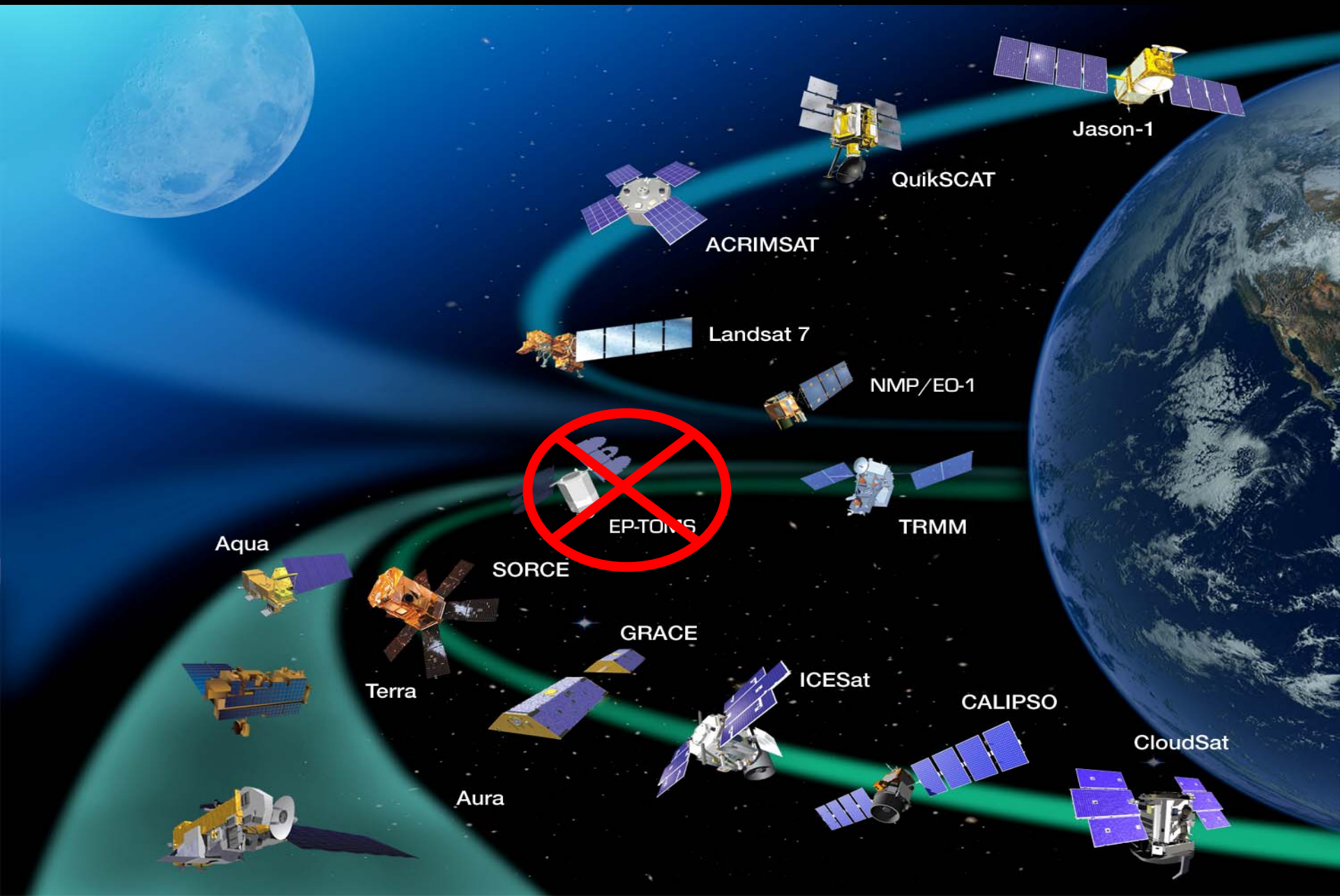
National Aeronautics and Space Administration

NASA's Earth Science Division Flight Missions Program

Theodore Hammer

June 20, 2007

Earth Science Division Operating Spacecraft



Senior Review Process

- Second Earth Science Sr. Review conducted 4/07 to evaluate operating missions that are beyond their baseline mission
  - Continuation of core missions
  - (Re)Allocation of resources between missions to optimize benefits
  - Identify and fund enhanced science
  - Based on Space Science Sr. Review, 2006 NRC Mission Extension report
- Changes from 2005 Earth Science Sr. Review
  - CoMRP panel explicitly evaluated contributions of NASA research missions to national operational objectives
  - Explicit emphasis on core vs. enhanced mission elements
- Summary of conclusions (final recommendations/reports still pending)
  - All missions extended through FY08-09
  - All but ACRIMSAT recommended for extension through FY11
    - ACRIMSAT pending comparative analyses with SORCE
  - All basic mission proposals accepted approximately as-is
  - Few (~2) enhanced mission proposals accepted

Earth Science Missions

Mission	Launch	FY07 Budget	Phase
TRMM	Nov-97	same	Implementation - Extended Operations
Landsat-7	Apr-99	same	Implementation - Extended Operations
QuikScat	Jun-99	same	Implementation - Extended Operations
Terra	Dec-99	same	Implementation - Extended Operations
ACRIMSAT	Dec-99	same	Implementation - Extended Operations
EO-1	Nov-00	same	Implementation - Extended Operations
Jason	Dec-01	same	Implementation - Extended Operations
GRACE	Mar-02	same	Implementation - Extended Operations
Aqua	May-02	same	Implementation - Prime Operations
ICESat	Jan-03	same	Implementation - Extended Operations
SORCE	Jan-03	same	Implementation - Prime Operations
Aura	Jul-04	same	Implementation - Prime Operations
Cloudsat	Apr-06	same	Implementation - Prime Operations
CALIPSO	Apr-06	same	Implementation - Prime Operations
OSTM	Jun-08	same	Implementation - Development
OCO	Sep-08	same	Implementation - Development
Glory	Dec-08	same	Implementation - Development
Aquarius	Jul-09	Mar-09	Implementation - Development
NPP	Sep-09	Apr-08	Implementation - Development
LDCM	Jul-11	same	Formulation
GPM	Jun-13	Dec-12	Formulation
ESSP-4	~2014	new in FY08	Solicitation in late US FY08

NRC Earth Science Decadal Survey

- **First-ever** comprehensive survey of all Earth sciences that could benefit from spaceborne observations
  - Study requested and supported by NASA, NOAA, USGS
  - Initiated 2004, preliminary report 2005, final report released 15 January 2007
- The Decadal Survey provides scientific priorities indirectly through a time sequencing of recommended missions
- NASA is developing a mission plan for the coming decade incorporating:
  - General scientific and societal impact guidance from the Decadal Survey
  - Potential mitigation for removal of climate sensors from NPOESS
    - NRC workshop report on NPOESS/Climate issues, due mid-July, 2008
  - NASA assessment of technical challenges and mission costs
  - International collaborations
  - Agency-wide and national budget priorities
  - Draft NASA plan to be completed in Fall, 2007
    - NAC and NRC review
    - Includes an update to the Earth Science portion of the SMD Science Plan
- FY08 Budget Request funds NASA precursor missions identified in Survey
  - Global Precipitation Measurement mission
  - Landsat Data Continuity Mission
  - NPOESS Preparatory Program

Decadal Survey Ongoing Actvities

Completing “building block” calibrations of NRC missions

- Ensure consistent, rational basis for costs
- Full (LCC) mission cost (including NASA science teams/analyses, mission extension)
- 2 additional independent cost-estimation efforts (Aerospace, LaRC IPAO)

Developing joint (with NOAA) mitigation strategies for NPOESS climate sensors

- NASA-NOAA study for OSTP
- NRC/SSB Workshop (science impacts, priorities, approaches)

Discussions with International Partners (Spring 07)

- Determine common interests, complementary capabilities
- JAXA/METI (2) CNES (2), CSA, ESA, CEOSS, WMO/SP, DLR meetings held
  - Bilateral new mission working groups initiating (CNES, JAXA, DLR)

Implementing “Early Mission” workshops

- Confirm/refine match between science objective and notional mission
- Determine necessary “context” measurements for science objective
- Community involvement, HQ lead
- Late June--late July for SMAP, CLARREO, ICESat-II, DESDynI

Developing integrated NASA mission plan

- Revised NASA Earth Science Plan
- Identify specific near-term missions to be initiated
- Mature plan to be coordinated with NOAA

Orbiting Carbon Observatory

Mission Science Objective: Collect the first space-based global measurements of atmospheric CO2 with the precision, resolution, and coverage needed to characterize its sources and sinks on regional scales and quantify their variability over the seasonal cycle

Key Science Products: Estimates of X_{CO2} with random errors and systematic biases no larger than 0.3% (1 ppm) on regional scales (1000 km by 1000 km) over both continents and oceans, on the sunlit hemisphere of the Earth at semi-monthly intervals, for at least 2 years

Mission Description:

S/C: LEOStar-2 (OSC)

Instrument:

- 3-Channel Grating Spectrometer (JPL/Hamilton Sundstrand)

Launch Vehicle: Taurus XL (OSC)

Orbit: 98.2° inclination, sun-synchronous at 705km, (A-Train) with a 1:26 PM Nodal Crossing Time

Mission Life: 2 years

Mission Project Management: JPL

Launch Date: 12/15/08

Status: Implementation (Phase D) in S/C and instrument I&T

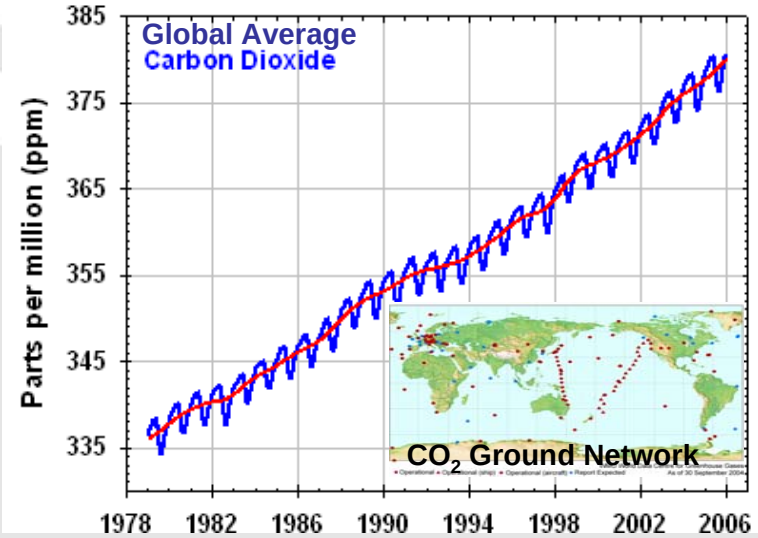
The Need for Global CO_2 Measurements

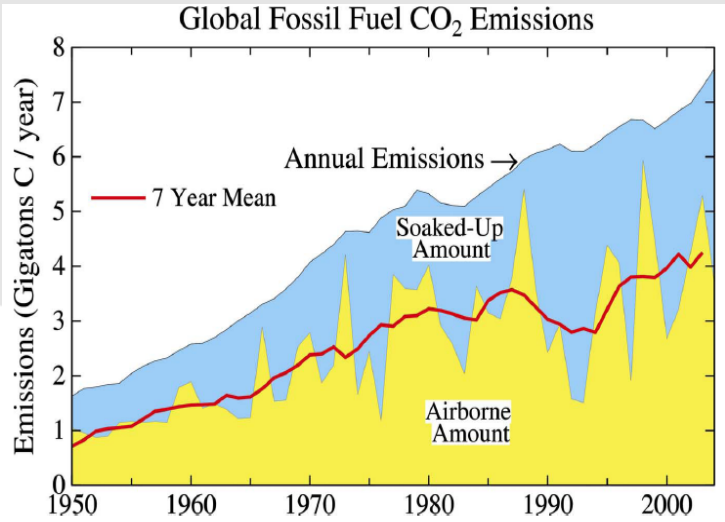
Carbon dioxide (CO2) is the primary man-made greenhouse gas

- CO2 concentrations have increased by 35% since the beginning of the industrial age
- Only half of the CO2 emitted by human activities is staying in the atmosphere

Outstanding Questions:

- Where is the CO2 being absorbed?
  - Oceans vs. land ecosystems?
  - North America vs. Eurasia?
- Why does the atmospheric buildup vary with uniform emission rates?
- How will the global carbon cycle respond to climate change and affect the rate of atmospheric CO2 buildup?



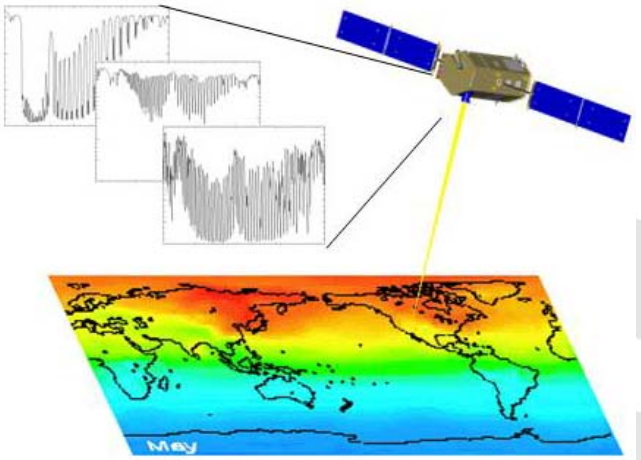


Global fossil fuel CO_2 emissions with division into portions that remain airborne or are soaked up by the ocean and land.

Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.

The Orbiting Carbon Observatory (OCO)

OCO will collect the space-based data needed to identify CO_2 sources and sinks and quantify their variability over the seasonal cycle

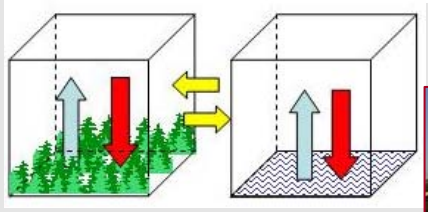


Approach:

Collect spatially resolved, high resolution spectroscopic observations of CO_2 and O_2 absorption in reflected sunlight

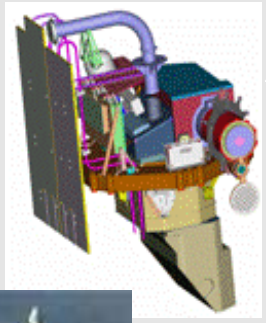
Use these data to quantify spatial and temporal variations in the *column averaged CO_2 dry air mole fraction, X_{CO2}* over the sunlit hemisphere

Employ independent calibration and validation approaches to produce XCO2 estimates with random errors and biases no larger than 1 ppm on regional scales at semi-monthly intervals for 2 years

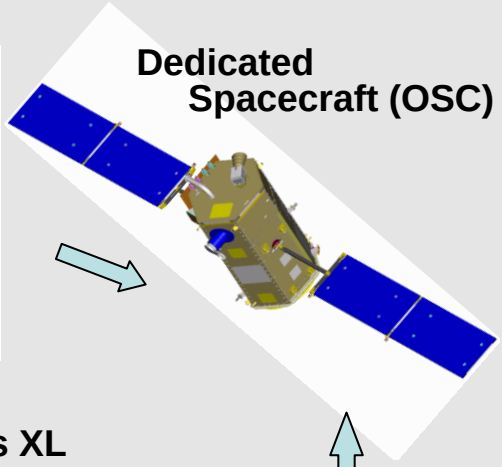


OCO Mission Overview

3-channel Spectrometer (JPL/HS)



Dedicated Spacecraft (OSC)

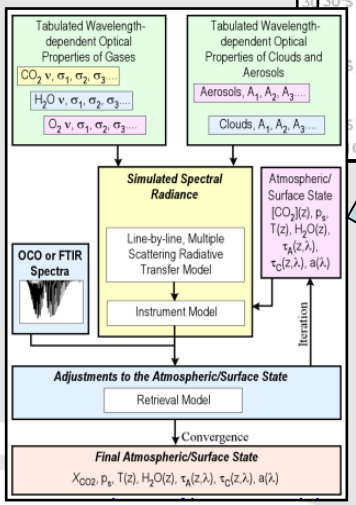


Taurus XL
3110 (KSC)
WTR Launch

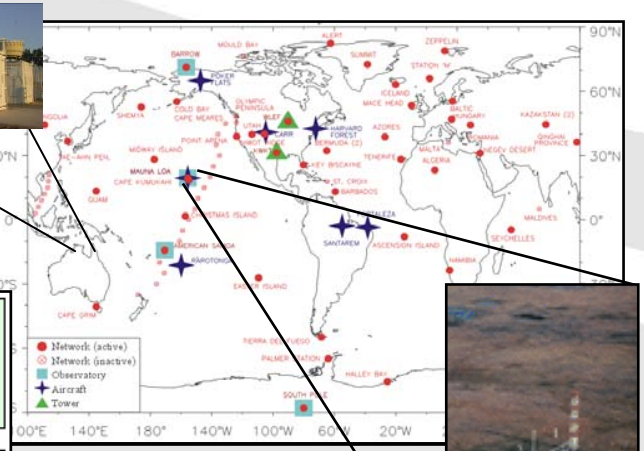
Mission Ops (OSC)

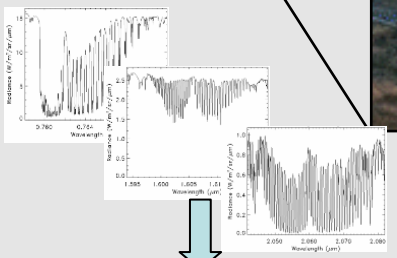
Ground Stations (GSFC/NASA)

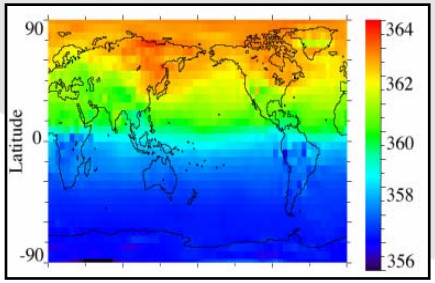
Data Processing Center (JPL)



Ground Validation Sites







Data Products

Please visit http://oco.jpl.nasa.gov for more information

Glory

Mission Science Objective : Improve our understanding of climate variability and change by determining the global distribution of natural and anthropogenic aerosols and clouds with accuracy and coverage sufficient for significantly improved quantification of direct and indirect aerosol climate effects, and also extend measurement of the Total Solar Irradiance (TSI) to determine the Sun's direct and indirect effect on Earth's climate

Key Science Products: Aerosol Properties - Optical thickness, size, shape, refractive index; Total Solar Irradiance with accuracy comparable to SORCE

Mission Description:

S/C: LEOStar Bus from VCL Mission (Orbital Sciences)

Instruments:

- Aerosol Polarimetry Sensor (APS) (Raytheon)
- Solar Total Irradiance Monitor (TIM) (U. Colorado/LASP)

Launch Vehicle: Taurus XL (Orbital Sciences)

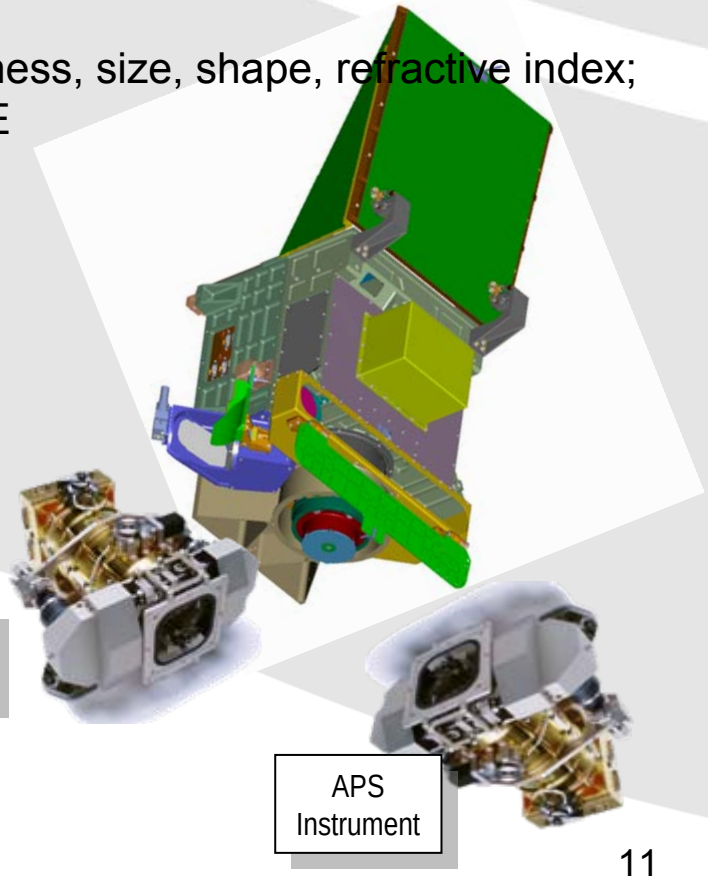
Orbit: 705 km sun-sync, 98.2^{o} inclin (A-Train Constellation)

Mission Life: 3 years

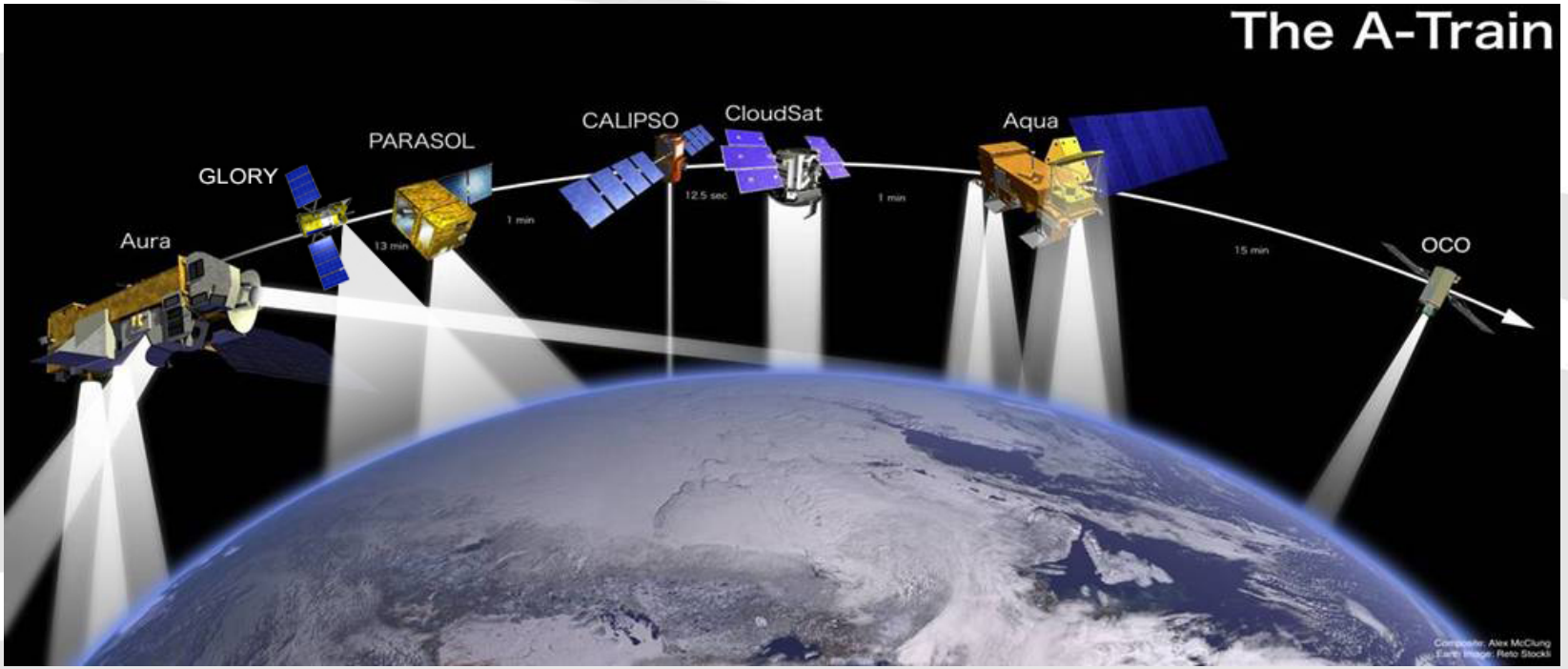
Mission Project Management: GSFC

Launch Date: 12/15/08

Status: Implementation (Phase D) in S/C and Instrument I&T

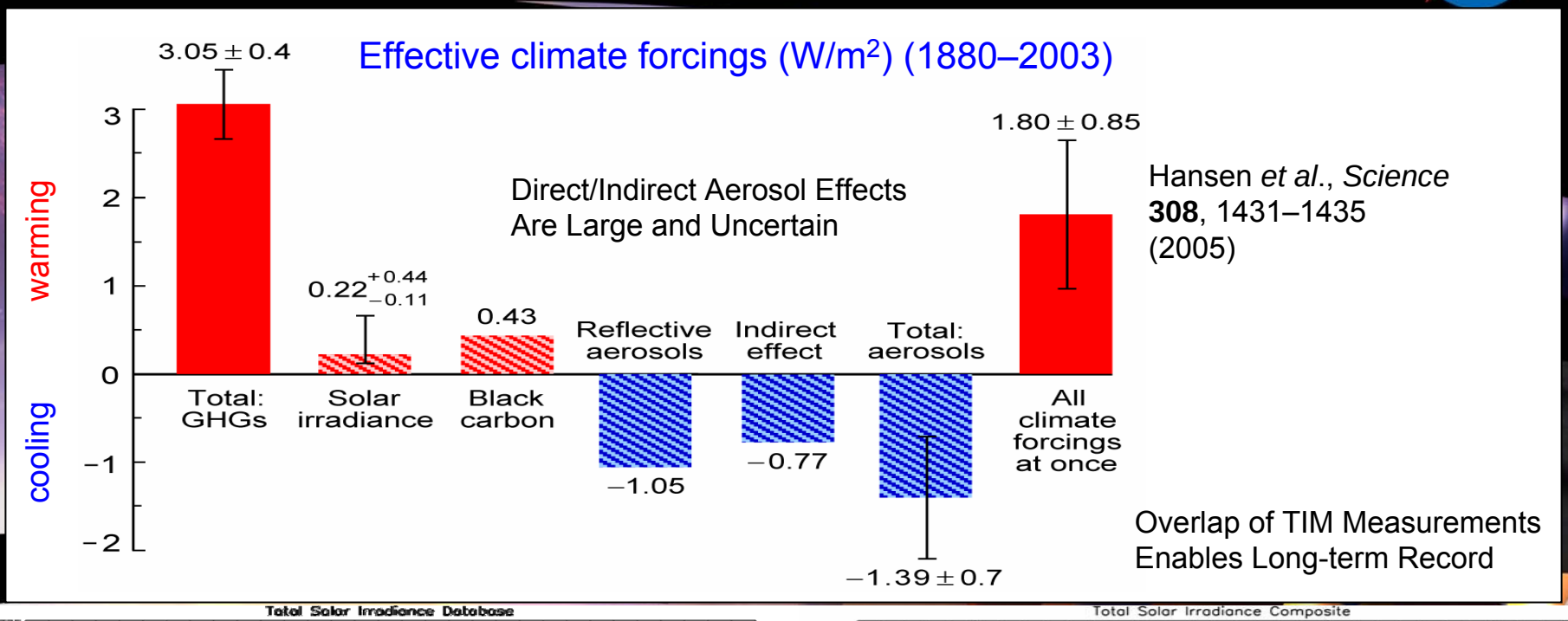


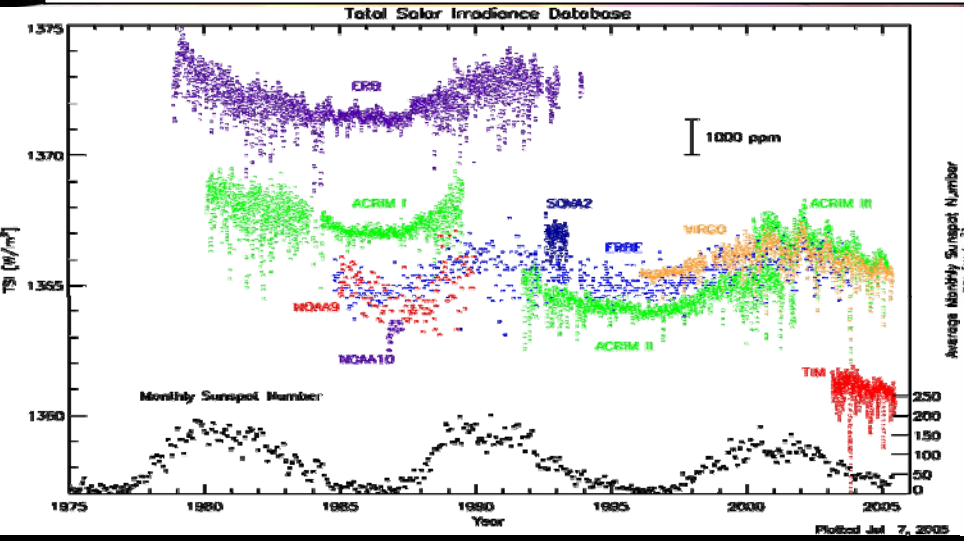
Glory in Afternoon Constellation

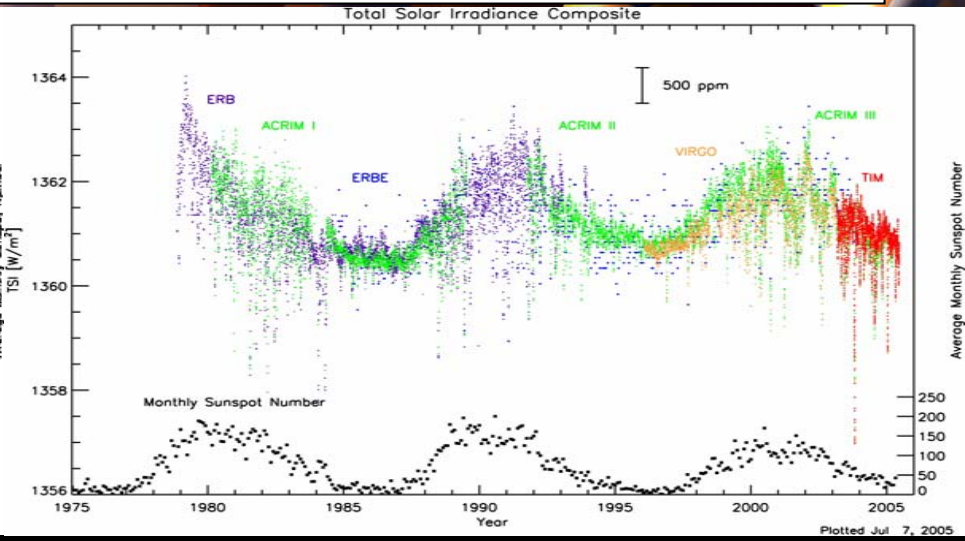


- **Glory will be formation flying with the NASA Afternoon Constellation (A-Train)**
  - **Orbit parameters:**
    - **705 km Sun-Synchronous**
    - **98.2° inclination**
    - **Ascending node Mean Local Time (MLT) crossing of 1:33:45.5 pm**
  - **Position relative to Aqua (based on nominal control box location)**
    - **3 minutes, 45.5 seconds behind at MLT crossing**
    - **270 km west offset (on WRS-2 grid)**
    - **1 minute, 34.5 seconds behind PARASOL**

Glory Will Increase Our Understanding of the Earth's Energy Budget







Glory Instruments Measure Important Parameters for Understanding Climate

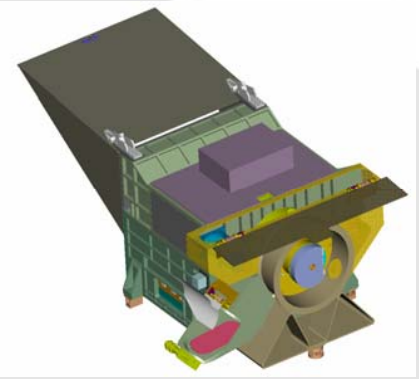
Understanding climate variability and change requires measuring:

- *Aerosol Properties - optical thickness (±/2), size (explicit), shape (new), and refractive index (new)*
- *Total Solar Irradiance*

APS Provides:

Determination of the global distribution of natural and anthropogenic aerosols and clouds with accuracy and coverage sufficient for significantly improved quantification of direct and indirect aerosol climate effects:

- Uncertainty in the effect of aerosols on global warming accounts for roughly 40 percent of the uncertainty in the radiative forcing function.
- Retrieval of aerosol particle microphysical properties by inverting multi-angle and multi-spectral radiance and polarization measurements will significantly extend the information content concerning aerosols from multi-spectral instruments such as MODIS and MISR.



TIM Provides:

Continued measurement of the Total Solar Irradiance to determine the Sun's direct and indirect effect on the Earth's climate.

- Total Solar Irradiance with precision of 10 ppm and accuracy of 100 ppm are needed to understand the role of the sun in climate change and to understand the astrophysics of the nearest star to the Earth.

Ocean Surface Topography Mission

Mission Science Objective: Provide continuity of ocean topography measurements beyond Topex/POSEIDON and Jason-1 for determining ocean circulation, climate change, sea level rise, and societal applications (El Nino, hurricane forecasting, etc.)

Key Science Products: Global sea surface height (3.4 cm), surface wave height (40 cm), near-real-time operational and validated science data products

Mission Description:
S/C: PROTEUS (CNES)
Instruments:

- Radar Altimeter (CNES)
- Advanced Microwave Radiometer (NASA)
- GPS Payload (NASA)
- DORIS (CNES)
- Laser Retroreflector Array (NASA)
- DORIS Auxiliary Instruments (CNES)

Launch Vehicle: Delta II 7320
Orbit: 66º inc., 1336 km, 10 day repeat
Mission Life: 3 years
Mission Project Management: JPL
Launch Date: 06/15/08
Status: Implementation (Phase D) in observatory I&T

Landsat Data Continuity Mission

Mission Science Objective: Extend the multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics

Key Science Products: Moderate resolution maps of land cover/land use change over multiple decades including deforestation, agricultural extensification, and urbanization; documentation of ecosystem fragmentation and connectivity; identification and quantification of regional to continental scale sources and sinks of carbon; the first high resolution image mosaic of Antarctica for the International Polar Year.

Mission Description:

S/C: Rapid Spacecraft Development Catalog Procurement

Instrument:

- Operational Land Imager (OLI) multi-spectral, 30m GSD, 185km swath (SEB in-process)

Launch Vehicle: Launch Service Procurement (medium-class)

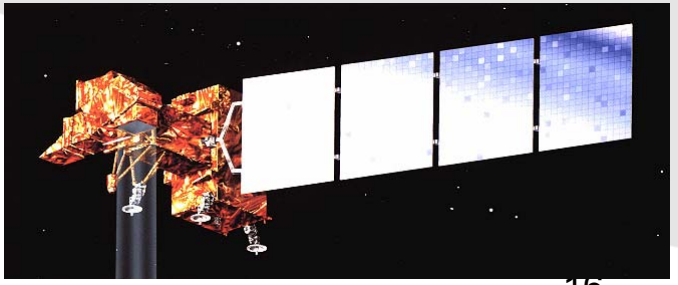
Orbit: 705 Km circular, sun-synch, 98.22°, 10:15 am (DN), 16-day repeat

Mission Life: 5 Years

Mission Project Management: GSFC

Launch Date: 07/3/2011

Status: Formulation (Phase A)



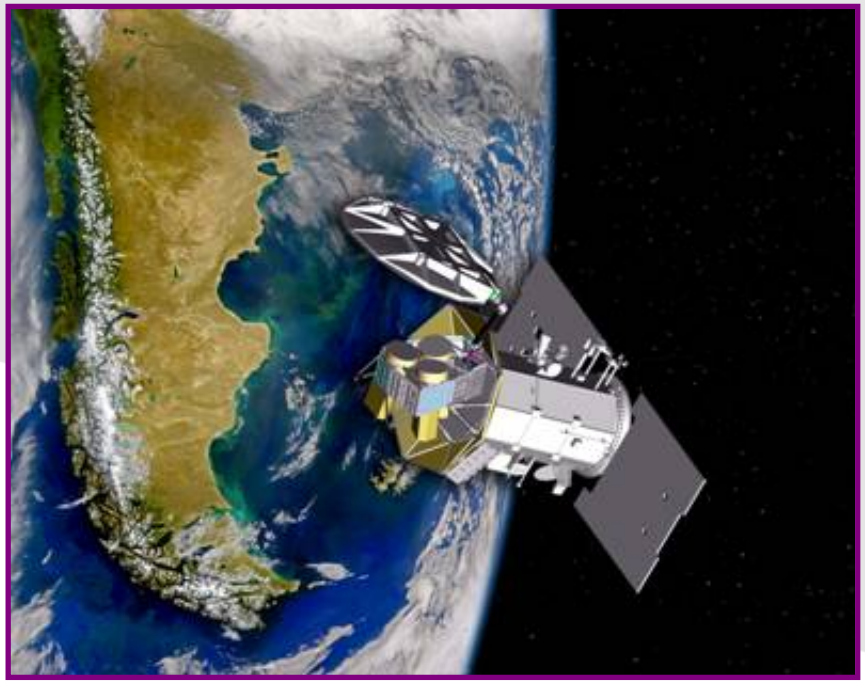
Aquarius

Mission Science Objective: Make pioneering space-based measurements of Sea Surface Salinity (SSS) with the precision, resolution, and coverage needed to characterize salinity variations and investigate the linkage between ocean circulation, the Earth's water cycle, and climate variability

Key Science Products: SSS with global root-mean-square (rms) random errors and systematic biases no larger than 0.2 psu on 150 km by 150 km scales over the ice-free oceans

Mission Description:
S/C: SAC-D (CONAE - Argentina)
Instruments:
- L-Band Radiometer/Scatterometer(GSFC/JPL)
- 7 SAC-D Instruments (CONAE)

Launch Vehicle: Delta II (Boeing)
Orbit: 98° inclination, sun-synchronous at 657 km;
6:00 PM Nodal Crossing Time
Mission Life: 3 years
Mission Project Management: JPL
Launch Date: 7/14/09
Status: Implementation (Phase C) in S/C critical design and instrument integration



NPOESS Preparatory Program

Mission Science Objectives: Bridge Mission: Provide NASA with new observations to continue the time series for a selected group of global change observations initiated by the Earth Observing System (EOS) Terra, Aqua, and Aura missions; **NPOESS Risk Reduction**: Provide the NPOESS operational community with pre-operational risk reduction demonstration and validation for selected NPOESS instruments, and algorithms, as well as ground processing.

Key Science Products: Atmospheric ozone, **OMPS**; Land cover and vegetation biophysical properties, **VIIRS;** Sea and land surface temperatures, **VIIRS**; Temperature and moisture profiles in the atmosphere, **CrIS/ATMS**; Clouds and aerosols, **VIIRS;** Ocean biological and biogeochemical properties, **VIIRS**

Mission Description:
S/C: BCP 2000, Ball Aerospace
Instruments:

- Visible/Infrared Imaging Radiometer Suite (VIIRS) (Raytheon/SBRS - IPO provided)
- Cross-track Infrared Sounder (CrIS), (ITT- IPO Provided)
- Ozone Mapping and Profiling Suite (OMPS), (Ball Aerospace - IPO Provided)
- Advanced Technology Microwave Sounder (ATMS), Northrop Grumman Electronic Systems (GSFC)

Launch Vehicle: Delta II (Boeing)
Orbit: 824 Km sun sync polar, 1:30pm crossing time, 98deg inclination
Mission Life: 5 years
Mission Project Management: GSFC
Launch Date: 9/30/09
Status: Implementation (Phase D) in S/C test and instrument I&T

Global Precipitation Measurement

Mission Science Objective: Initiates the measurement of global precipitation, providing uniformly calibrated measurements every 3 hours for scientific research and societal applications.

Key Science Products: Precipitation intensity and distribution, instantaneous precipitation rate, 3-hourly precipitation rate, daily and monthly precipitation accumulation, latent heat distribution and outreach precipitation products

Mission Description:

S/C: Core (GSFC-industry) Constellation (GSFC/RSDO)

Instruments:

- Core: Dual-frequency PR (JAXA) GMI (Ball)
- Constellation: GMI (Ball)

Launch Vehicle:

- Core - H-IIA 202A (JAXA - TBD)
- Constellation -Taurus

Orbit: 65º inc., 400 km (Core), 30º inc., 635 km (Const.)

Mission Life: 3 years (for both Core and Constellation)

Mission Project Management: GSFC

Launch Date: 06/01/13 (Core), 06/01/14 (Const.)

Status: Formulation (Phase B) in preliminary design

BACKUP

NOAA Missions (2.5)

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (NOAA portion)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometer	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate, and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	MEO, SSO	Backscatter radar	$350 M

NASA Near-Term Missions (3.5/14.5 total)

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	$ Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M

NASA Mid-Term Missions (5/14.5 total)

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	$ Estimate
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M

NASA Far-Term Missions (6/14.5 total)

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

*Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement