National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Earth Science Programs

Tony Freeman and Eastwood Im

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Earth Science and Technology Directorate

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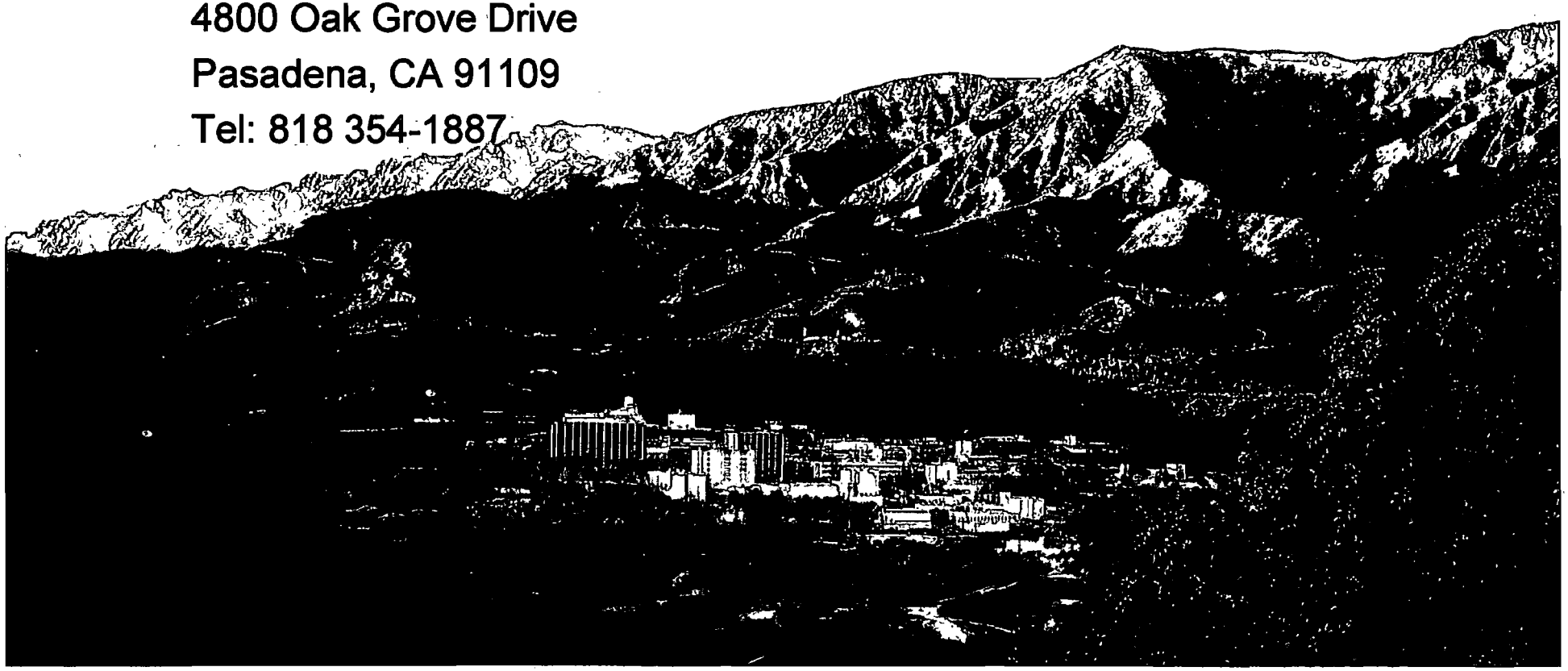

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Missions to Enable Atmospheric Science

ATMOS & MLS were instrumental in understanding ozone depletion

ACRIMSAT is measuring the total amount of solar energy reaching the Earth

MISR/ACE * distinguishes different aerosols, and cloud forms to develop 3-D models

AIRS/GACM * measures air temperature and humidity for input into weather forecasts

TES makes the first-ever measurements of tropospheric ozone from space

CloudSat/ACE * will improve estimates of cloud properties

OCO/ Ascends * will improve estimates of carbon sources and sinks

GPSRO * will provide all-weather temperature, water vapor, and electron density profiles for weather, climate and space weather

ATMOS (1985)

UARS MLS (1991-Present)

ACRIMSAT (1999-Present)

MISR on TERRA (1999-Present)

AIRS on AQUA (2002-Present)

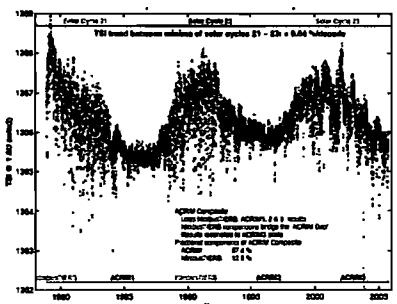
TES on AURA (2004-Present)

MLS on AURA (2004-Present)

CloudSat (2006)

Orbiting Carbon Observatory Mission (2008)

GPSRO (2010-2013)



Wilson & Morovinov, GRL, 2003

1985 **1991** **1999** **2002** **2004** **2005** **2008** **2010**

*** Decadal Survey Mission**

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Missions to Enable Ocean Science

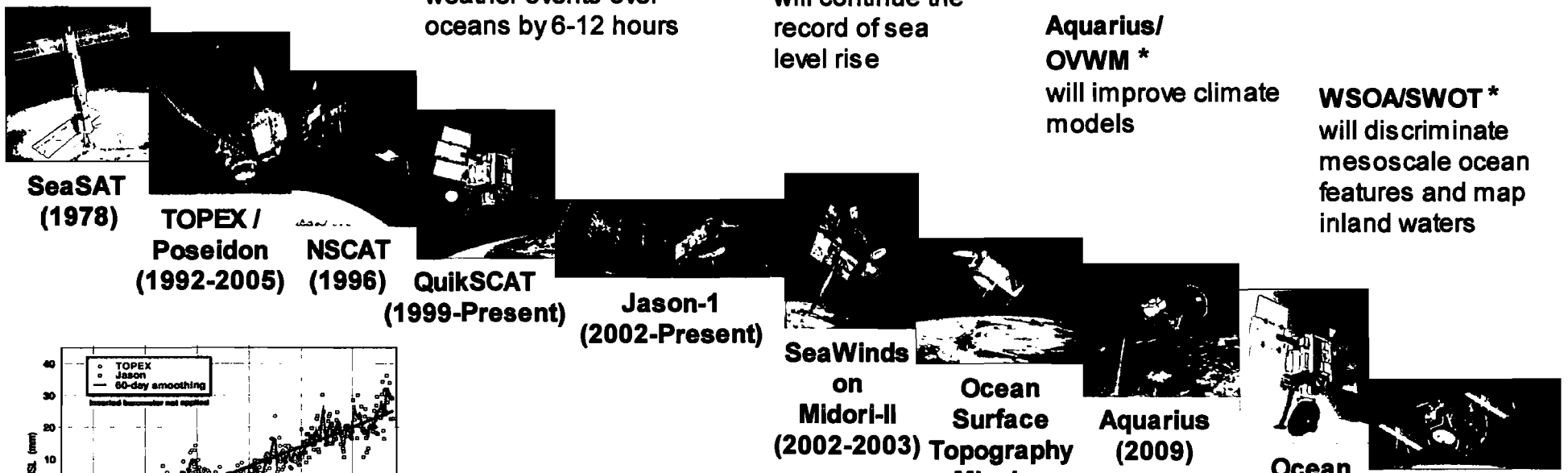
TOPEX/Poseidon
provide global views of El Niño/La Niña Pacific Decadal Oscillation

SeaWinds
increases prediction time for hazardous weather events over oceans by 6-12 hours

Jason/OSTM
will continue the record of sea level rise

Aquarius/ OVWM *
will improve climate models

WSOA/SWOT *
will discriminate mesoscale ocean features and map inland waters



SeaSAT (1978)

TOPEX / Poseidon (1992-2005)

NSCAT (1996)

QuikSCAT (1999-Present)

Jason-1 (2002-Present)

SeaWinds on Midori-II (2002-2003)

Ocean Surface Topography Mission (2008)

Aquarius (2009)

Ocean Vector Winds Mission

Wide Swath Ocean Altimeter

S. Nerem/U. Colorado

(2013-2016)

1978 1992 1996 1999 2002 2003 2008 2009 2013

* Decadal Survey Mission

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Missions that Address the Land, Biosphere and Cryosphere

SIR series demonstrated the most advanced radar technology ever flown

ASTER Provides critical data for hazard assessment

SRTM data were used to create the most accurate and highest resolution global topographic

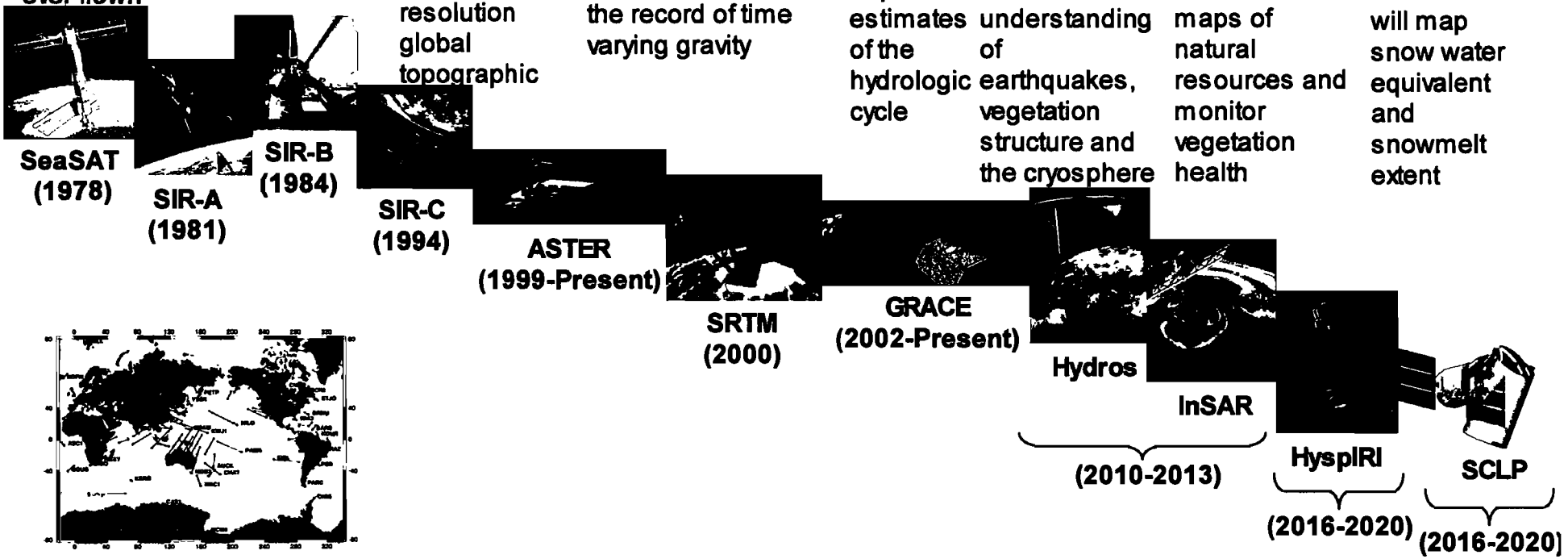
GRACE/GRACE II * improved our estimates of Earth's gravity by a factor of 50-100X and began the record of time varying gravity

Hydros/ SMAP * will improve estimates of the hydrologic cycle

InSAR * will improve our understanding of earthquakes, vegetation structure and the cryosphere

HyspIRI * will make maps of natural resources and monitor vegetation health

SCLP * will map snow water equivalent and snowmelt extent



* Decadal Survey Mission

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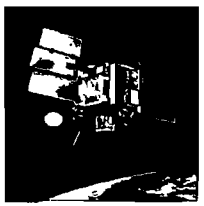
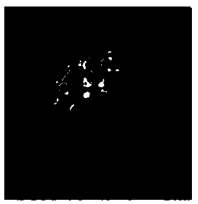
JPL Earth Science Flight Projects

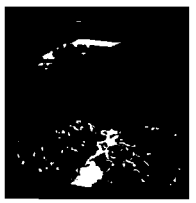
Operational

QuikSCAT (1998)

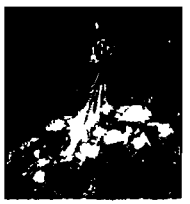




ACRIMSAT (1999)

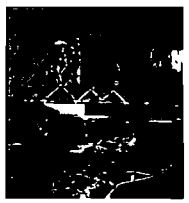


ASTER (1999)



MISR (1999)

Jason-1 (2001)

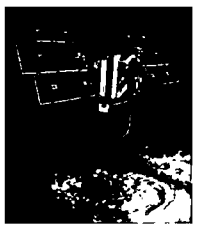


AIRS (2002)

GRACE (2002)

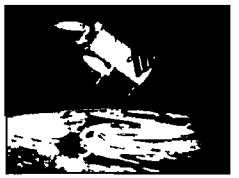
TES (2004)

MLS (2004)



CloudSat (2006)

Development

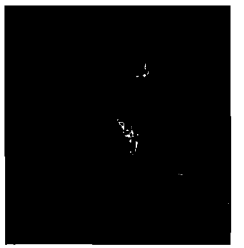


Ocean Surface Topography Mission ***(2008)***

Carbon Cycle: OCO ***(2008)***

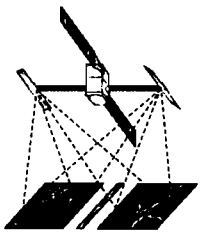
Sea Surface Salinity: Aquarius ***(2009)***

Mission Studies

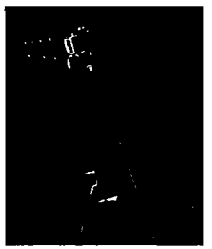


Soil Moisture: Hydros*

L-Band InSAR

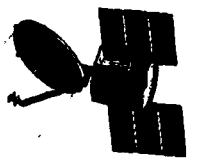


Sea Surface and Terrestrial Water



Hyperspectral Mission

GRACE F/O



Ocean Vector Winds

***Approved for formulation (7/02)**
Not funded for completion of formulation (12/05)

Observations from Space Reduce Uncertainties In Climate Models

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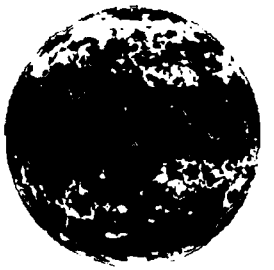
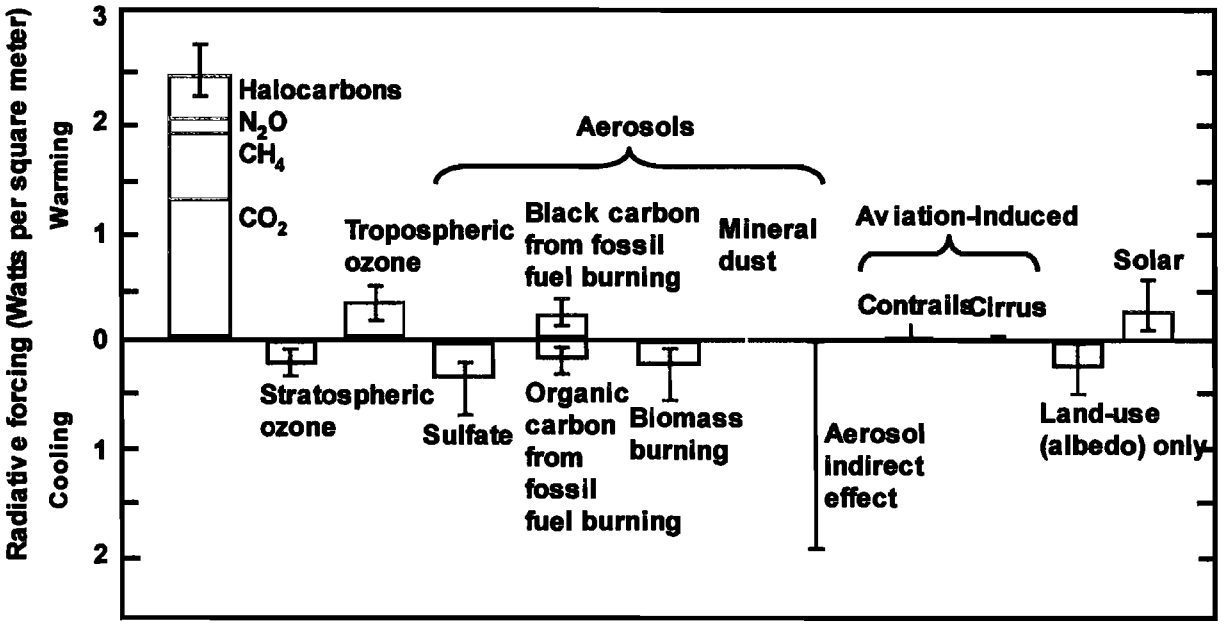
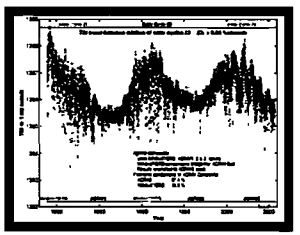
The Tropospheric Emission Spectrometer (TES) is making the first-ever measurements of tropospheric ozone from space

Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps



Orbiting Carbon Observatory (OCO) will measure 1 molecule of CO_2 in 1,000,000 molecules of air





ACRIMSAT measures the total amount of solar energy reaching the Earth

The Microwave Limb Sounder (MLS) is making measurements of stratospheric ozone

CloudSat is providing profiles of clouds

Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps

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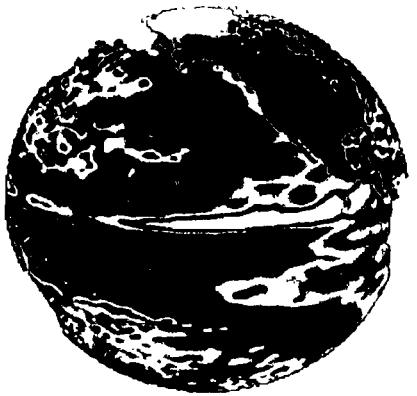
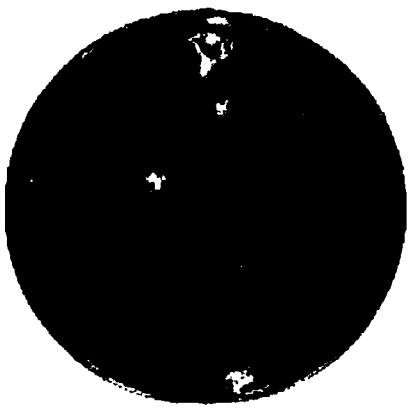
New Ways to See a Changing Earth

Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps



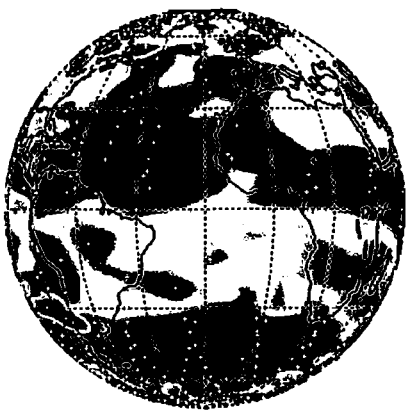
Jason provides global sea surface height maps every 10 days

Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth's gravity



QuikSCAT provides near global (90%) ocean surface wind maps every 24 hours

Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps



Tropospheric Emission Spectrometer (TES) provides monthly global maps of Ozone

Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry

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Recent JPL Earth Science Highlights

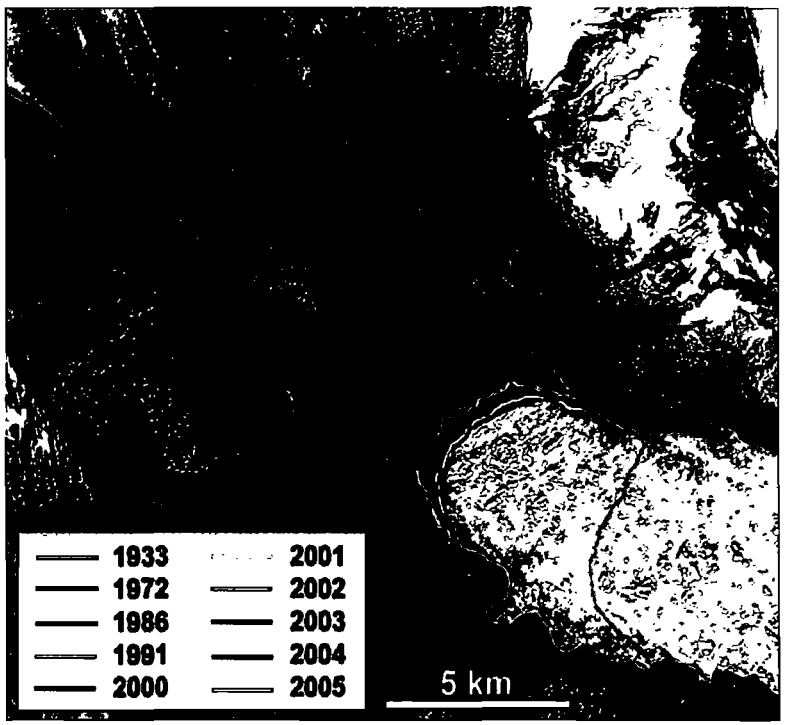
East Greenland Glacier Flow from ASTER

Similar responses at nearly coincident times implies that climate change is common trigger mechanism

Acceleration of Greenland glacier flow causes estimate of it's contribution to global sea level rise to increase to ~20%

Other outlet glaciers in Greenland might exhibit similar responses as climate change effects migrate northwards

Kangerdlugssuaq Glacier



~300% flow speed acceleration

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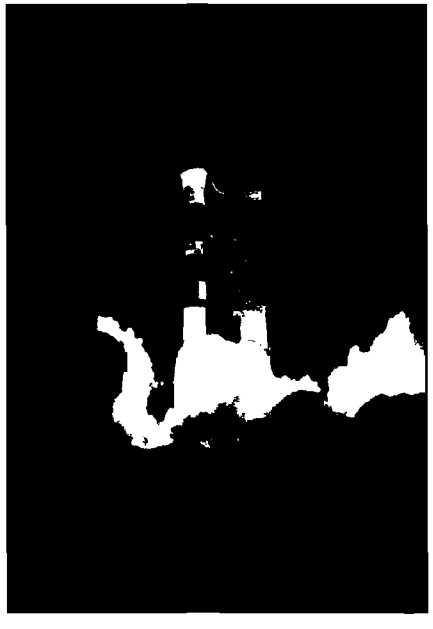
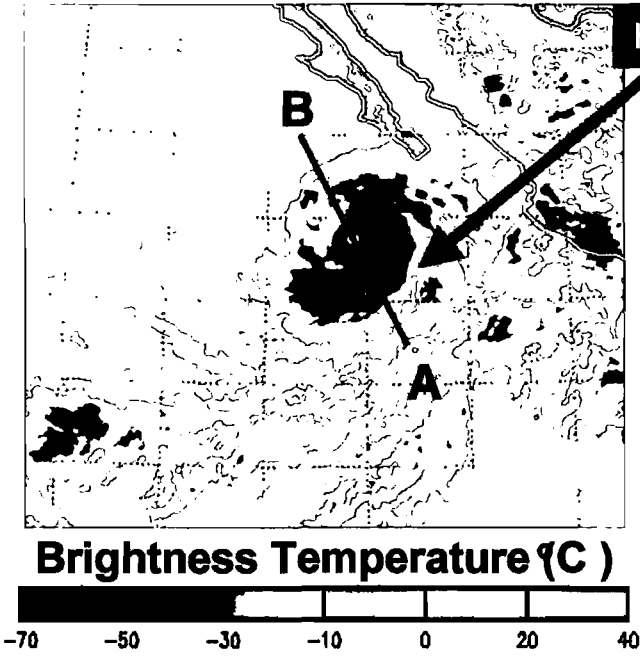
CloudSat reveals 3-D cloud structure globally for the first time

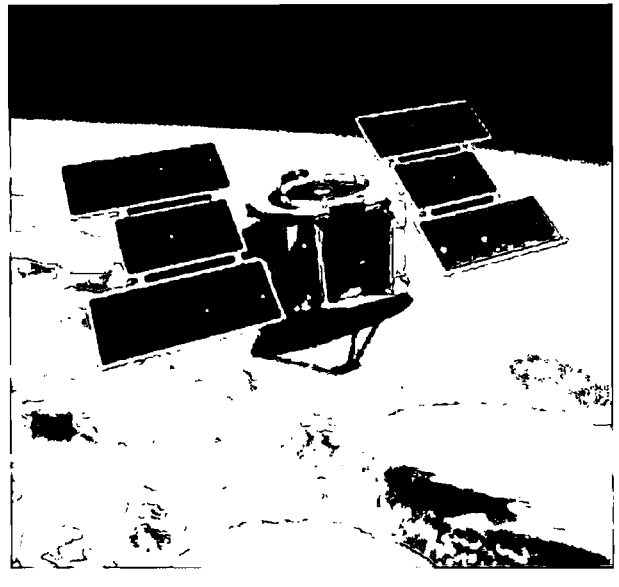
- We expect Cloudsat will still be in operation when the ESA/JAXA Earthcare mission launches in 2012



CloudSat Launch
April 28,2006



23 Aug 2006 GOES-11 21:00 UTC



Courtesy Graeme Stephens (CSU) - Cloudsat

B

A

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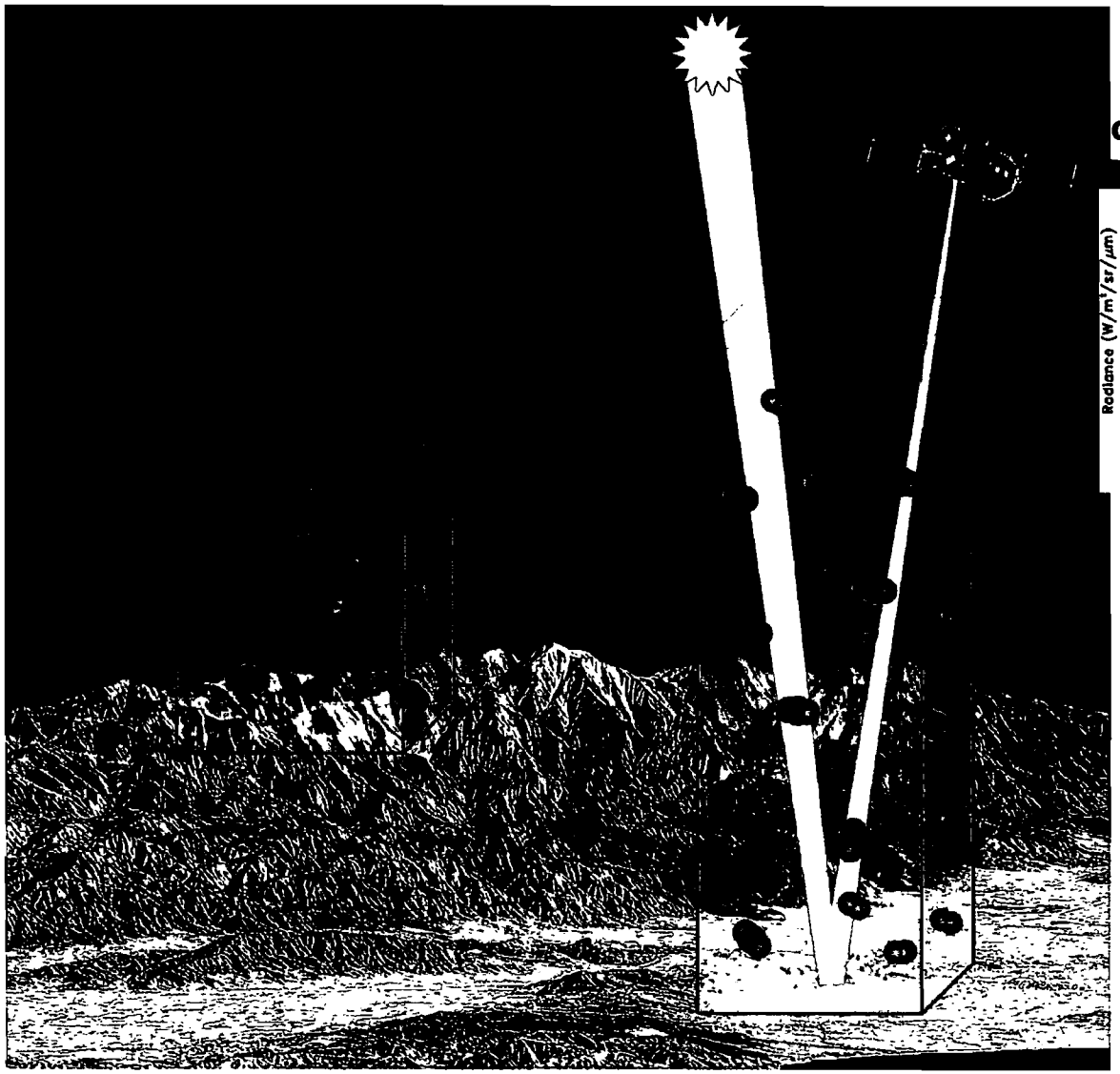
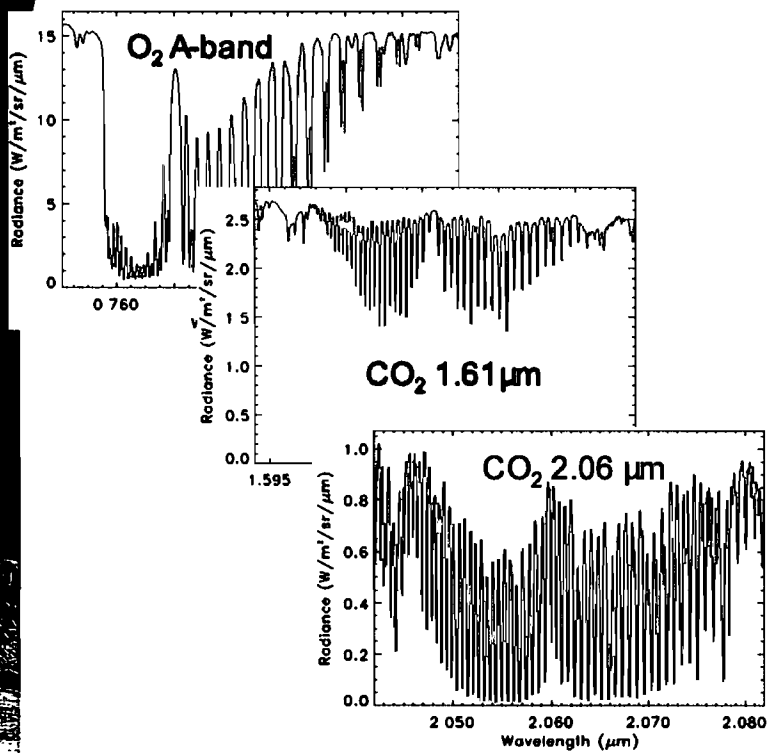
Pasadena, California

Orbiting Carbon Observatory (OCO) will measure CO_2 from space



OCO multi-spectral data products on columnar CO_2, clouds/aerosols, H_2O, etc.



X_{CO2} is the normalized CO_2 mixing ratio in a column of air.

Accuracy: 1 part per million ppm (or 0.3%)

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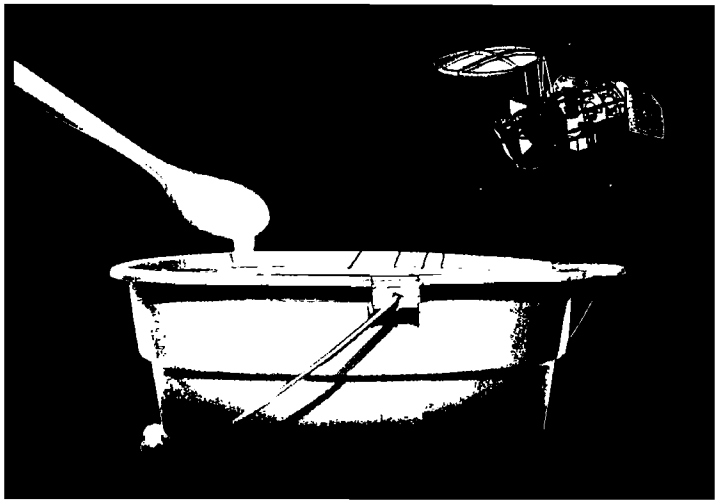
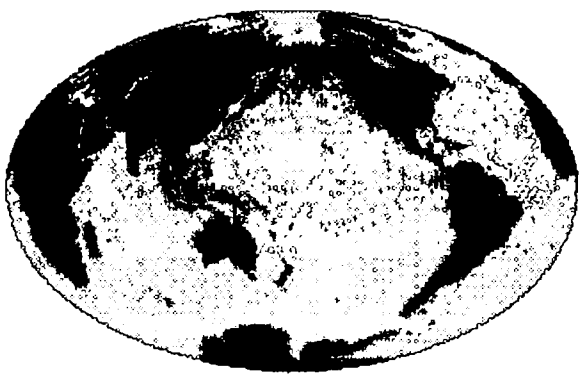
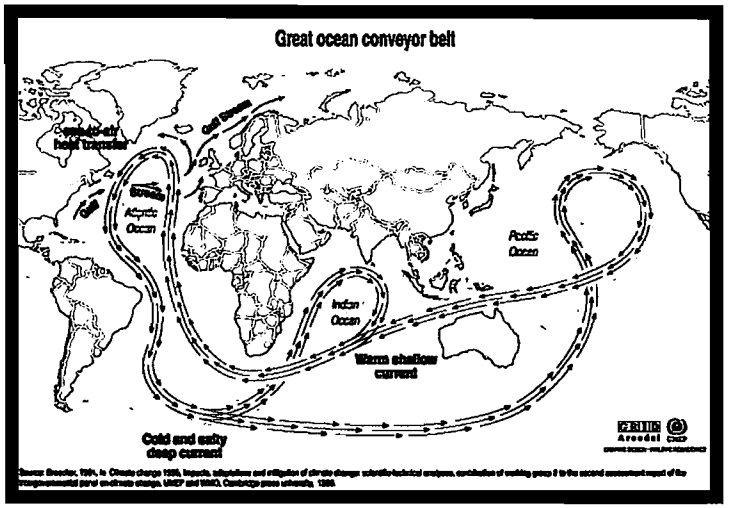
Salinity of the world's oceans is another key barometer of climate change



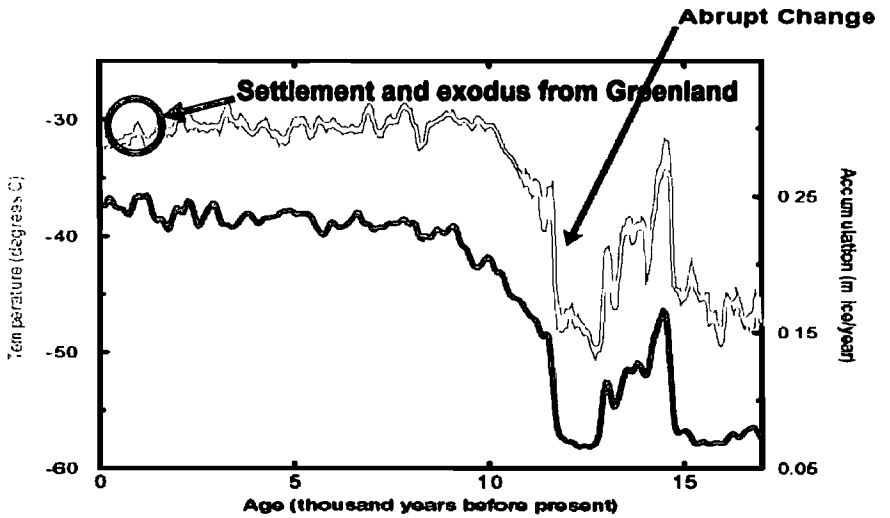
Aquarius (2009) will measure changes less than 0.2 grams per kilogram of water.



Ship observations (very sparse)



Cold, dense salty water in the North Atlantic sinks, allowing warmer water into the region.



Slowing of the "conveyor belt" causes severe winters in New England and Europe

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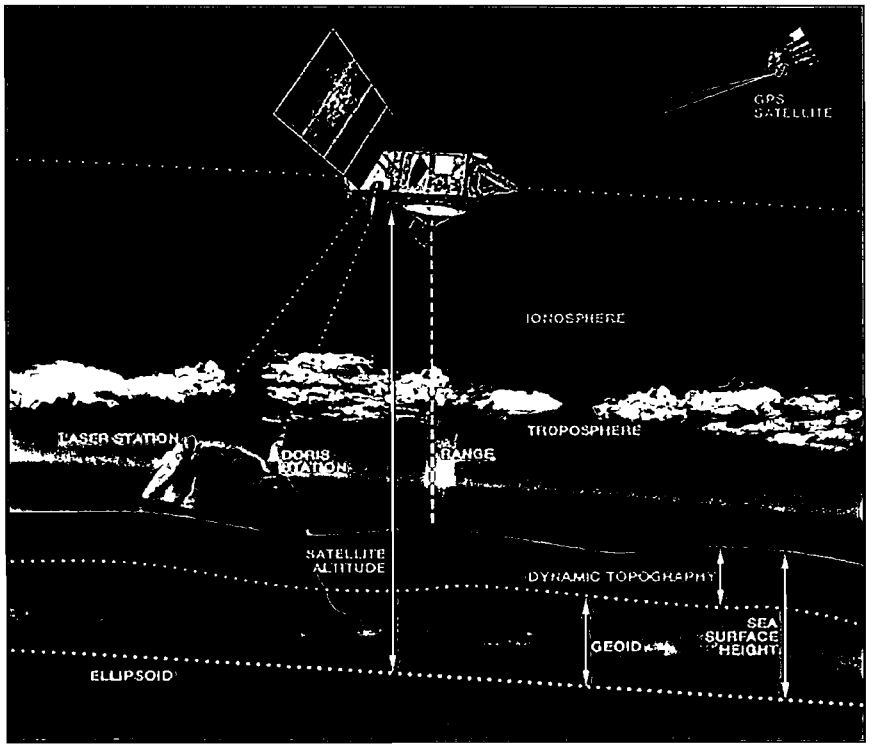
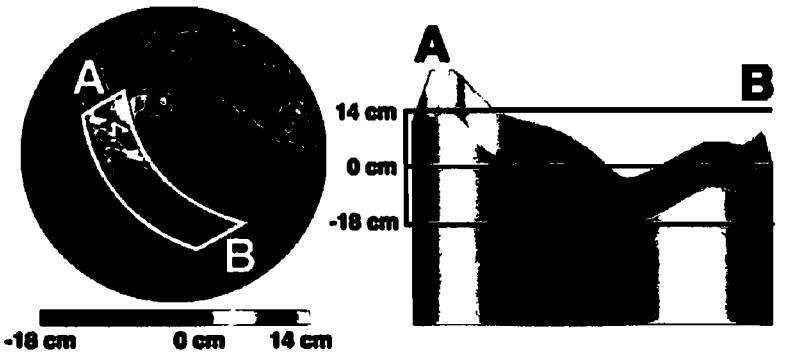
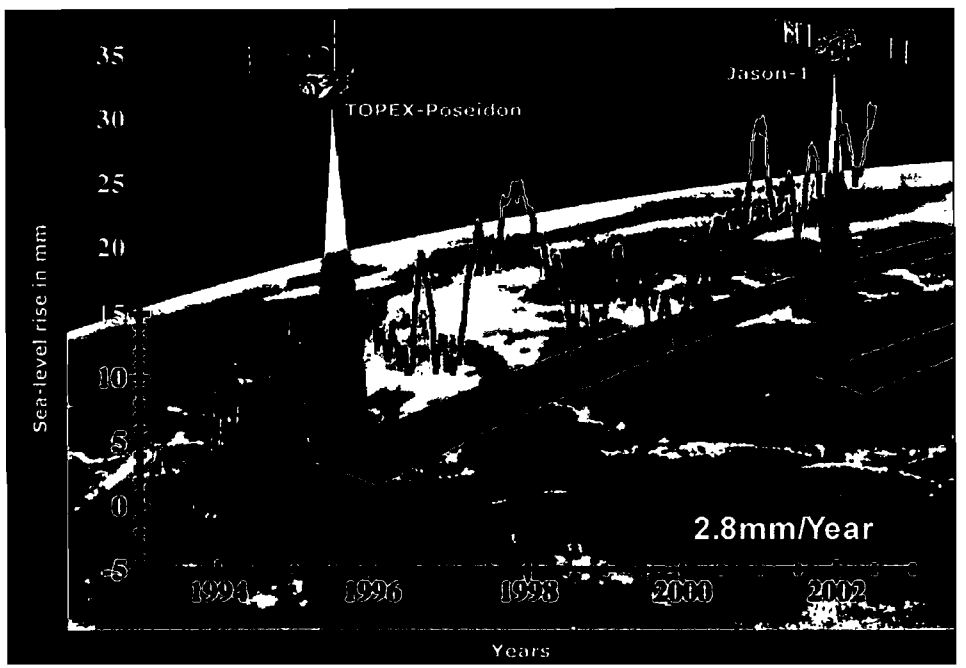
Measuring Sea Level Rise







- **Radar altimeters measure the exact distance from the spacecraft to the ocean surface**
- **Precise knowledge of the spacecraft position and orbit allows us to measure very small changes in the ocean surface height**
- **This vital climate data record will be continued by OSTM (launch 2008)**

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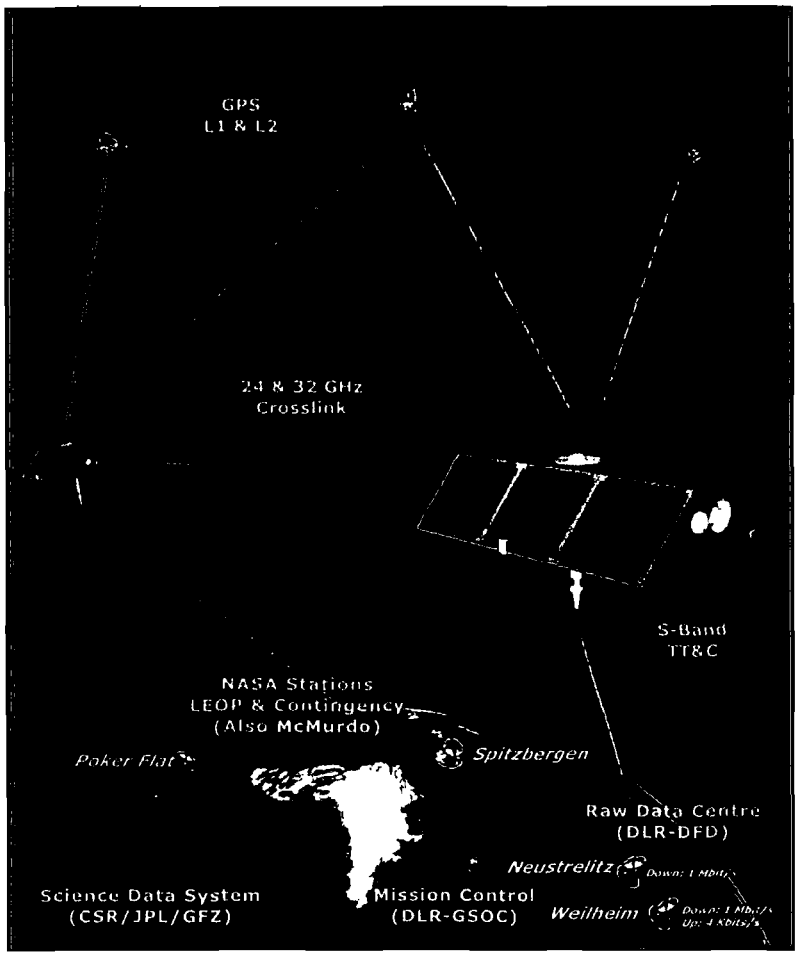
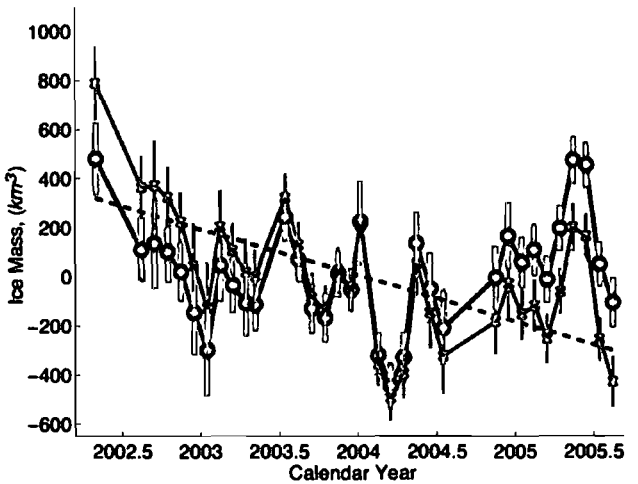
Measuring Changes In Ice Mass



The Gravity Recovery and Climate Experiment (GRACE) has improved estimates of Earth's gravity field by 100x



Ice mass changes in Antarctica measured by GRACE result in about 0.4 millimeters (.016 inches) per year of global sea level rise

Velicogna and Wahr, Science (2006)

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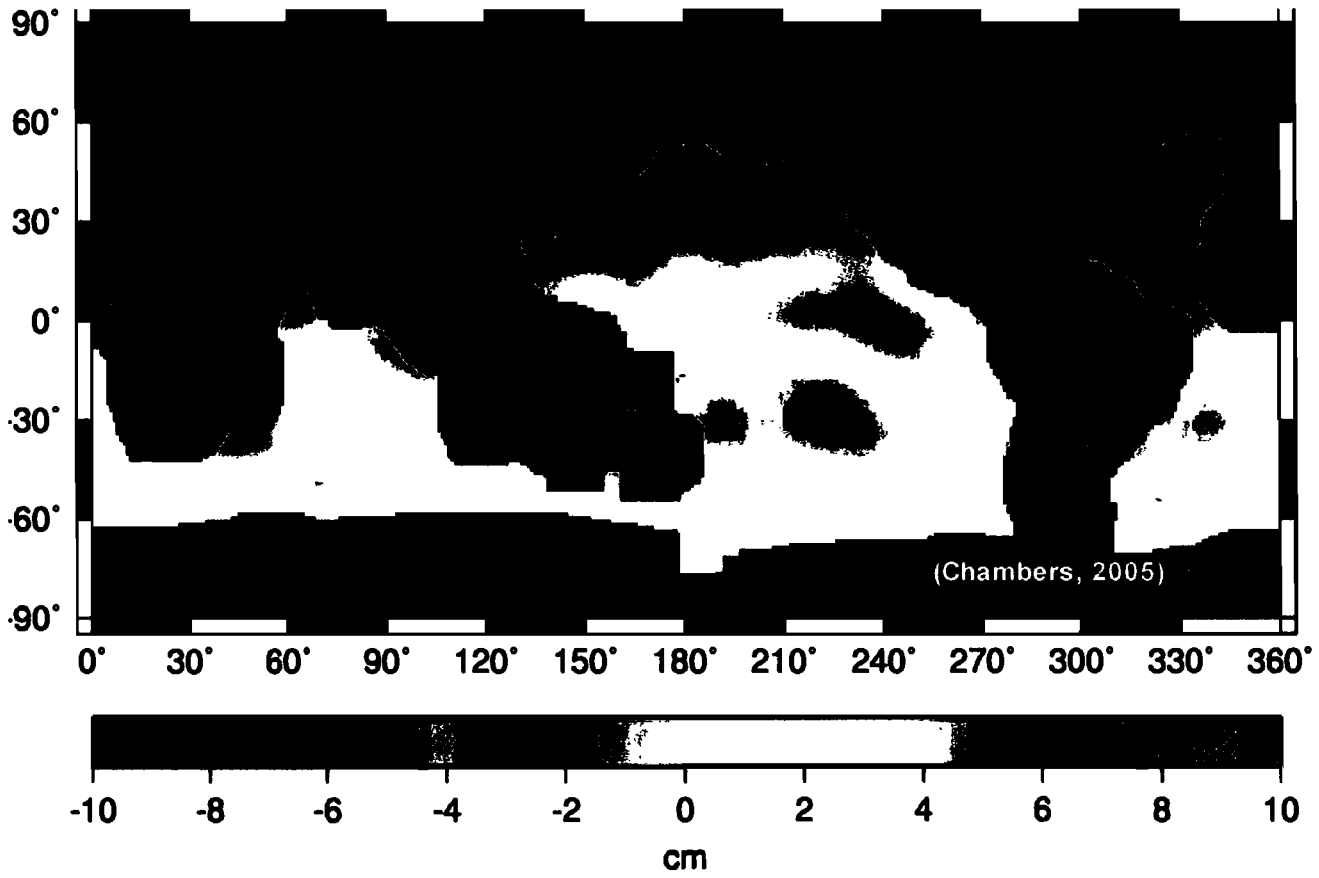
How much of sea level change is due to thermal expansion?



Sea Surface Topography - Mass change = Thermal Expansion of the ocean
(Altimeter measurements) (Gravity fields)

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Looking Toward the Future

- JPL has a long history of implementing cost-effective and successful Earth Science Missions, and currently represents about 10% of NASA's Earth Science budget.

- JPL operates five Earth Science missions and five major instruments (about 1/3 of NASA's Earth Science on-orbit capability) including NASA's first successful ESSP mission (GRACE).

- We are looking forward to implementing our part of the program recommended by the NRC Decadal Survey in support of "Science for Society."

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NAS Space Studies Board Decadal Report "An integrated strategy for Earth science and applications from space."

Missions of Interest to JPL

Decadal Survey Mission	Mission Description	Instruments	JPL Contribution		
Timeframe 2010 – 2013, Missions listed by cost					
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	Spectrally resolved interferometer	Mission		
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	L-band radar L-band radiometer	Mission + Instrument		
GPSRO	Temperature, water vapor, and electron density profiles	GPS receiver	Mission + Instrument		
DESDynI	Surface and ice sheet deformation and vegetation structure	L-band InSAR Laser altimeter	Mission + Instrument		
Timeframe: 2013 – 2016, Missions listed by cost					
HyspIRI	Land surface composition; vegetation types for ecosystem health	Hyperspectral spectrometer	Mission + Instrument		
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	Multifrequency laser	Mission + Instrument		
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	Ka-band wide swath radar C-band radar	Mission + Instrument		
XOVWM (NOAA)	Sea surface wind vectors for weather and ocean ecosystems	Backscatter radar	Mission + Instrument		
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color	High and low spatial resolution hyperspectral images	Mission + Instrument		
ACE	Aerosol and cloud profiles; ocean color for open ocean biogeochemistry	Backscatter lidar Multiangle polarimeter Doppler radar	Mission + Instrument		

☐ = <$300 million ☐ = $300 - $600 million ☐ = $600 - $900 million

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NAS Space Studies Board decadal report "An integrated strategy for Earth science and applications from space."

Missions of Interest to JPL

Timeframe: 2016 – 2020, Missions listed by cost			
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST	MW array spectrometer	Mission + Instrument
GRACE-II	High temperature resolution gravity fields for tracking large-scale water movement	Microwave or laser ranging systems	Mission + Instrument
SCLP	Snow accumulation for fresh water availability	Ku and X-band radars K and Ka-band radiometers	Mission + Instrument
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	UV spectrometer IR spectrometer Microwave limb sounder	Instrument

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Extended Ocean Vector Winds Mission (XOVWM)

Mission & Science Objective:

- OVWM will produce the next generation observations of vector winds over the ocean
  - Improve spatial resolution by an order of magnitude
  - Improve high wind speed accuracy and rain correction
- Vector winds will drive the next generation of ocean and coastal circulation models
- Improved spatial resolution improves coastal monitoring and understanding of the ocean mesoscale
- Improved high winds and resolution key for tropical and extratropical cyclone monitoring (hurricanes…,)
- The XOVWM concept has been endorsed by the NRC decadal study for launch in 2013-2016

OVWM will improve ocean wind vector spatial resolution by a factor of ten, enabling new science and providing a high-value data set essential for meeting NASA goals

Benefits for Society:

- Represents a key observable for understanding the ocean circulation
- Will help address climate change issues through data assimilation with predictive ocean model
- Will allow for a better understanding of coastal circulation: impact for fisheries and human coastal communities
- Will enable more accurate predictions of marine weather
- Will allow improved tracking and prediction of hurricanes and monitoring of flooding

Mission Description:

- Ku- and C-band scatterometer/radiometer system integrated into a single instrument
- High spatial resolution (2.5 km - 5 km) through synthetic aperture processing
- Launch: TBD
- Mission Duration: 5 yrs
- Orbit: LEO, Sun-synchronous
- Payload description: Ku and C band synthetic aperture scatterometer integrated with microwave radiometer covers 90% of the ocean in one day
- Potential Mission Partners: NOAA, JAXA

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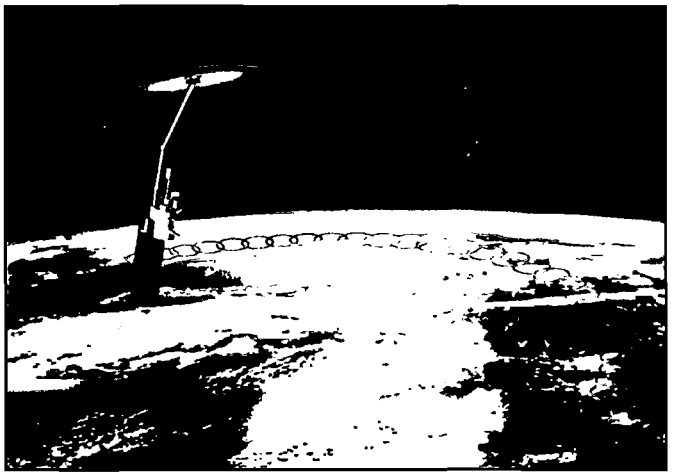
SMAP Mission Concept

- SMAP concept derived from Hydros heritage
  - *Hydros risk-reduction performed during Phase A (instrument, spacecraft dynamics, science, ground system)*
  - *Mission components all at TRL 7 and higher*
- L-band radar and radiometer system with offset-fed 6-m deployable mesh reflector rotating about nadir axis
  - *Single feed (dual-pol radar and polarimetric radiometer)*
  - *Conical scan, fixed incidence angle across swath*
  - *Optimized scan rate and footprint dimensions for overlapping footprints and mapping coverage*
    - *Contiguous 1000 km swath*
- Unfocused synthetic aperture processing provides higher resolution for active channels
  - *Radiometer resolution: 40 km*
  - *Radar resolution: 1-3 km (Radar resolution degrades over center 30% of swath)*



- Sun-synchronous dawn/dusk orbit
  - ➢ *Orbit and radar instrument duty cycle trades performed to maximize coverage and revisit over regions of interest*
- Mission duration 3 years
  - ➢ *Analysis of seasonal and interannual variability over at least three annual cycles*
  - ➢ *Demonstrate operational utility*

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The Aerosol/Cloud/Ecosystems (ACE) Mission

Mission Science Objectives and Questions

- Reduce the uncertainty in cloud-aerosol interaction through simultaneous measurement of aerosol and cloud properties.
  - What are the trends in anthropogenic and natural contributions to aerosol pollution near the surface?
  - How do aerosols affect the Earth's radiation budget (ERB)?
  - How do aerosol affect the radiative properties of clouds (also see section below), and how do these effects vary with aerosol properties?
- Estimate the carbon uptake by ocean ecosystems through global measurements of organic material in the surface ocean layers
  - How do aerosols deposited on the ocean surface influence nutrient levels and stressors for ecosystems?
  - How do climate and habitat changes influence the productivity and elemental cycles of the global oceans?

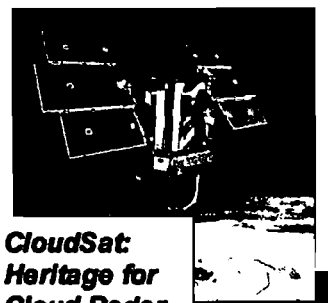
Instrument Requirements

- Multi-beam cross-track dual wavelength lidar (cloud and aerosol profiles)
  - 30m vertical resolution; 532 & 1024 nm; Dual polarization
- Dual frequency (94/34GHz) Cross-track scanning cloud radar (cloud profile and characterization)
  - <200m vertical resolution; <1km footprint; >-30dBze Sensitivity
- Multi-angle Multi-spectral Polarimeter (cloud and aerosol properties and height)
  - 5 angles; 380-164 nm; >350km swath; 500m resolution
- Multi-band cross-track visible/UV spectrometer (aerosols and ocean color)
  - 2nm ozone band (317nm); 5nm resolution 345-800nm; 58.3 cross-track scanning

Mission Description

- One or more spacecraft (flying in formation) making simultaneous measurements of clouds, aerosols, and ocean biological processes
- Four instruments (see below, left)
- LEO, Sun-Synchronous early afternoon orbit, to minimize sun glint and optimize passive instrument performance
- 500-650km orbit to optimize coverage, and active instrument requirements

Mission Depictions



CloudSat: Heritage for Cloud Radar

MISR on Terra: Heritage for Multi-Angle Polarimeter

CALIPSO and the A-Train: Aerosol Lidar, constellation and formation flying heritage

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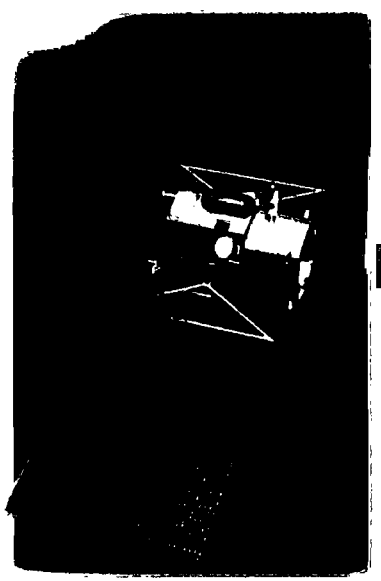
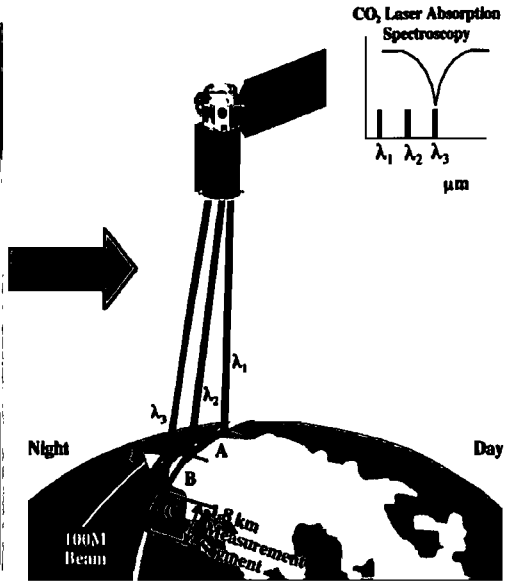
Active Sensing of CO_2 over Nights, Days, Seasons (ASCENDS)



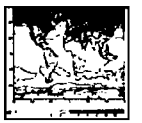


Mission Objectives

CO_2 measurements: Day/night, all seasons, all latitudes

Inventory of global CO_2 sources and sinks

Connection between climate and CO_2 exchange



Improved climate models and predictions of atmospheric CO_2

Identification of human-generated CO_2 sources *and sinks* to enable effective carbon trading

Closes the carbon budget for improved policy and prediction

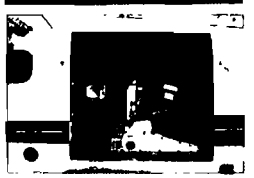
Approach

- ASCENDS will deliver laser based remote sensing measurements of CO_2 mixing ratios
  - Day and night
  - At all latitudes
  - During all seasons
- ASCENDS includes simultaneous measurements of
  - Temperature profile: improved CO_2 accuracy
  - O_2 Column: surface pressure, CO_2 mixing ratios
  - Altimetry: surface elevation, cloud top heights
  - CO profile: identify combustion sources of CO_2
- ASCENDS will be a logical extension of OCO and GOSAT capabilities

Status

- ASCENDS identified as a medium size mission in the NRC Decadal Survey
- LRD 2013-2016 to overlap with OCO (OCO scheduled launch: Dec 2008)
- NASA has collected data from two airborne demonstrators to verify the CO_2 measurement capability of laser based approaches
- ASCENDS mission point design options evaluated by JPL's Team X

Airborne Demonstrators



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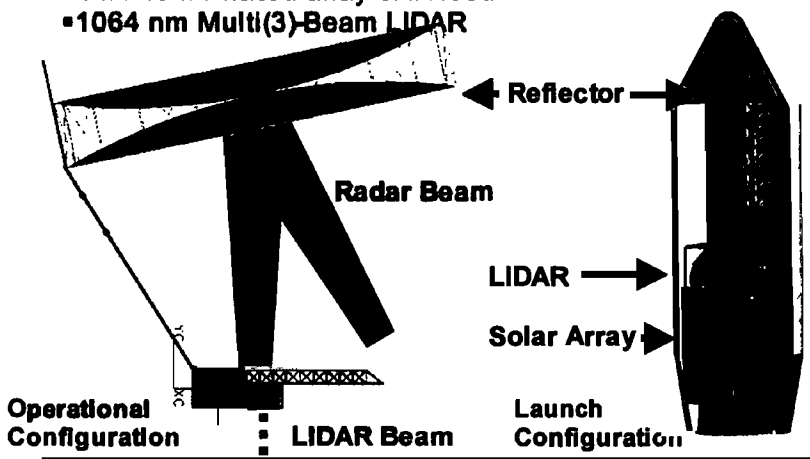
DesDynI Mission

Observatory Concept

- 15 m Deployable Mesh Reflector
- 4m x .5m Phased array SAR feed
- 1064 nm Multi(3)-Beam LIDAR



Features

Mission Design:

- Mission Mode 1: 275 days/yr, 8-day repeat orbit; full global InSAR access
- Mission Mode 2: 90 days/yr, 90-day repeat orbit: high density LIDAR ground tracks

Instrument Performance

- 1353 x 3 (beams) Unique LIDAR Ground tracks every year
- Q-Pol L-Band – LIDAR dual coverage for 90 days/year
- Fully capable InSAR surface Deformation system 275 days/yr

Significant Cost Savings realized by co-manifested InSAR-LIDAR

Features of the Mission Concept

- **Launch Date: Mid-2014**
- **Launch Vehicle: Delta II 2X20-10 (Medium Class)**
- **Orbit: 98° Inc., 500 km Alt., 8/90 day repeating ground track (SunSync) 6am ascending**
- **Mission Duration: 5 years (nominal)**
- **Instrument Payload: L-Band Quad Pol SAR; Vegetation LIDAR**
- **Orbit Avg. Power: ~560W (Payload) ~1470W (S/C)**
- **Mass: 1001 (Dry); 1108 (Wet)**
- **Pointing: 180 arcsec (control); 4 arcsec (knowledge); 10 arcsec/sec (stability)**
- **Downlink: Dual Channel X-Band, 640Mbps Svalbard/Alaska SAR**

Technology Development Needs

- **Low-Loss Patch Feed Array**
- **Autonomous Orbit Maintenance Planning**

Science Objectives

1. Understand and characterize Earth Surface deformation related to earthquakes and volcanic activity
2. Assess impact of ice sheet and glacier system dynamics on sea level rise, climate, and temporal variability
3. Develop globally consistent and spatially resolved estimates of aboveground biomass, carbon stocks and vegetation 3D structure

- Potential for coordination with international partners to increase InSAR revisit frequency (and enhance science)

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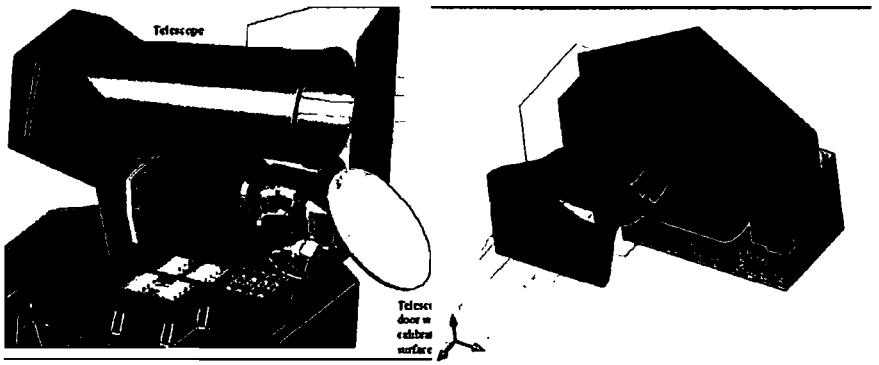
HysplRI Mission Concept Overview
(Hyperspectral Infrared Imager)

Observatory Concept



FLORA SAVII

Features of the Mission Concept

- **Launch Date: 2013-2016**
- **Launch Vehicle: Medium Class**
- **Orbit: 705 km sun-synch**
- **Mission Duration: 3 years**
- **Payload: Hyperspectral imager (FLORA, 102 kg), thermal multispectral scanner (e.g. SAVII)**
- **Power: TBD**
- **S/C Wet Mass: ~830 kg**
- **Pointing: TBD**
- **Downlink: TBD**
- **More detailed mission study recommended to develop/refine power, mass, downlink, and pointing estimates**

Technology Development Needs

- **Minimal, TBD**

Science Objectives

Climate Change

- Detect responses of ecosystems to human land management and climate change and variability
- Detect early signs of ecosystem changes through altered physiology, including agricultural systems

Surface Composition

- Observe condition and types of vegetation on the surface
- Identify buried mineral and petroleum deposits and environmental disturbances accompanying resource exploitation

Technical and Programmatic

Technical

- Excellent heritage from Moon Mineral Mapper
- SAVII design heritage
- Onboard data compression/data downlink

Programmatic

- Highly ranked in recent NRC decadal survey
- Potential ESSP mission
- International partners, e.g. JAXA and GCOM-C
- Current study for NASA HQ ongoing

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Discussion Topics

- Status of GCOM-W and GCOM-C?
- OCO/GOSAT cooperation
- ALOS follow-on plans? Potential for coordination with NASA's DesdyNI mission
- JPL is looking for partners on future ESSP mission concepts
- Launch co-manifest or even co-fly opportunities with GCOM-W, GCOM-C, and GPM?
- US interest in Ocean Vector Winds mission is on the increase - JPL expect to implement this for NOAA
- SMAP mission
- ASCENDS mission
- ACE mission
- Next steps…?

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