NASA Earth Science Division

Presentation to the
NASA Astrobiology Institute
December 1, 2006

Stephen Volz

Presentation Outline

- NASA's and Earth Science's Mission and Goals
  - NASA strategic plan and NASA Science plan
- Earth Science Research and Analysis
- Earth Science Missions and Measurements
- Technology and Data Systems

NASA's Strategic Goals*

- **Strategic Goal 1:** Fly the Shuttle as safely as possible until its retirement, not later than 2010.
- **Strategic Goal 2**: Complete the International Space Station in a manner consistent with NASA's international partner commitments and the needs of human exploration.
- **Strategic Goal 3:** Develop a balanced overall program of science exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration.
- **Strategic Goal 4:** Bring a new Crew Exploration Vehicle into service as soon as possible after Shuttle retirement.
- **Strategic Goal 5:** Encourage the pursuit of appropriate partnerships with the emerging commercial space sector.
- **Strategic Goal 6**: Establish a lunar return program having the maximum possible utility for later missions to Mars and other destinations.

** 2006 NASA Strategic Plan*

NASA's Strategic Goals*

- **Strategic Sub-goal 3A:** Study planet Earth from space to advance scientific understanding and meet societal needs.

- **Strategic Sub-goal 3B:** Understand the Sun and its effects on Earth and the solar system.
- **Strategic Sub-goal 3C:** Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.
- **Strategic Sub-goal 3D:** Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.
- **Strategic Sub-goal 3E:** Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems.
- **Strategic Sub-goal 3F:** Understand the effects of the space environment on human performance, and test new technologies and countermeasures for long-duration human space exploration.

** 2006 NASA Strategic Plan*

NASA's Earth Science Mission

- NASA's mission in Earth science, as mandated by the Space Act of 1958, is to "… *conduct aeronautical and space activities so as to contribute materially to …the expansion of human knowledge of the Earth and of phenomena in the atmosphere and space*".

- NASA's Earth Science program is dedicated to advancing Earth remote sensing and pioneering the scientific use of global satellite measurements to improve human understanding of our home planet in order to inform economic and policy decisions and improve operational services of benefit to the Nation. The program is responsive to several Congressional mandates and Presidential initiatives. ***(From NASA Science Plan to be released Dec. 2006: sec. 4.1 "Intellectual Foundation")***

Science Mission Directorate Organization

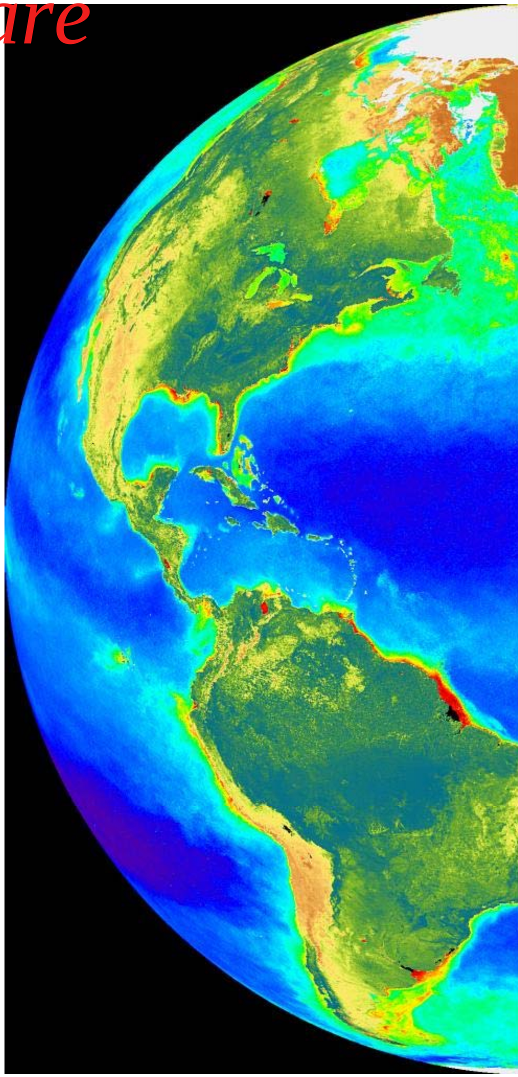
- **Associate Administrator (AA) (M. Cleave)**
  Deputy AA (C. Hartman)
  - Deputy AA for Programs (M. Luther)
  - Deputy AA for Technology (G. Komar-Act)
  - Chief Scientist (P. Hertz)
  - Chief Engineer (K. Ledbetter)
    - **Management & Policy Division**
      Dir. (R. Maizel)
      Deputy (Vacant)
      - Budget (C. Tupper)
      - Policy (Vacant)
      - Administration (Vacant)
    - **Heliophysics Division**
      Dir. (R. Fisher)
      Deputy (C. Gay)
    - **Earth Science Division**
      Dir. (M. Freilich)
      Deputy (B. Cramer)
      - Flight (T. Hammer-Act)
      - Applied Science (M. Frederick- Act)
      - Research (J. Kaye)
    - **Planetary Science Division**
      Dir. (J. Green-Act)
      Dep. (S. Wojnar-Act)
      - Mars Program (D. McCuistion)
    - **Astrophysics Division**
      Dir. (R. Howard-Act)
      Deputy (Vacant)

As of: October 1, 2006

Earth Science Research and Analysis

Earth Science Research Fundamental Science Questions

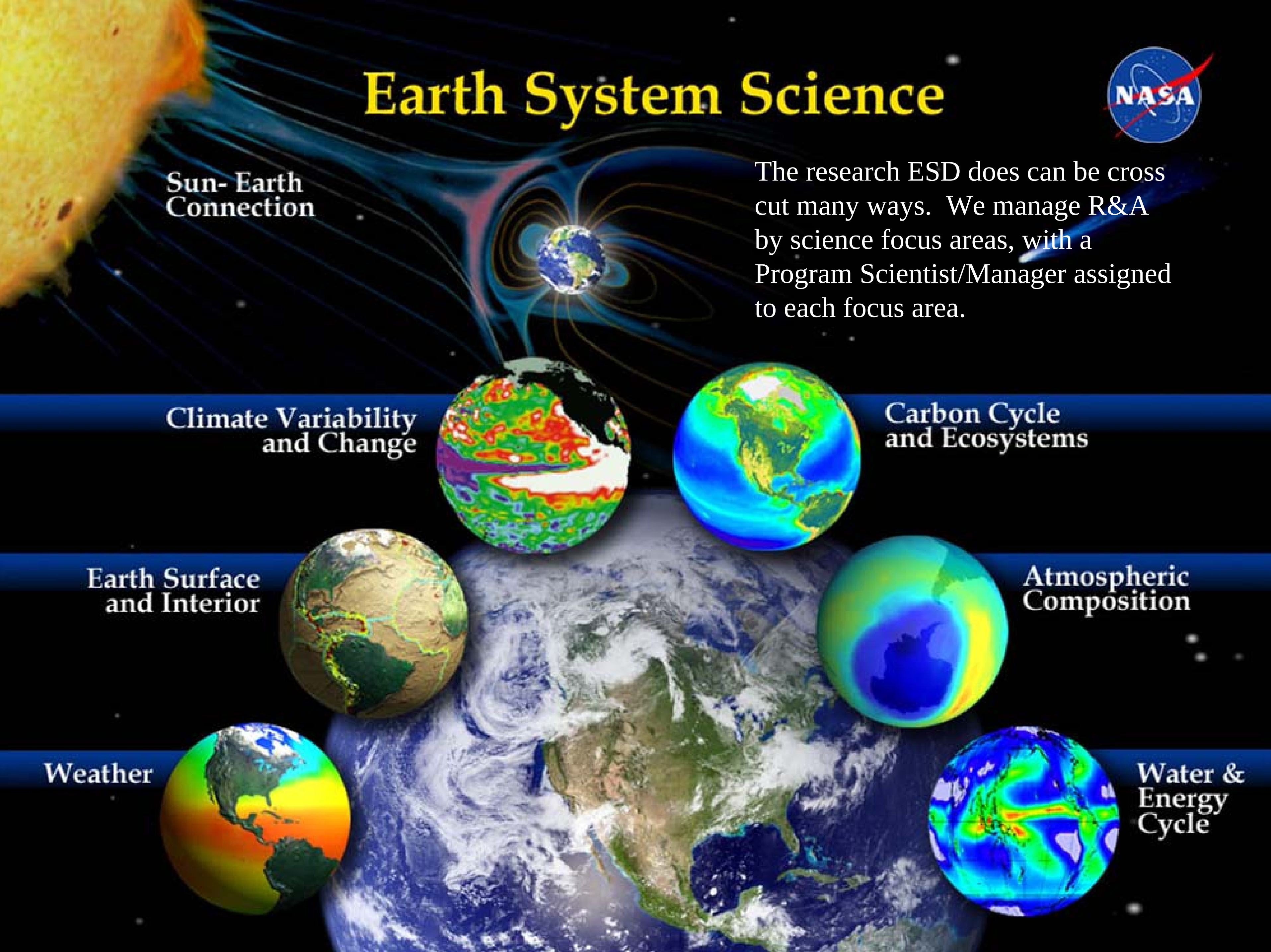
How is the Earth changing and what are the consequences of life on Earth?



- How is the global Earth system *changing*?
- What are the primary *forcings* of the Earth system?
- How does the Earth system *respond* to natural and human-induced changes?
- What are the *consequences* of changes in the Earth system for human civilization?
- How well can we *predict* future changes in the Earth system?

Earth Science Research Questions

- How is the global Earth system changing? (Variability)
  - How are global precipitation, evaporation, and the cycling of water changing?
  - How is the global ocean circulation varying on interannual, decadal, and longer time scales?
  - How are global ecosystems changing?
  - How is atmospheric composition changing?
  - What changes are occurring in the mass of the Earth's ice cover?
  - How is the Earth's surface being transformed by naturally occurring tectonic and climatic processes?
- What are the primary forcings of the Earth system? (Forcing)
  - What trends in atmospheric constituents and solar radiation are driving global climate?
  - What changes are occurring in global land cover and land use, and what are their causes?
  - What are the motions of the Earth's interior, and how do they directly impact our environment?
- How does the Earth system respond to natural and human-induced changes? (Response)
  - What are the effects of clouds and surface hydrologic processes on Earth's climate?
  - How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?
  - How can climate variations induce changes in the global ocean circulation?
  - How do atmospheric trace constituents respond to and affect global environmental change?
  - How is global sea level affected by natural variability and human-induced change in the Earth system?
- What are the consequences of change in the Earth system for human civilization? (Consequences)
  - How are variations in local weather, precipitation and water resources related to global climate variation?
  - What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
  - What are the consequences of climate change and increased human activities for coastal regions?
  - What are the effects of global atmospheric chemical and climate changes on regional air quality?
- How will the Earth system change in the future, and how can we improve predictions through advances in remote sensing observations, data assimilation and modeling? (Prediction)
  - How can weather forecast duration and reliability be improved?
  - How can predictions of climate variability and change be improved?
  - How will future changes in atmospheric composition affect ozone, climate, and global air quality?
  - How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?
  - How will water cycle dynamics change in the future?
  - How can our knowledge of earth surface change be used to predict and mitigate natural hazards?


Earth System Science
NASA
Sun- Earth Connection
The research ESD does can be cross cut many ways. We manage R&A by science focus areas, with a Program Scientist/Manager assigned to each focus area.
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

Science Questions and Focus Areas

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use?	Ecosystems, land cover & biogeochemical cycles?	Consequences of land cover & land use change?	Improve prediction of climate variability & change?
Global ecosystems changing?	Motions of the Earth & Earth's interior?	Changes in global ocean circulation?	Coastal region impacts?	Ozone, climate & air quality impacts of atmospheric composition?
Atmospheric composition changing?		Atmospheric trace constituents responses?	Regional air quality impacts?	Carbon cycle & ecosystem change?
Ice cover mass changing?		Sea level affected by Earth system change?		Change in water cycle dynamics?
Earth surface transformation?				Predict & mitigate natural hazards from Earth surface change?

The research mix across the focus areas is dynamic, with changes driven by resources, data (missions), and national need.

Climate Variability and Change
Carbon Cycle and Ecosystems
Water and Energy Cycle
Atmospheric Composition
Weather
Earth Surface and Interior

Research Objectives [from multi-year Outcomes in the 2006 NASA Strategic Plan – Appendix 1]

Science Focus Areas

- 3A.1: Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition.
- 3A.2: Enable improved predictive capability for weather and extreme weather events.
- 3A.3: Quantify global land cover change and terrestrial and marine productivity, and improve carbon cycle and ecosystem models.
- 3A.4: Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and fresh water availability.
- 3A.5: Understand the role of oceans, atmosphere, and ice in the climate system and in improving predictive capability for its future evolution.
- 3A.6: Characterize and understand Earth surface changes and variability of the Earth's gravitational and magnetic fields
- 3A.7: Expand and accelerate the realization of societal benefits from Earth system science (Applications)

A Broad Range of Partnerships

- An inherently international endeavor
  - Nearly 200 agreements with over 60 countries
  - Actively engaged in international observing system planning following the July 2003 Earth Observation Summit

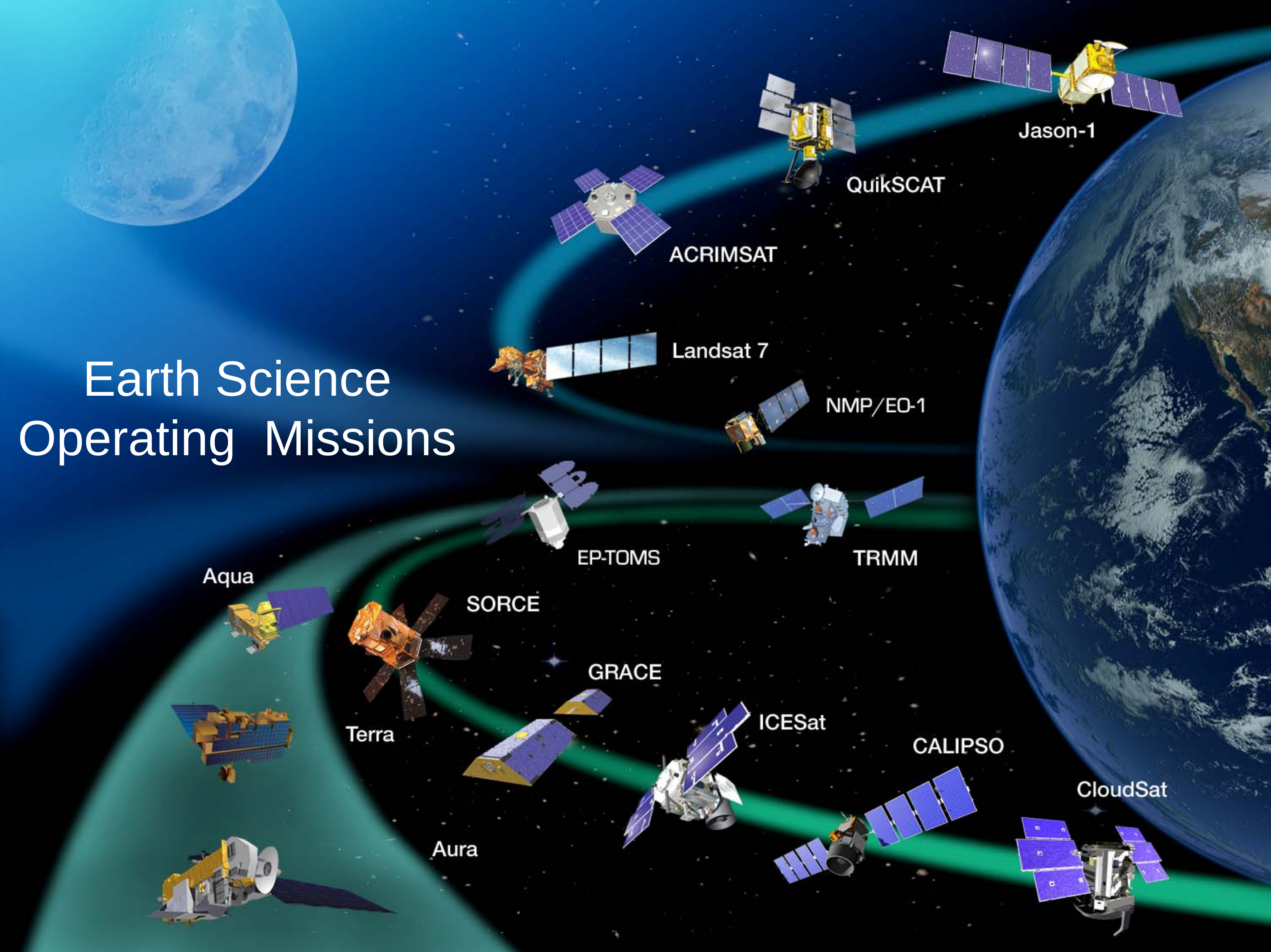
- A variety of interagency collaborations
  - Climate Change Science & Technology Programs
  - NOAA and DoD on operational environmental satellites
  - National Ocean Partnership Program & Ocean.US
  - US Weather Research Program
  - USGS on land remote sensing and data management
  - 10 agencies on 12 National Applications

- All science, applications, and technology research announcements are open competitions; about 2000 grants & contracts:
  - Half won by university researchers; A quarter by NASA center scientists; A quarter by other agencies and industry scientists

Earth Science Missions & Measurements

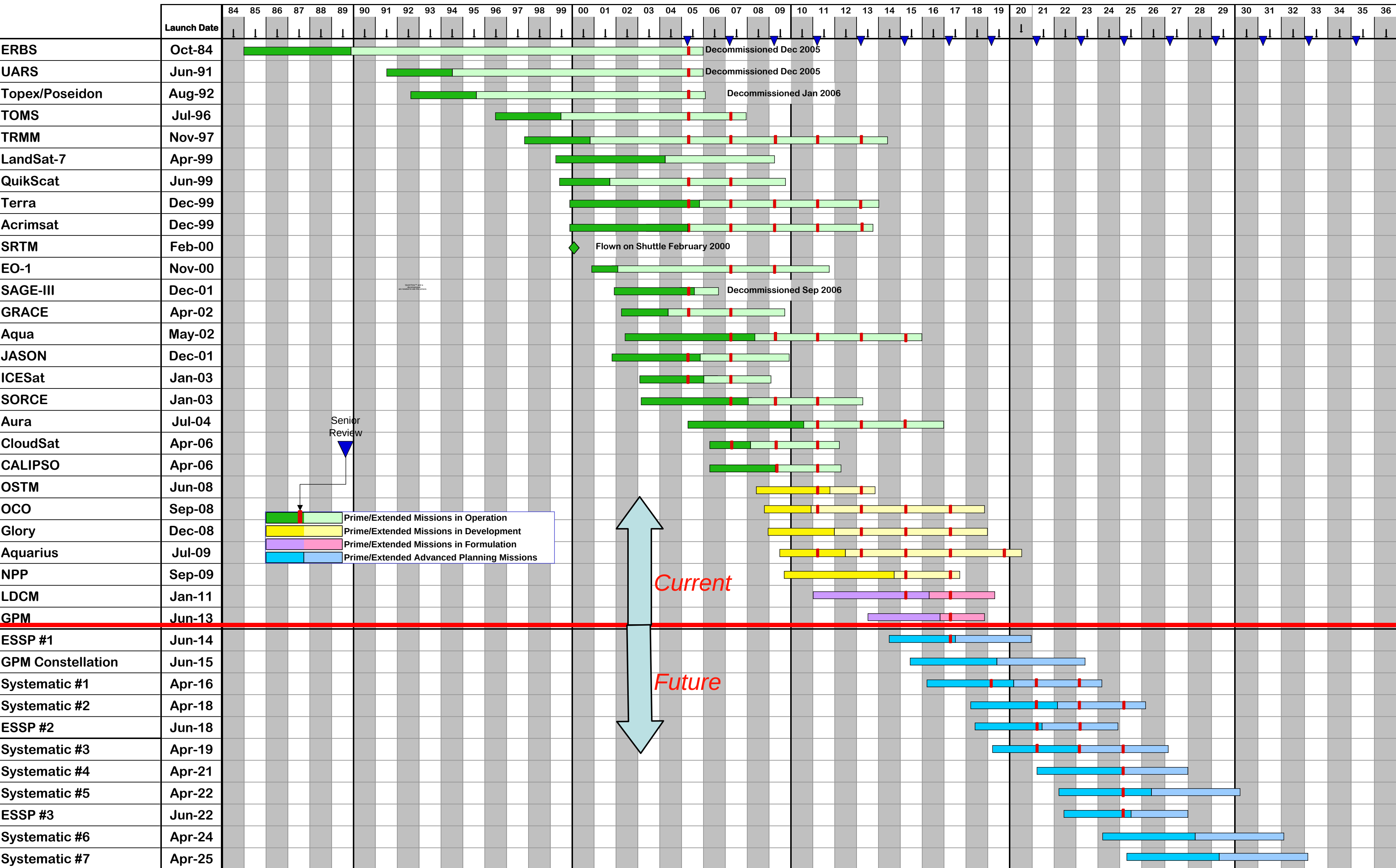
Earth Science Missions

- Currently have 15 missions in operation
  - Additionally, we have several more collaborative missions with other Agencies and other nations
- These satellites are generally well characterized
  - Mature core data products for instruments and satellites
- We are working now to exploit cross platform data fusion to better address earth system science questions
  - Two constellations of satellites are currently in place
    - Morning constellation: Landsat 7, EO-1, SAC-C, and Terra
    - Afternoon constellation: Aqua, CloudSat, CALIPSO, PARASOL, and Aura, with OCO and Glory to be added in 2008



Earth Science
Operating Missions
Jason-1
QuikSCAT
ACRIMSAT
Landsat 7
NMP/EO-1
EP-TOMS
TRMM
Aqua
SORCE
GRACE
Terra
ICESat
CALIPSO
CloudSat
Aura

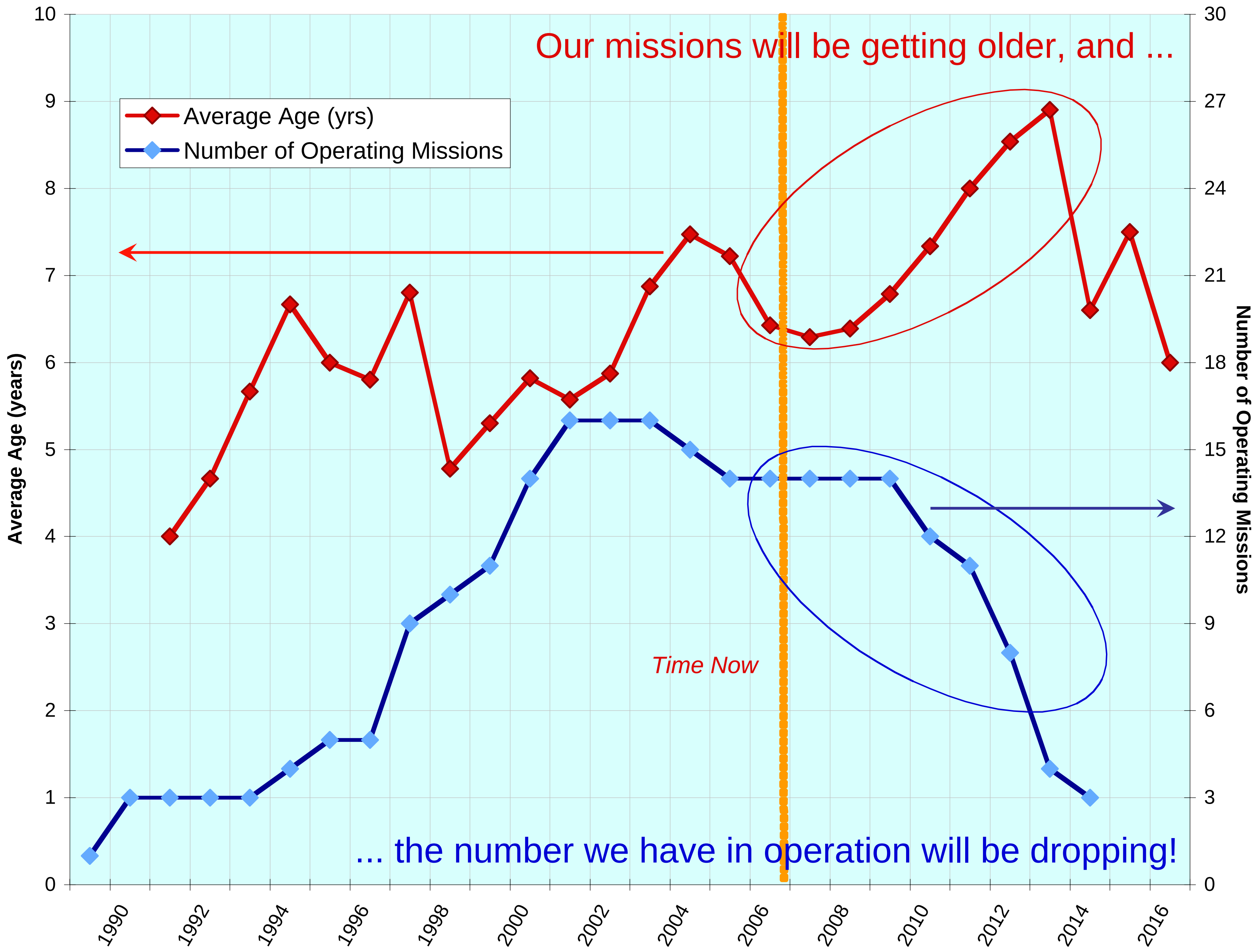
Earth Science Missions



Shown here is the complete suite of missions and instruments operating under direct management of the Earth Science Division

Not including collaborative missions where ESD is not the lead, but may have an instrument on board

Mission	Instruments	Launch Date	End of Prime Mission
ACRIMSAT	ACRIM3 (Active Cavity Radiometer Irradiance Monitor)	Dec 2003	Dec 2006
Aqua	AIRS (Atmospheric Infrared Sounder)	May 2006	May 2012
	AMSR-E (Advanced Microwave Scanning Radiometer for the EOS)		
	AMSU-A (Advanced Microwave Sounding Unit-A)		
	CERES (Clouds and the Earth's Radiation Energy System)		
	MODIS (Moderate Resolution Imaging Spectroradiometer)		
CloudSat	CPR (Cloud Profiling Radar)	Apr 2010	Feb 2012
EO-1	ALI (Advanced Land Imager)	Nov 2004	Nov 2006
	Hyperion (Hyperspectral Instrument)		
	LEISA (Linear Etalon Imaging Spectral Array)		
	LAC (Atmospheric Corrector)		
GRACE	GPS (Black-Jack Global Positioning System Receiver)	Apr 2006	Apr 2011
	HAIRS (High-Accuracy Inter-satellite Ranging System)		
	SCA (Star Camera Assembly)		
	SSA (SuperStar Accelerometer)		
	USO (Ultra Stable Oscillator)		
ICESat	GLAS (Geoscience Laser Altimeter System)	Jan 2007	Jan 2010
JASON	DORIS (Doppler Orbitography & Radiopositioning Integrated by Satellite)		
	JMR (Jason Microwave Radiometer)		
	LRA (Laser Retroreflector Array)		
	Poseidon-2 Altimeter		
	TRSR (Turbo Rogue Space Receiver (a GPS))		
QuikScat	SeaWinds	Jun 2003	Jun 2006
SORCE	SIM (Spectral Irradiance Monitor)	Jan 2007	Jan 2012
	SOLSTICE (Solar Stellar Irradiance Comparison Experiment)		
	TIM (Total Irradiance Monitor)		
	XPS (XUV Photometer System)		
Terra	CERES (Clouds and the Earth's Radiation Energy System) **(FAILED)**	Dec 2003	Dec 2009
	MODIS (Moderate Resolution Imaging Spectroradiometer)		
	MISR (Multi-angle Imaging SpectroRadiometer)		
	MOPITT (Measurements of Pollution in the Troposphere)		
	ASTER (Advanced Spaceborne Thermal Emission & Reflection Radiometer)		
TOMS	TOMS (Total Ozone Mapping Spectrometer)	Jul 2000	Jul 2002
TRMM	CERES (Clouds and the Earth's Radiation Energy System)	Nov 2001	Nov 2004
	LIS (Lightening Imaging Sensor)		
	PR (Precipitation Radar)		
	TMI (TRMM Microwave Imager)		
	VIRS (Visible and Infrared Imager)		
Aura	HIRDLS (High Resolution Dynamics Limb Sounder)	Jul 2008	Jul 2014
	MLS (Microwave Limb Sounder)		
	OMI (Ozone Monitoring Instrument)		
	TES (Tropospheric Emission Spectrometer)		
CALIPSO	CALIOP (Cloud-Aerosol Lidar with orthogonal Polarization)	Apr 2010	Apr 2013
	IIR (Imaging Infrared Radiometer)		
	WFC (Wide Field Camera)		



Our missions will be getting older, and ...
Average Age (yrs)
Number of Operating Missions
Time Now
... the number we have in operation will be dropping!
Average Age (years)
Number of Operating Missions
0
1
2
3
4
5
6
7
8
9
10
0
3
6
9
12
15
18
21
24
27
30
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016

How Earth Science Does Its Missions: Systematic and ESSP

- Systematic Missions, also called directed missions, are selected to address specific science questions
  - They tend to use more established and validated approaches and to focus on long term data products (sea surface height, precipitation, ozone, ...)
  - May have AO selected instruments
  - Often have international or interagency components
- NASA's Earth Science System Pathfinder (ESSP) satellites are designed to explore new measurements and observing approaches
  - Selected through Announcement of Opportunity (AO) process
  - Allowed to try novel technologies (at least novel for orbiting observations), and have specific requirements but are also encouraged to demonstrate new measurement capabilities
  - Allows & encourages more flexibility in the observing approach
  - GRACE launched in 2002, CloudSat & CALIPSO launched in 2006
  - Orbiting Carbon Observatory (OCO, 2008) and Aquarius (2009) are in the queue

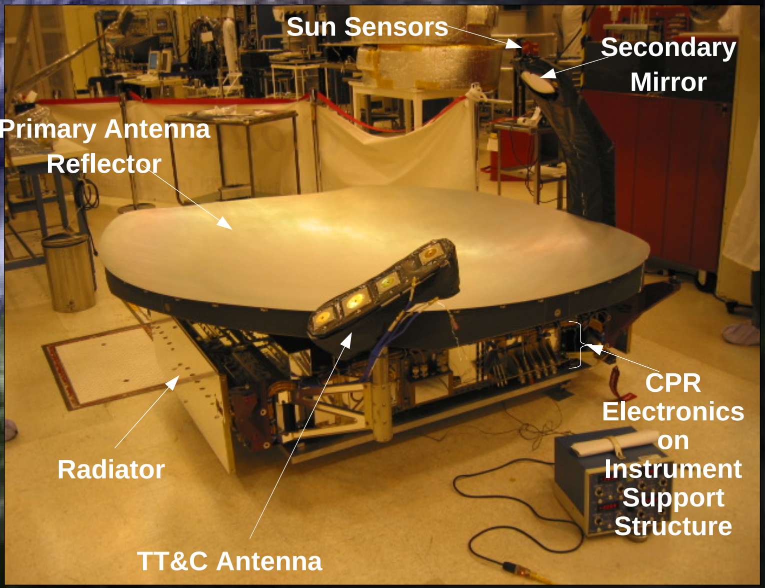
Mission Portfolio

I will show a subset of the missions and instruments

A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

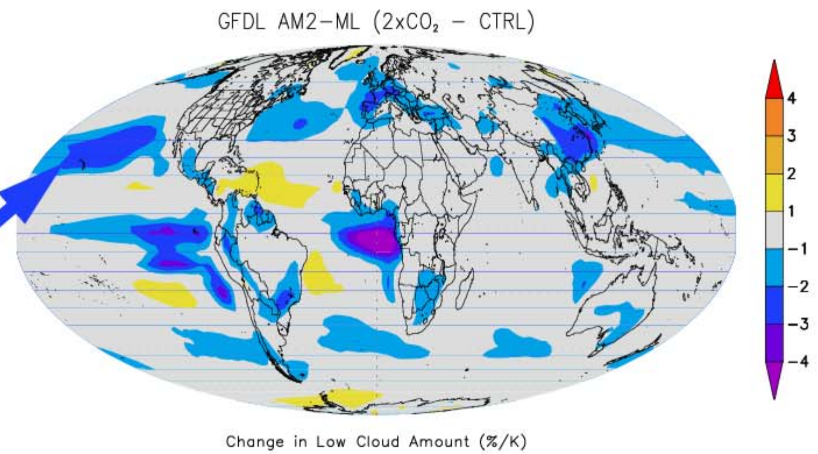
CloudSat Mission Objective:

Provide, from space, the first global survey of cloud profiles (height, thickness) and cloud physical properties (water, ice, precip) needed to evaluate and improve the way clouds, moisture and energy are represented in global models used for weather forecasts and climate prediction.

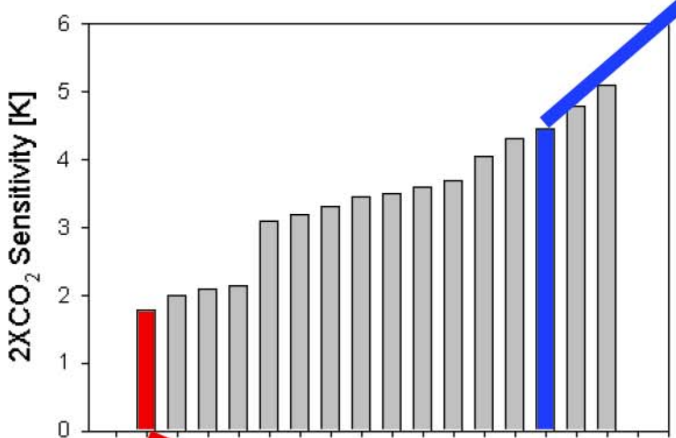


94-GHz Cloud Profiling Radar (CPR)

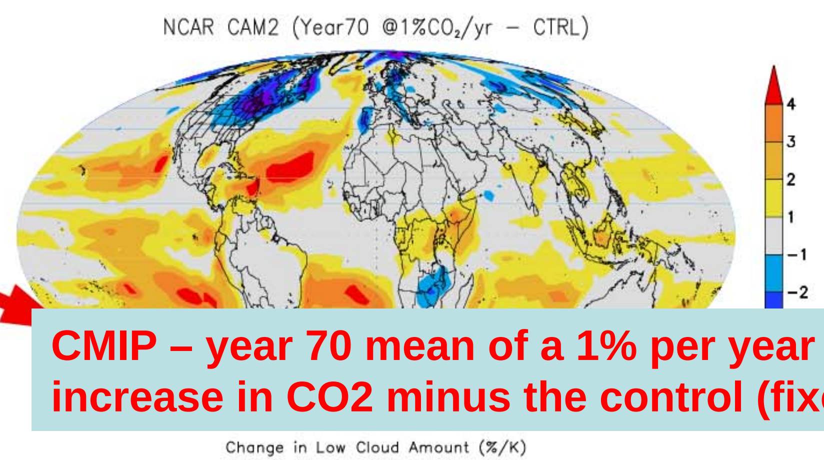
The Importance of Clouds:
The Global Warming Wild Card



One 'IPCC' climate model



A different 'IPCC' climate model

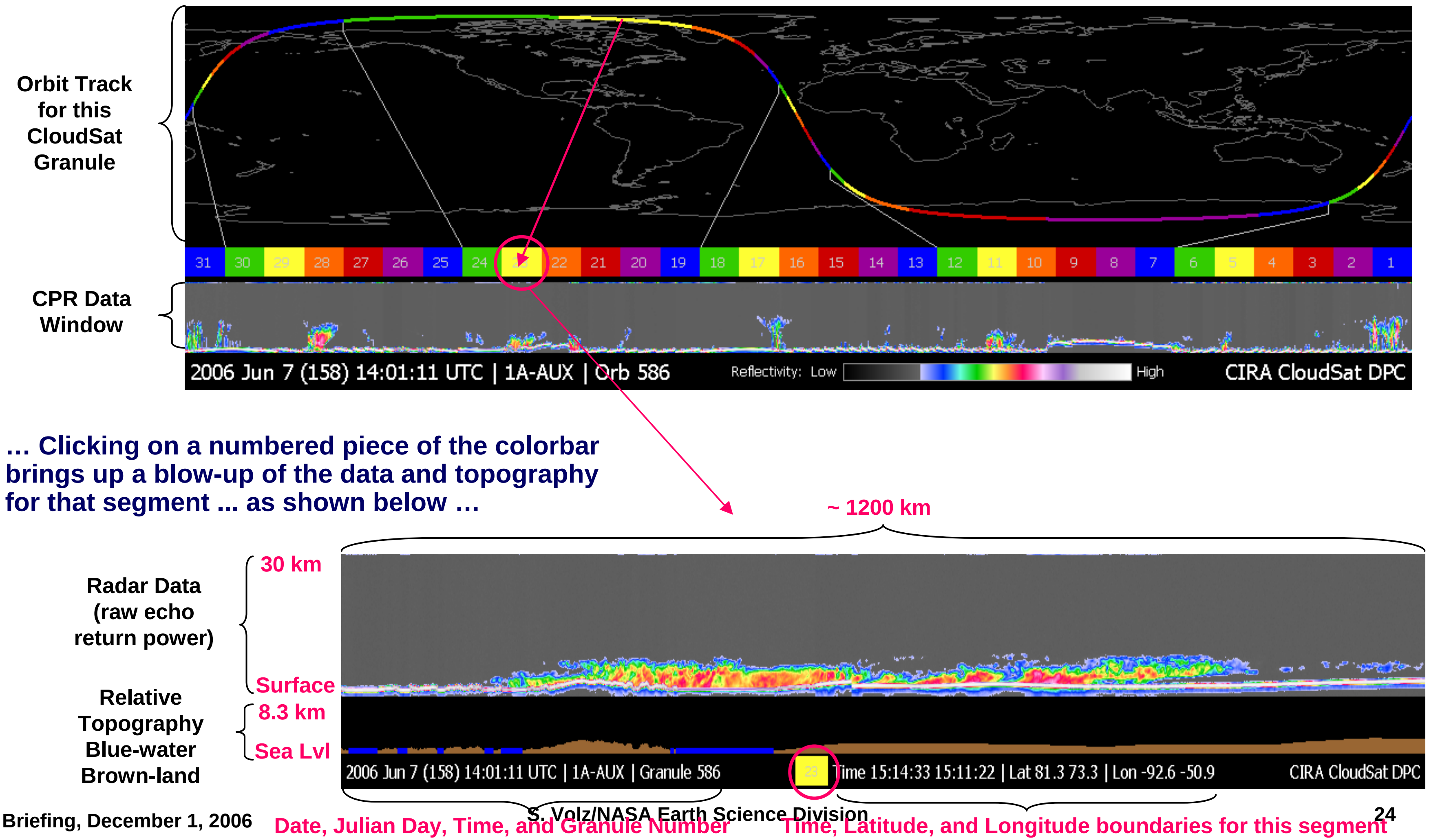


The model-to-model spread is a measure of 'uncertainty' and it is thought to be largely governed by uncertain climate 'feedbacks' that all involve cloud processes.

CMIP – year 70 mean of a 1% per year increase in CO2 minus the control (fixed CO2)

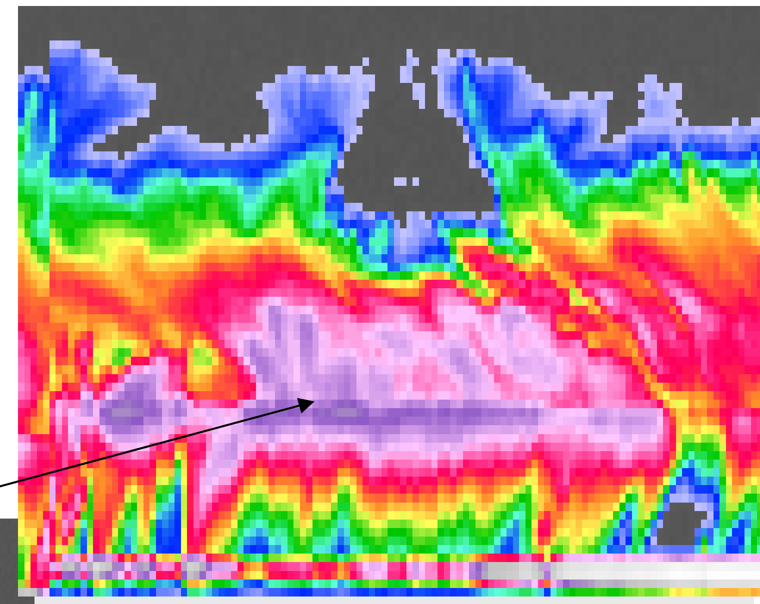
"Quicklook" Images of the Level 0 CPR data

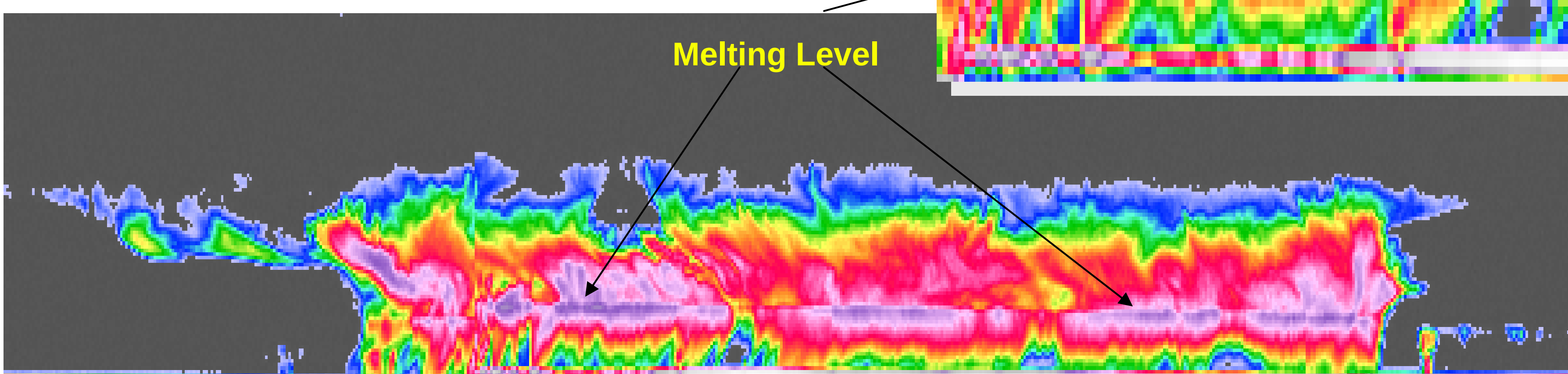
Quicklook images show the orbit track for a given granule and a compressed view of the CPR data for that granule



CloudSat Data Sample – “Melting Level”

- CloudSat has been producing striking images of the “Melting Level” (a horizontal line of brighter echo returns in the middle of a cloud layer)
- This signature happens when snow / ice crystals fall below the freezing level (air temperature of 0OC) and begin to melt. At 94GHz, the water covered ice is highly reflective compared to the reflectivity of snow or ice. (The Melting Level is generally less than 1-km below the Freezing Level)
- This provides a direct measurement of the potential for aircraft icing … a significant flight hazard that is impossible to measure directly with standard meteorological satellite sensors.





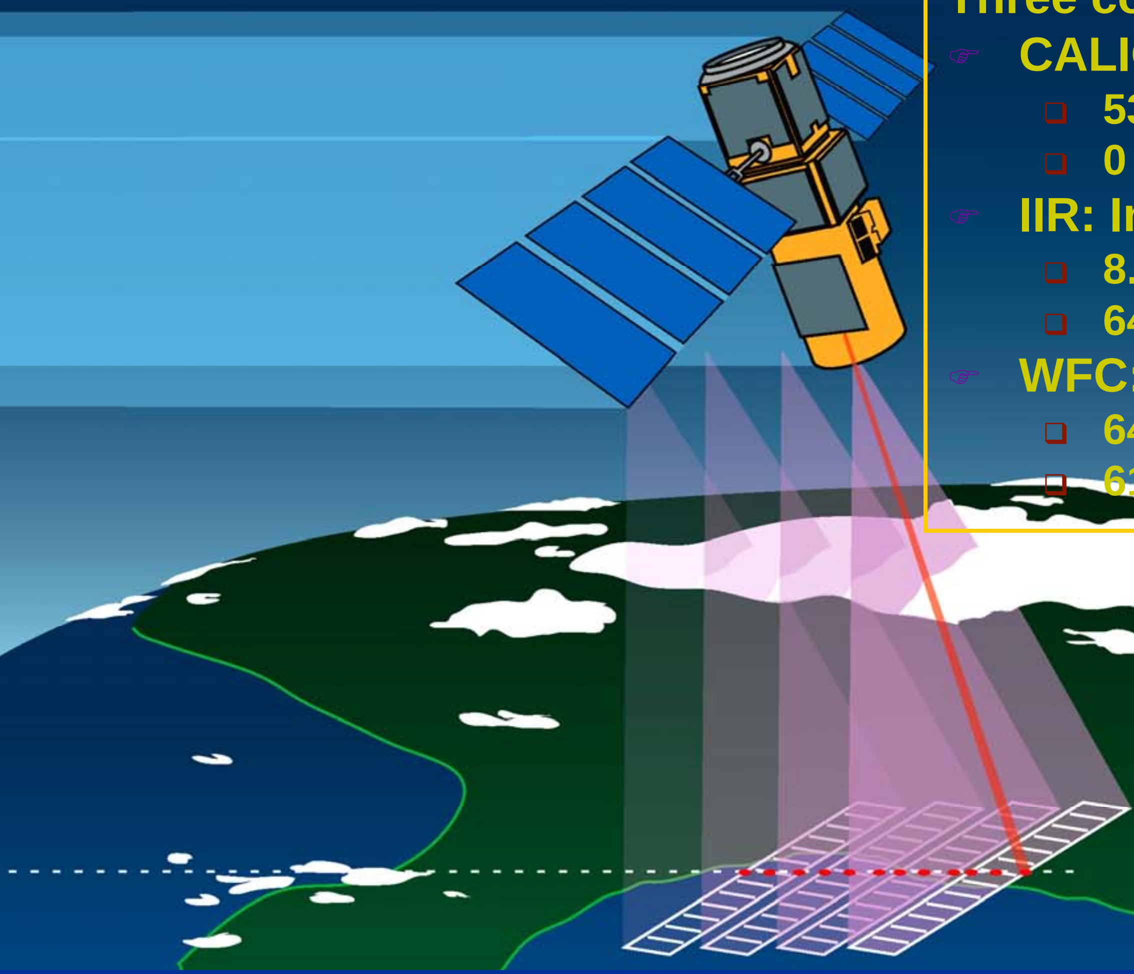
CALIPSO Mission Overview

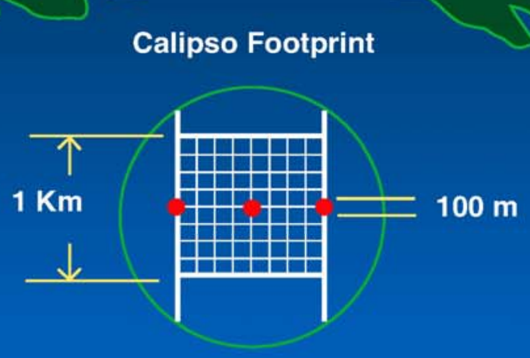
- CALIPSO will profile the optical and microphysical properties of clouds and aerosols to:
  - Improved understanding of aerosol and cloud effects on radiation budget
  - Improved understanding of cloud-climate feedback processes
  - Improve aerosol and cloud information from other A-train sensors
  - Improved predictive capability for climate, weather, and air quality
- Approach:
  - Produce a global uniformly-calibrated aerosol and cloud dataset
    - Profiles, optical properties, microphysical properties
    - Identify cloud ice-water phase, aerosol type
  - Combine CALIPSO and other A-train observations
  - Provide profile data/validation to other A-train sensors
- Leading to:
  - Improved predictions of climate and weather
  - Improved forecasts of air quality

705 km, sun-synchronous orbit (1:30 PM)

Three co-aligned instruments:

- CALIOP: polarization lidar
  - 532 nm || and ⊥, 1064 nm
  - 0 – 40 km altitude, 30 - 60 m
- IIR: Imaging IR radiometer (CNES)
  - 8.6 um, 10.5 um, 12 um
  - 64 km swath, 1 km IFOV
- WFC: Wide-Field Camera
  - 645 nm
  - 61 km swath, 125 m IFOV





UNIQUE CAPABILITIES:

wide dynamic range, for cloud/aerosol sensing

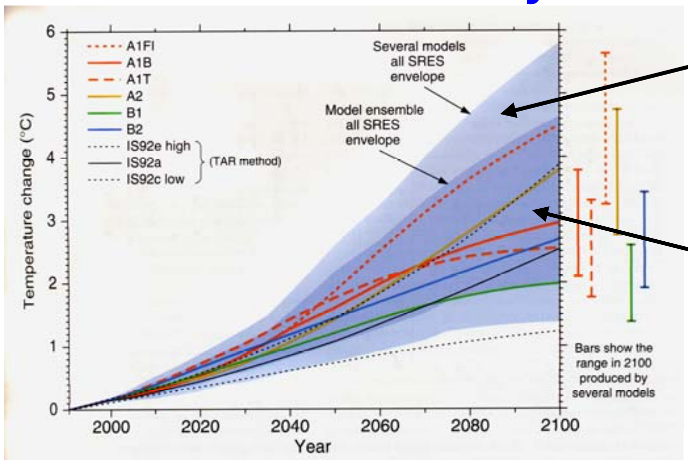
two sensitive lidar wavelengths (532/1064 nm)

polarization-sensitive receiver (532 nm)

coincident active/passive sensors

CALIPSO will contribute to Climate Change Science Questions

Prediction Uncertainty



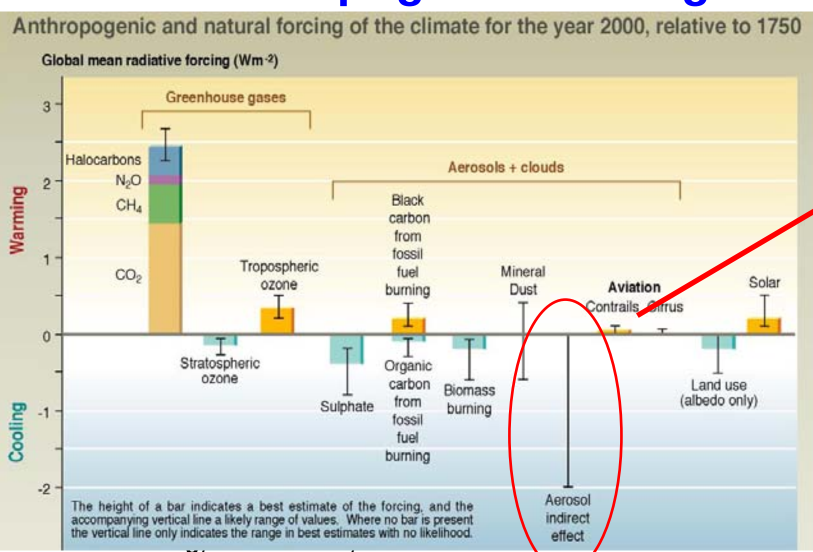
cloud feedback uncertainty (light blue)

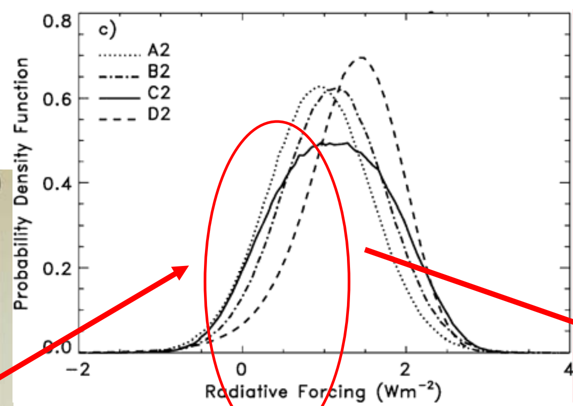
carbon use uncertainty (dark blue)

Source: IPCC 2001

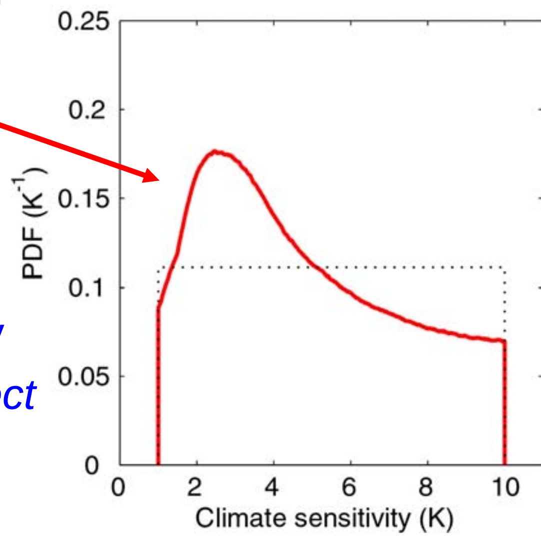
- Predictions of global temperature increase by the year 2100 range from 1.5C to 6C.
- Uncertainties in forcing (aerosols) and feedback (clouds) dominate the climate prediction problem
- Cloud feedback processes represent the largest uncertainty in determining climate sensitivity (how climate responds to increasing surface temperature)

The Anthropogenic Forcing



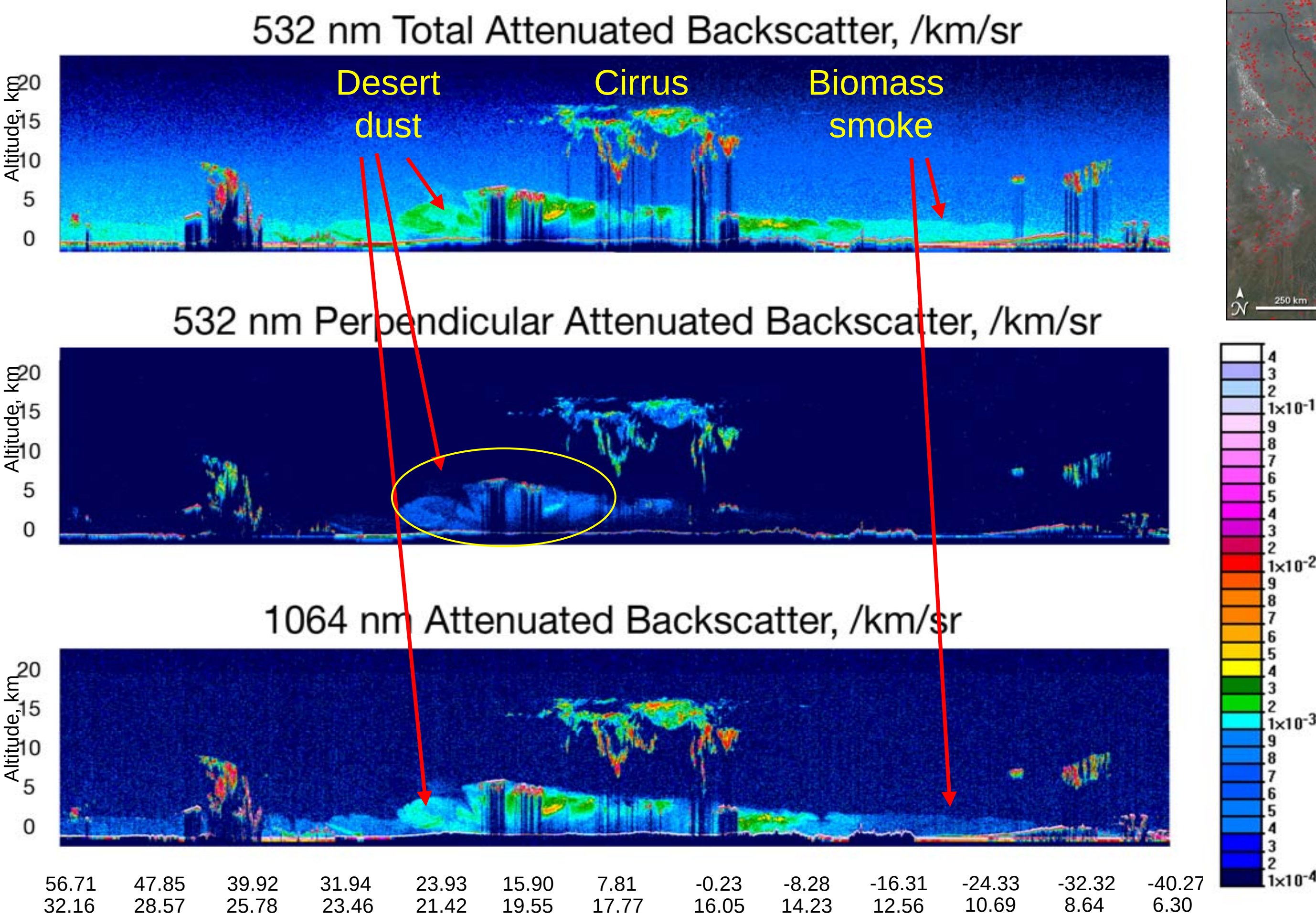


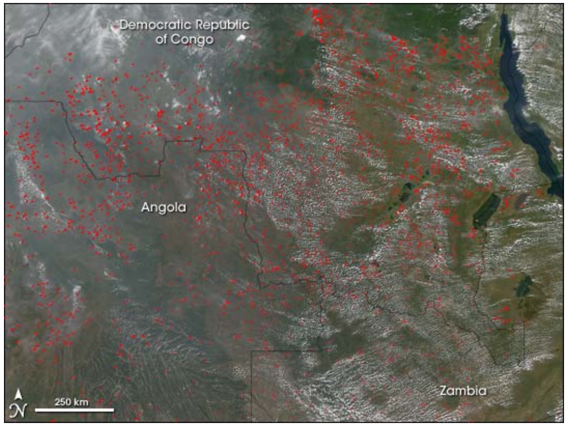
Can we constrain climate sensitivity from 20th century climate trends? *Indirect effect is key* for the high end.



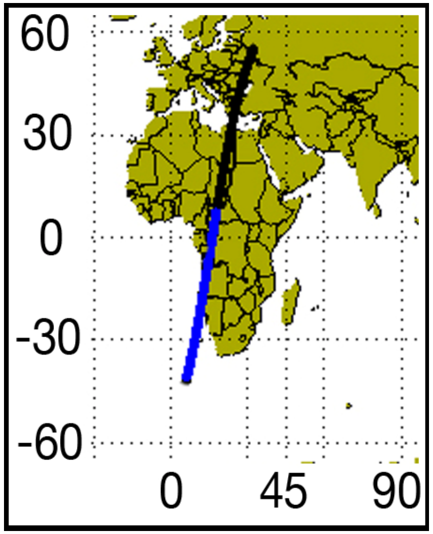
CALIPSO Observations

9 June 2006

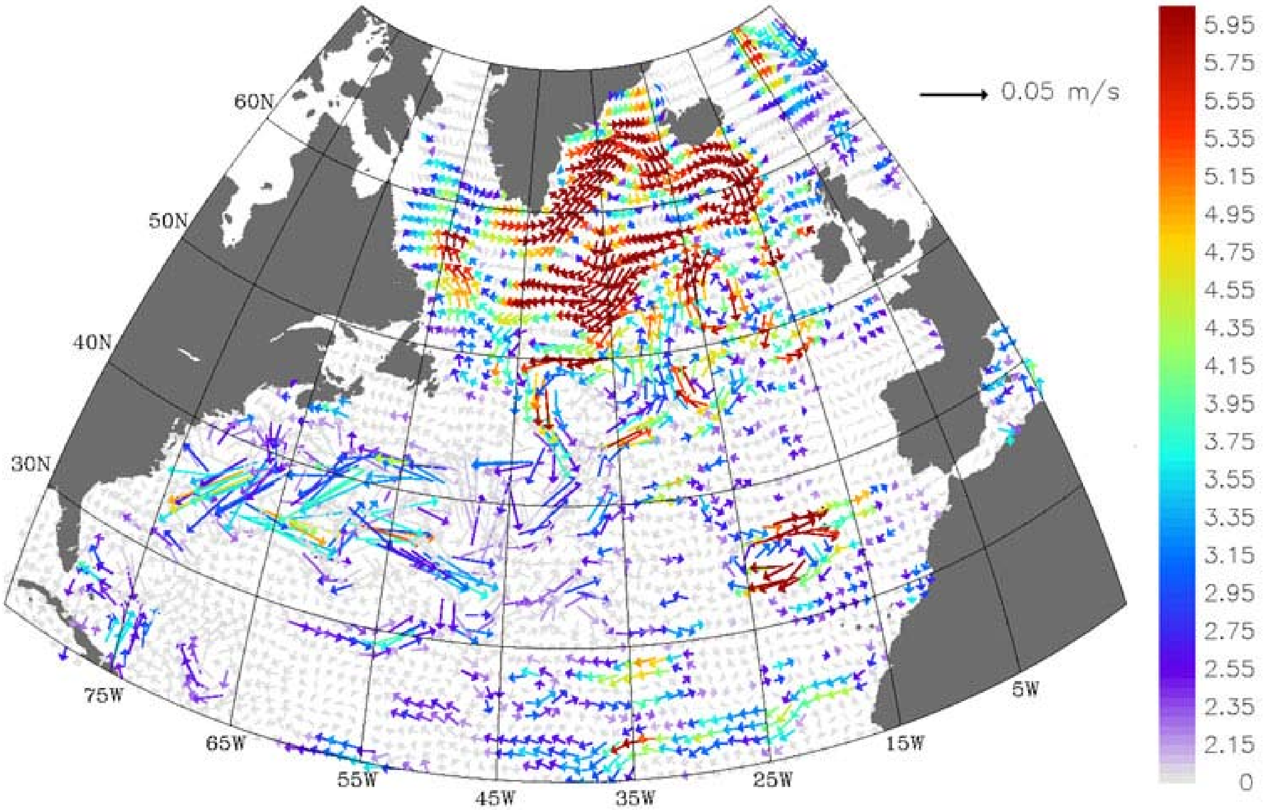




Fire locations in southern Africa from MODIS, 6/10/06



Satellites Record Weakening of the North Atlantic Current



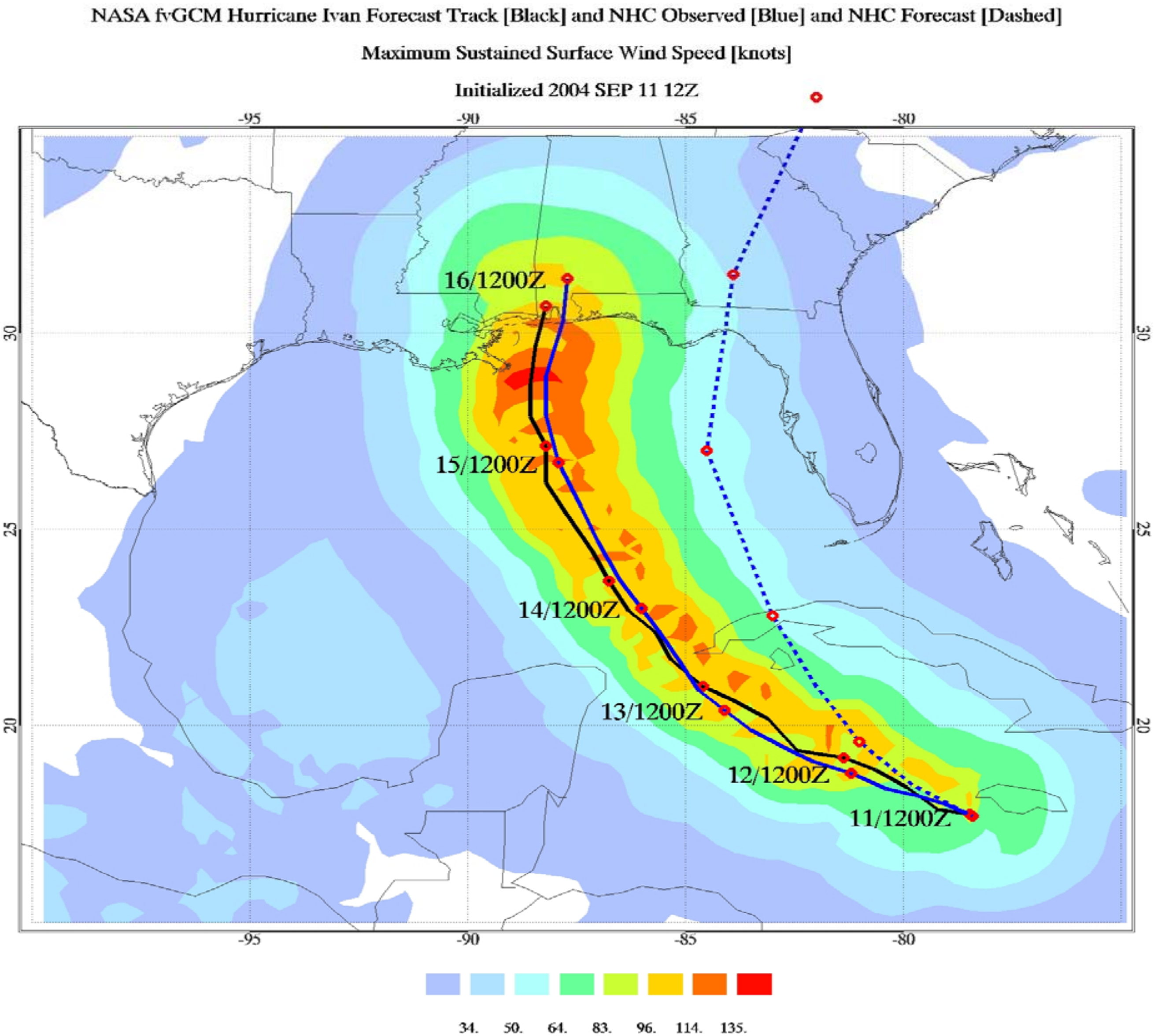
QuikSCAT

- This figure shows the slowing of the North Atlantic Ocean circulation system. The trend of the velocities (meters per sec per decade) is going the opposite direction of the current, indicating slower speeds. These data are from May 1992 to June 2002 from the NASA Pathfinder Altimeter. The colored vectors show the height, direction, and velocity of the current.

Hurricane Ivan
fvGCM Track and Intensity Forecast

• NASA fvGCM 5-day forecast shows vast improvement in accuracy of track, landfall, and intensity over operational prediction in this case

QuikSCAT TRMM and SSM-I

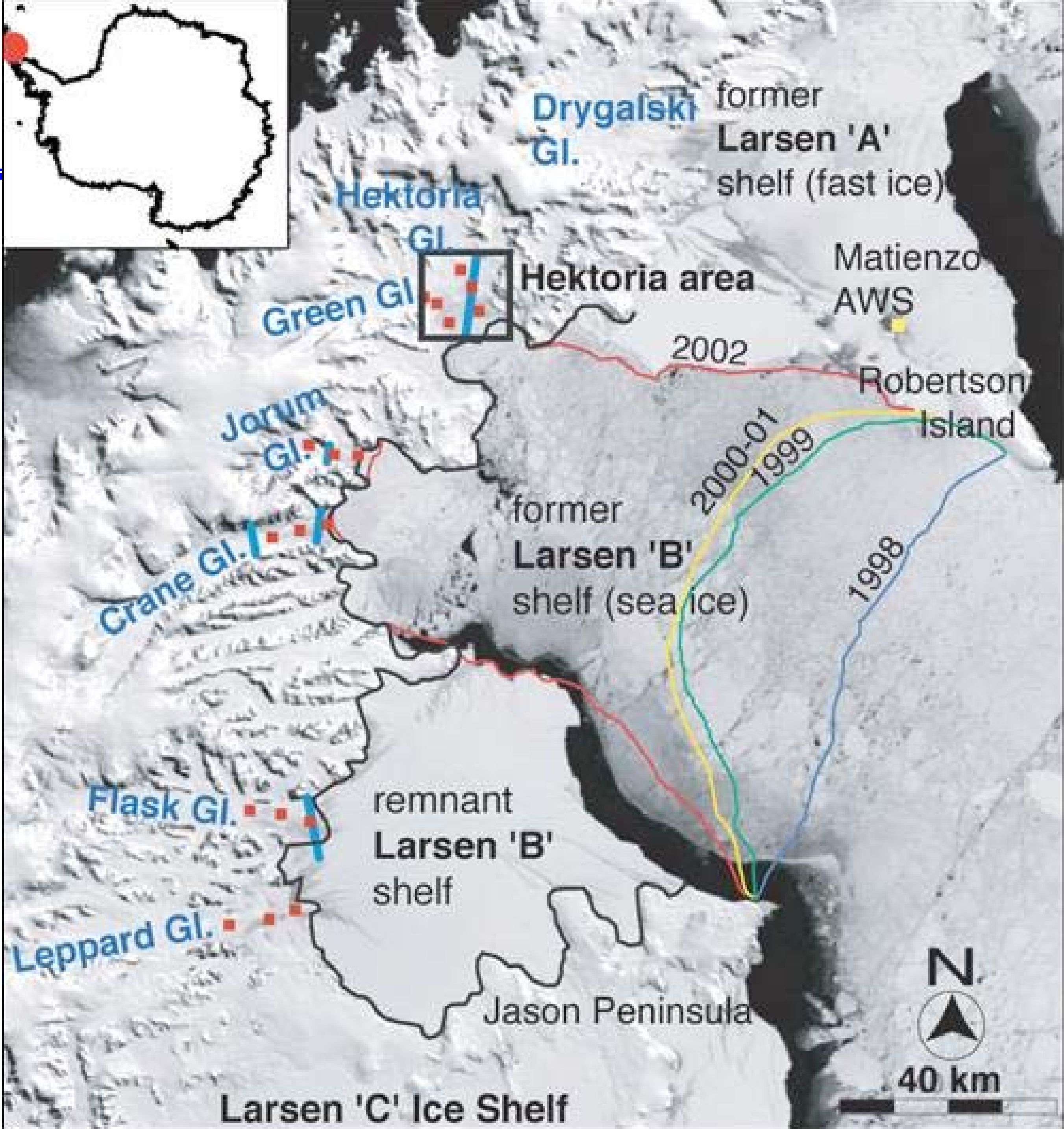


ICESat

Results from Antarctic Peninsula

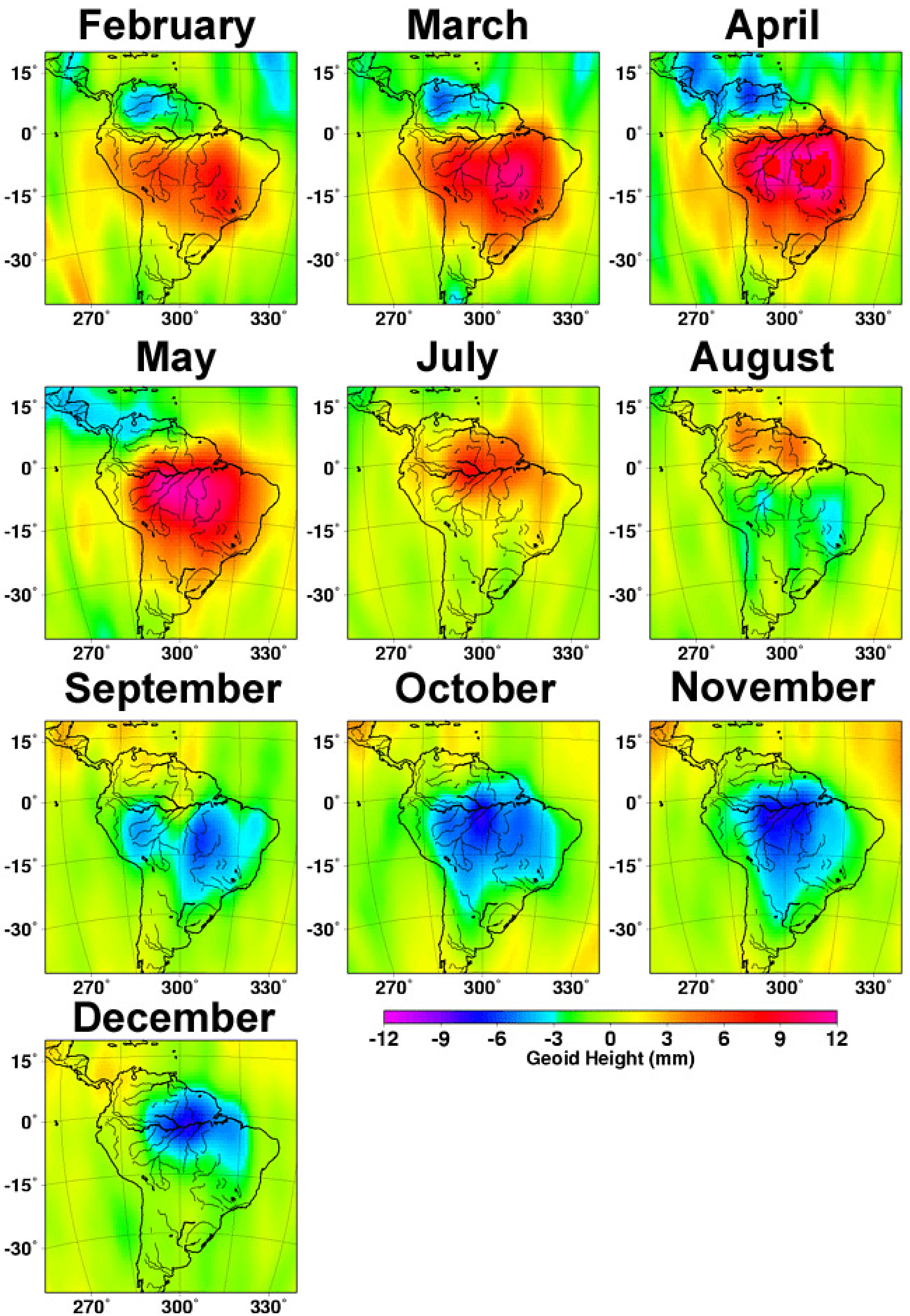
- Following Larsen ice shelf break-up glaciers accelerated 8x
- ICESat shows thinning by 38 m (blue lines)

Scambos et al., GRL 2004



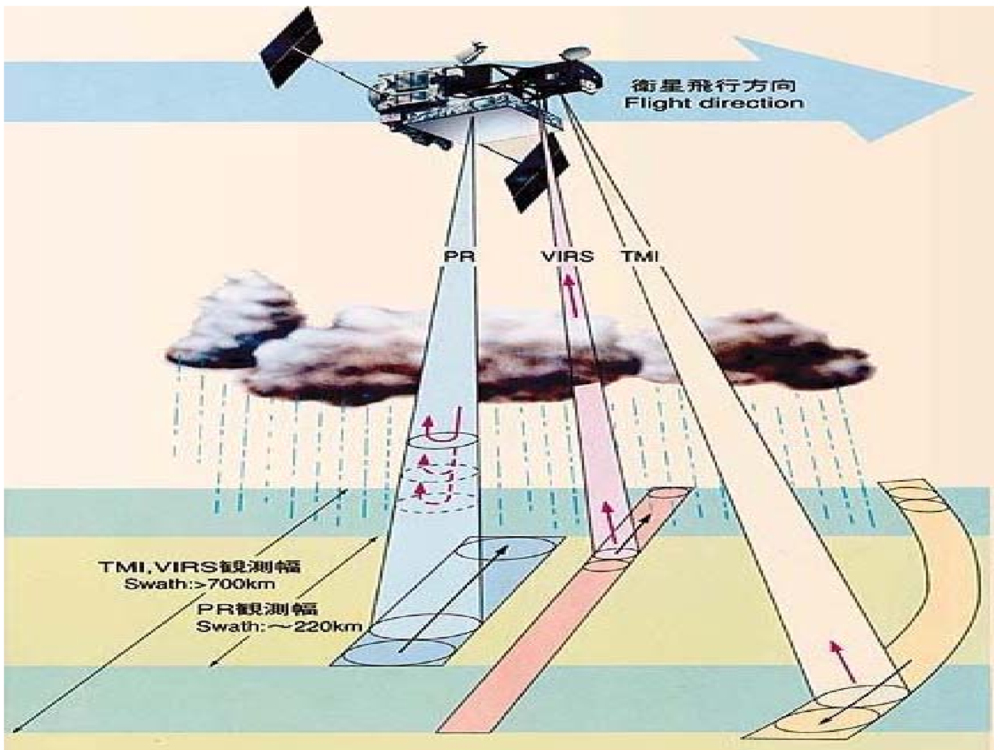
GRACE

Results published in *Science* show monthly changes in the distribution of water and ice masses could be estimated by measuring changes in Earth's gravity field. The GRACE data measured the weight of up to 10 millimeters of groundwater accumulations from heavy tropical rains, particularly in the Amazon basin and Southeast Asia. Smaller signals caused by changes in ocean circulation were also visible.



Tropical Rainfall Measuring Mission (TRMM)

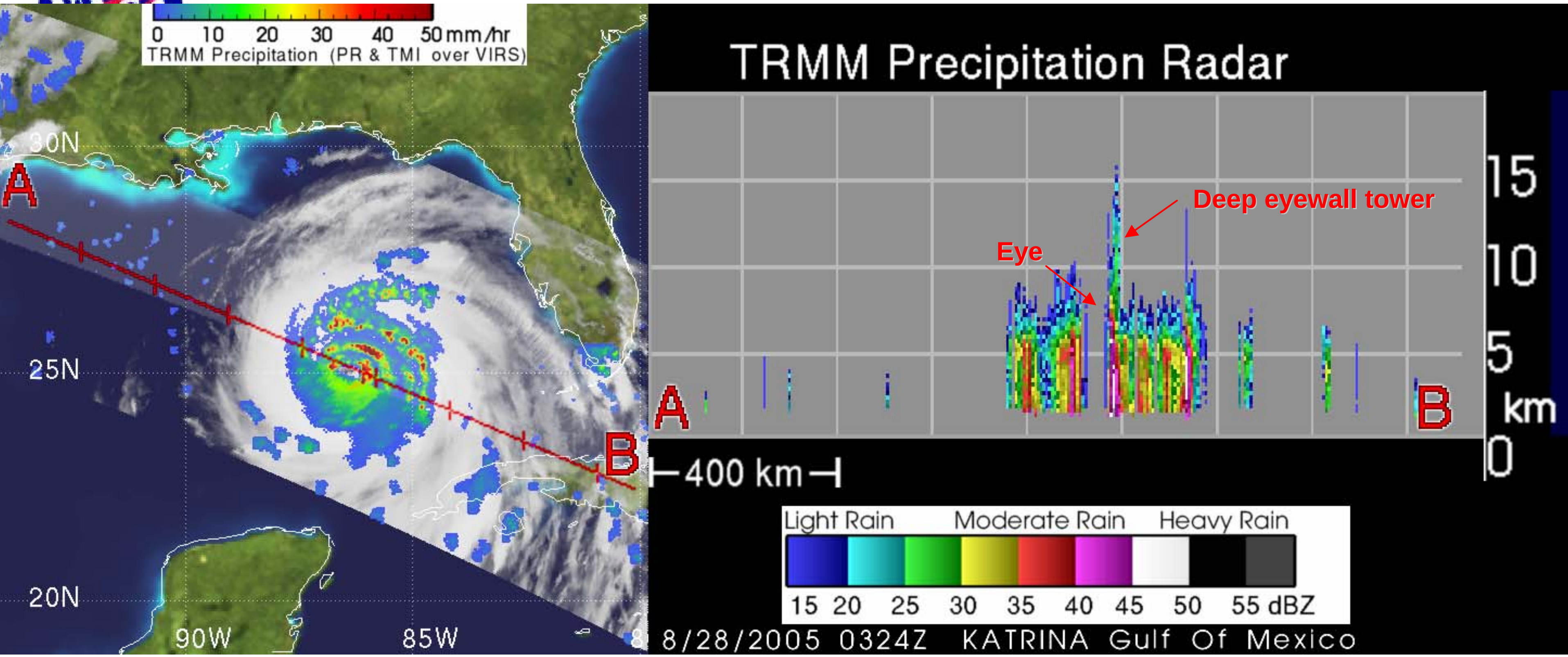
- **Science Objective:** ***Advance knowledge of global water and energy cycles through observed time and space distributions of tropical rainfall, hydrometeor structure and latent heating.***



- Joint NASA/JAXA mission launched in Nov. 1997 into inclined, 35º orbit; 402 km altitude; spacecraft and instruments in excellent condition after 8+ years--fuel remains for mission extension to ~2012 (possible overlap with GPM)
- NASA's Precipitation Measurement Missions (PMM) Science Team covers TRMM and GPM (includes NOAA, DoD members)
- **Instrument Payload:**
  - **TRMM Microwave Imager (TMI)**
    - **10, 19, 37, 86 GHz, conical scanning**
  - **Precipitation Radar (PR) [Japan]**
    - **14 GHz, cross-track scanning (250m vertical res.)**
  - **Lightning Imaging Sensor (LIS) [MSFC]**
    - **Staring optical array**
  - **Visible IR Scanner (VIRS)**
    - **5-channel, cross-track scanning**
  - **Cloud & Radiant Energy System (CERES) [LRC]**
    - **Radiation budget (failed after 6 mos.)**

National Academy Review (2004), NASA Senior Review (2005)

TRMM View of Hurricane Katrina

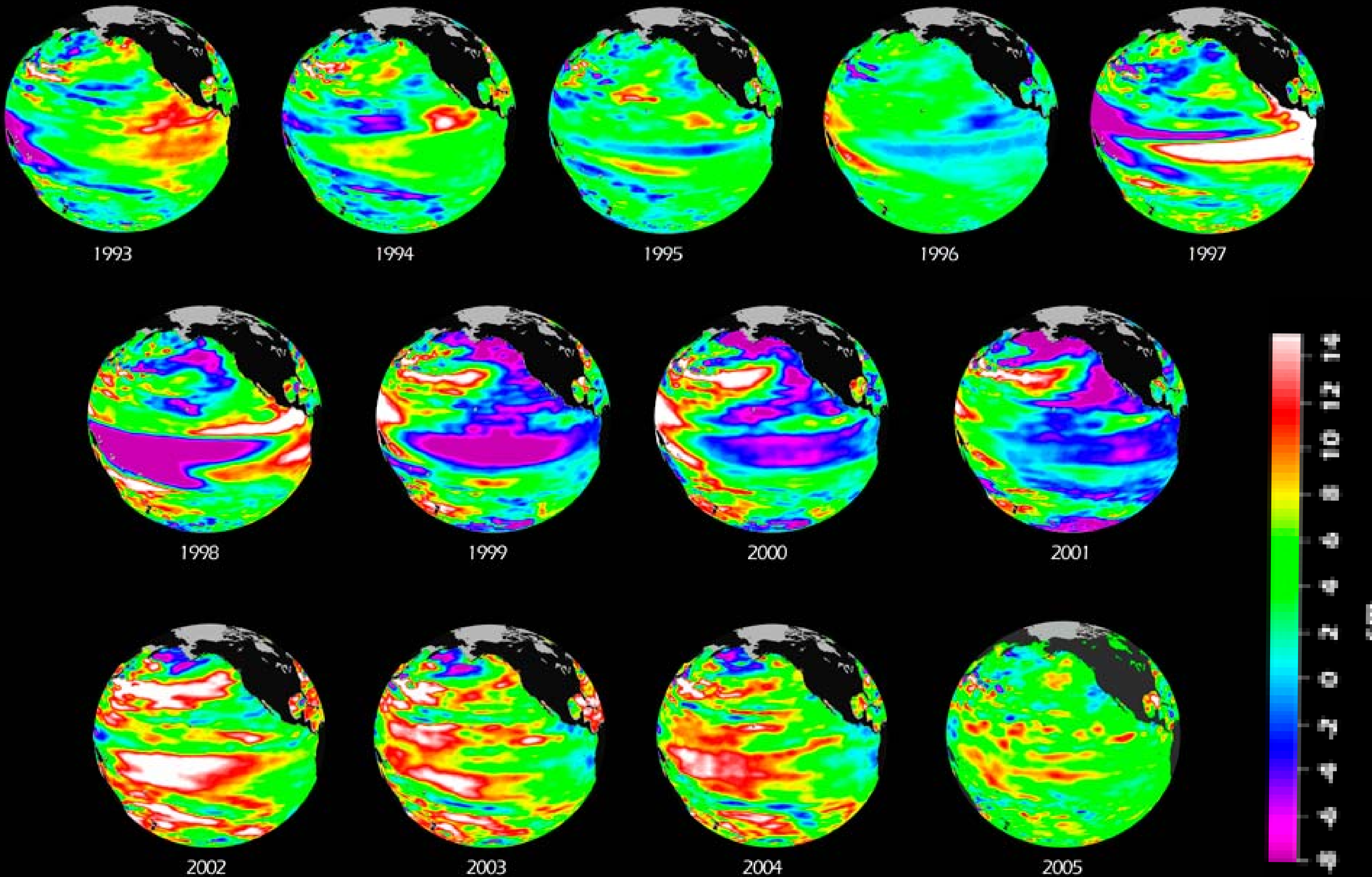


- **Vertical rain structure as indicated by the TRMM Precipitation Radar in near-real time via TRMM web site**
- **TRMM is only satellite that provides rain structure information over open oceans**
- **Deep convective clouds (to 16 km) in the eyewall of Katrina on August 28 occurred while the storm was intensifying to Cat 5; The connection between these extreme towers and storm intensification has been documented.**

Kelley, O.A., J. Stout & J. Halverson, 2004: Tall precipitation cells in tropical cyclone eyewalls are associated with tropical cyclone intensification. *Geophys. Res. Let*., **31**, L24112.

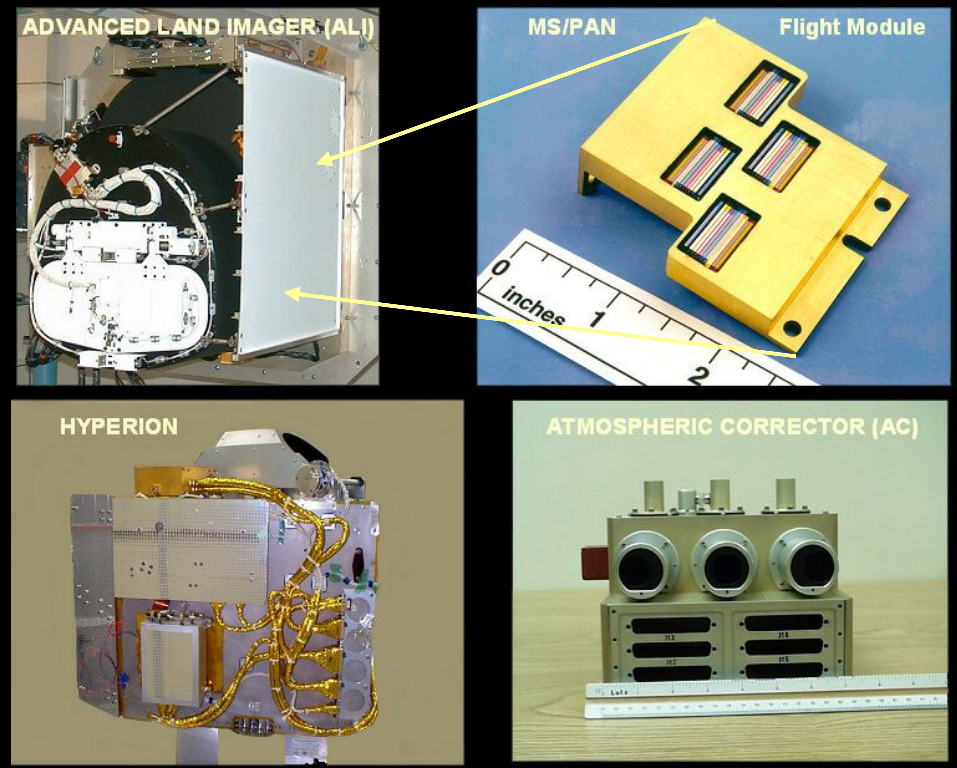
Measurement of Ocean Surface Topography

TOPEX/Poseidon (past)/JASON (present)/OSTM (future)



EO-1

- Hyperspectral land surface imagery
- A technology demonstration mission launched in 2000
- Part of the morning constellation with Landsat 7, Terra and SAC-C



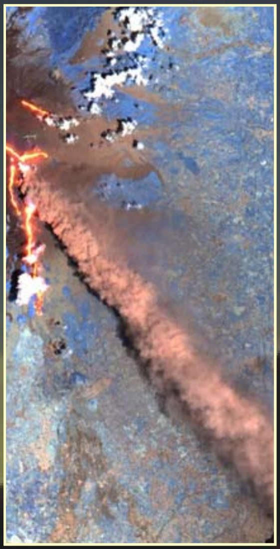
Eruption of Mt. Etna, Sicily

July 22, 2001

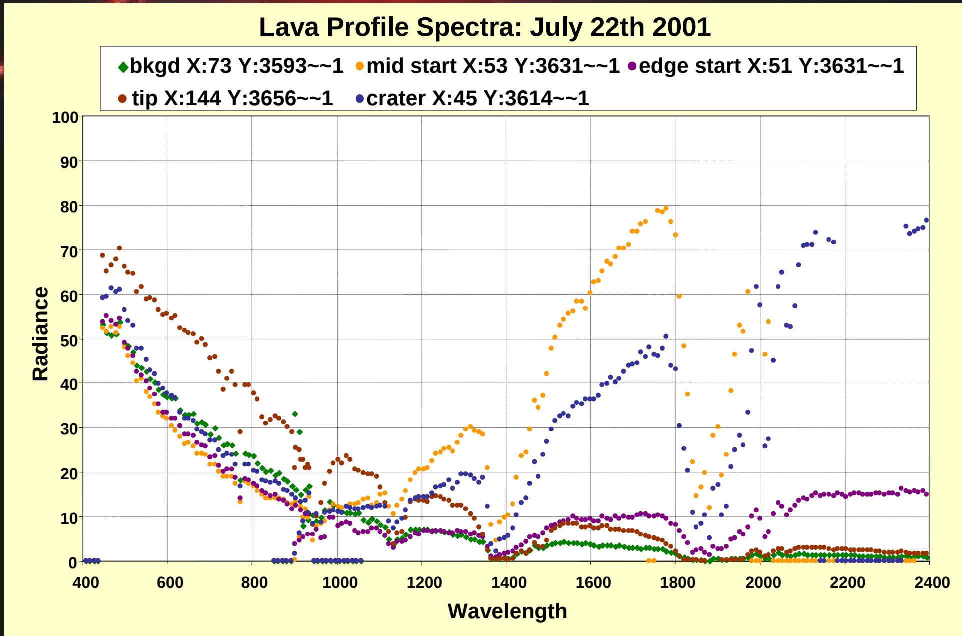
ALI Pan Enhanced Bands 3-2-1

Hyperion 7-5-4 Equiv

EO-1 ALI Bands 7-5-5'



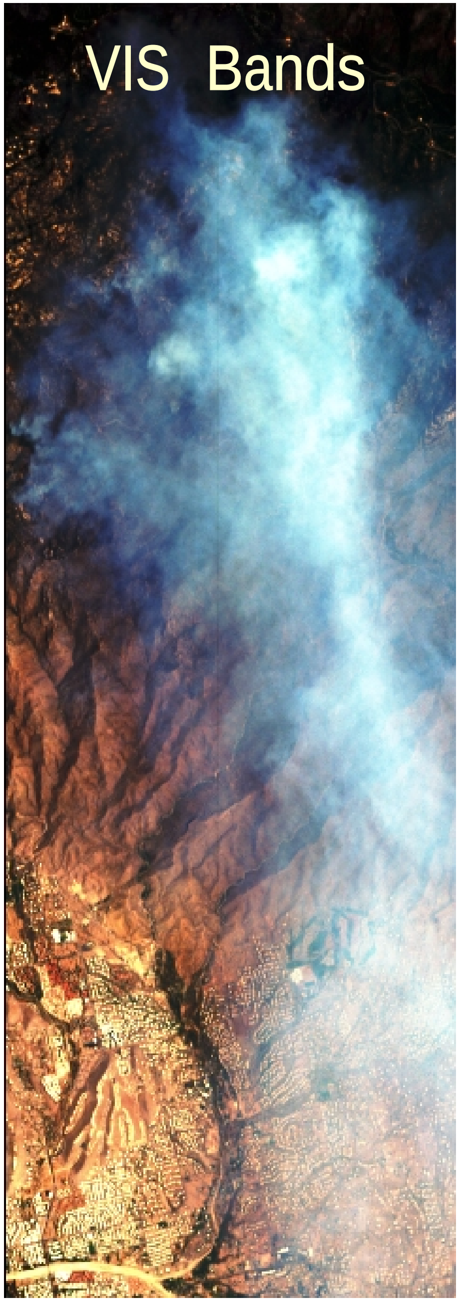
EO-1 Hyperion Spectra

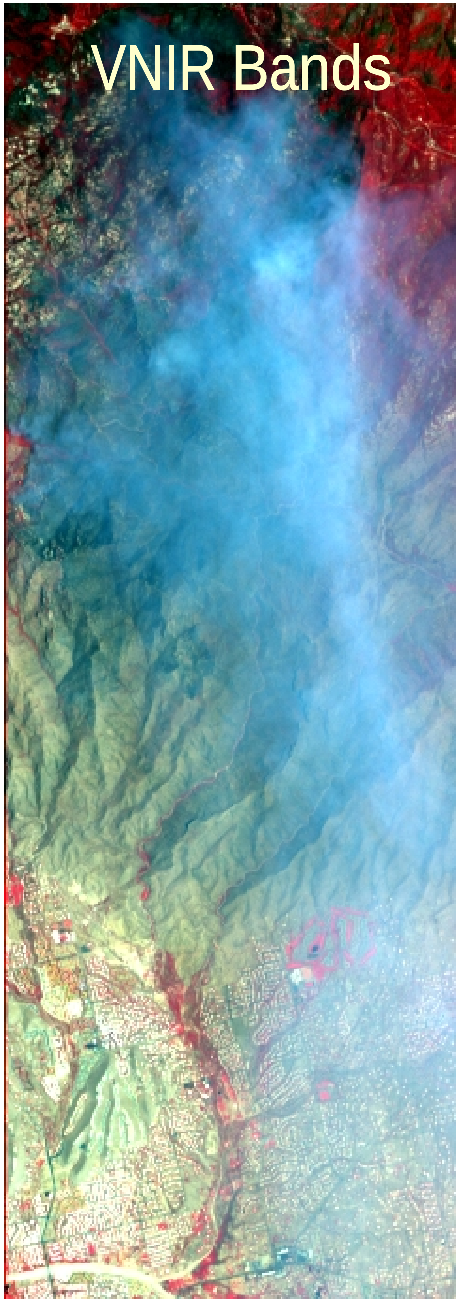


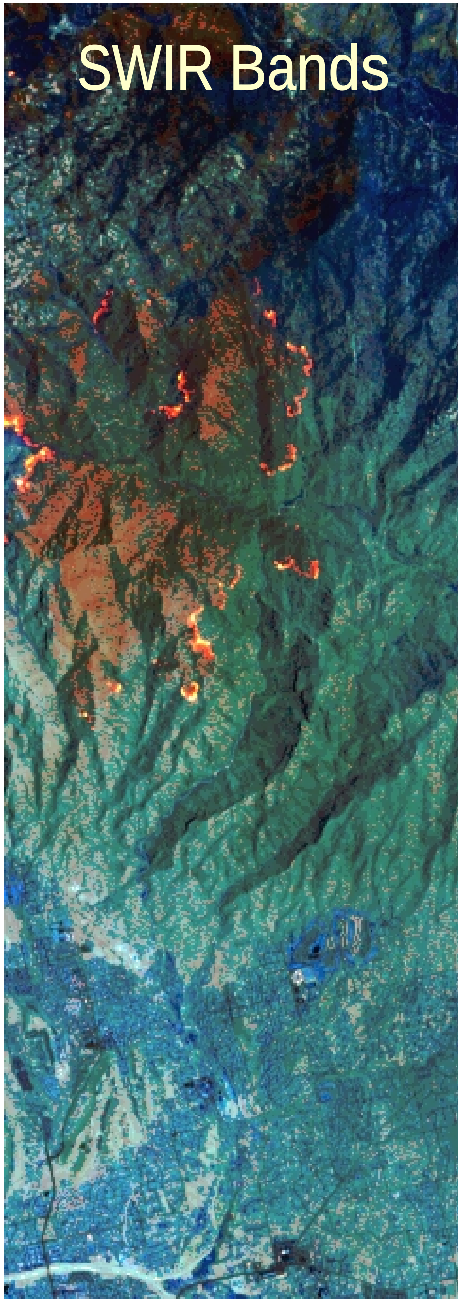
Hyperion Temperatures for Etna

Spectrum	Crust Temp	Hot Temp	Area Hot
J 13 - CTB	346 C	994 C	0.0025
J 13 - MM	874 C	876 C	0.45
J 13 - CTS	976 C	978 C	0.47
J 13 - TipX	210 C	900 C	0.00034
J 22 - MS	726 C	1075 C	0.090
J 22 - CX	487 C	1075 C	0.022
J 22 - RS*	1054 C	1058 C	0.690

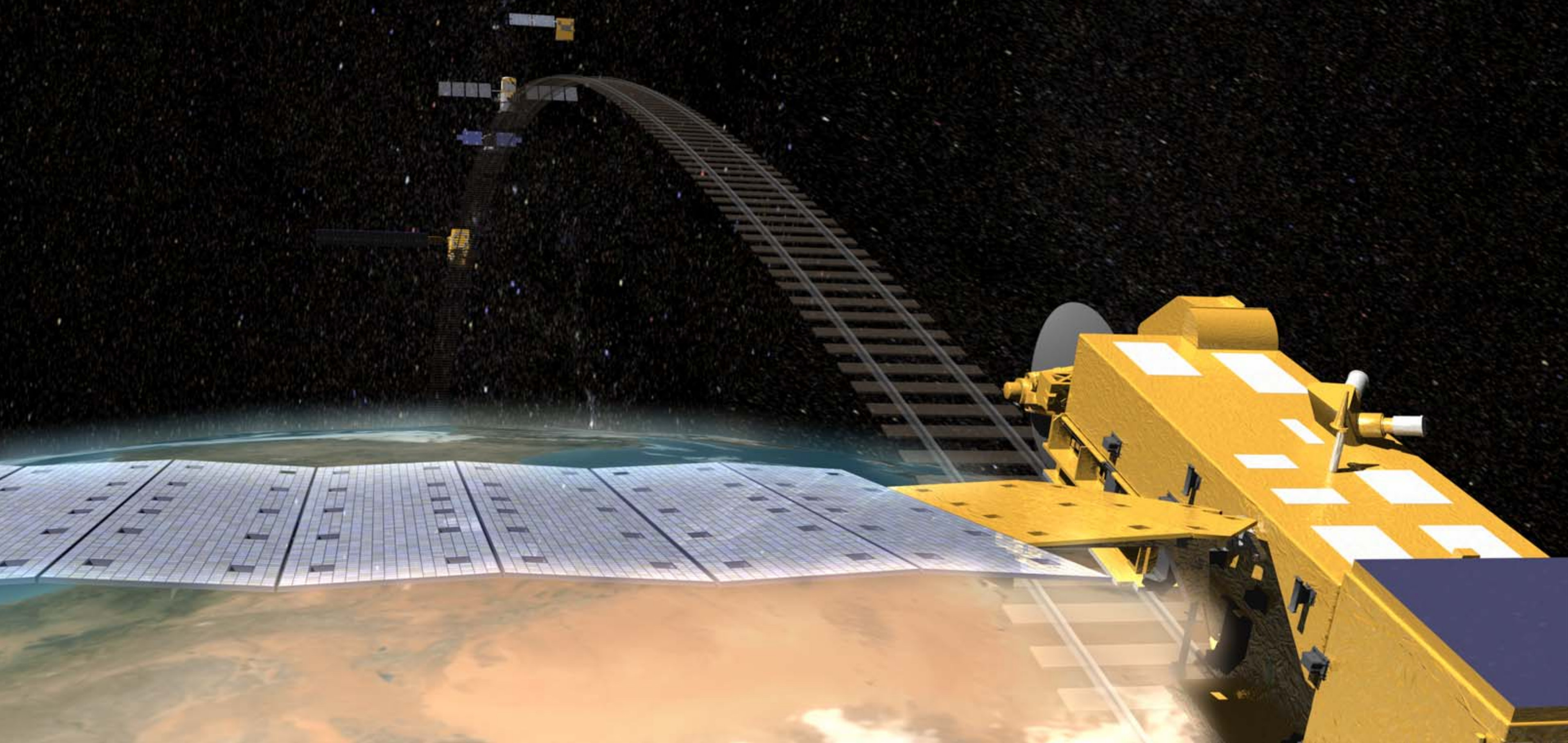
Hyperion Views Tucson Wildfires - July 3, 2003







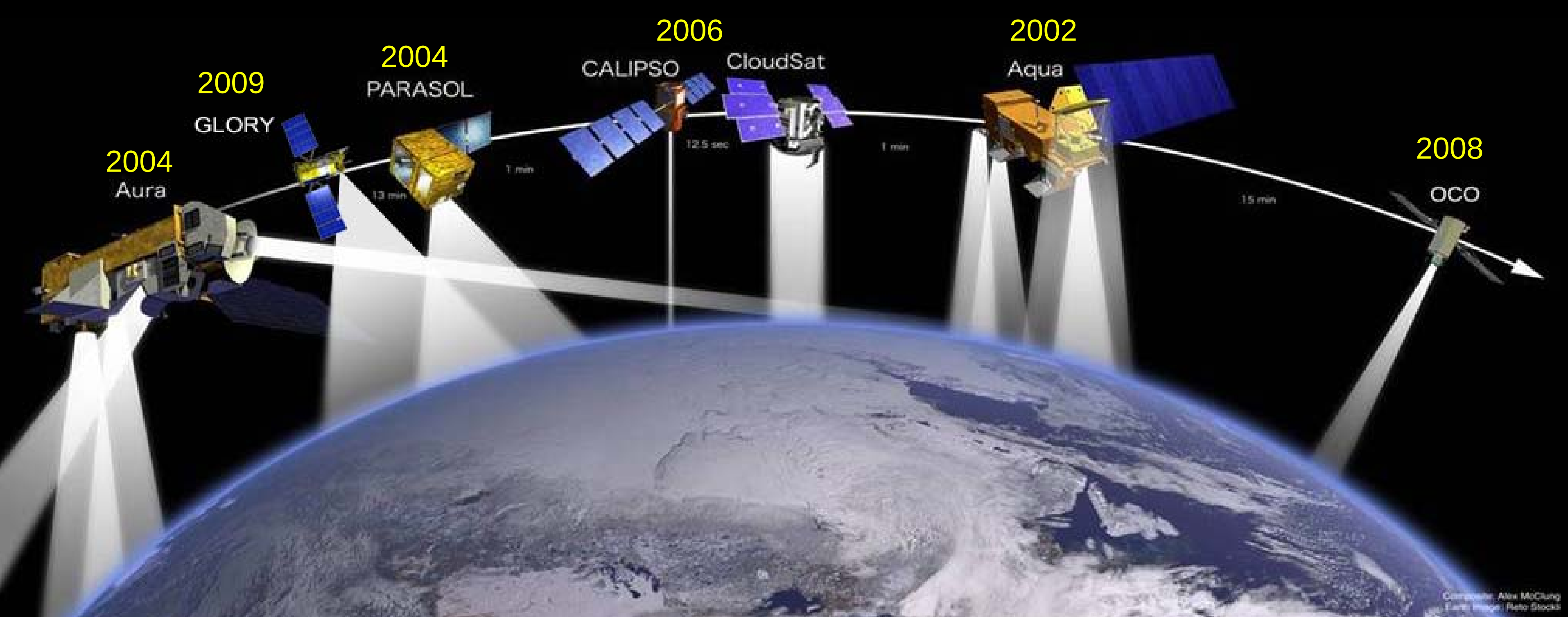
Earth Science Constellations:
The Morning Constellation and the Afternoon, or“A-train” Constellation



The Morning Constellation

The Afternoon, or A-Train

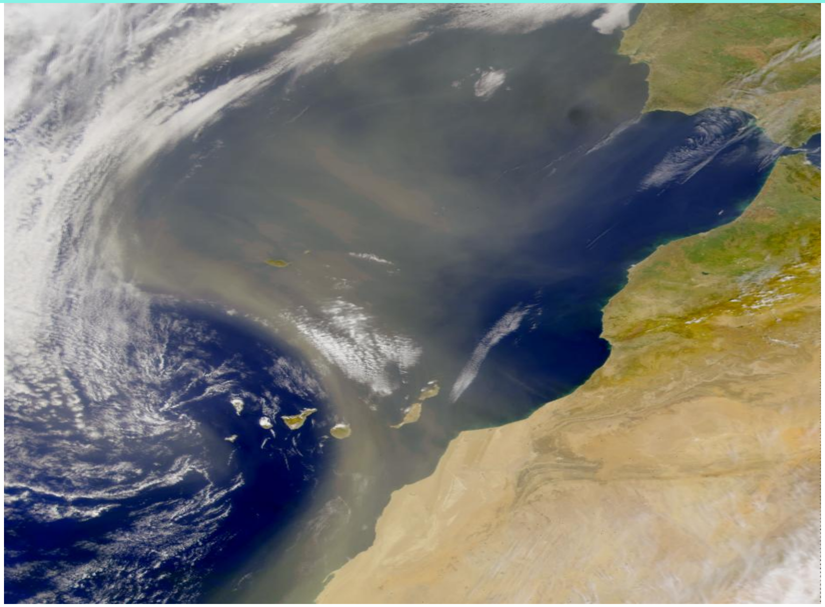
- NASA has assembled in orbit five satellites in the same orbit to conduct Earth Science research.
- The Afternoon Constellation, or A-Train as it is called, functions as a virtual observatory supporting multi-instrument and cross-platform research



The A-Train presents the first opportunity to study the aerosol effect on clouds and precipitation.

Fusing of the A-Train data will allow us to address the following questions:

- Is aerosol changing cloudiness?
- Is aerosol suppressing regional precipitation?



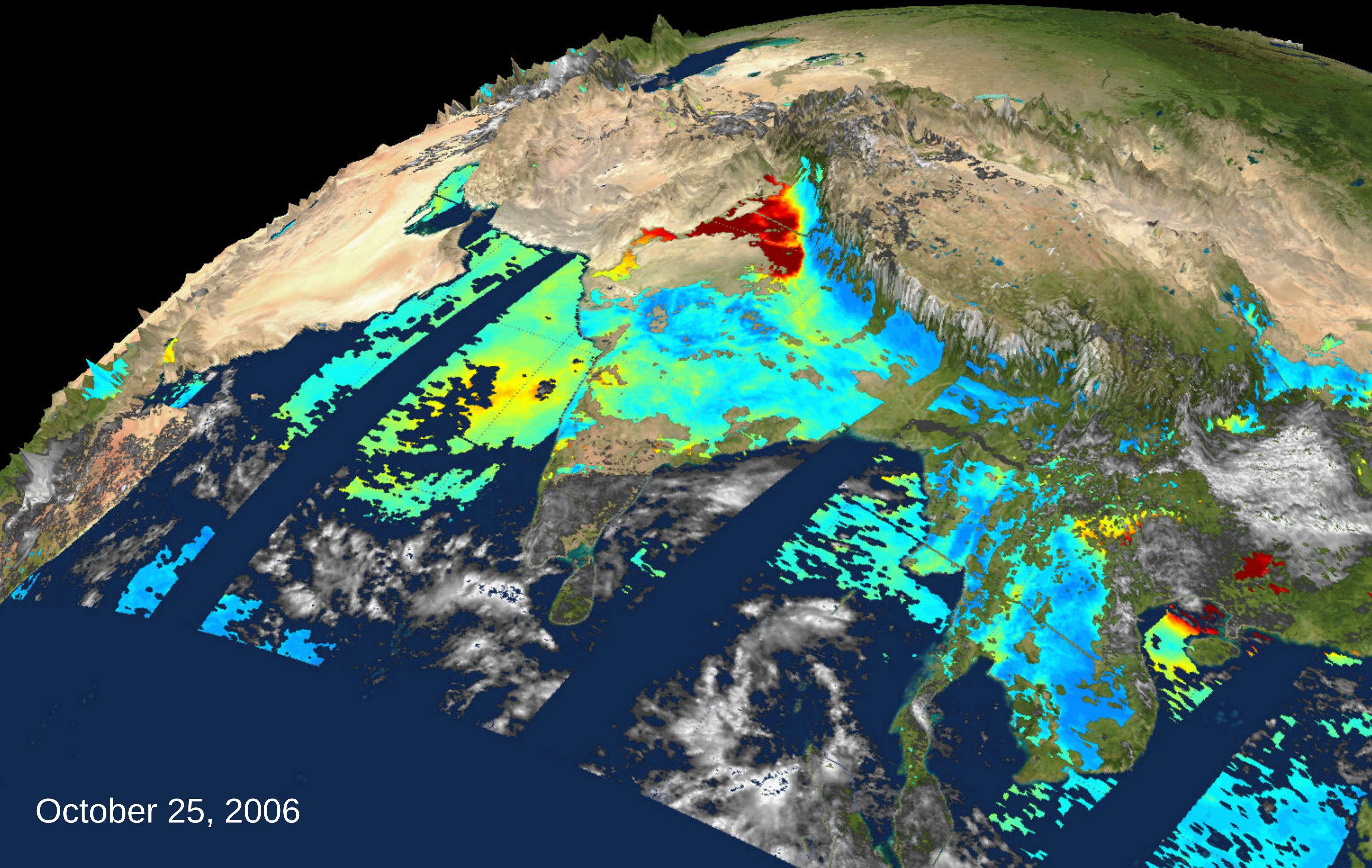
Example of dust being swept up by winds into clouds

A-Train provides the necessary measurements needed to begin this study

Cloud condensate	CloudSat MLS AMSR
Precipitation	CloudSat AMSR
Cloud microphysics	CloudSat MODIS PARASOL
Cloud optics	PARASOL MODIS CALIPSO
Aerosol optics	CALIPSO MODIS AIRS PARASOL
Radiative fluxes	CERES CloudSat
Chemistry	Aura

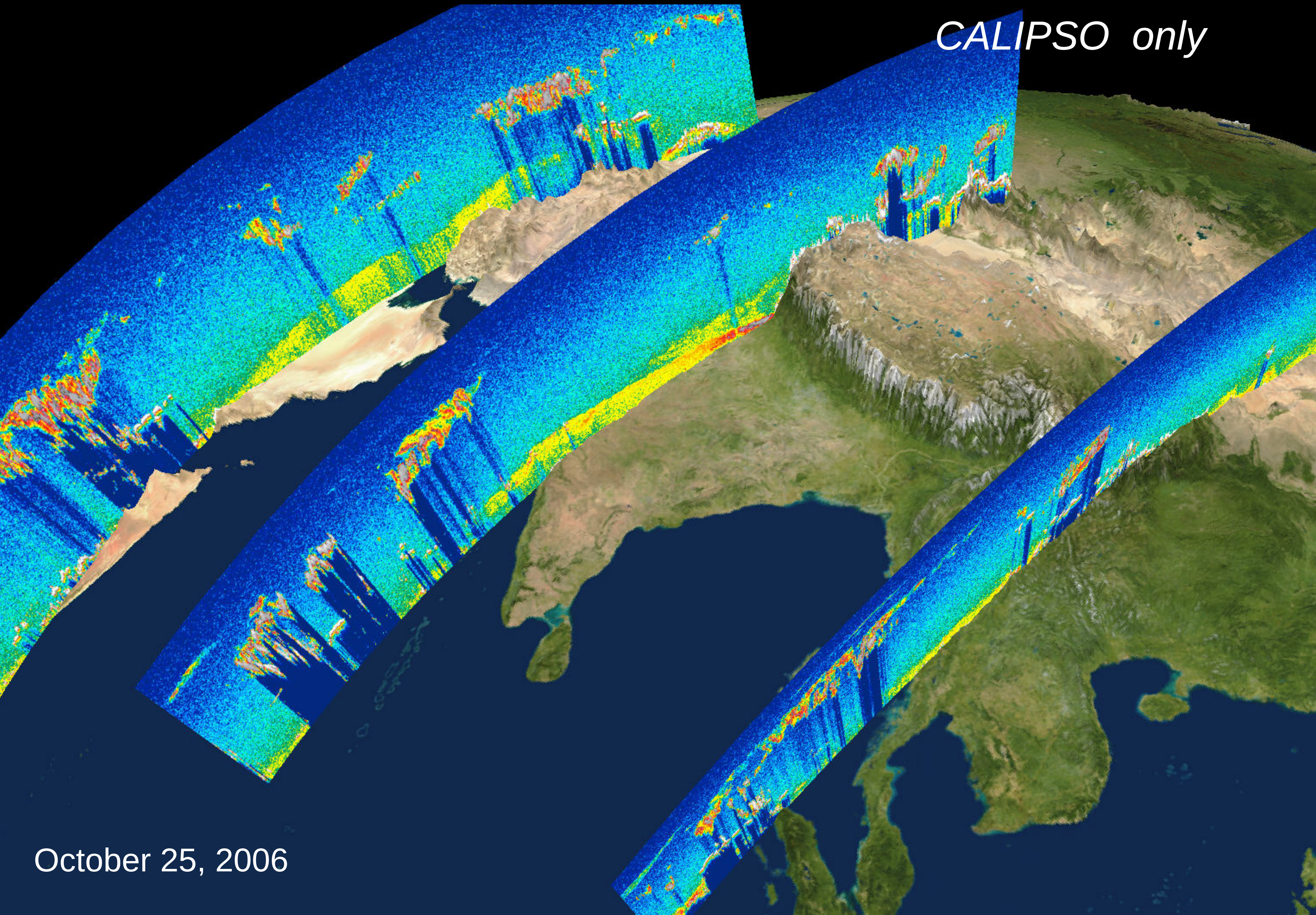
Aerosol and Cloud Observations over Southern Asia

MODIS on Aqua only



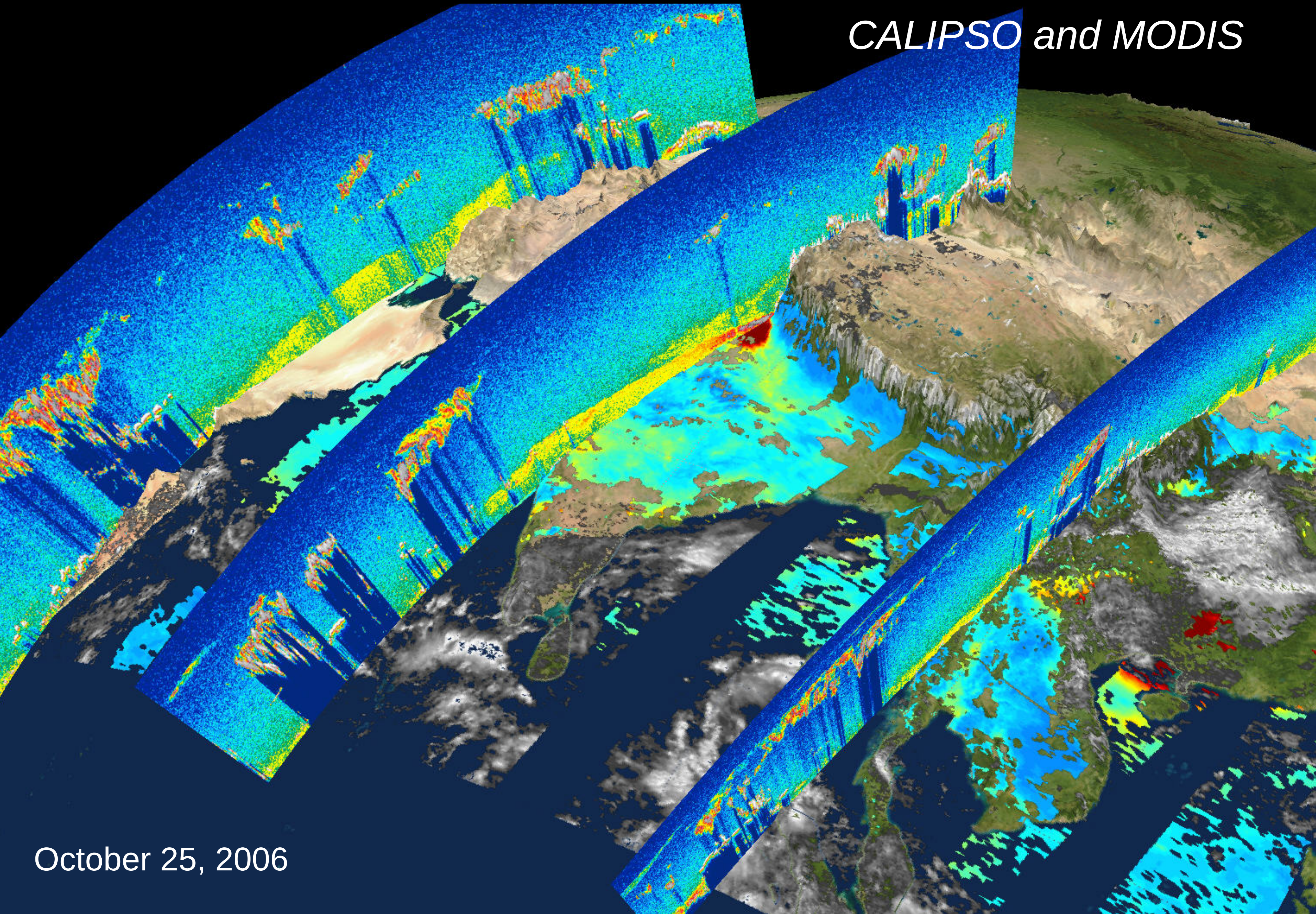
October 25, 2006

Aerosol and Cloud Observations over Southern Asia



Aerosol and Cloud Observations over Southern Asia

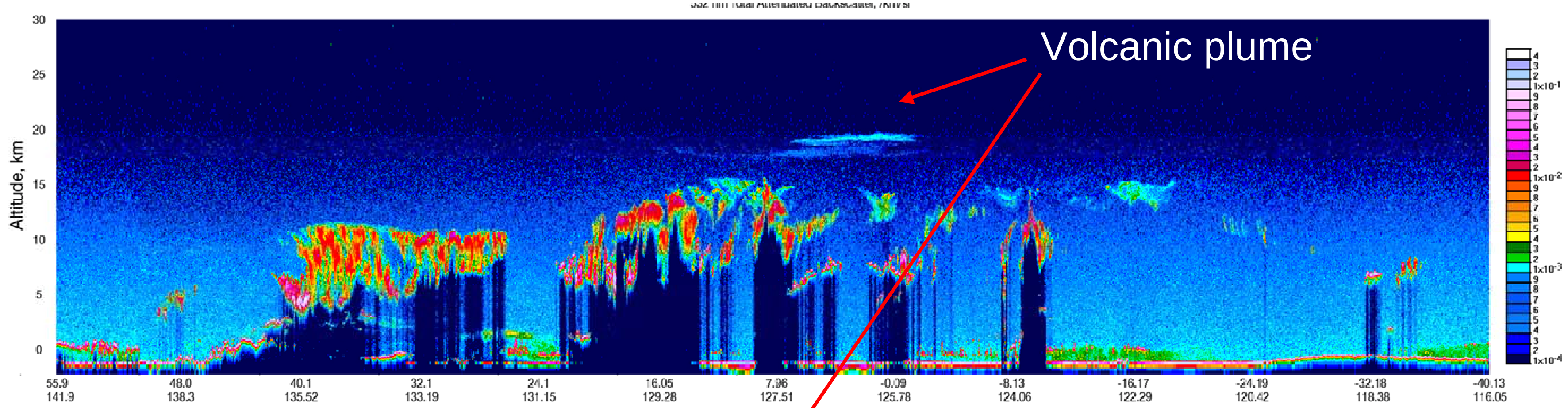
CALIPSO and MODIS



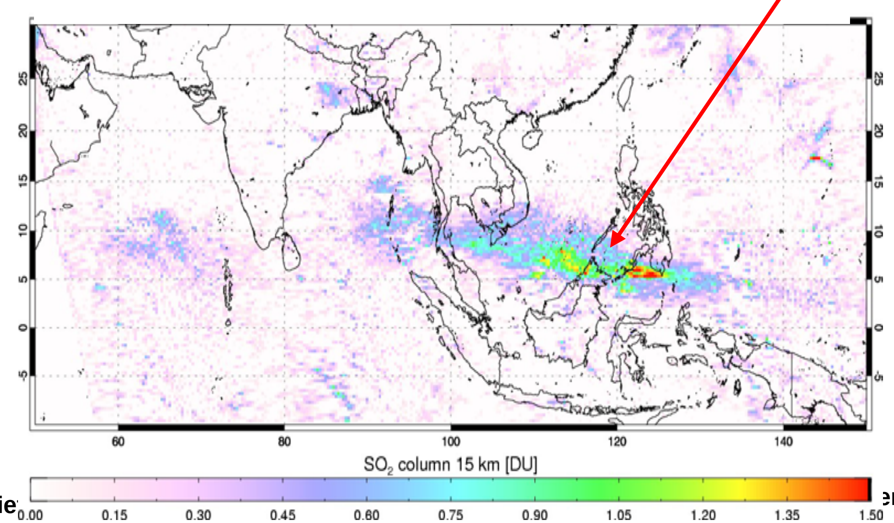
October 25, 2006

Observations of a Volcanic Plume from the Eruption of Soufriere Hills, Montserrat, on May 20

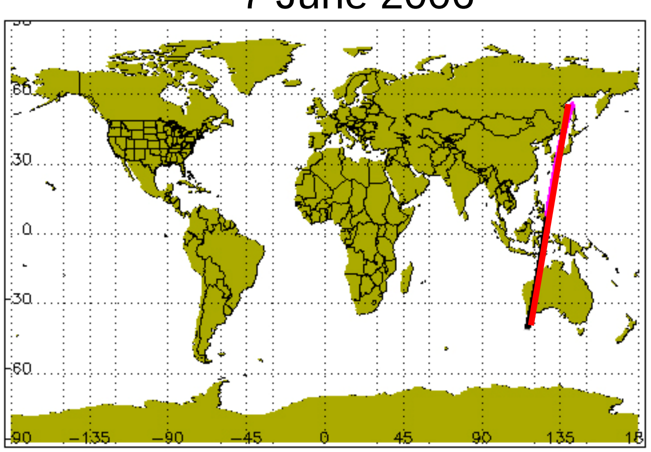
CALIPSO Total Attenuated Backscatter 532 nm   7 June 2006



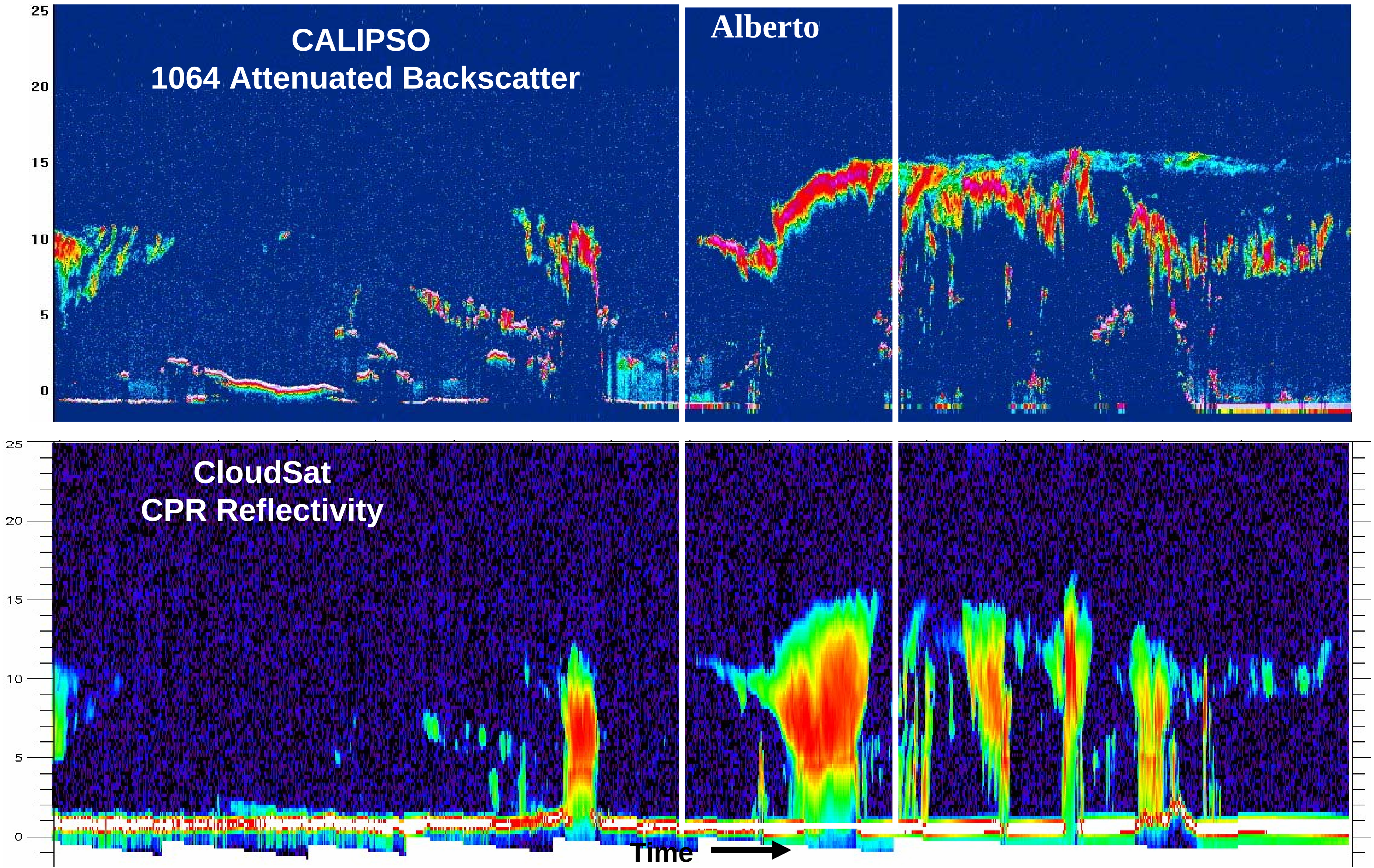
Aura/OMI Column SO_2
8 June 2006



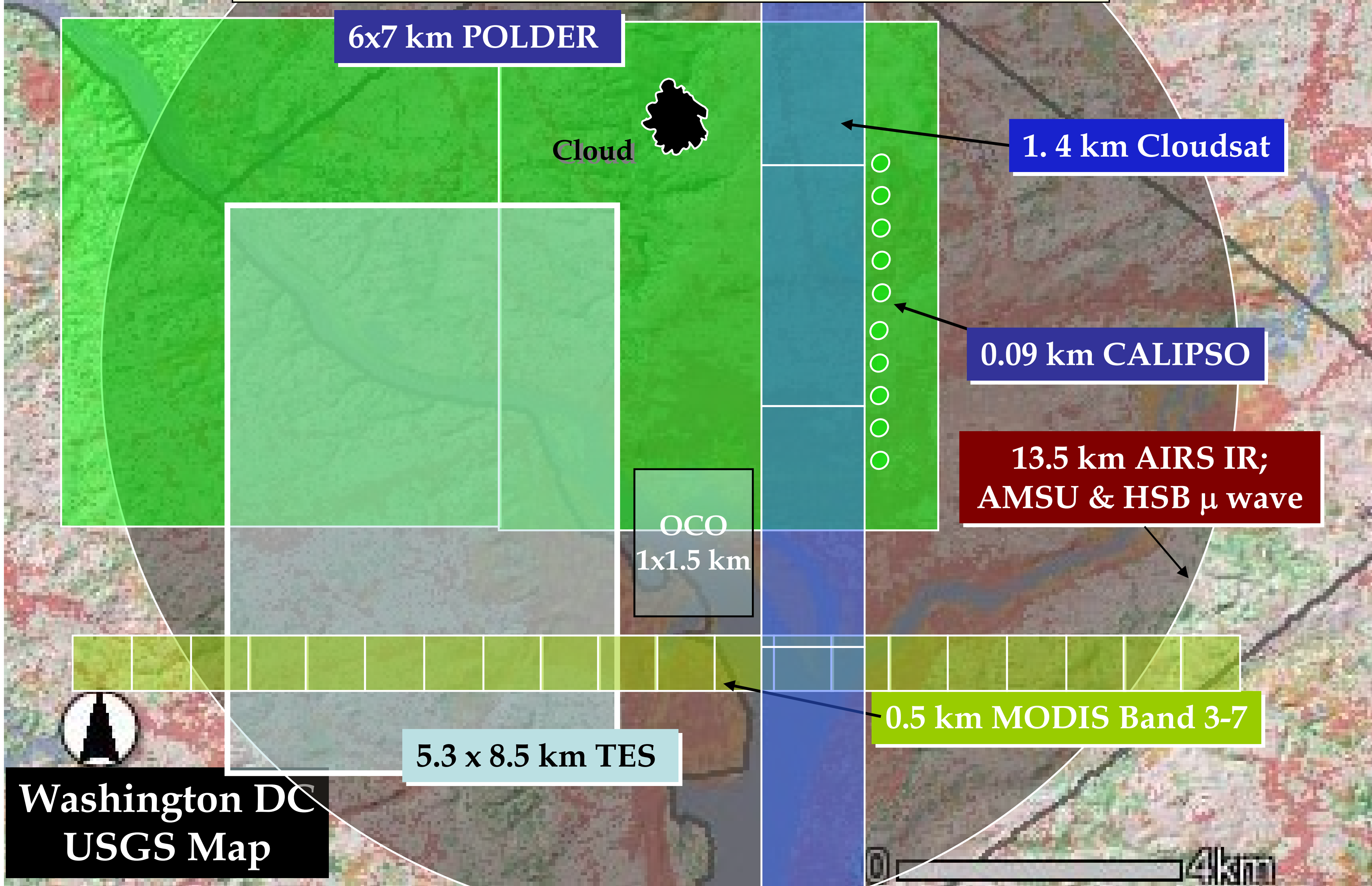
CALIPSO Orbit Track
7 June 2006



CloudSat & CALIPSO Together: Tropical Storm Alberto



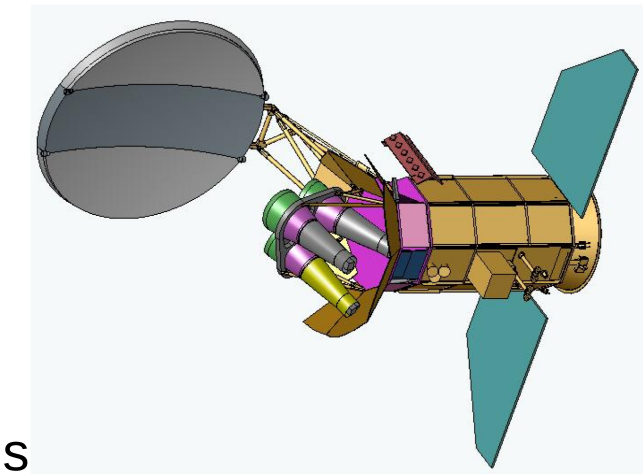
The Afternoon Constellation observational "footprints" vary greatly



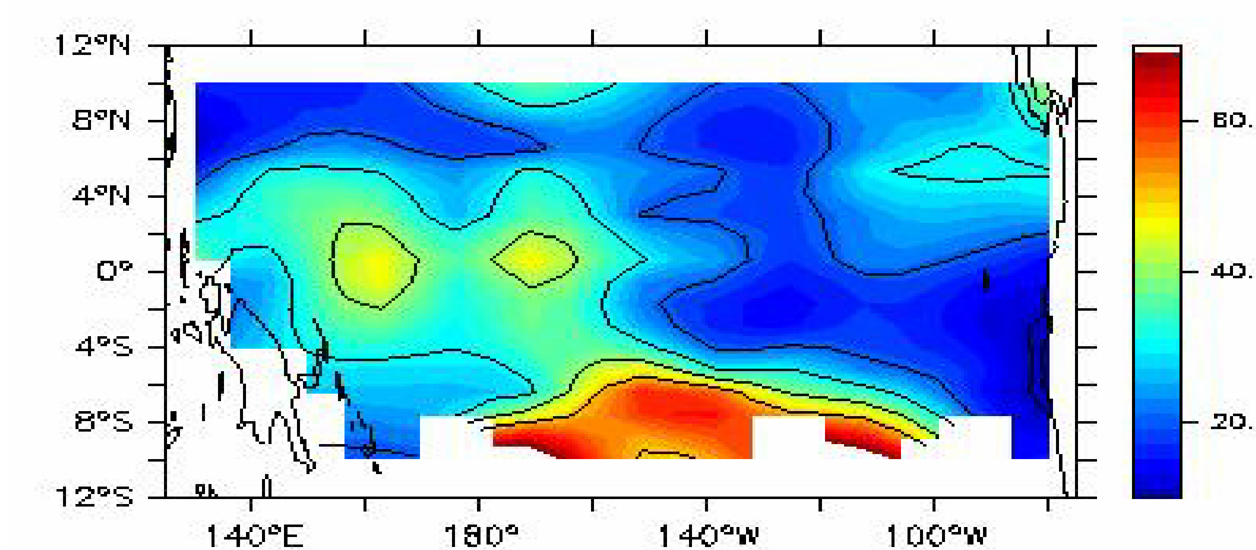
Missions in Development or Planning

Ocean Salinity: Aquarius

- Purpose: explore the variability of surface salinity in the oceans.
  - Requires improved antennas, signal processing, and algorithms.
  - Remotely sensed salinity data will greatly improve our knowledge of heat storage an important driver of significant climate signals



In the western tropical Pacific Ocean, the birth place of El Nino, the effect of salinity on the density and thereby ocean topography can be equal to or more than the effect of temperature.

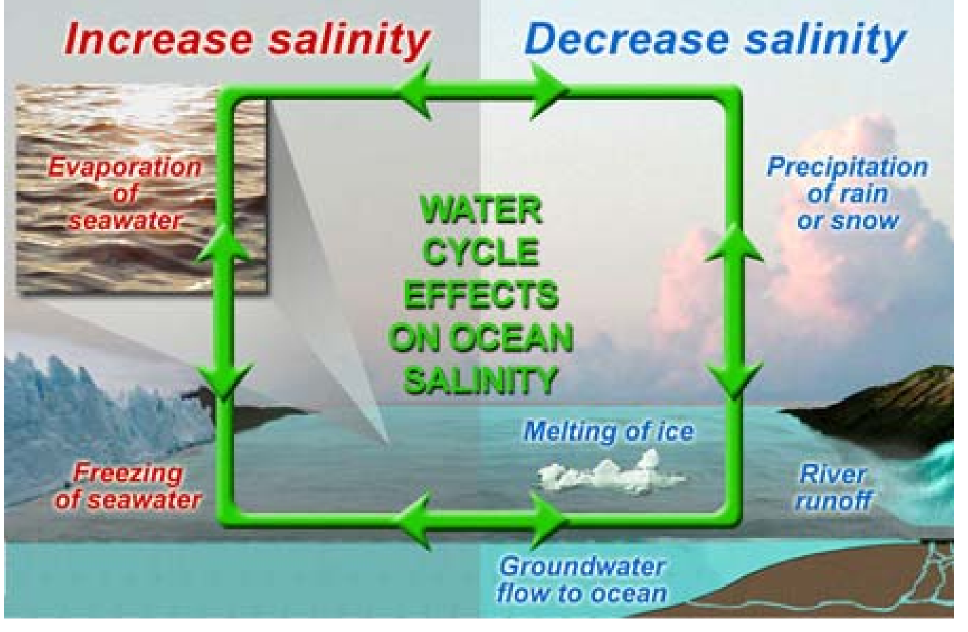


Percentage of ocean topography variability due to salinity (Maes and Behringer, 2000)

Aquarius Science Objectives

Sea Surface Salinity (SSS)

•**The specific science objectives** are to quantify these physical processes as they vary on the seasonal cycle and from year to year, as well as reduce the uncertainty in the net freshwater budget, with global SSS measurements for at least three years.



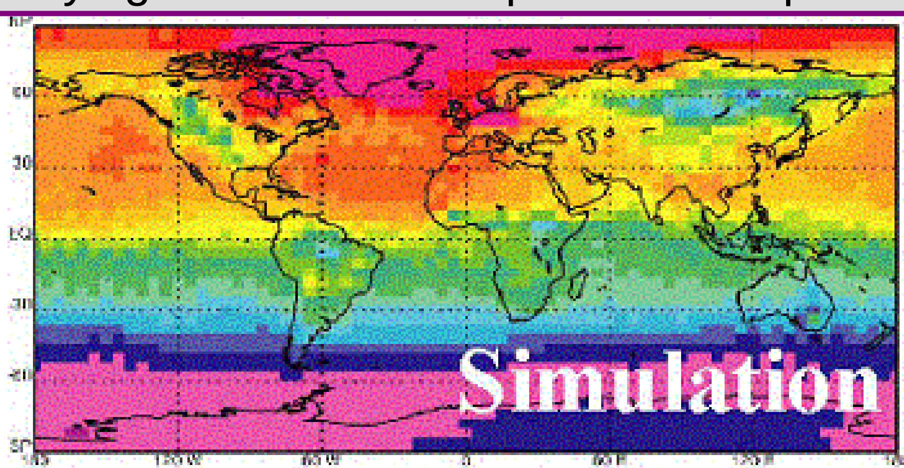
In Development

Orbiting Carbon Observatory (OCO)

Watching The Earth Breathe . . . Mapping CO_2 From Space

Science & Applications

- OCO will collect the first space-based measurements of atmospheric CO_2 (*Column Averaged Dry Air Mole Fraction of CO_2*) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability.
- OCO measurements are needed to:
  - Identify and constrain CO_2 sources and sinks
  - Aid in balancing the global carbon budget
  - Monitor carbon management activities
  - Aid in verifying C emissions/sequestration reports



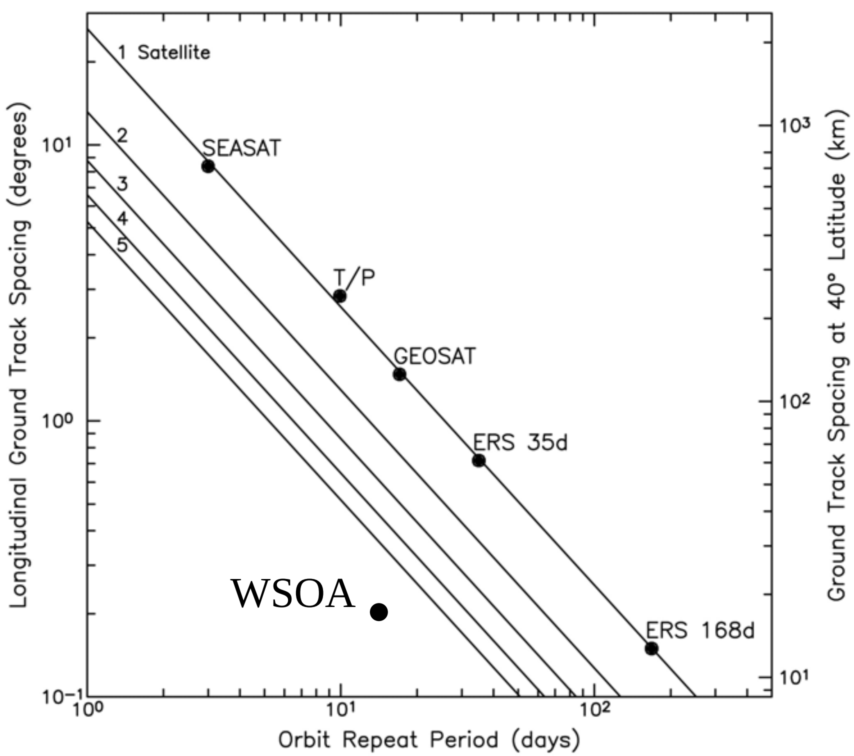
OCO Features

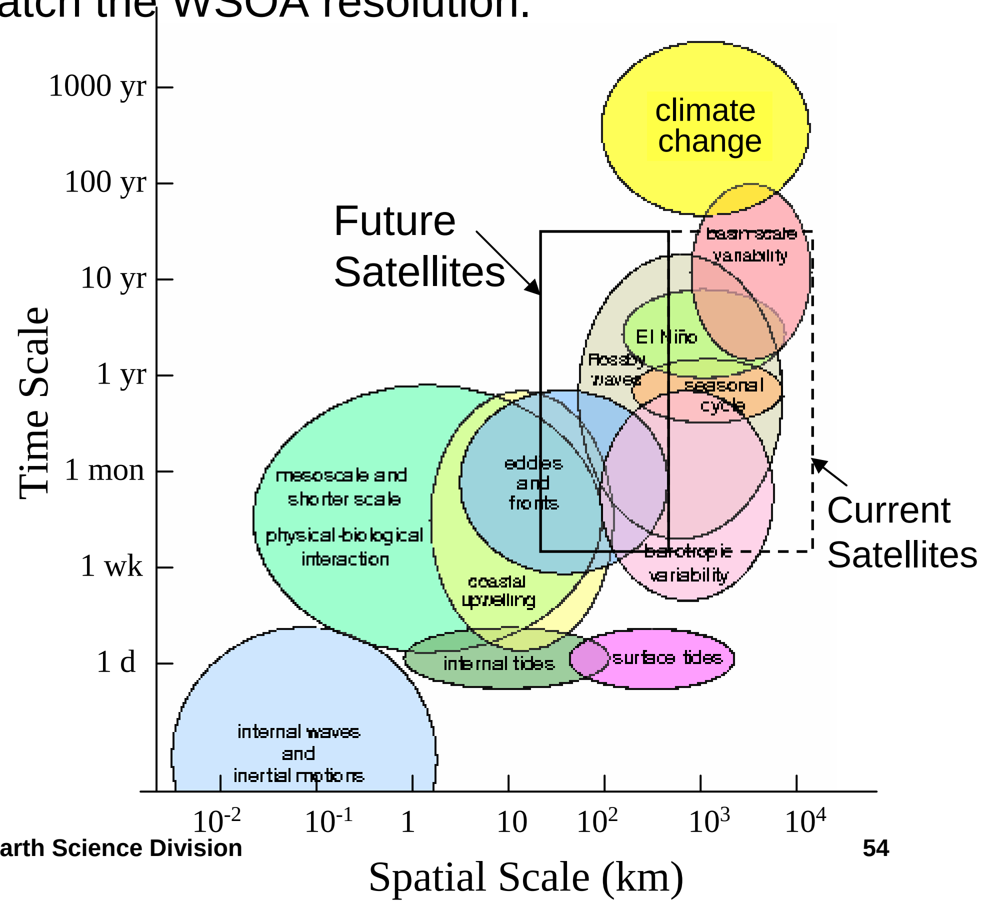
- High Resolution, 3-channel grating spectrometer
- Spacecraft flies in formation with the A-Train
- Launch date: 2007
- Operational life: 2 years
- PI: David Crisp, JPL

An ESSP Mission

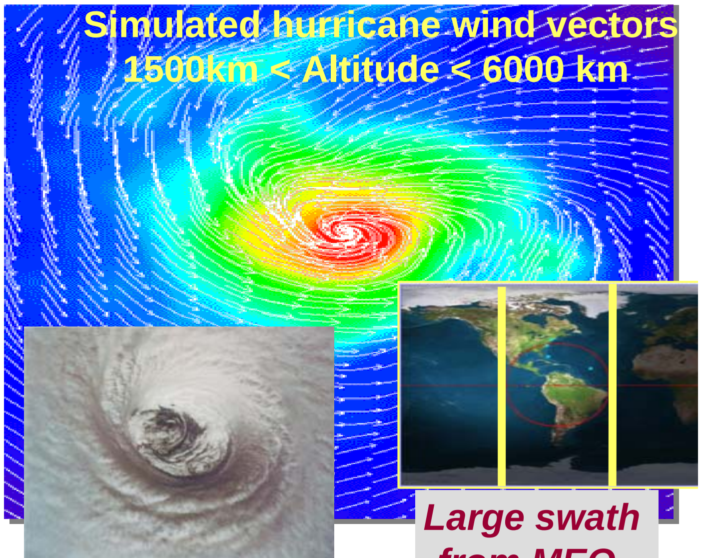
Enhancing Ocean Altimetry: Wide Swath

- Wide Swath Ocean Altimetry (WSOA) will measure ocean surface topography with a spatial resolution that is required to sample ocean eddies, an important component of the ocean circulation.
- WSOA (solid box plus dashed box) will resolve eddies in most of the oceans. It takes more than 5 nadir altimeters to match the WSOA resolution.

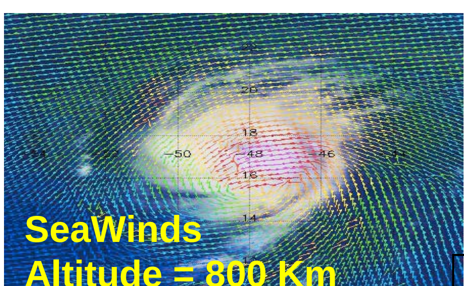




The Future Enhancing Ocean Winds: MEO



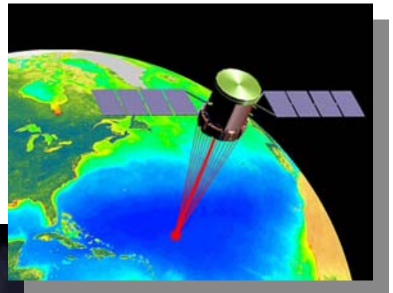
Resolution: 2 km
Swath: Larger than 3000 km
Ave Revisit: Less than 9 hrs



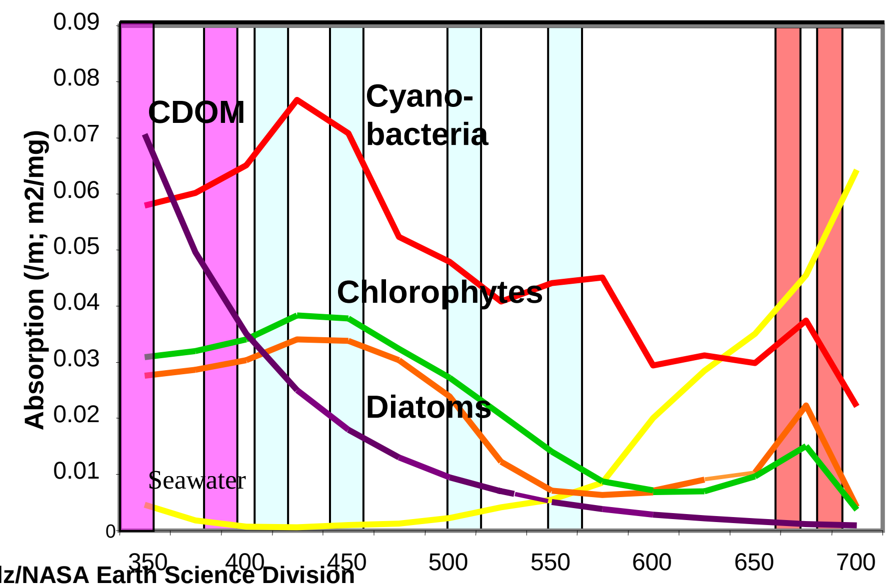
Resolution: 25 km
Swath: 1800 km
Ave Revisit: 18 hrs

- Next Generation Ocean Winds mission would increase temporal resolution (revisit time) by more than a factor of 2 which would improve hurricane tracking, weather prediction, and oceanographic models when compared with the current generation satellites.
- Large antenna technology enables high spatial resolution measurements (as high as 2 km compared with the current 25 km SeaWinds resolution) which is required to study phenomena such as tropical cyclones, coastal zones, and oceanic mesoscale eddies
- Simultaneous active/passive measurements improve not only the accuracy of ocean vector wind measurements but also the identification of errors due to rain

Enhancing Ocean Color
with LIDAR + Hyperspectral



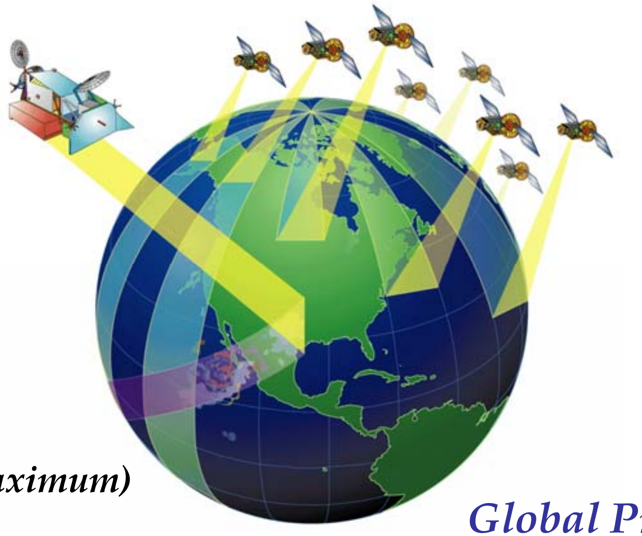
- Ultraviolet to Near Infrared Sensor to measure dissolved organic carbon and estimate atmospheric deposition of iron
- High Resolution Imaging to discriminate “functional” groups of algae and highly dynamic properties of coastal waters
- Laser-based sensors Lidar to actively measure Particulate Carbon in surface mixed layer, in parallel with passive remote sensing, to characterize algal physiological variability



The Future — Global Precipitation Measurement (GPM) Reference Concept

OBJECTIVE: Provide Enough Sampling to Reduce Uncertainty in Short-term Rainfall Accumulations. Extend Scientific and Societal Applications.

OBJECTIVE: Understand the Horizontal and Vertical Structure of Rainfall and Its Microphysical Element. Provide Training for Constellation Radiometers.



Core Satellite

- *Dual Frequency Radar*
- *Multi-frequency Radiometer*
- *H2-A Launch*
- *TRMM-like Spacecraft*
- *Non-Sun Synchronous Orbit*
- *~65° Inclination*
- *~400 - 500 km Altitude*
- *~4 km Horizontal Resolution (Maximum)*
- *250 m Vertical Resolution*

Constellation Satellites

- *Multiple Satellites with Microwave Radiometers*
- *Aggregate Revisit Time, 3 Hour goal*
- *Sun-Synchronous Polar Orbits*
- *~600 km Altitude*

Precipitation Validation Sites

- *Global Ground Based Rain Measurement*

Global Precipitation Processing Center

- *Capable of Producing Global Precip Data Products as Defined by GPM Partners*

Earth Science Technology & Data Systems

Earth Science Technology Development

- New measurements require advances in technology, often in areas outside of any immediate commercial interest

- We choose limited, narrowly targeted thrusts to provide seed funding to enable key technologies

- Supports both flight instrument and spacecraft development as well as calibration/validation field campaigns, airborne instruments and UAVs

Implementation - Program Elements

- Observational Technologies:
  - Advanced Technology Initiatives (ATI) - provides for concept studies and development of component and subsystem technologies (Advanced Component Technology (ACT) Program) for instruments and platforms
  - Instrument Incubator Program (IIP) - provides new instrument and measurement techniques, including lab development and airborne validation
- Information Systems Technologies:
  - Advanced Information Systems Technologies (AIST)/Computational Technologies (CT) - provides innovative on-orbit and ground capabilities for the communication, processing, and management of remotely sensed data and the efficient generation of data products and knowledge. Includes data manipulation, and visualization of very large, highly distributed remotely sensed data sets consistent with modeling needs
- Focused Technology Efforts:
  - NASA Laser Risk Reduction Program (LRRP) and Airborne Repeat Pass Interferometric Synthetic Aperture Radar (UAVSAR)

Example Infusions: Missions

- ***Six Instrument Incubator projects related to ESSP-3 proposals***
  - Ultra Stable Microwave Radiometer --> AQUARIUS (sea surface salinity)
  - Low Mass, Low Power Radar (OSIRIS) --> HYDROS (soil moisture)
  - Delay Doppler-Phase Radar Altimeter (D2P)
  - Gas and Aerosol Monitoring Sensorcraft (GAMS)
  - Self-Calibrating H2O and O3 Near Earth Remote Sensor (SCH$_2$OO$_3$NERS)
    - an integrated UV-IR spectrograph and imager
  - Wide Field Imaging Spectrometer (WFIS)

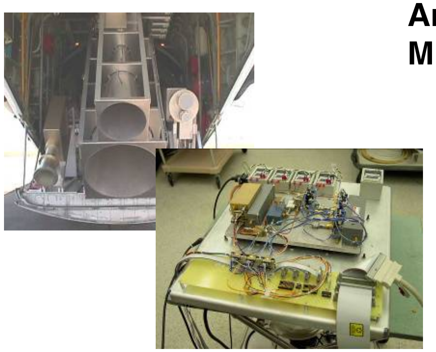
- **CALIPSO**:
  - Portable Diode Laser Array Test Facility used to evaluate/validate the CALIPSO flight laser
  - FAR Infrared Spectrometer for Troposphere (FIRST) participating in flight validation.

- **OSTM**: Wide Swath Altimeter
  - planned for Ocean Surface Topography Mission

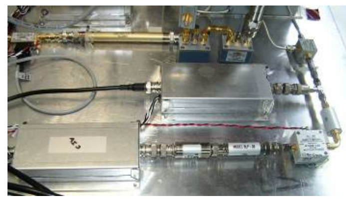
ESTP Infusion Into A Flight Mission

Examples

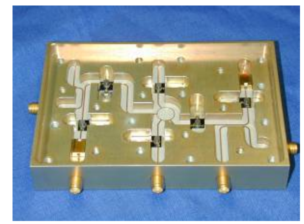
Ultra-Stable Radiometers
IIP: Bill Wilson



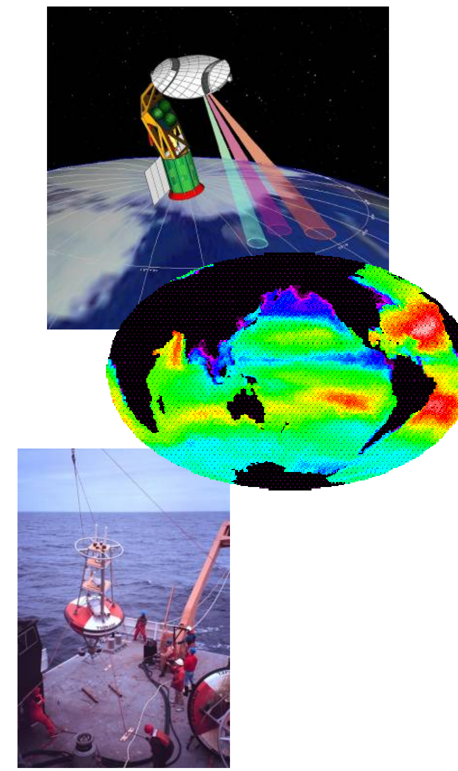
ACT: Jeff Piepmeier and Joe Knuble
Analog RFI Suppression System for
Microwave Radiometers

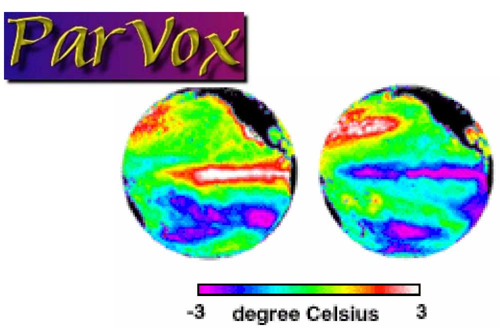


Controlled-Correlation
Calibration Subsystem (CCCS)
ACT: Ed Kim & Jeff Piepmeier

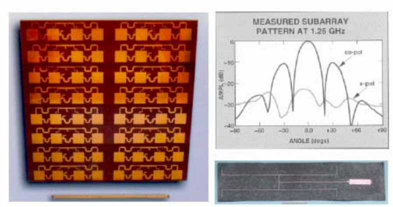


Aquarius ESSP





Parallel Volume Rendering
CT In-House Team Peggy Li



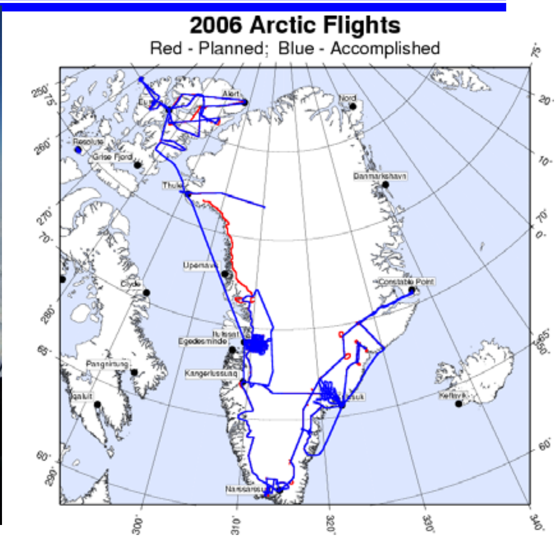
Lightweight Feed For Future
Salinity Missions
ACT: Simon Yueh

Aquarius
Chet Koblinsky, PI
Yi Chao, Project Scientist

Example Infusions: Campaigns

- Science Campaigns: 2006
  - Quantum Well Infrared Photoconductor (QWIP) → BASE-ASIA
  - Glaciers and Ice Sheets Interferometric Radar (GISIR) → Greenland
  - Multi-Function Fiber Laser Lidar (MFLL) for Ice Sheet Topography → ACCLAIM
  - RFI Detection and Mitigation System for Spaceborne Radiometers → Gulf of Mexico
- Science Campaigns: 2007
  - Glaciers and Ice Sheets Interferometric Radar (GISIR) → Greenland
  - Multi-Function Fiber Laser Lidar (MFLL) for Ice Sheet Topography → Greenland
  - Pathfinder Advanced Radar Ice Sounder (PARIS) → Greenland
  - Push Broom Laser Altimeter for Space Based Cryospheric Topographic and Surface Property Mapping → Greenland
  - Raman Airborne Spectroscopic Lidar (RASL) → CLASIC (US Great Plains)
  - Compact, Lightweight Dual-Frequency Microstrip Antenna Feed for Future Soil Moisture and Sea Surface Salinity Missions → CLASIC

Examples ESTP Infusion Into A Campaign



Instrument Incubator Projects In Planning for 2007 Greenland Campaign

Pathfinder Advanced Radar
Ice Sounder/Raney

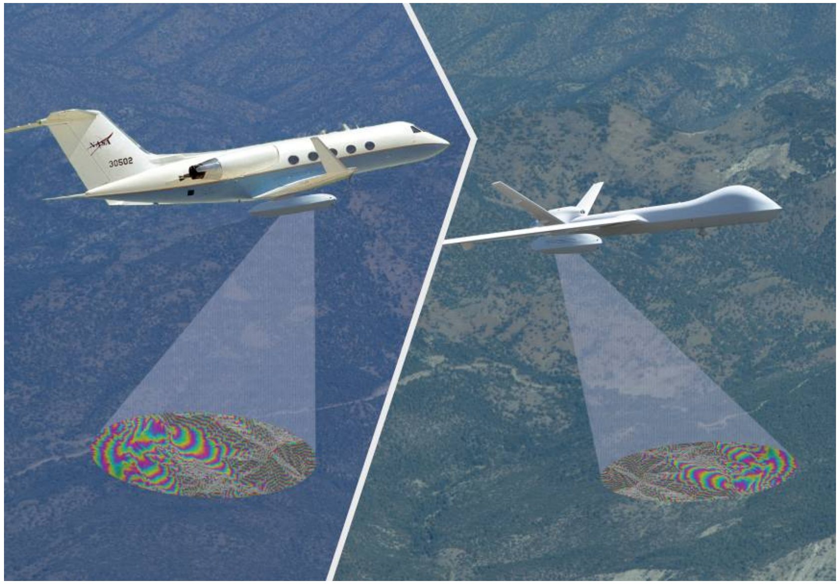
Global Ice Sheet Interferometric
Radar/Jezek

Multi-Function
Fiber Laser/Dobbs

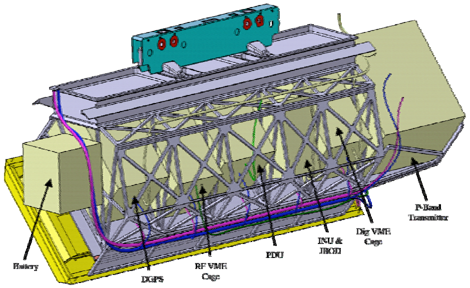
UAVSAR System Overview

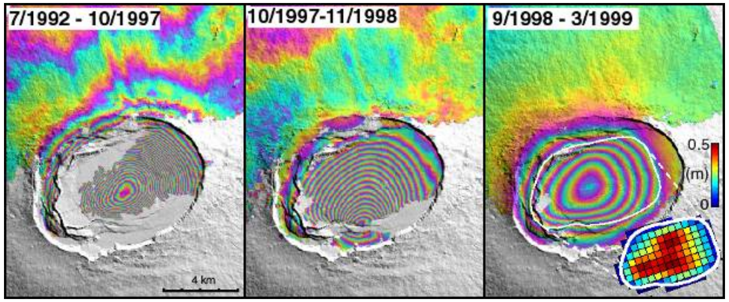
☞ ***Salient Features***

- *Robust repeat pass interferometry for deformation measurements*
- *Fully polarimetric at L-Band (1.2 GHz,80 MHz BW)*
- *Initial operations on NASA's Gulfstream III*
- *Design allows for transition to a UAV platform*
- *Steerable electronically scanned array antenna*
- *Flight path controlled to be within a 10 m tube using real-time GPS and modified autopilot*
- *Autonomous radar operation in flight*
- *Flexible, light-weight, reconfigurable design*



Instrument Pod Internal Layout





Volcanic Surface Deformation

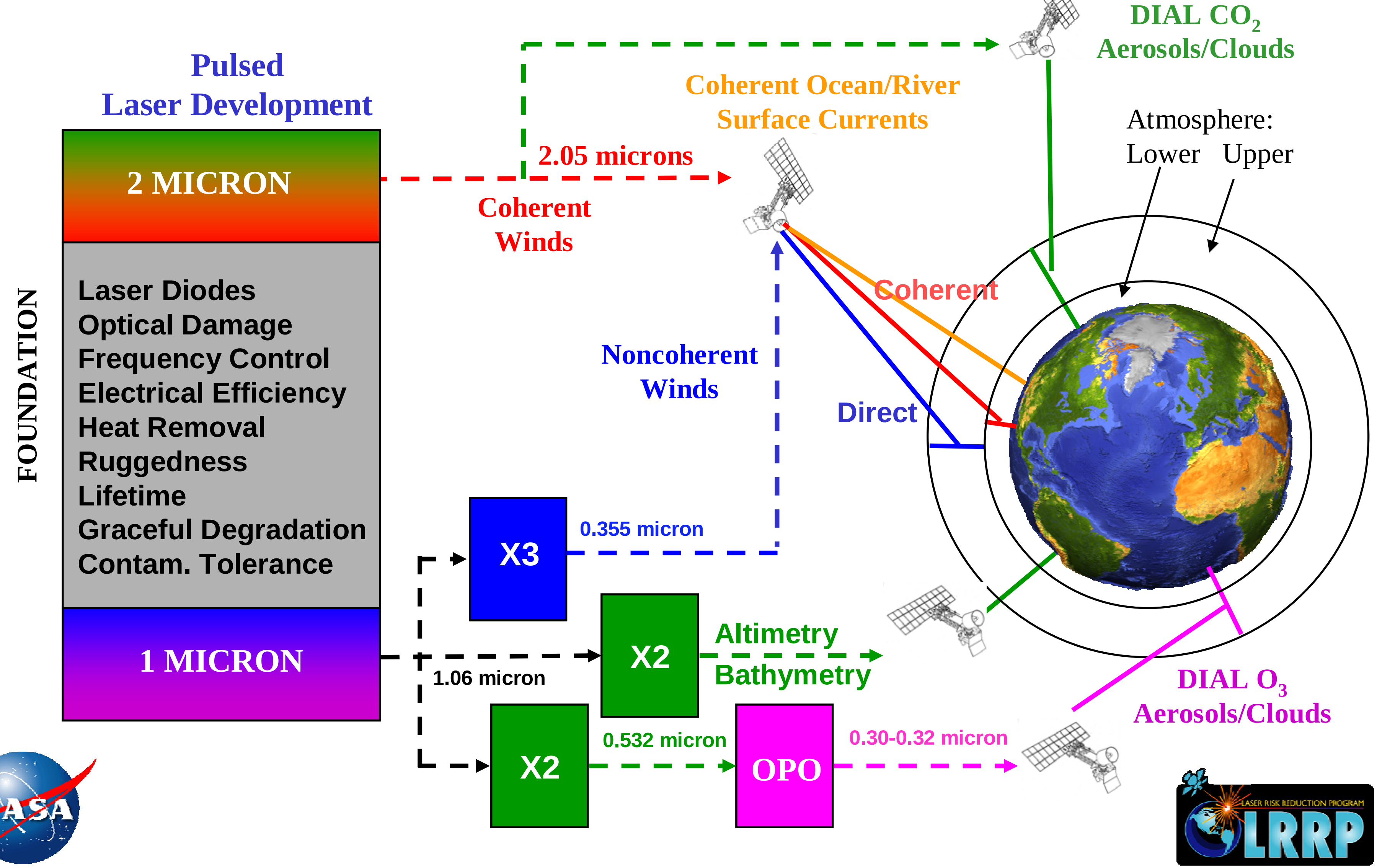
☞ Science

- Based on IIP NRA Award
- Global and regional volcanic inflation, flooding, land and coastal erosion, fault strain, fire hazard, tectonic strain, precision topography
- Local continuous observation of deformation for prediction of eruption, landslide and flooding
- Provide crustal structure, high temporal resolution, regional deformation processes for increased predictability of earthquake and volcanic activity.

Examples

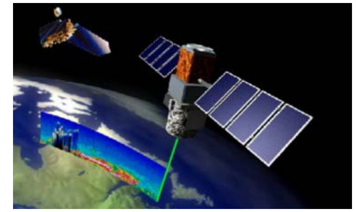
Laser Risk Reduction Program

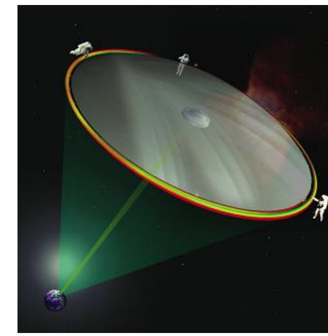
2 Lasers, 4 Techniques, 6 Priority Measurements

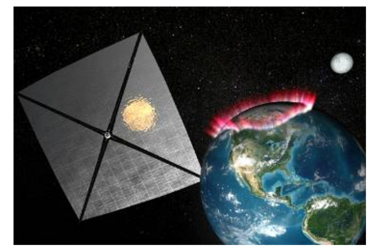


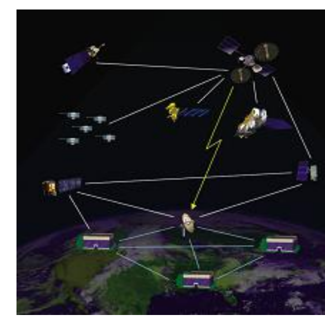
Future Mission Technology Development Priorities

- **Active Remote Sensing Technologies** to enable atmospheric, carbon, cryospheric and earth surface measurements
- **Large Deployable Apertures** to enable future weather, climate, and natural hazards measurements
- **Platform Technologies** to enable measurements from unique vantage points
- **Intelligent Distributed Systems** using advanced communication, on-board radiation-tolerant reprogrammable processors, autonomous operations and network control, data compression, high density storage
- **Information Knowledge Capture** through 3-D visualization, holographic memory and seamlessly linked models





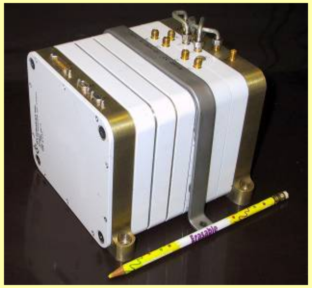




Example Infusions Information Systems

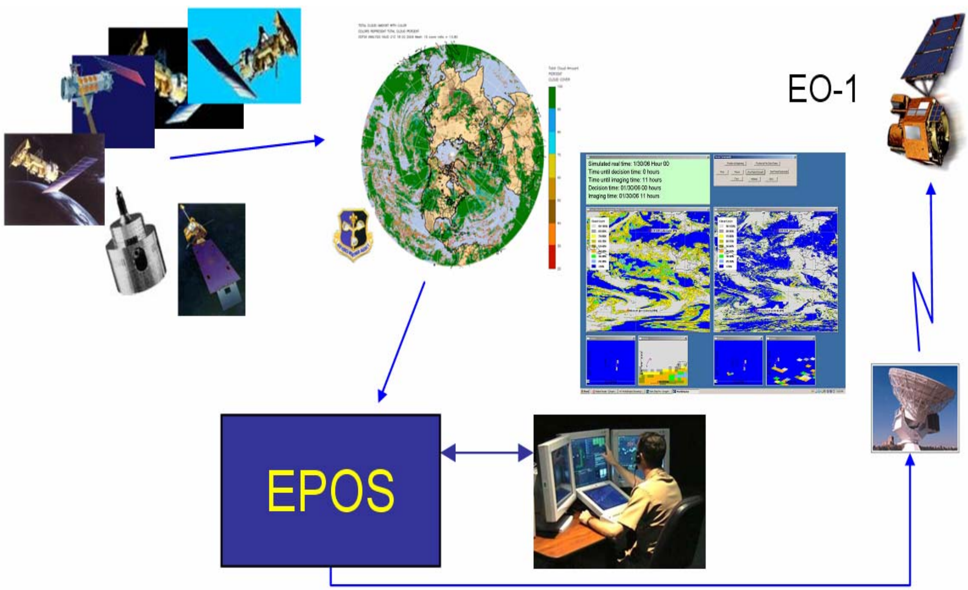
- **Low Power Transceiver (LPT) (Partnering, NRA-99 & NRA-02)**
  - Flew successfully on STS-107 – First Space-based Mobile IP use
  - Competitively selected to fly on AFRL XSS-11 mid-2005
  - Will fly on Air Force TacSat 2 December 2006

LPT Modular Design for Reconfigurable Communications



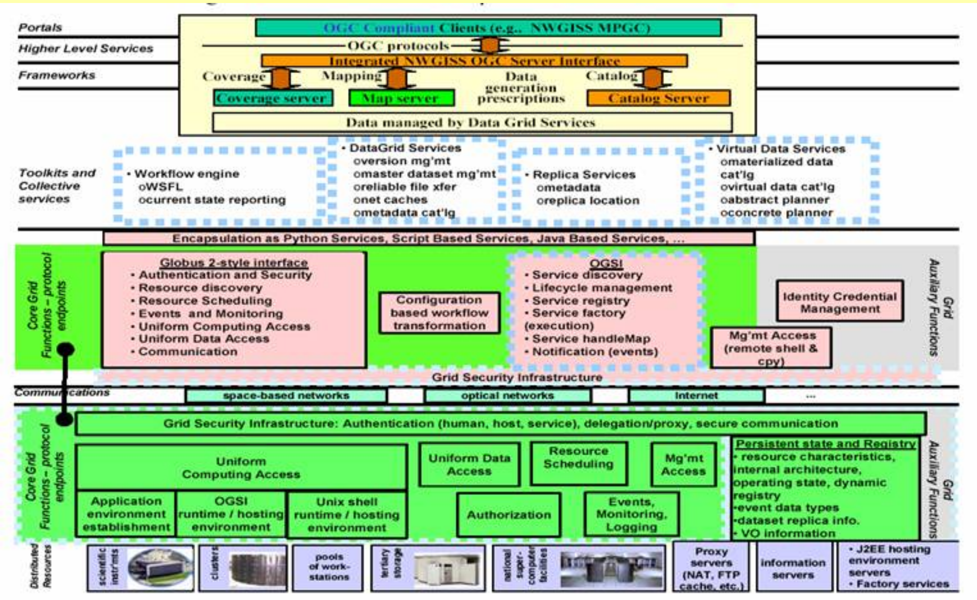
Earth Phenomena Observing System (EPOS)

- EPOS Autonomously collects data from the Air Force Weather Agency (AFWA)
- Uses Stochastic Cloud Forecast Model (SCFM) to predict cloud coverage
- Recommends observation targets to be scheduled for EO-1 planning
- Fully integrated within EO-1 operations for dynamic replanning
- Increased overall useful images by 12% due to alternative targets chosen

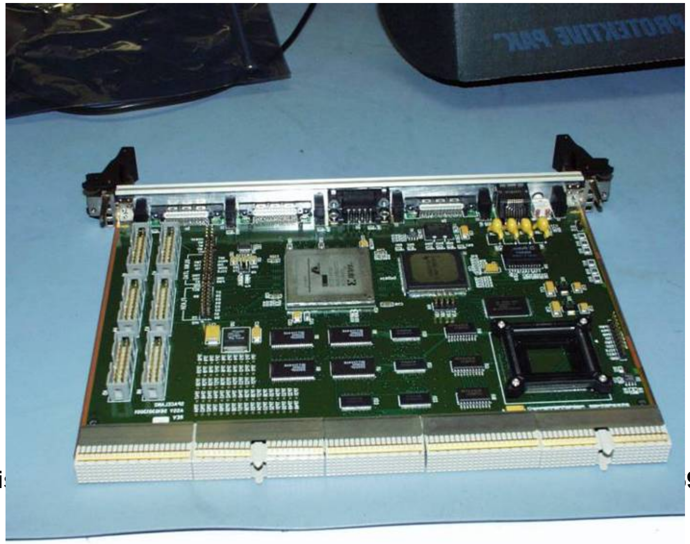


Example Infusions Information Systems (Cont’)

- **Integration of OGC and Grid Technologies for Earth Science Modeling and Applications (NRA-02)**
  - Integrate GRID and OGC technologies to make GRID-managed data accessible through NASA HDF-EOS Web GIS Software Suite (NWGISS) OGC servers and allow users to focus on science rather than issues with data receipt, format, and data manipulation
  - Leverages the OGC-compliant NWGISS, CEOS Grid testbed, Globus and NASA Information Power Grid (IPG) and DOE’s Earth System Grid (ESG)

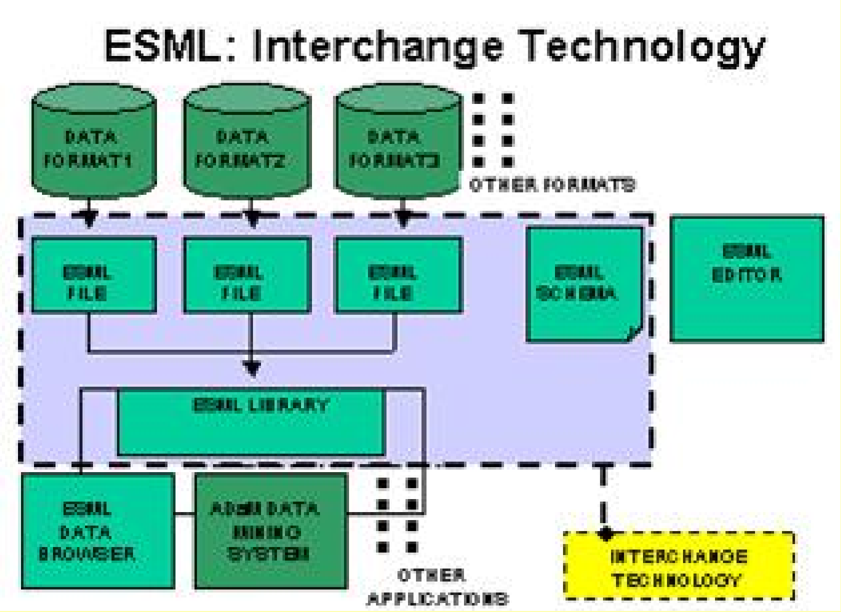


- **Flight Ethernet Switch selected for GPM and JWST (Partnering & NRA-02)**
  - Use commercially standardized 10/100 Mb/sec Ethernet bus technology in place of military standard 1553 or custom proprietary bus architectures on all future spacecraft

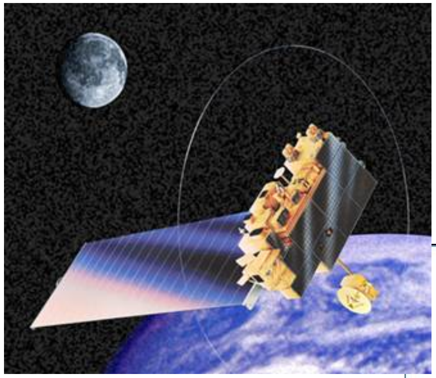


Example Infusion Information Systems (Concluded)

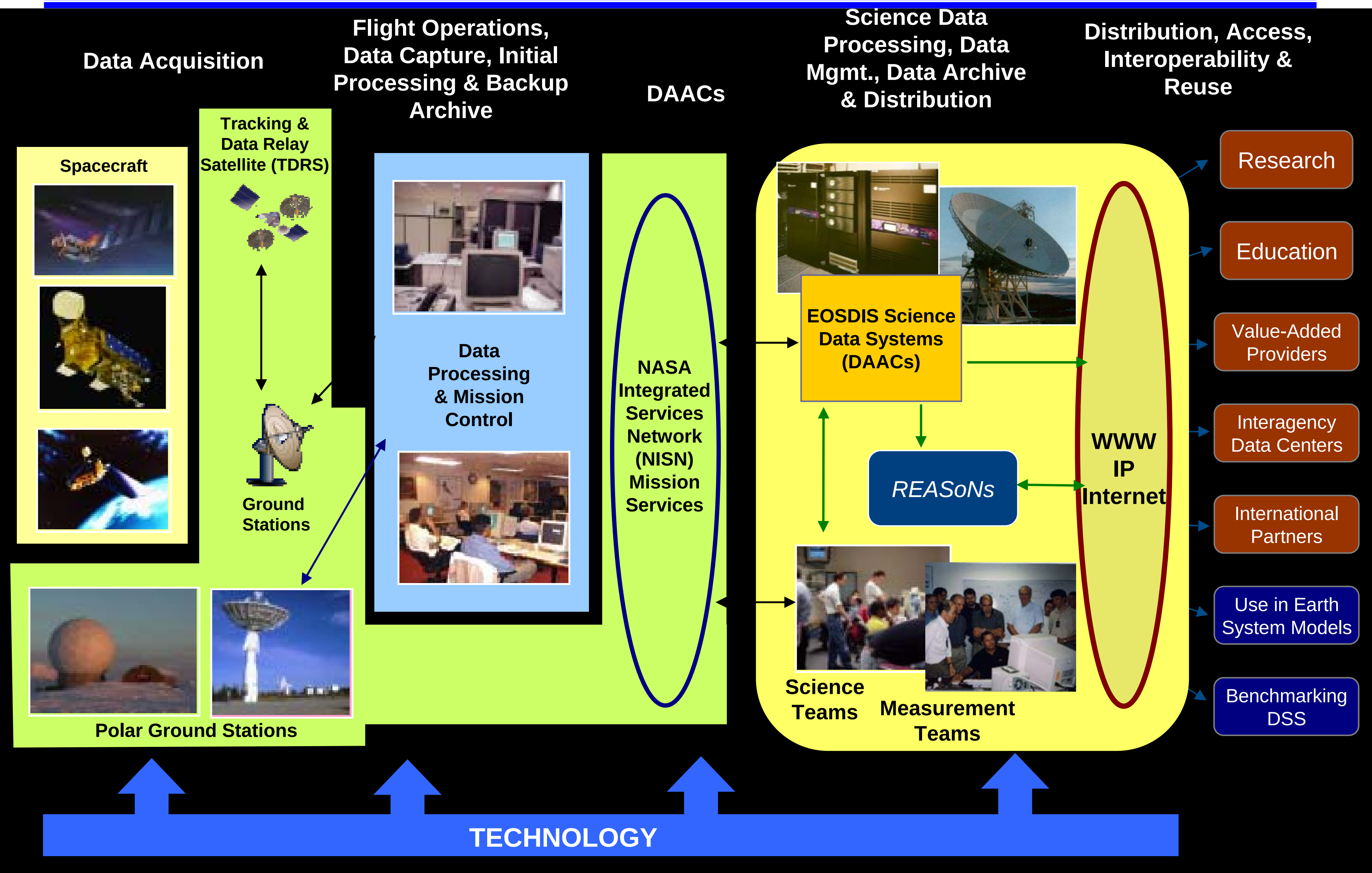
- **Earth Science Mark-up Language (ESML) (NRA-99, Partnering)**
  - An interchange technology that enables data (both structural and semantic) interoperability with applications without enforcing a standard format within the Earth science community
  - Semantic tags can be added to the ESML files by linking different domain ontologies to provide a complete machine understandable data description
  - Integrated into the Atmospheric Science Modeling at University of Alabama Huntsville and Adam Data Mining System



- **Advanced SSR SchEduling Tool (ASSET) (Partnering-SOMO Leverage)**
  - Reduce the manually intensive activity of planning Solid State Recorder (SSR) buffer playbacks for Terra spacecraft special events and difficult scheduling period
  - Result: What was once a 20-hour task now takes only one hour using ASSET to plan and document non-nominal satellite procedures on Terra



From Data Acquisition to Data Access



Earth System Data Resides in Distributed Active Archive Centers (DAAC)

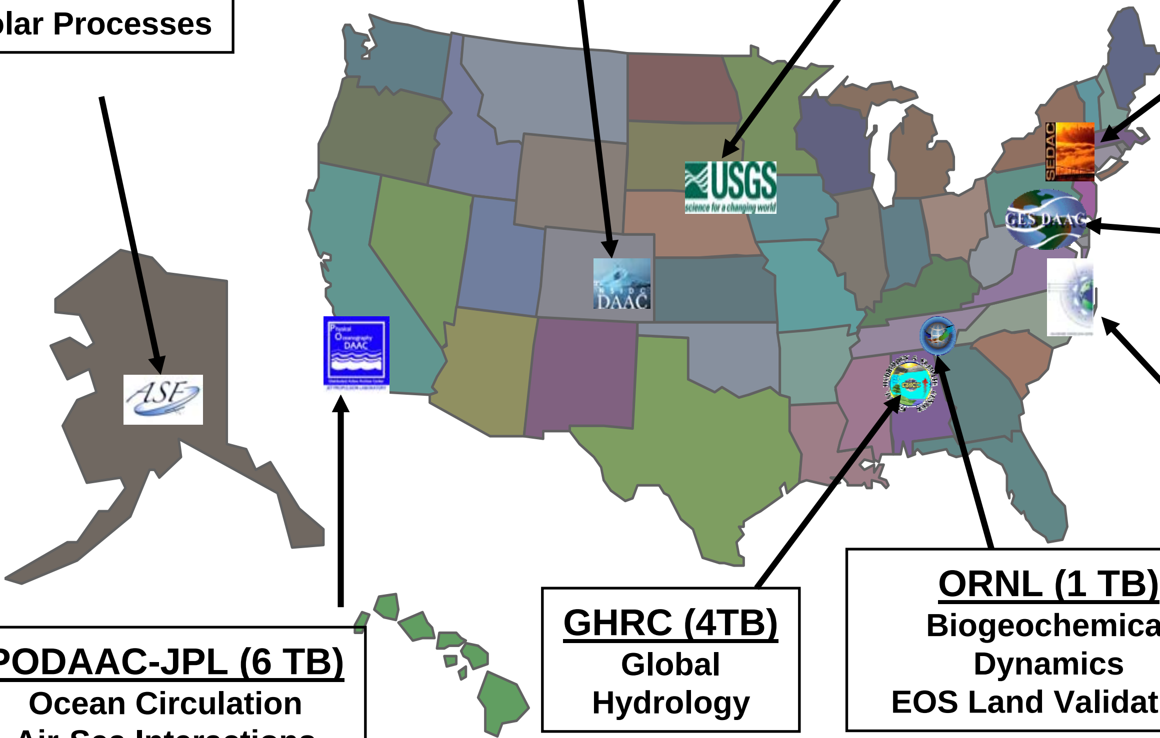
ASF (256 TB)
SAR Products
Sea Ice
Polar Processes

NSIDC (67 TB)
Cryosphere
Polar Processes

LPDAAC-EDC (1143 TB)
Land Processes
& Features

SEDAC (0.1 TB)
Human Interactions in
Global Change

GES DAAC-GSFC (1334 TB)
Upper Atmosphere
Atmospheric Dynamics, Ocean Color, Global Biosphere, Hydrology, Radiance Data



PODAAC-JPL (6 TB)
Ocean Circulation
Air-Sea Interactions

GHRC (4TB)
Global
Hydrology

ORNL (1 TB)
Biogeochemical
Dynamics
EOS Land Validation

ASDC-LaRC (340 TB)
Radiation Budget,Clouds
Aerosols, Tropospheric
Chemistry