National Aeronautics and Space Administration

The Future of NASA's Aerosol and Cloud Measurements from Satellites

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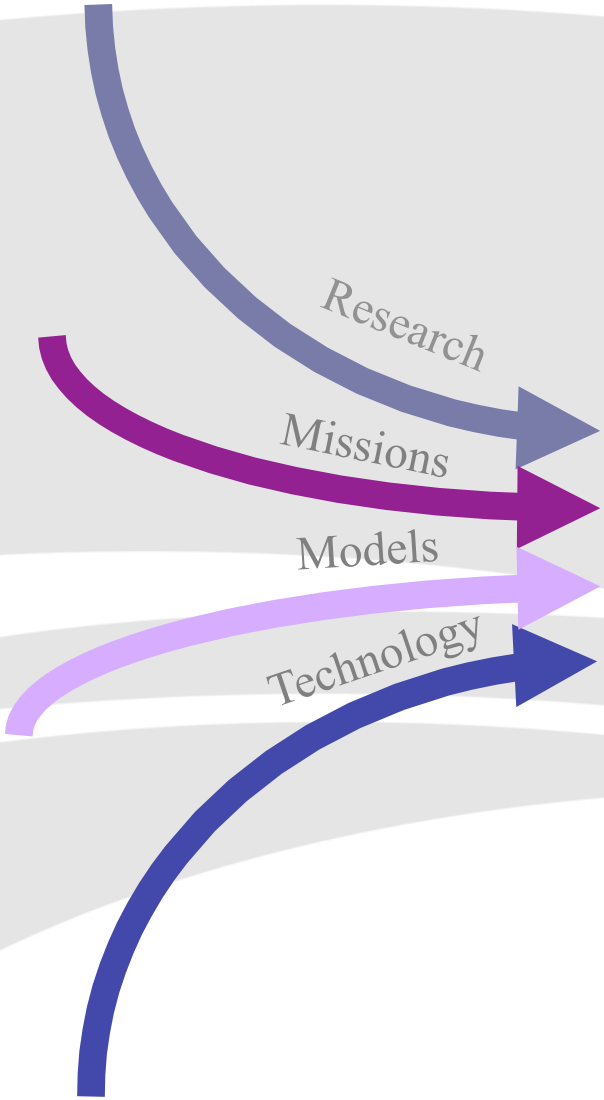
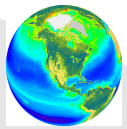
Earth Science Division, Science Mission Directorate

November 2013

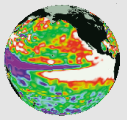
Atmospheric Composition Research at NASA



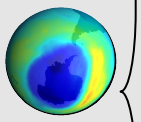
Carbon Cycle & Ecosystems (CO_2, CH_4)



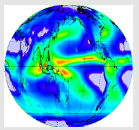
Climate Variability & Change (atmospheric constituent effects on climate)



Atmospheric Composition

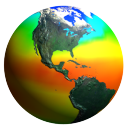


Water & Energy Cycle (atmospheric water vapor)



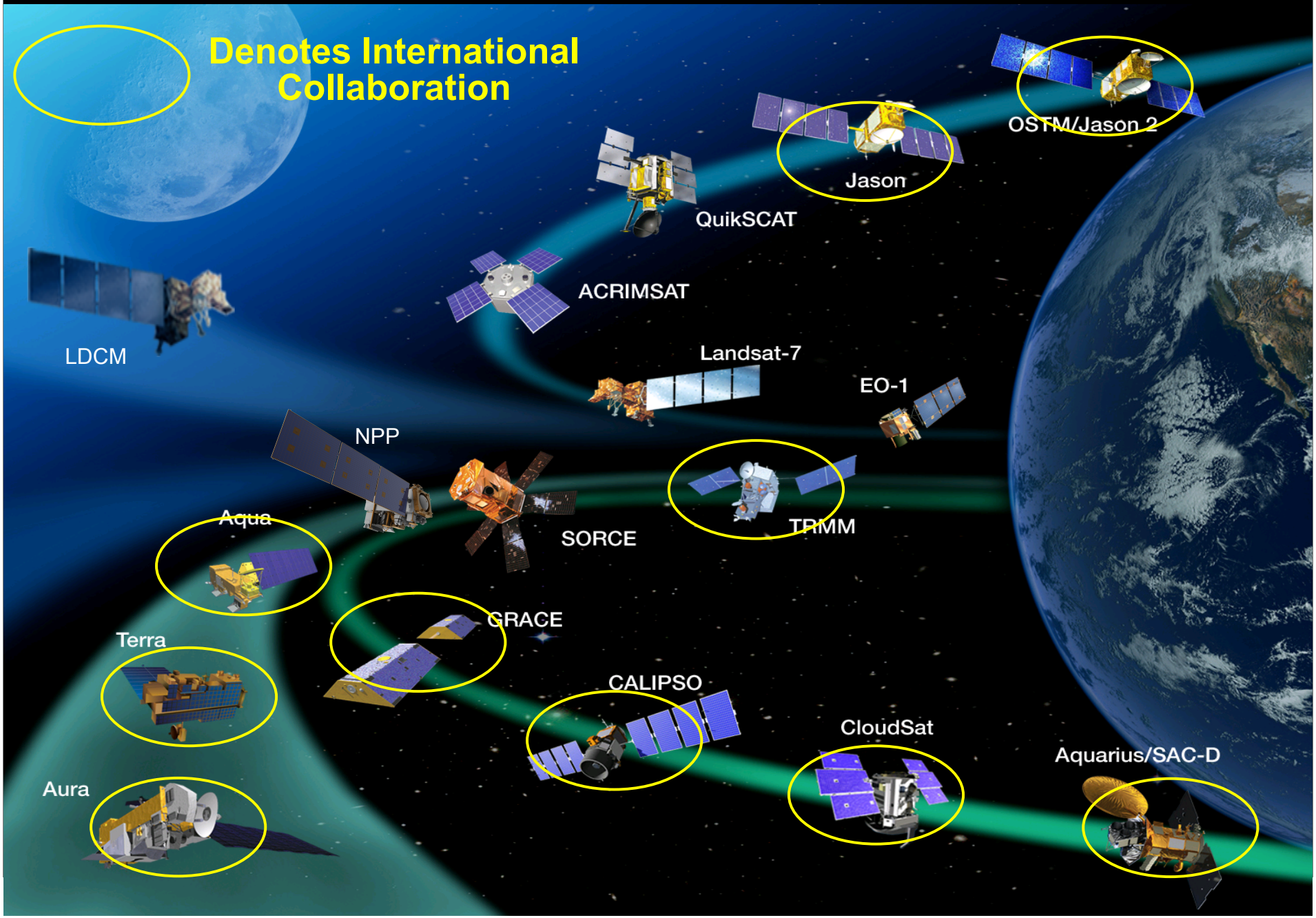
Earth Surface & Interior (volcanic effects on atmosphere)

Weather (effects on air quality)



- How is atmospheric composition changing?
- What chemical & physical processes are important for air quality, radiative transfer and climate?
- What trends in atmospheric constituents, clouds and cloud properties as well as solar radiation are driving global climate?
- How do atmospheric trace constituents respond to and affect global environmental change?
- How will changes in atmospheric composition affect ozone and regional-global climate?

NASA Operating Missions



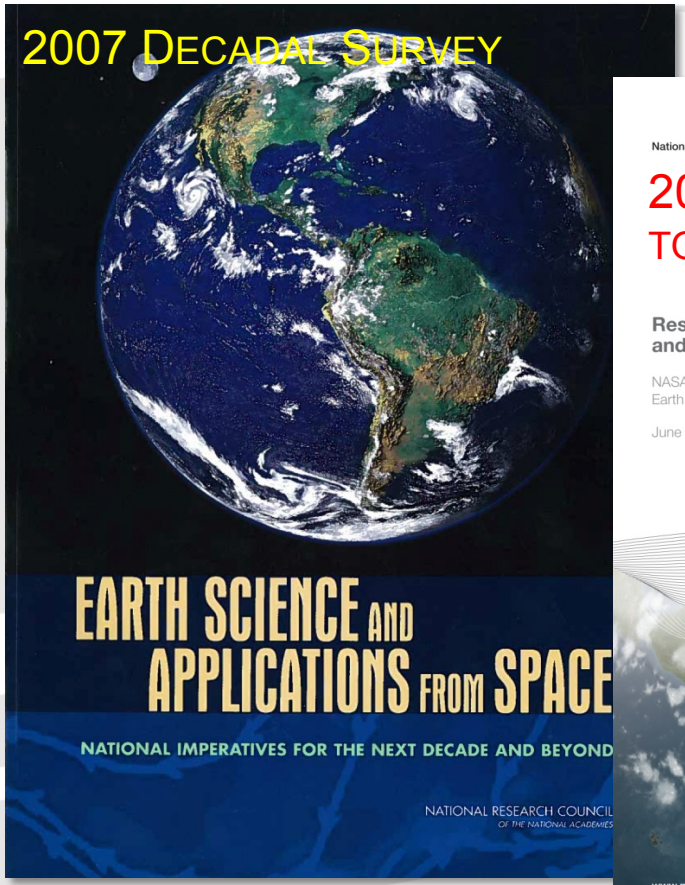
Operating Satellite Status

Mission	Launch	Phase	Design Life (yr)	Current Life (yr)	Expected End
Terra	18-Dec-99	Extended	5	13.3	2017
ACRIMSat	20-Dec-99	Extended	5	13.3	2020
Aqua	03-May-02	Extended	5	11.0	2022
SORCE	25-Jan-03	Extended	5	10.2	2015
Aura	15-Jul-04	Extended	5	8.8	2018
Cloudsat	28-Apr-06	Extended	3	7.0	2015
CALIPSO	28-Apr-06	Extended	3	7.0	2016
OCO - 1	24-Feb-09	Launch Failure	2	N/A	N/A
Glory	04-Mar-11	Launch Failure	3	N/A	N/A
Suomi-NPP	25-Oct-11	Prime till Oct 2016	5	1.4	not enough data

Operating Instrument Status

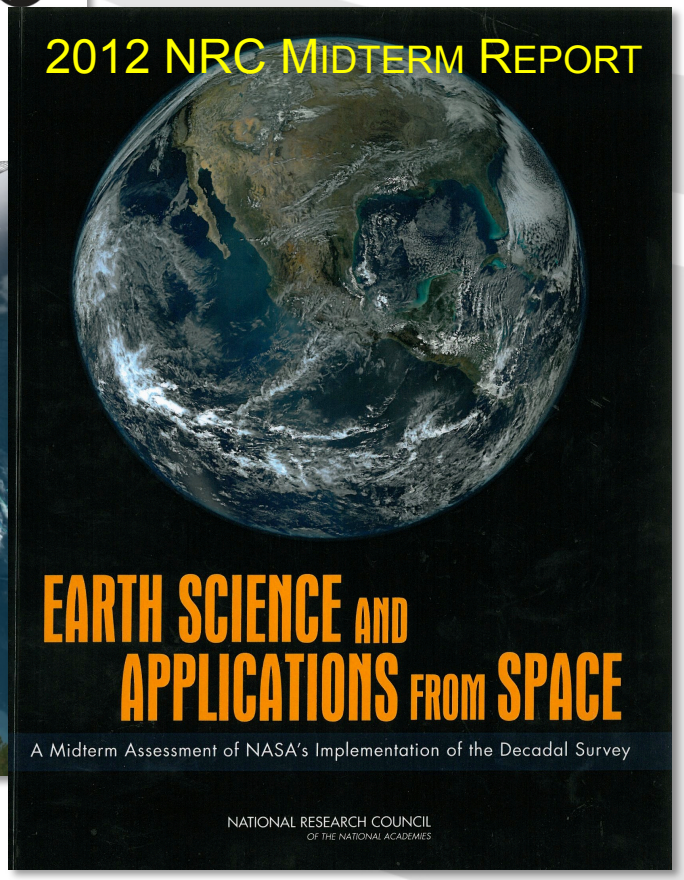
INSTRUMENT	INSTRUMENT	MISSION	STATUS
Spectral Irradiance Monitor	SIM	SORCE	Operating in daylight only
Solar-Stellar Irradiance Comparison Experiment	SOLSTICE	SORCE	Operating in daylight only
Total Irradiance Monitor	TIM	SORCE	Operating in daylight only
XUV Photometer System	XPS	SORCE	Operating in daylight only
Clouds and the Earth's Radiation Energy System	CERES	Terra	Operating nominally
Moderate Resolution Imaging Spectroradiometer	MODIS	Terra	Operating nominally
Multi-Angle Imaging Spectrometer	MISR	Terra	Operating nominally
Measuerment of Pollution in the Troposphere	MOPITT	Terra	Operating nominally
Advanced Spaceborne Thermal Emission & Reflection Radiometer	ASTER	Terra	SWIR failed (VNIR & TIR operational)
High Resolution Dynamics Limb Sounder	HIRDLS	Aura	Failed
Ozone Monitoring Instrument	OMI	Aura	Row anomaly
Microwave Limb Sounder	MLS	Aura	Operating nominally with Band 13 powered off & THz channel in standby; on redundant mirror switching mechanism electronics
Troposphere Emission Spectrometer	TES	Aura	Interferometer Control System currently working
Cloud-Aerosol Lidar with orthogonal Polarization	CALIOP	CALIPSO	Operating nominally second laser unit
Imaging Infrared Radiometer	IIR	CALIPSO	Operating nominally
Wide Field Camera	WFC	CALIPSO	Operating nominally
Active Cavity Radiometer Irradiance Monitor-III	ACRIM-III	ACRIMSAT	
Atmospheric Infrared Sounder	AIRS	Aqua	Operating nominally
Advanced Microwave Scanning Radiometer for EOS	AMSR-E	Aqua	Operating at 2rpm for cross-calibration with GCOM-W1 AMSR2
Advanced Microwave Sounding Unit-A	AMSU-A	Aqua	10 of 15 channels performing well
Humidity Sounder-Brazil	HSB	Aqua	Failed
Clouds and the Earth's Radiation Energy System	CERES	Aqua	Operating nominally
Moderate Resolution Imaging Spectroradiometer	MODIS	Aqua	Operating nominally
Cloud Profiling Radar	CPR	Cloudsat	Daylight Only operations
Visible Infrared Imaging Radiometer Suite	VIIRS	Suomi-NPP	Operating nominally
Cross-track Infrared Sounder	CrIS	Suomi-NPP	Operating nominally
Clouds and the Earth's Radiation Energy System	CERES	Suomi-NPP	Operating nominally
Advanced Technology Microwave Sounder	ATMS	Suomi-NPP	Operating nominally
Ozone Mapping and Profiler Suite	OMPS	Suomi-NPP	Operating nominally

Science Objectives are Provided through External Recommendations



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

- Identified new Climate Measurements
- Matched against President's budget
- Vetted w/OSTP, OMB & Admin



- Endorsed NASA's implementation
- "Encouraged" more rigorous cost control
- Endorsed additional Venture calls

Common in all guidance is the focus on the long term science objectives

Formulation & Development Mission Plans

GPM
Feb 2014
w/ JAXA; Precip

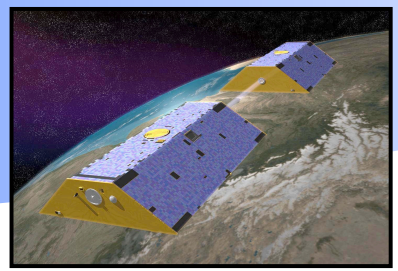
OCO-2
July 2014
Global CO_2

SMAP
Oct 2014
w/CSA
Soil Moist., Frz/Thaw

SAGE III on ISS
Mar 2015
Ozone & Trace Gases

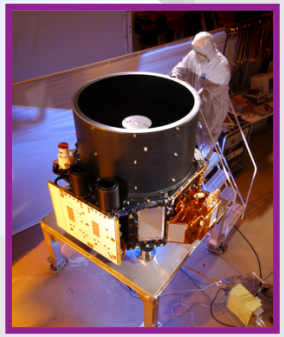
SWOT
Oct 2020
w/CNES; Sea surface &
Fresh water height, slope

TEMPO
2019
Hosted Payload:
Tropospheric
pollution

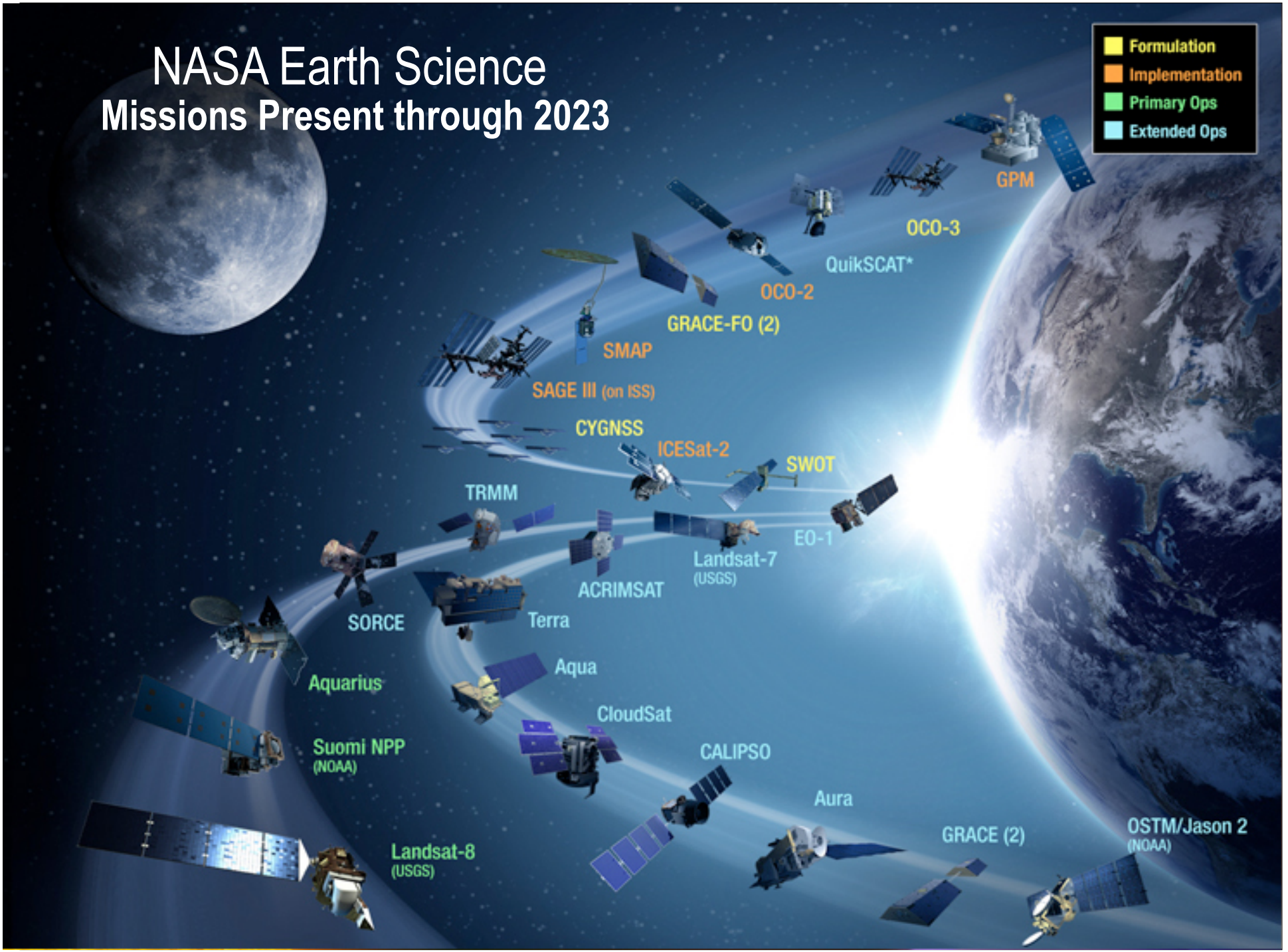


GRACE FO
Aug 2017
w/Germany; Global Mass
& Water Variation

CYGNSS
2016
Cyclone
Generation



ICESat-2
2016
Ice Dynamics


NASA Earth Science
Missions Present through 2023
Formulation
Implementation
Primary Ops
Extended Ops
GPM
OCO-3
QuikSCAT*
OCO-2
GRACE-FO (2)
SMAP
SAGE III (on ISS)
CYGNSS
ICESat-2
SWOT
TRMM
EO-1
Landsat-7
(USGS)
ACRIMSAT
SORCE
Terra
Aqua
Aquarius
CloudSat
Suomi NPP
(NOAA)
CALIPSO
Aura
Landsat-8
(USGS)
GRACE (2)
OSTM/Jason 2
(NOAA)

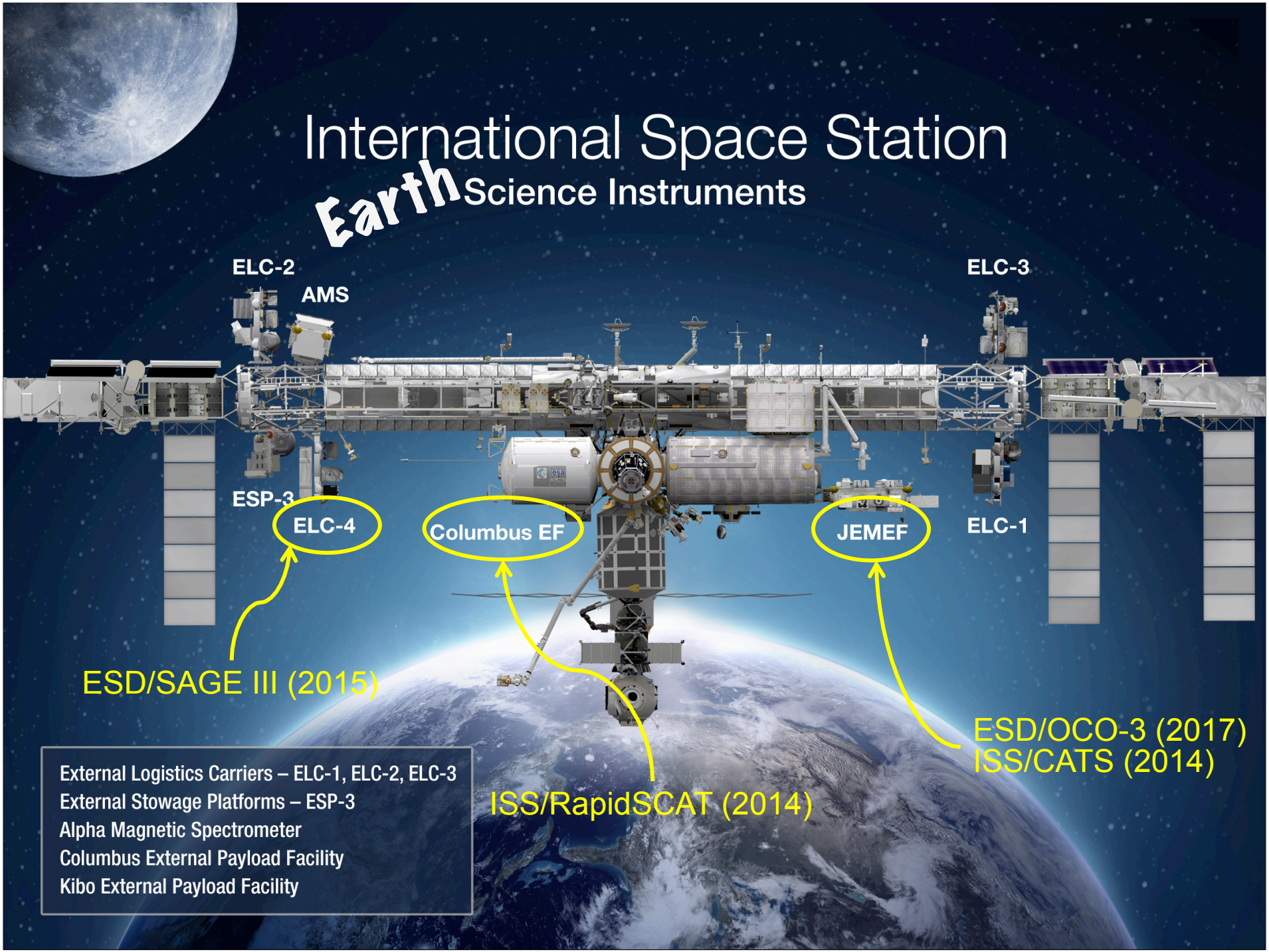
NASA ESD Flight Portfolio 2013 - 2022

- **GPM** (2/2014) – Global Precipitation mapping, w/JAXA
- **OCO-2** (7/2014) – Atmospheric CO_2 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** (12/2016) – Precision Ice Topography, Ecosystem monitoring
- **CYGNSS [EVM-1]** (late 2016)
- **GRACE-FO** (8/2017) – Gravity/Ice Mass/Ground Water, w/GFZ & DLR
- **OCO-3/ISS** (Fall 2017) – CO_2 continuity, from ISS, OCO-2 spares
- **TEMPO [EVI-1]** (2019) – Tropospheric Emissions from geosynchronous vantage
- **SWOT** (2020) – Wide-swath ocean altimetry, land water, w/CNES
- **EVI-2 Venture-Class** (NLT 2020)
- **PACE** (2020) – Ocean Color, possibly Aerosols
- **L-band SAR** (2021) – Solid Earth, Cryosphere, Ecosystems, w/ISRO
- **CLARREO** (2022?) – Precise global radiation balance, possibly w/UK
- **EVM-2** (NLT 2022)
- **EVI-3** (NLT 2022)
  - Significant studies ongoing for all other Tier-2 Decadal Survey missions
- ***And on the horizon:***
  - ***Sustained Land Imaging program for the U.S. for 2018 – 2038***
  - ***Solar Irradiance, Ozone profiles, and Earth Radiation Budget measurements for beyond 2020***

PACE and ACE

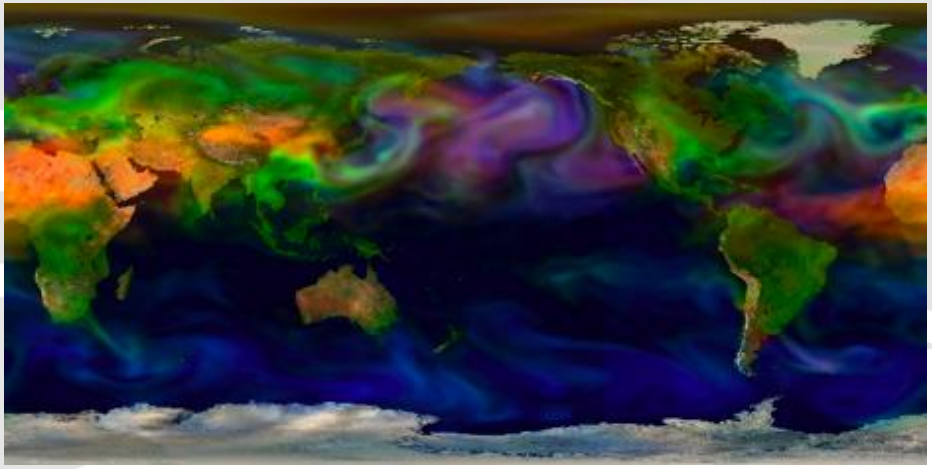
- Pre-ACE (Foundational - data continuity)
  - Goals
    - make global ocean color measurements to provide extended data records on ocean ecology and global biogeochemistry
    - polarimetry measurements to provide extended data records on clouds and aerosols - maybe
  - Instruments
    - Ocean Ecosystem Spectrometer (UV to SWIR)
    - Aerosol/Cloud Polarimeter - maybe
  - LRD: 2019 – 2020 (soon to go into formulation, sequester permitting)

- ACE (DS Tier 2)
  - Goals
    - quantify the roles of aerosols, clouds, and aerosol-cloud-precipitation interactions
    - measure the ocean ecosystem changes and quantify ocean carbon uptake
    - improve air quality forecasting
  - Instruments
    - Imaging Aerosol/Cloud Polarimeter
    - Multi-frequency Doppler Cloud (precip) Radar
    - High Spectral Resolution Lidar
    - Ocean Ecosystem Spectrometer
  - LRD: >2023 (new Decadal Survey)

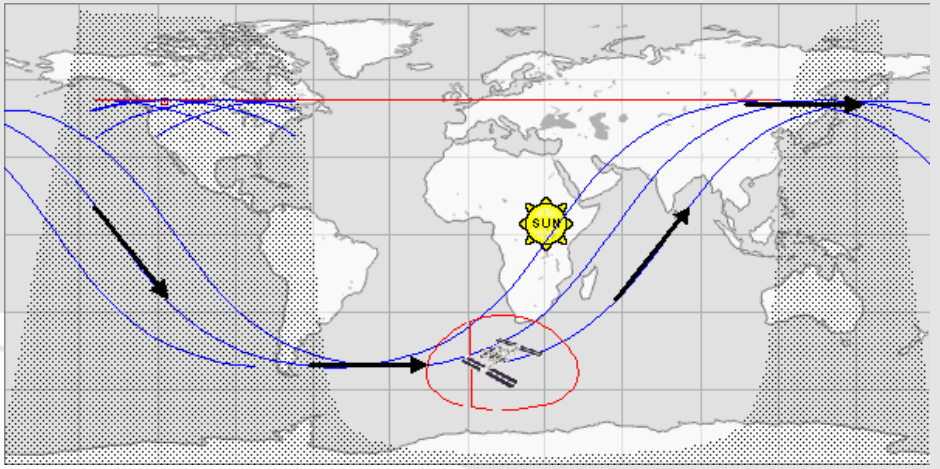

International Space Station
Earth Science Instruments
ELC-2
AMS
ELC-3
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
ESD/SAGE III (2015)
ESD/OCO-3 (2017)
ISS/CATS (2014)
ISS/RapidSCAT (2014)
External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

Cloud-Aerosol Transport System (CATS): Key Science Objectives

- Demonstrate multi-wavelength aerosol and cloud retrievals.
- Provide cloud and aerosol data to help bridge the gap between CALIPSO and future missions.
- Enable aerosol transport models with real-time data downlink from ISS
- ISS orbit is intriguing for tracking of plumes and study of diurnal effects (something not possible with A-Train orbit).



Snapshot of GEOS-4 model global aerosol distribution forecast for March 20, 2006
Orange = dust; Blue = sea salt; Green = smoke and sulfate; Saturation ~ species column amount



ISS orbit. The low-inclination orbit permits extensive measurements over aerosol source and aerosol transport regions.

Venture Class Activities

- **Venture-Class is a Tier-I Decadal Survey recommendation**
  - Science-driven, PI-led, competitively selected, cost- and schedule-constrained, regularly solicited, orbital and suborbital
  - Venture-class investigations complement the systematic missions identified in the Decadal Survey, and provide flexibility to accommodate scientific advances and new implementation approaches
- **Venture-Class is fully funded, with 3 "strands"**
  - EV Suborbital (EVS-#): suborbital/airborne investigations (5 years duration)
    - Solicited in FY09 (selections in FY10) ***and every 4 years***
  - EV Mission (EVM-#): small complete missions (5 years duration)
    - Small-sat or stand-alone payload as part of larger mission; $150M total development cost
    - Solicited in FY11 ***and every 4 years***
  - EV Instrument (EVI-#): Spaceborne instruments for flight on MoO (≤5 years development)
    - PI-led instrument(s) for NASA ESD-managed MoO; $90M (class C) and $30M (class D) total development cost for development and operations
    - Instrument accommodations to spacecraft outside of PI budget
    - Solicited in FY12 ***and every 15-18 months***

CYGNSS:
Cyclone Global Navigation Satellite System

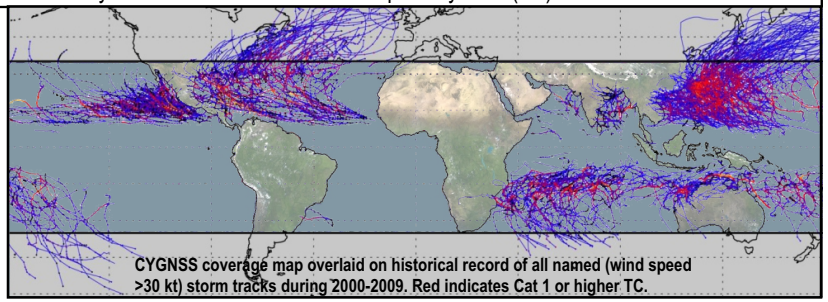
Science Goal and Objectives

The CYGNSS Science Goal is to understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a Tropical Cyclone (TC).

Primary Objectives:

- Measure ocean surface wind speed in all precipitating conditions, including those experienced in the TC eyewall
- Measure ocean surface wind speed in the TC inner core with sufficient frequency to resolve genesis and rapid intensification

Secondary Science: Support the operational hurricane forecast community by producing and providing ocean surface wind speed data products, and helping them assess the value of these products for use in their retrospective studies of potential new data sources.

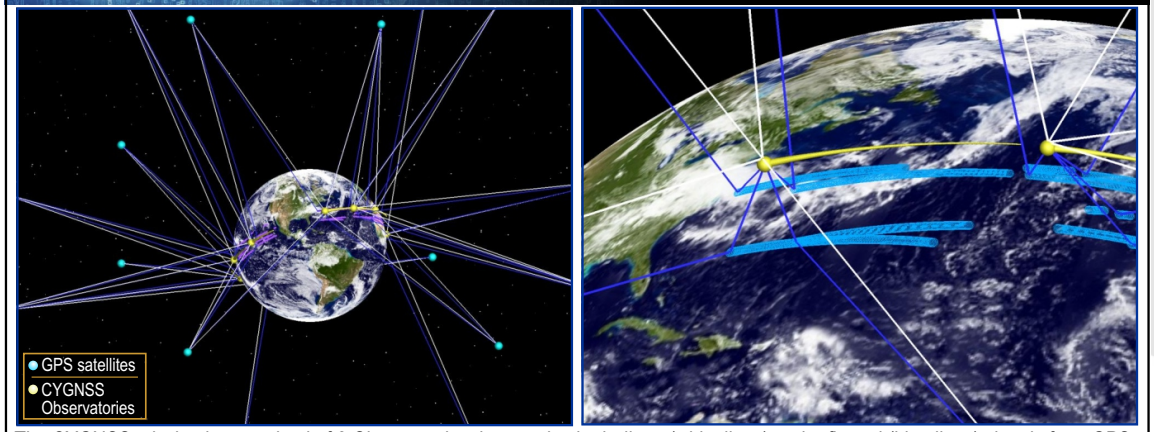


CYGNSS coverage map overlaid on historical record of all named (wind speed >30 kt) storm tracks during 2000-2009. Red indicates Cat 1 or higher TC.

Importance to NASA

- Resolve TC inner core dynamics and energetics, leading to fundamental improvements in our understanding of the genesis and intensification processes
- Provide post-QuikScat ocean wind measurement capability recommended by NRC Decadal Survey with enhanced coverage and performance in precipitating and high wind conditions
- Initiate an operational hand-off of unique observing capabilities to the operational hurricane forecast community

Mission Overview



The CYGNSS mission is comprised of 8 Observatories that receive both direct (white lines) and reflected (blue lines) signals from GPS satellites. The direct signals pinpoint CYGNSS Observatory positions, while the reflected signals respond to ocean surface roughness, from which wind speed is retrieved. GPS bi-static scatterometry measures ocean surface winds at all speeds and under all levels of precipitation, including TC conditions. In the right figure, instantaneous wind samples are indicated by individual blue circles. Five minutes of wind samples are shown.

TEMPO Tropospheric Emissions: Monitoring of Pollution

Hourly atmospheric pollution observations from geostationary Earth orbit

PI: Kelly Chance, Smithsonian Astrophysical Observatory

Instrument Development: Ball Aerospace

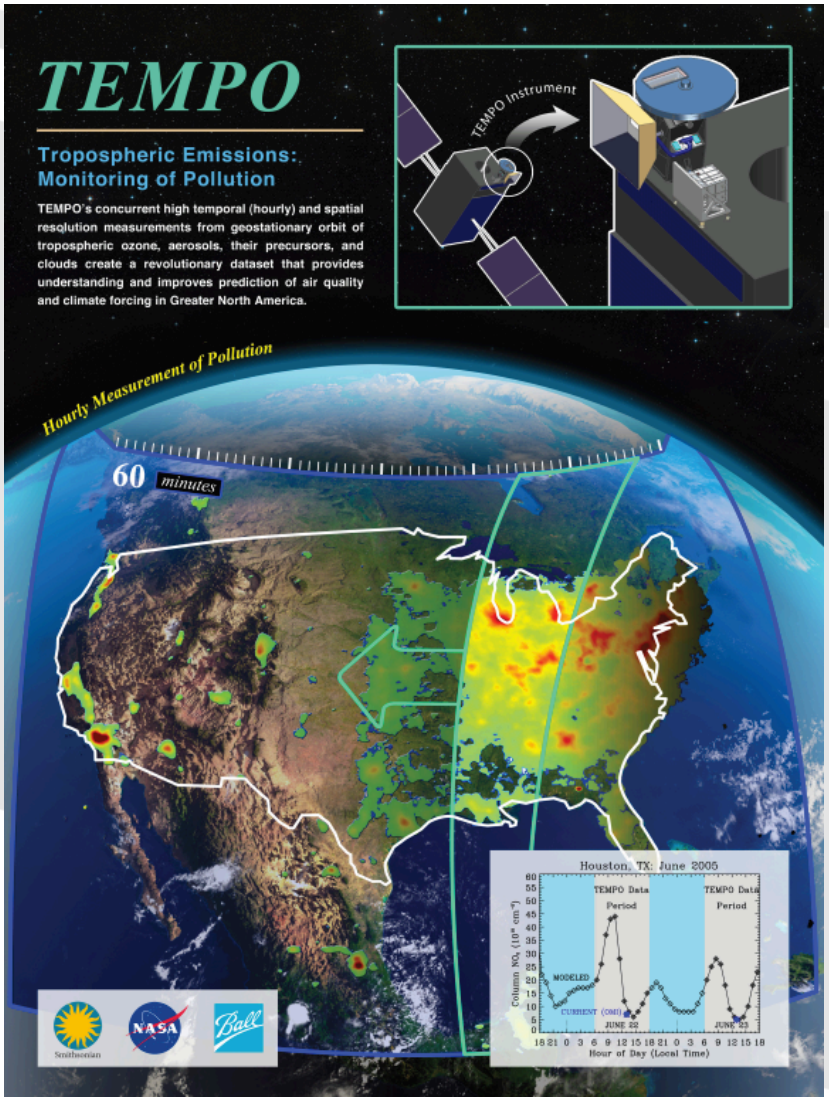
Project Management/Science: NASA LaRC

Other Institutions: NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, SLU, UAH, Nebraska

Selected: Nov. 2012 through NASA's first Earth Venture Instrument solicitation

Features:

- Instrument delivery 52 months from Authority to Proceed
- NASA will arrange hosting on commercial geostationary communications satellite with expected ~2018 launch
- Provides hourly daylight observations to capture rapidly varying emissions & chemistry
- UV-Visible grating spectrometer to measure key elements in tropospheric ozone and aerosol cycles
- Distinguishes boundary layer from free tropospheric & stratospheric ozone
- The North American geostationary component of an international constellation for air quality monitoring



President's FY14 Budget

- NASA ESD FY14 annual budget ~$1.8B (stable)
- NASA given the responsibility to study and develop the next generation of land observing satellite sensors in consultation with USGS
- NASA given responsibility for long-term observations by climate sensors
  - OMPS-Limb
  - TSIS
  - CERES