CubeSat platform
- Compact, lower-mass instrument has shorter fabrication times and lower costs which could reduce the risk of future TSI-measurement data gaps

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