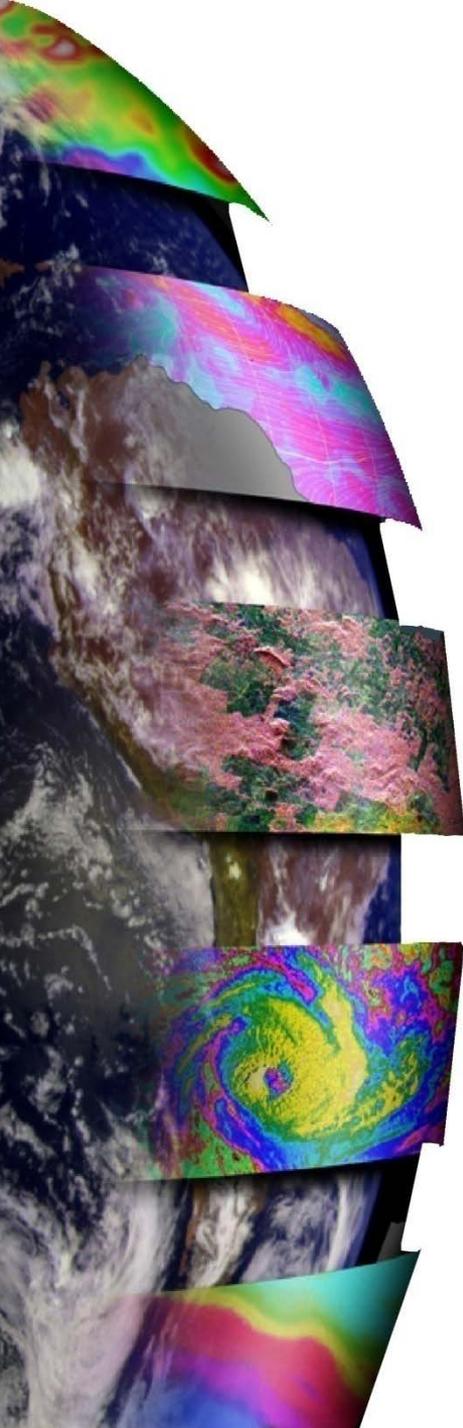


# Earth Science at JPL

Dr. Diane Evans  
Director for Earth Science  
and Technology  
Jet Propulsion Laboratory

Presentation to Santa Barbara City College  
February 24, 2012

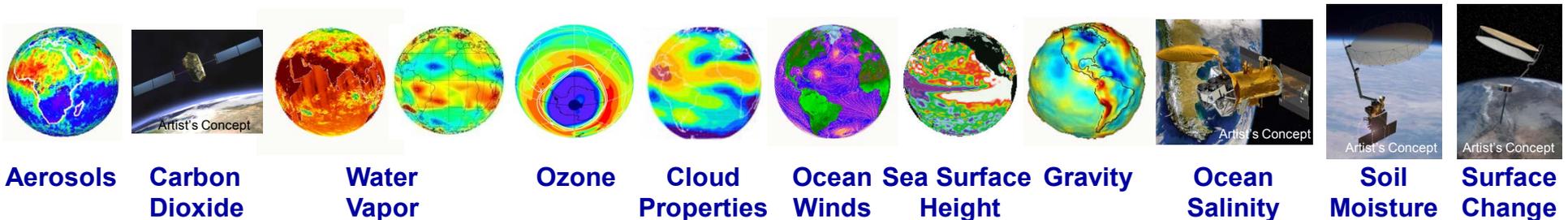
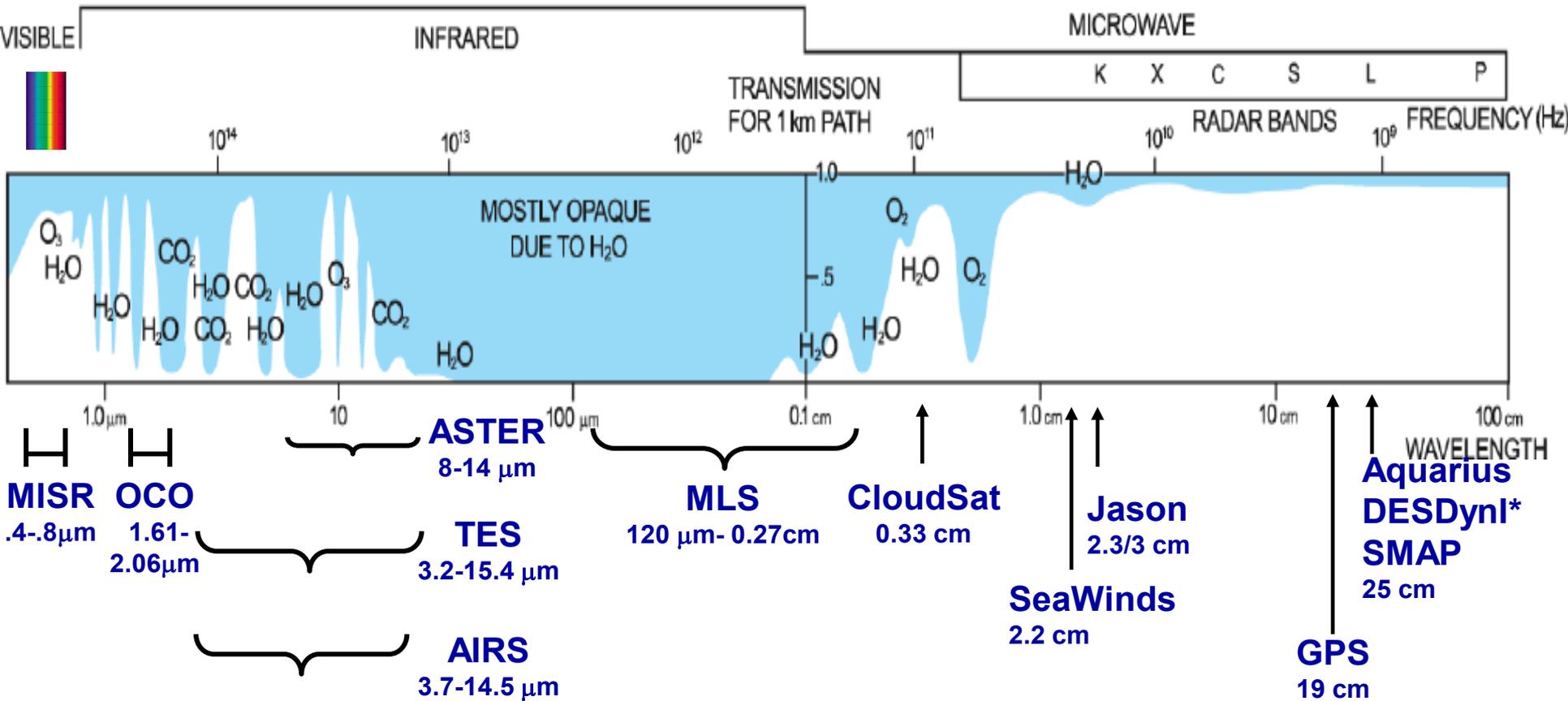


# Outline

- Climate
  - Direct Observations
  - Model Improvements
- Water Cycle
- Carbon Cycle
- Natural Hazards



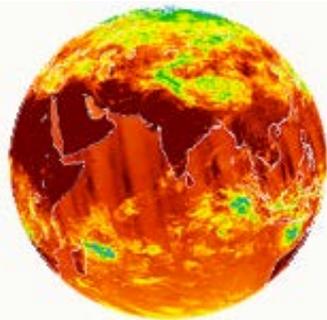
# Seeing Earth in a New Way



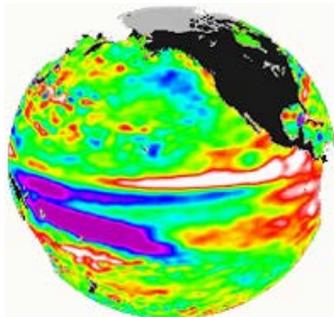
\*Proposed Mission

Pre-decisional – for Planning and Discussion Purposes Only

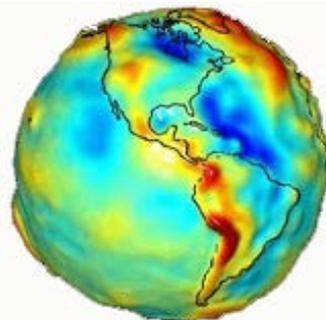
# Examples of NASA's Earth Science Observations



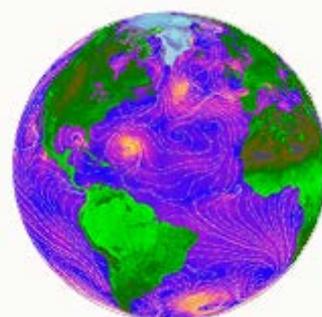
Atmospheric Infrared Sounder (**AIRS**) provides monthly global temperature maps



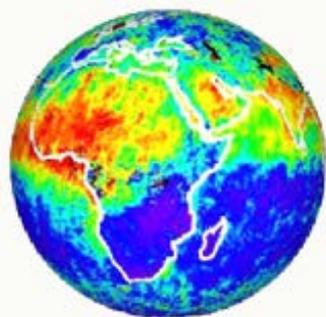
**Jason** provides global sea surface height maps every 10 days



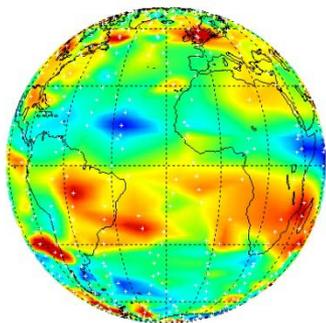
Gravity Recovery and Climate Experiment (**GRACE**) provides monthly maps of Earth's gravity



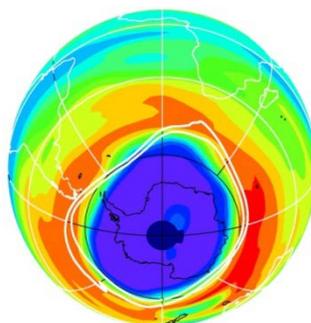
**Quikscat** collects data over the polar regions, and supports Cal/Val of India's Oceansat-2



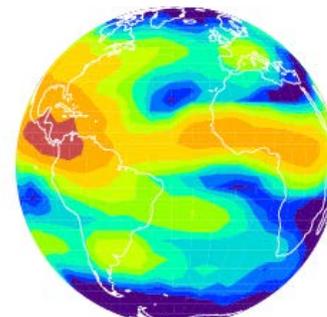
Multi-angle Imaging Spectro Radiometer (**MISR**) provides monthly global aerosol maps



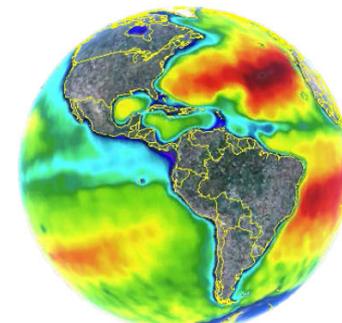
Tropospheric Emission Spectrometer (**TES**) provides monthly global maps of Ozone



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

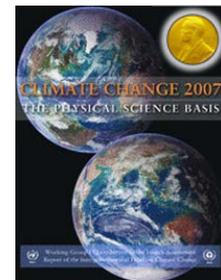


**CloudSat** provides monthly maps of cloud ice water content

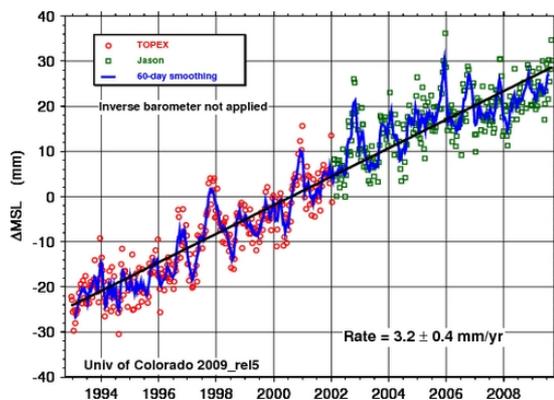


**Aquarius** provides monthly maps of sea surface salinity

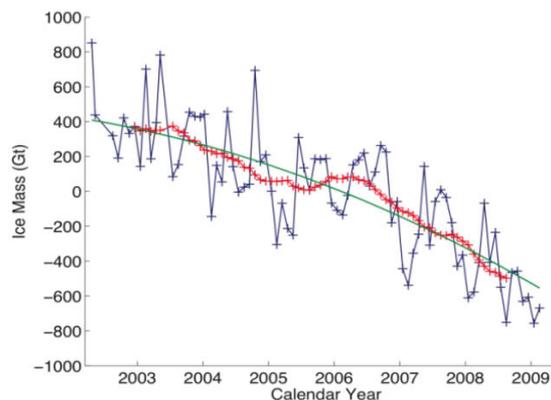
# Role of Satellites in Global Change



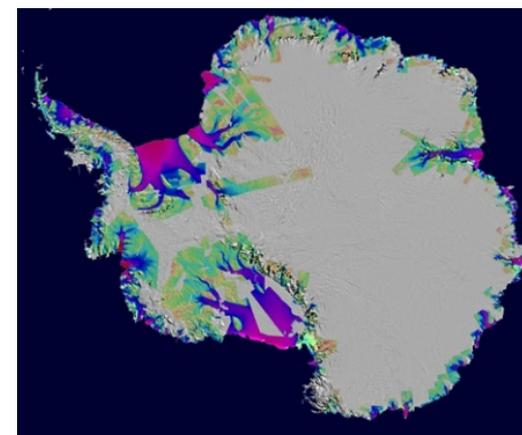
## Direct Observations



Altimetry  
Sea Level Rise  
1992-2009  
(Nerem, 2009)

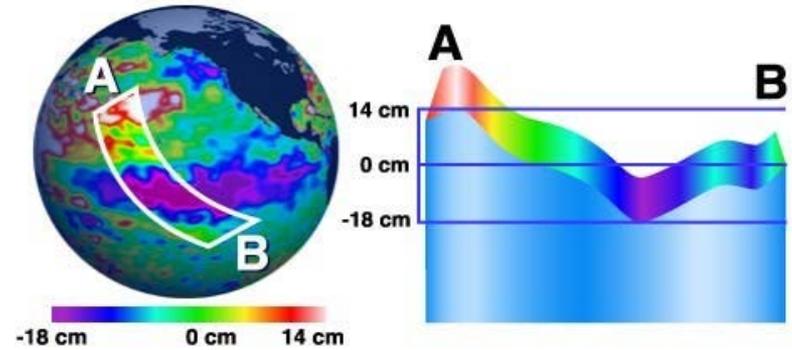
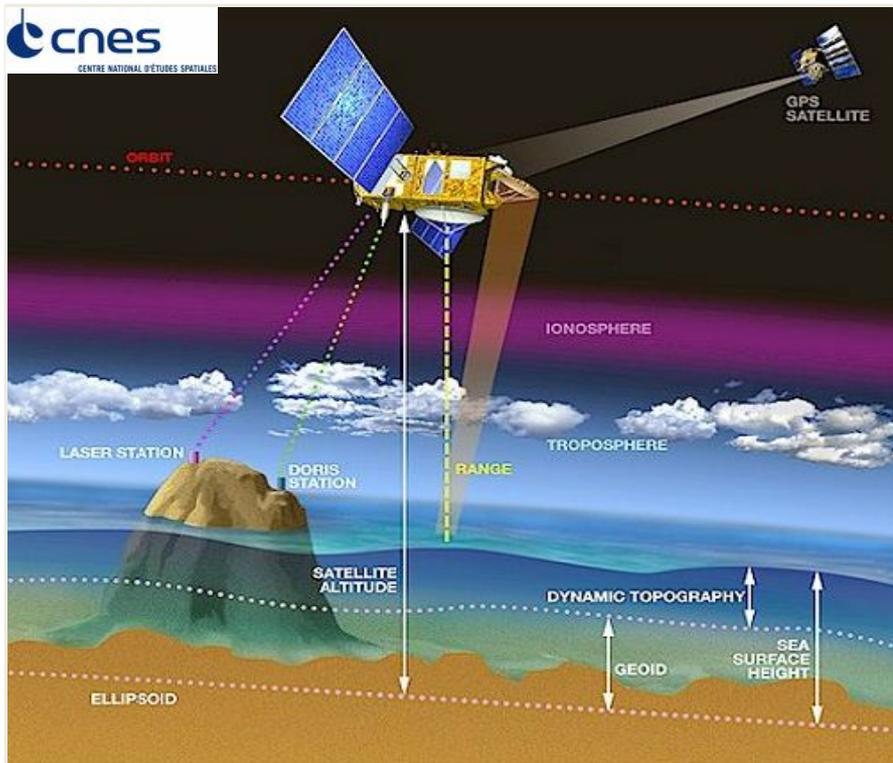


GRACE  
Antarctic ice loss  
2002-2009  
(Velicogna, 2009)

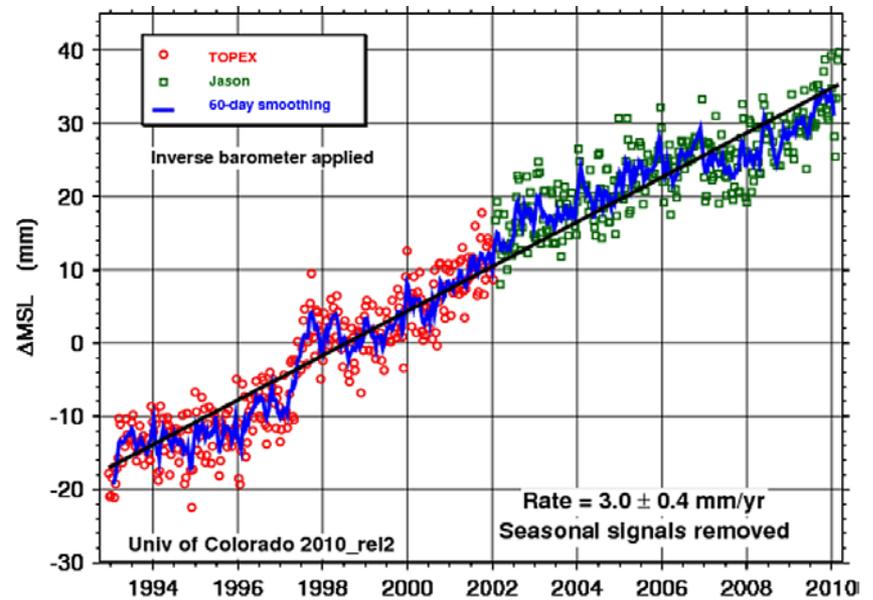


InSAR  
Antarctic ice loss  
1996-2006  
(Rignot, 2008)

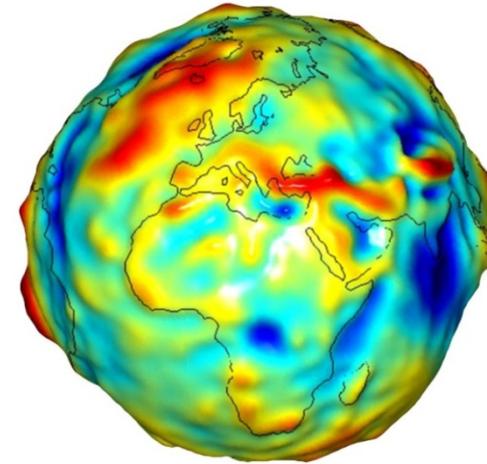
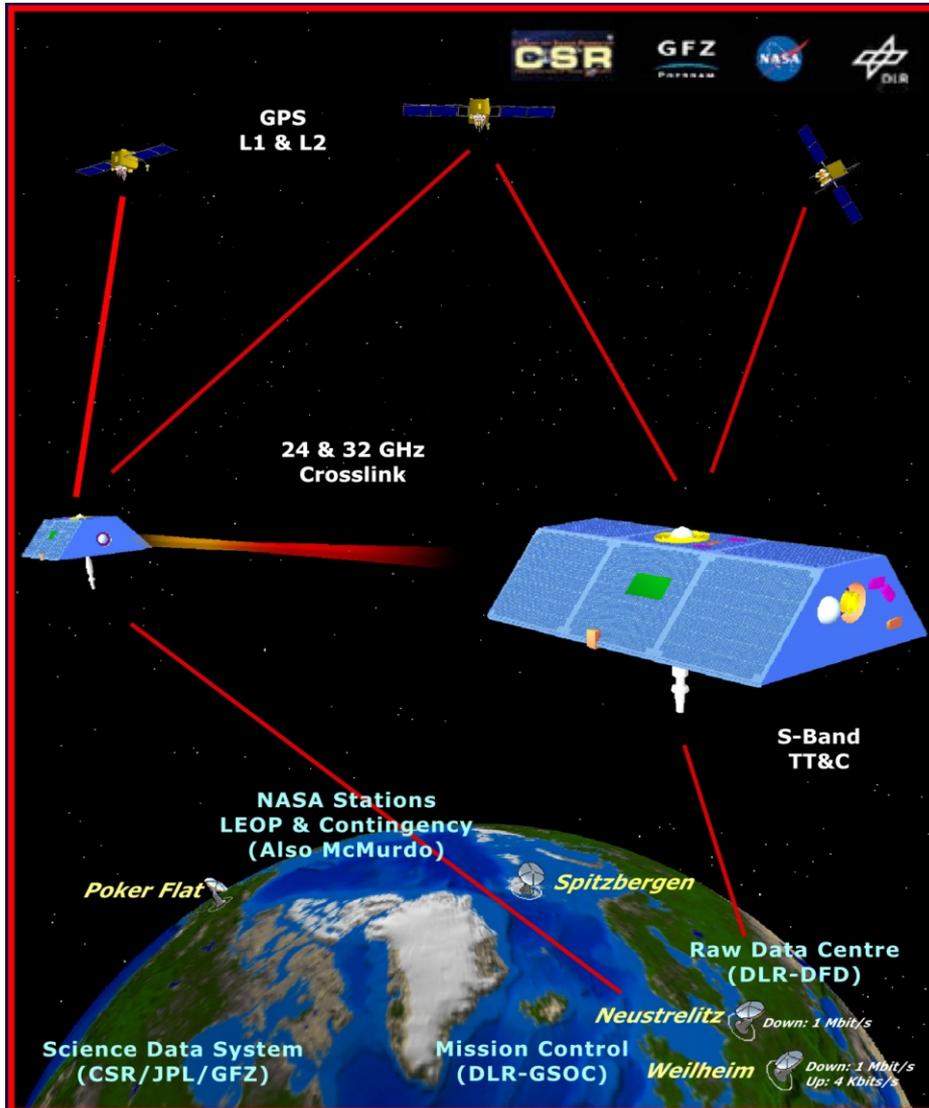
# Measuring Changes in Sea Level



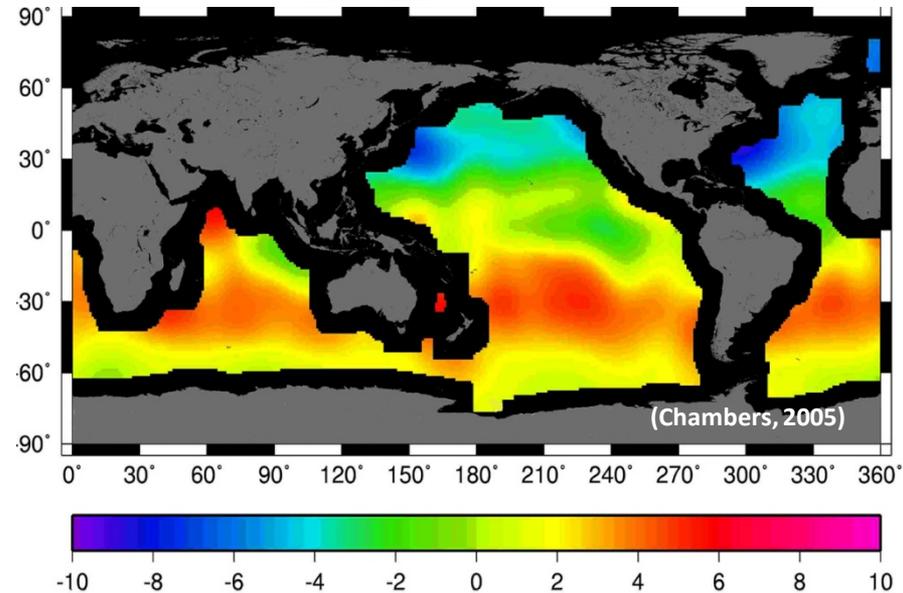
Globally-averaged sea level rise



# Gravity Recovery and Climate Experiment (GRACE)

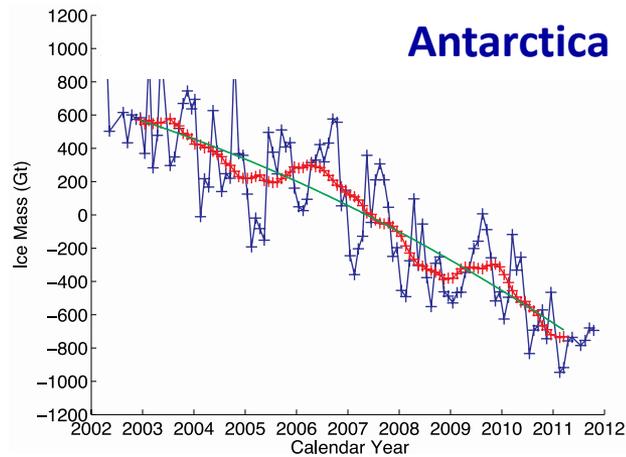


GRACE Gravity Model

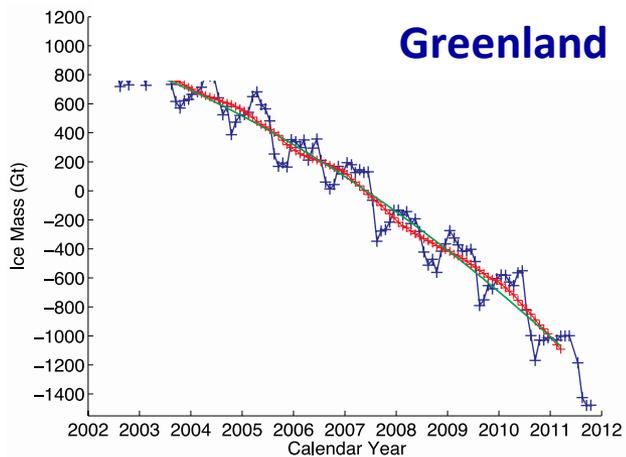


Sea Surface Topography - Mass change = Thermal Expansion of the ocean

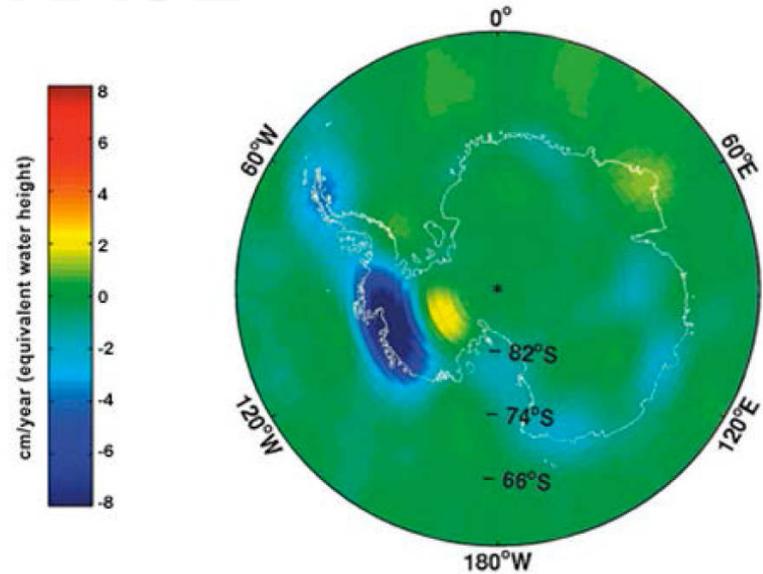
# Measuring Changes In Ice Mass with GRACE



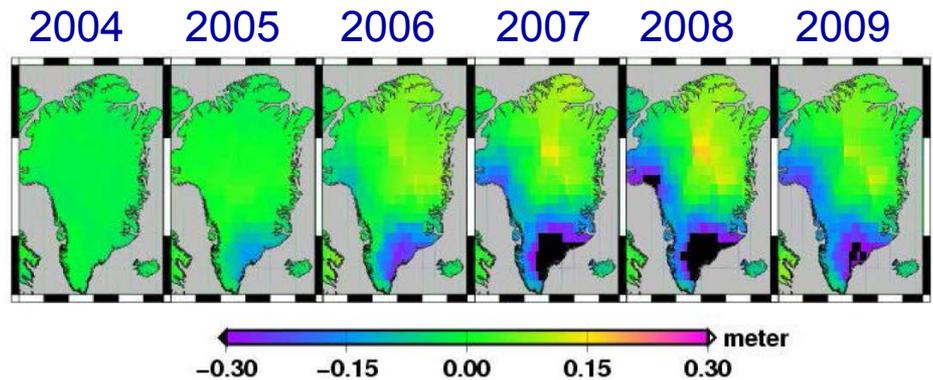
**Trend Apr 2002-Oct 2011:  $-152 \pm 33$  Gt/yr**



**Trend Apr 2002-Oct 2011:  $-220 \pm 33$  Gt/yr**



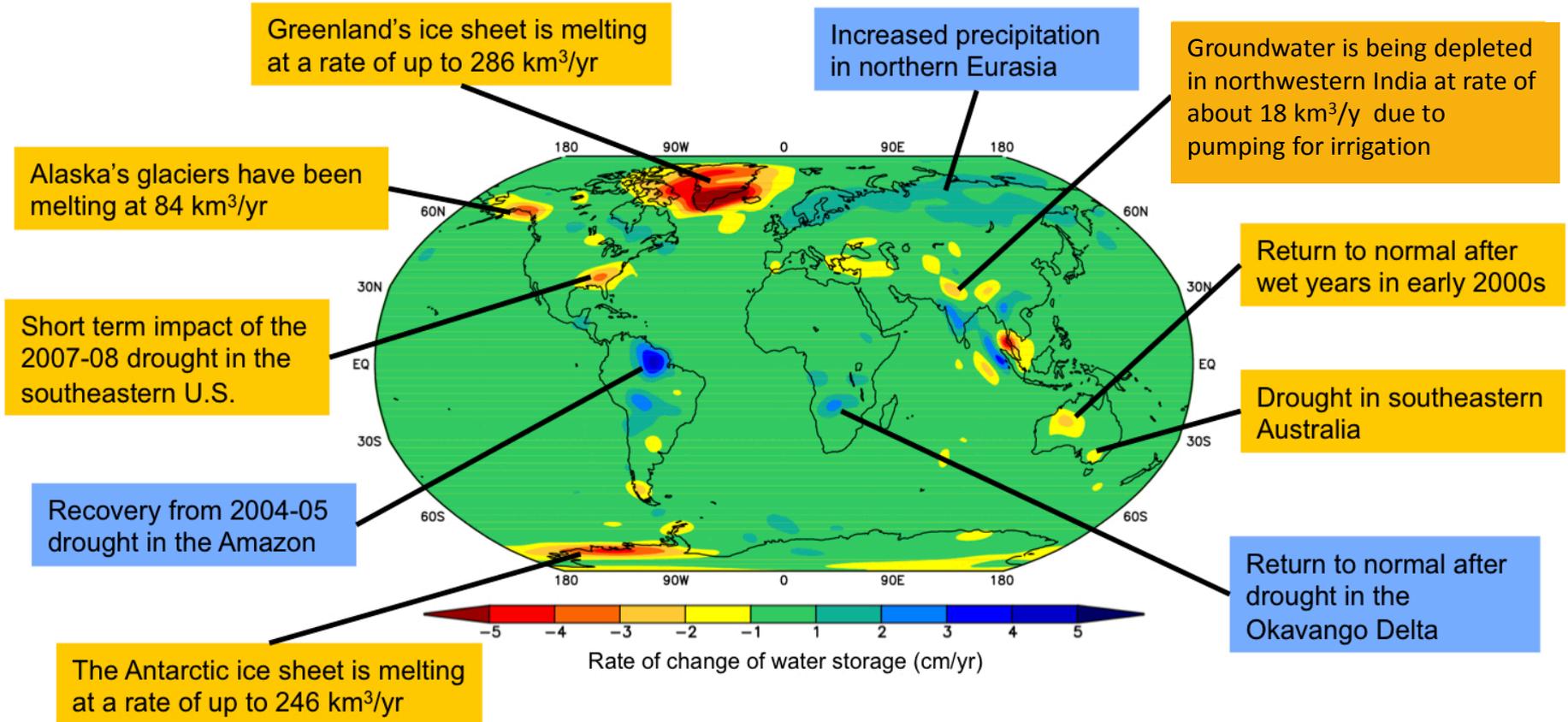
University of Texas at Austin Center for Space Research



From Watkins et al, 2009

# GRACE 2002 – 2010

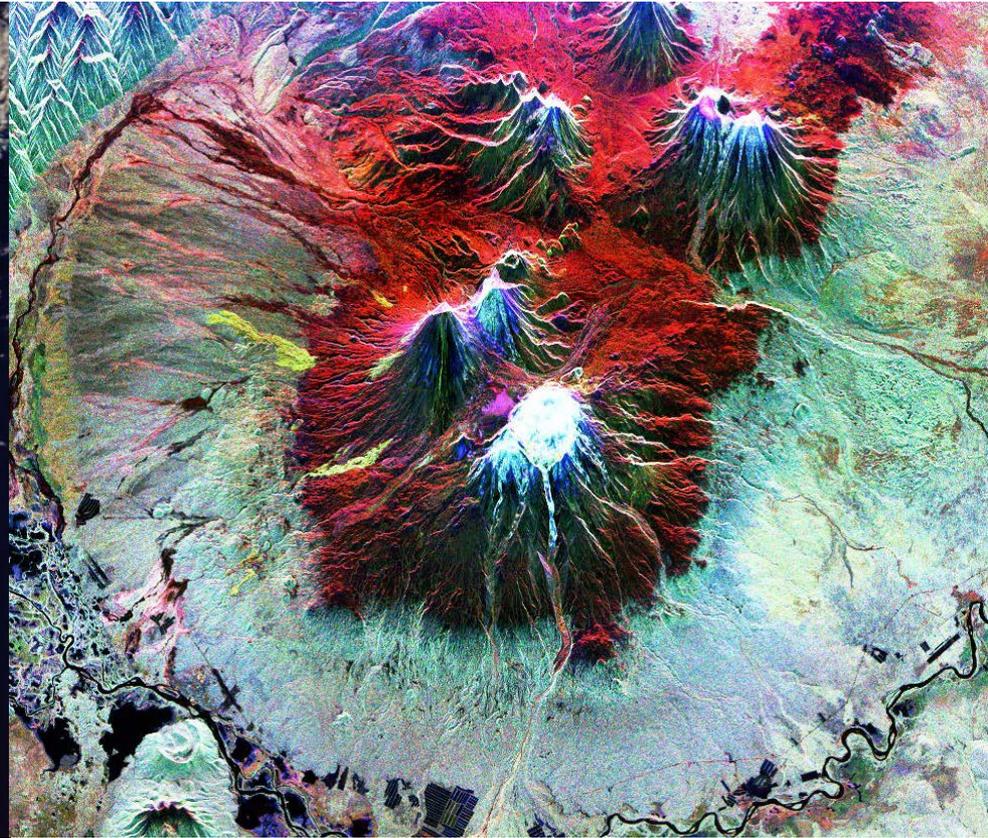
## Major Climate Mass Trends



# Synthetic Aperture Radar

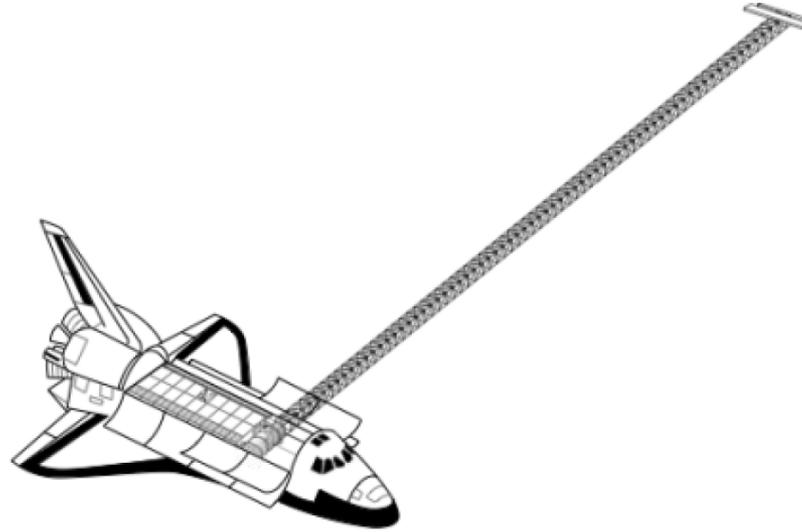
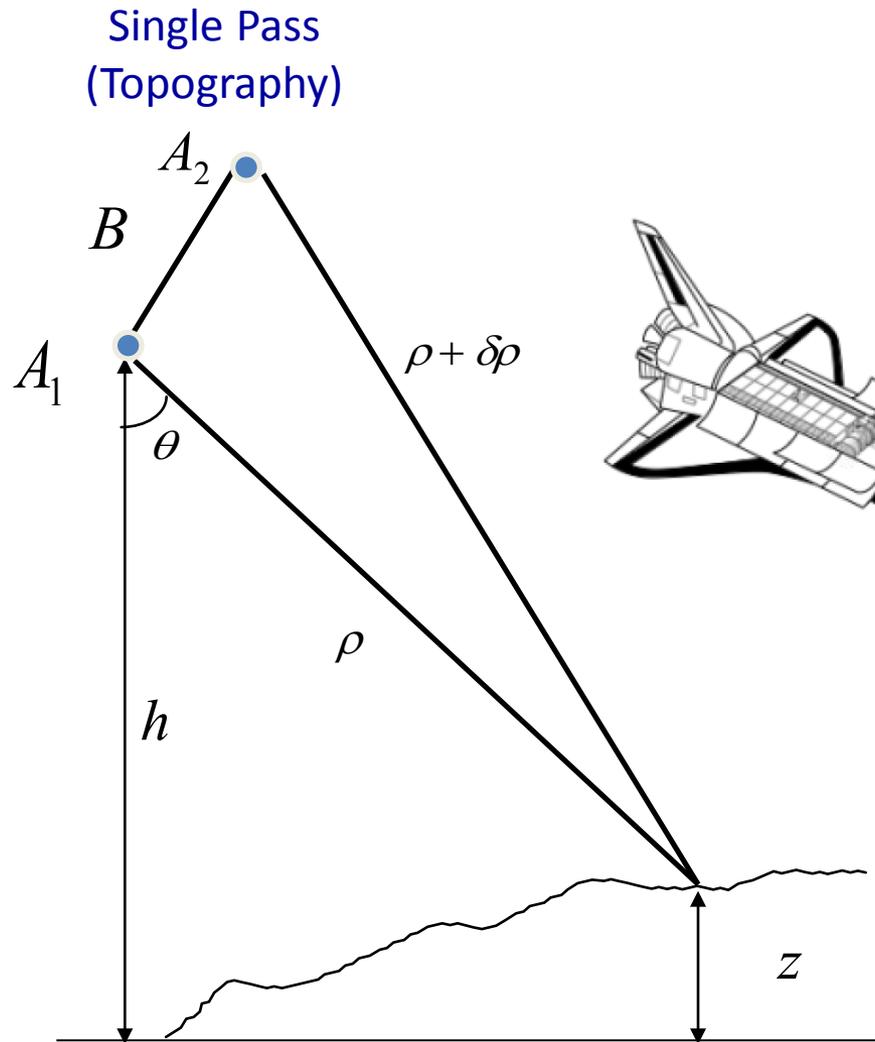


Shuttle hand-held photo

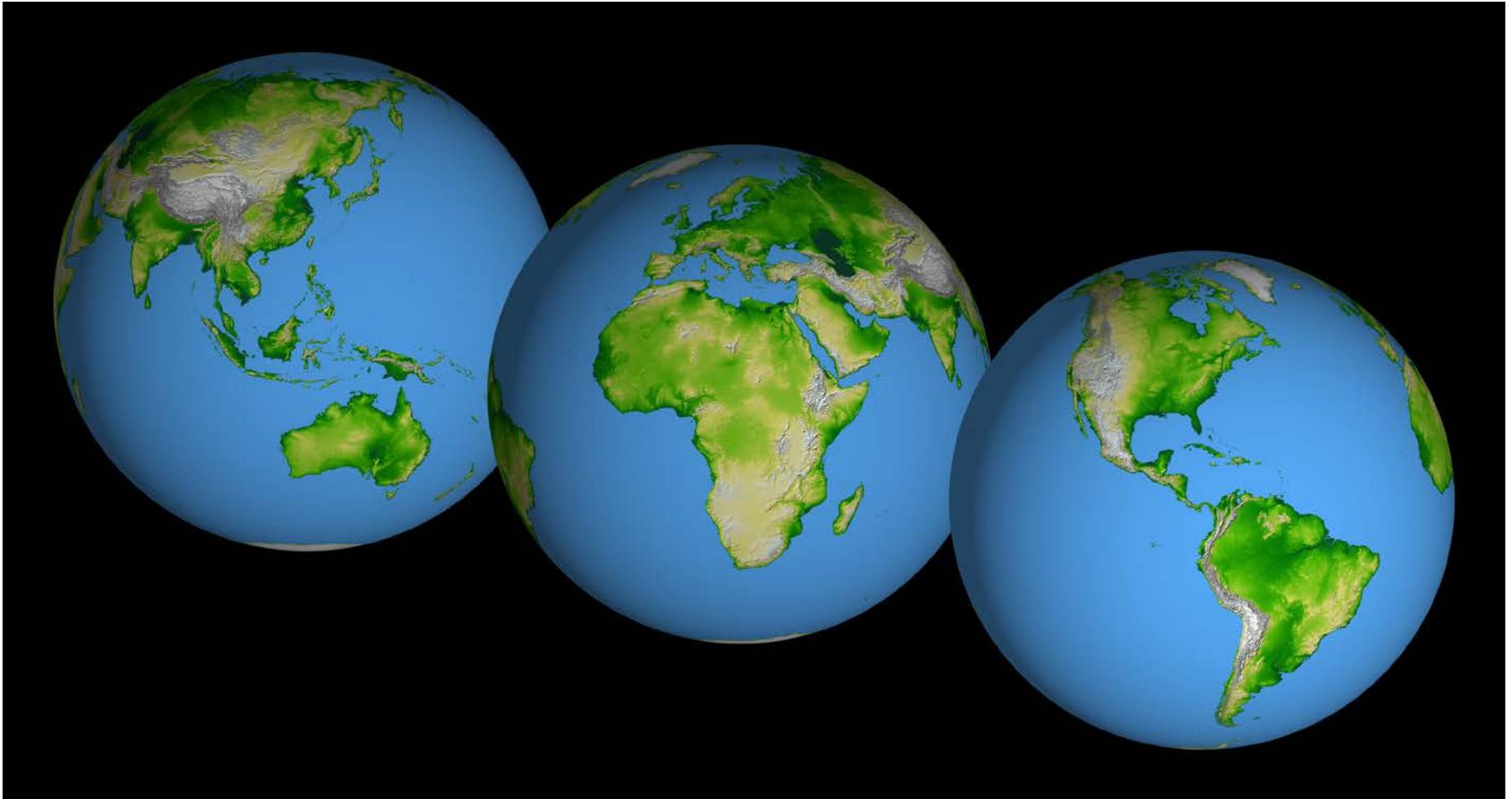


SIR-C (1994)

# Interferometry Basics

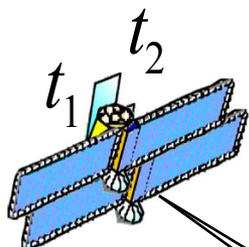


Shuttle Radar Topography Mission  
February 11-22, 2000

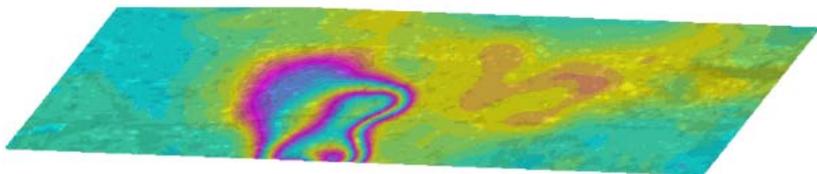




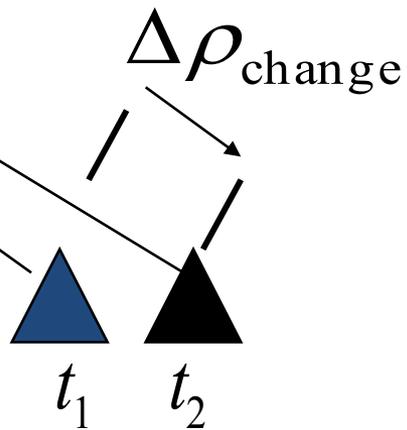
# Interferometry Basics (2)



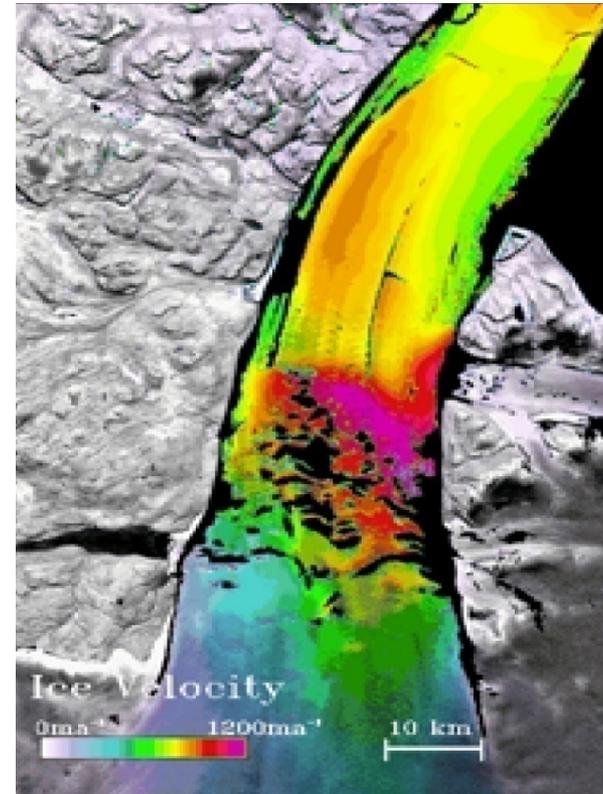
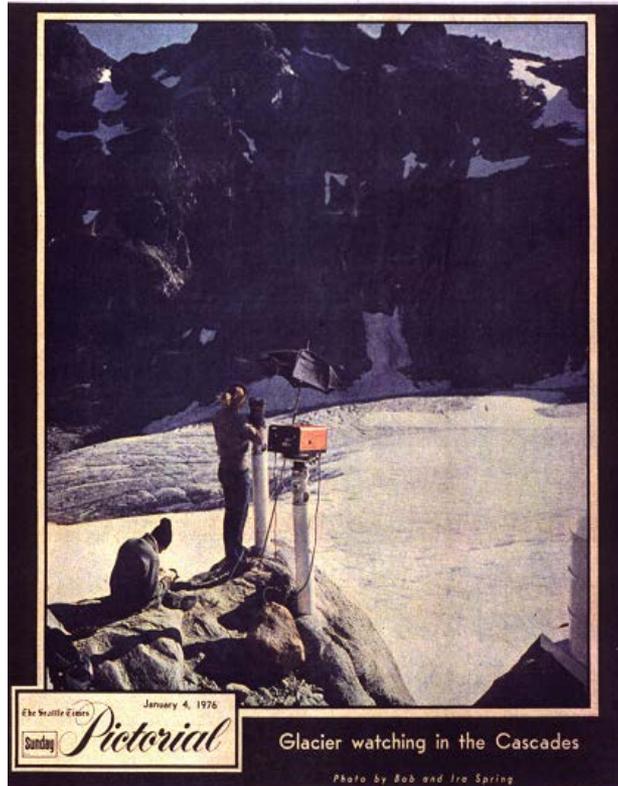
Repeat Pass  
(Topographic Change)



$\rho(t_2)$   
 $\rho(t_1)$

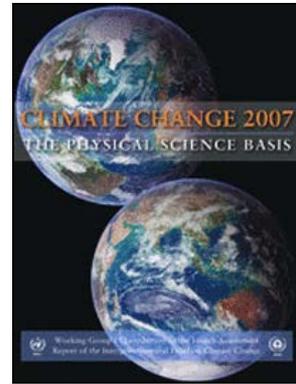


# Monitoring Glaciers: Then And Now

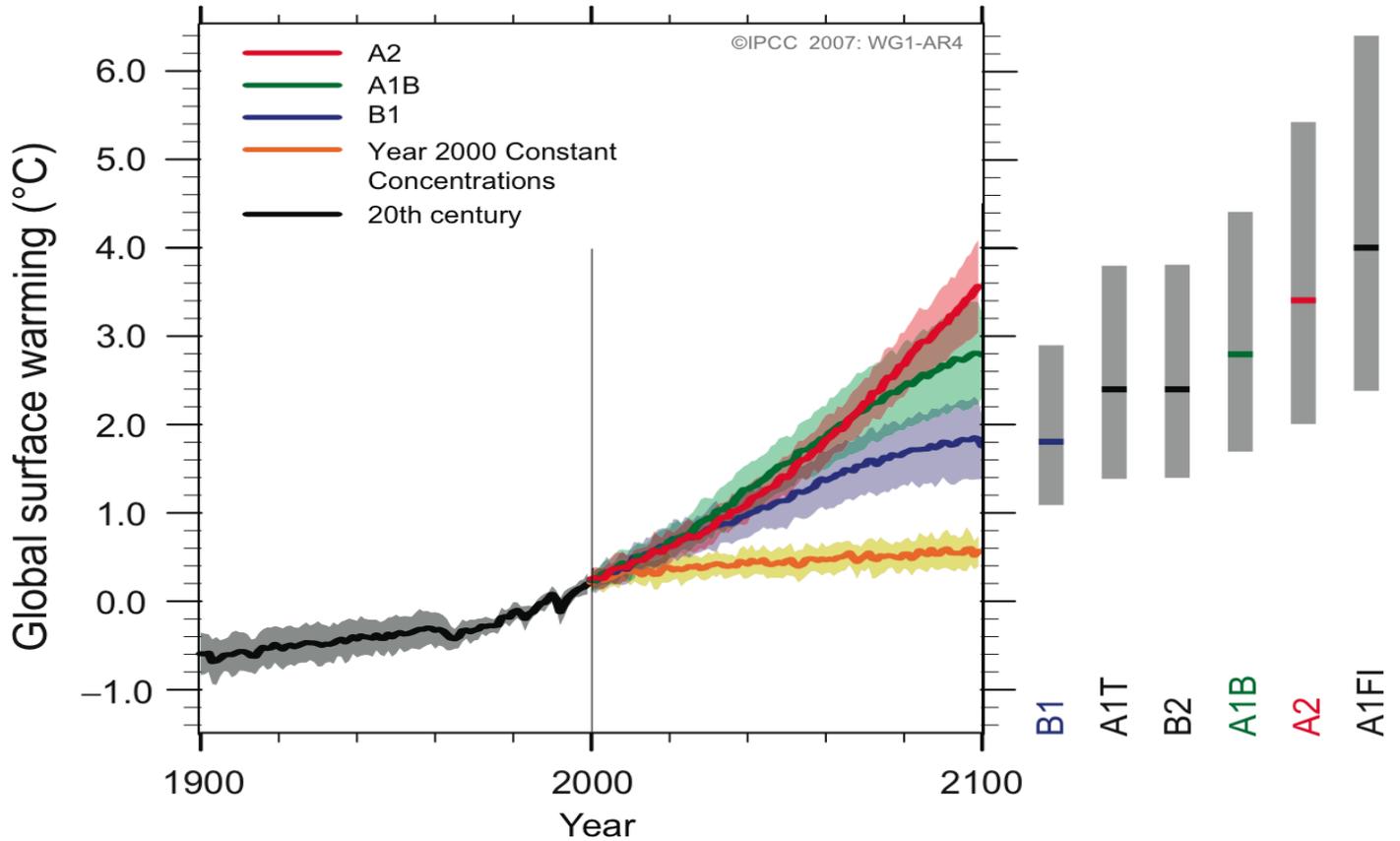
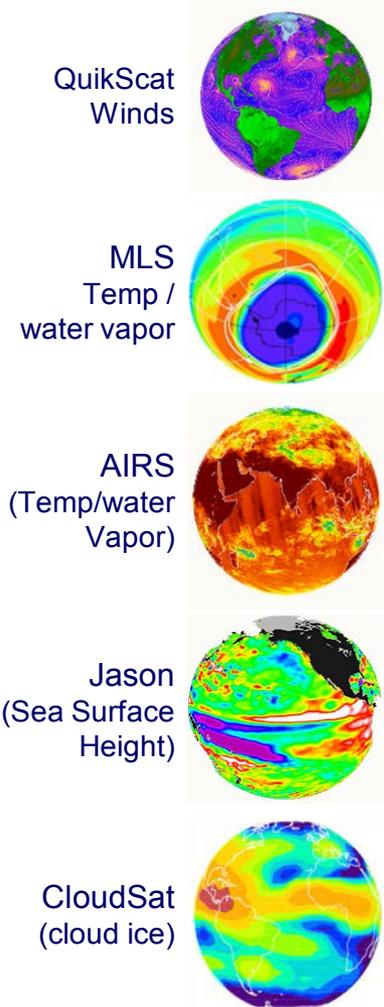




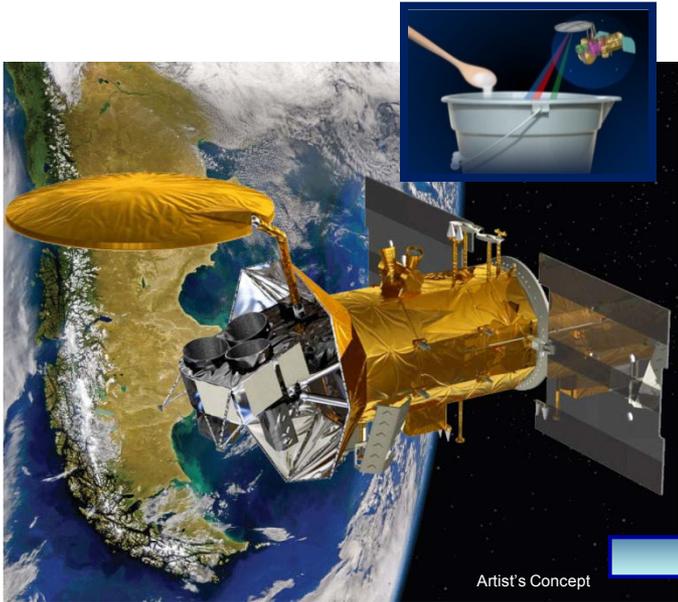
# Role of Satellites in Global Change



## Minimizing Uncertainties in Models

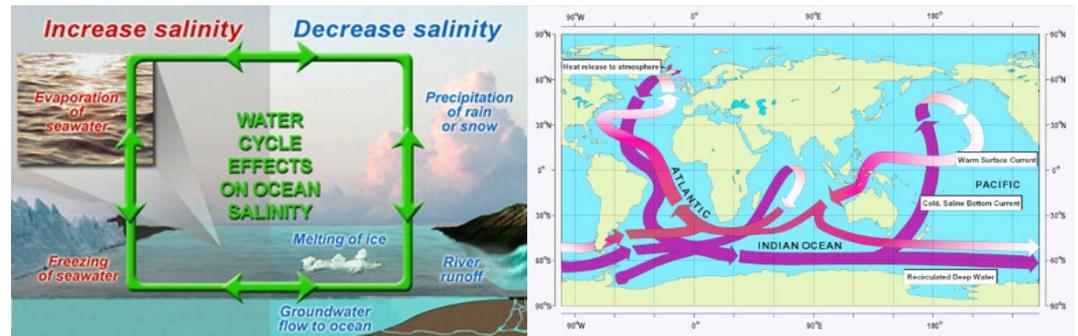
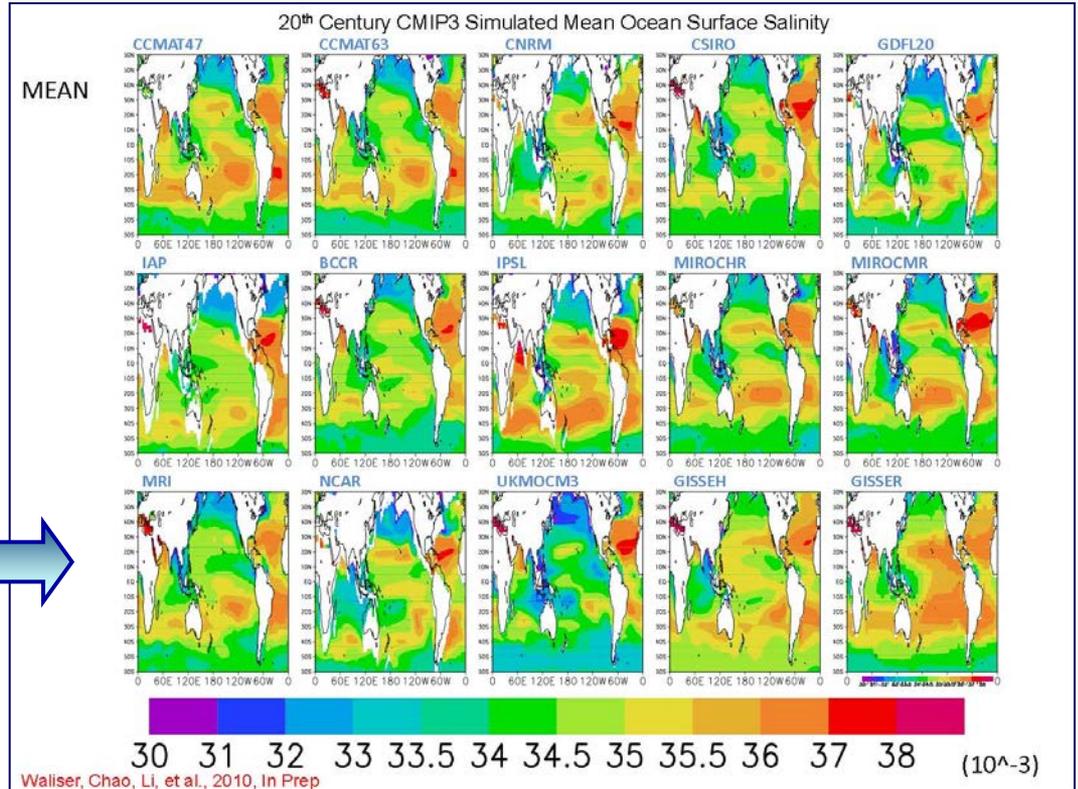


# Aquarius



Aquarius uses an L-band radar (JPL) and radiometer (GSFC) to make monthly maps of sea surface salinity with precision of 0.2 PSU ( $.2 \text{ gkg}^{-1}$ ) and resolution of  $150 \times 150 \text{ km}$

Partners:  
CONAE  
(INPE, ASI, CNES, CSA)



# Aquarius Launch



Aquarius Instrument delivered to Argentina June, 2009



Aquarius integrated with SAC-D spacecraft and shipped from the INVAP integration facility (Bariloche, Argentina) to Brazil June, 2010

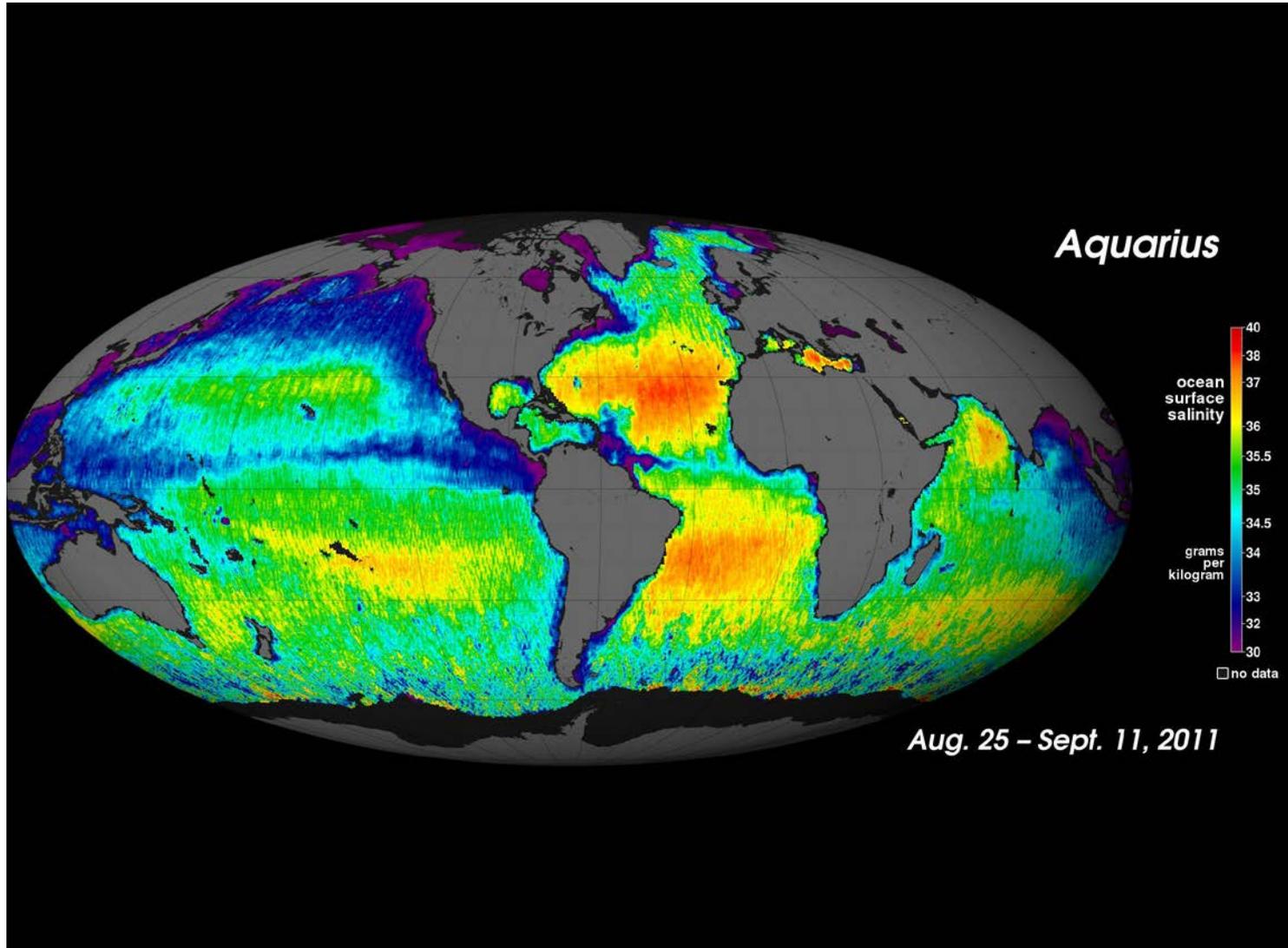


Observatory underwent environmental testing at the INPE-LIT facility (Sao Jose dos Campos, Brazil) and was shipped from Brazil to VAFB, April 2011

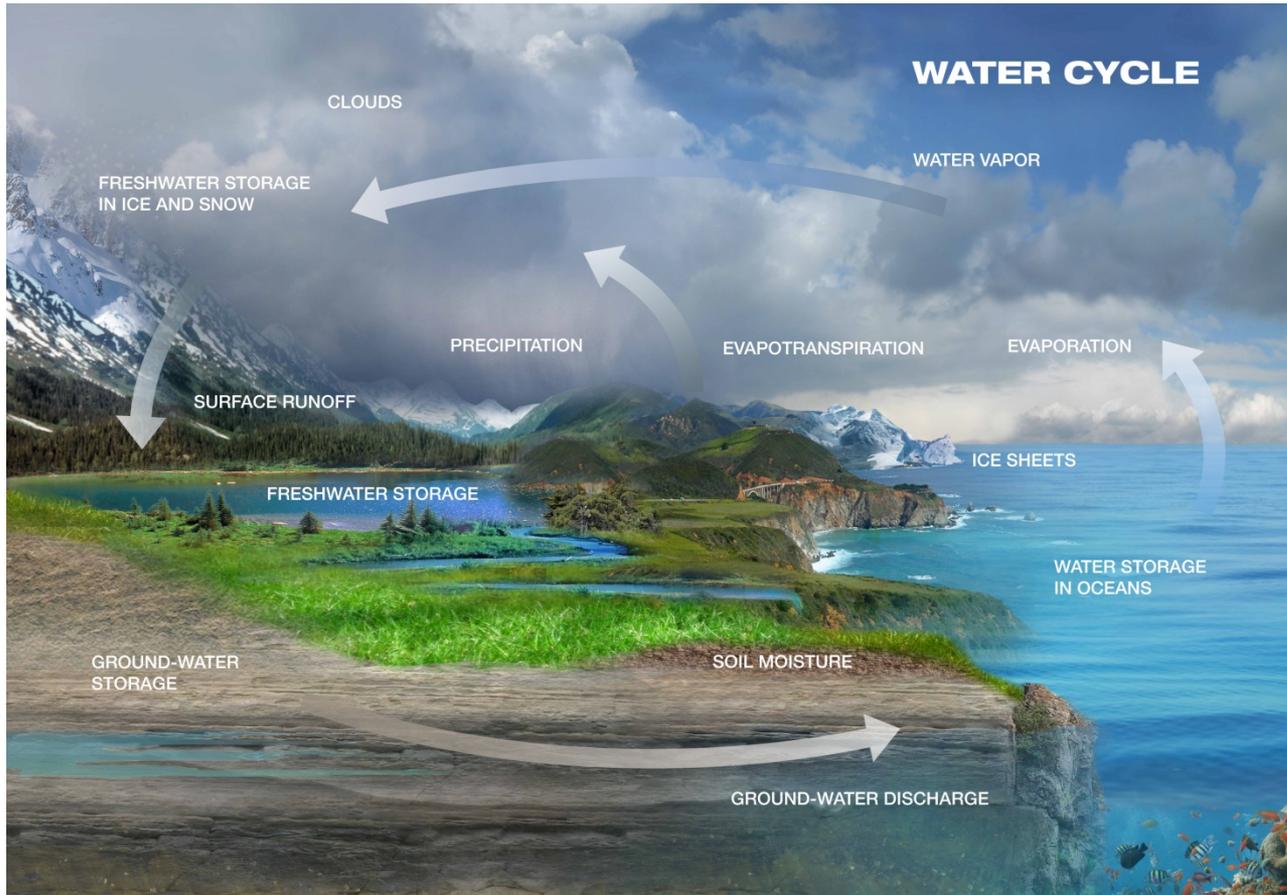


Delta-II liftoff at 07:20:13 AM PDT on June 10, 2011 from VAFB with the Aquarius/SAC-D Observatory on an international mission to study Earth's salty seas.

# Aquarius First light



# The Water Cycle



## GRAVITY

Groundwater, ice sheets, ocean circulation

## RADARS

Ice sheets, lake, river & ocean levels, ground water, clouds, precipitation, salinity, soil moisture, winds/fluxes and transport

## RADIOMETERS

Soil moisture, sea ice, clouds, water vapor, salinity

## SPECTROMETERS

Snow, ET

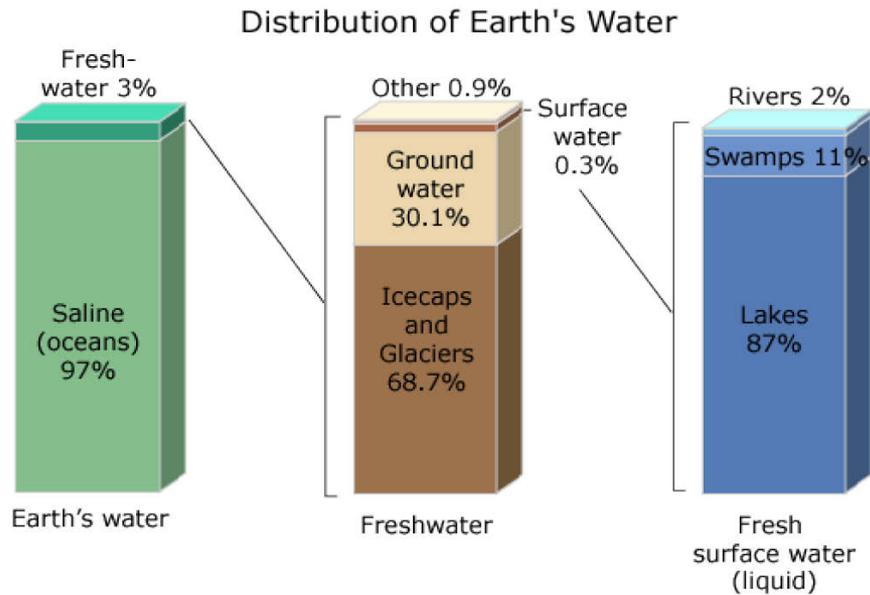
## SOUNDERS

Atmospheric water vapor, isotopes, water ice

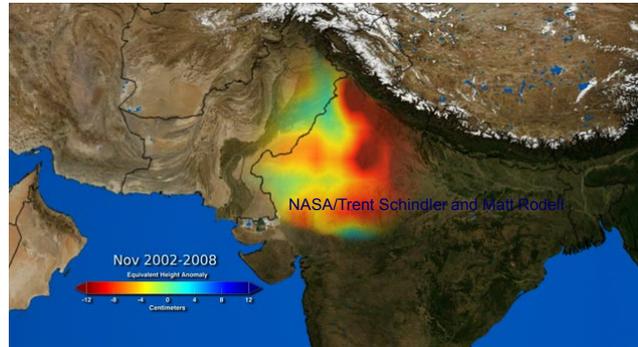
## LIDARS

Ice sheets, winds

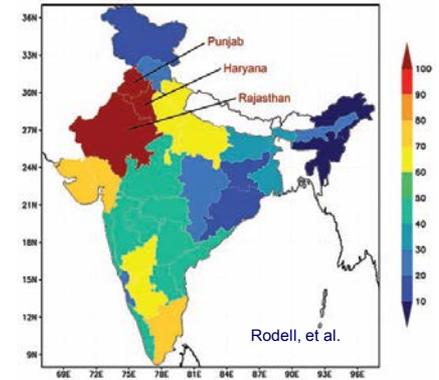
# Understanding Changes in Water Storage



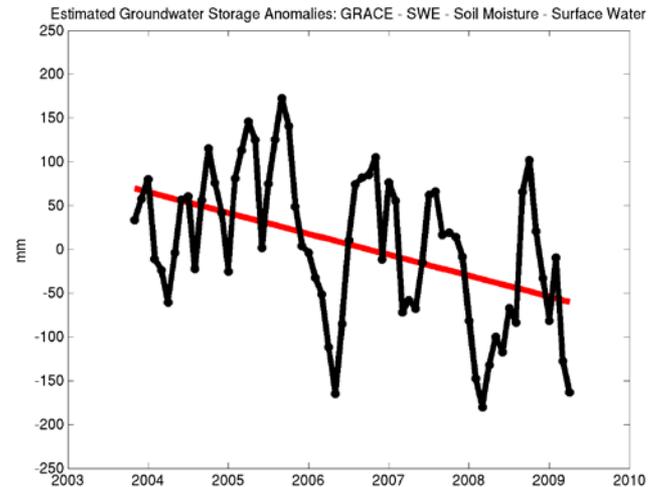
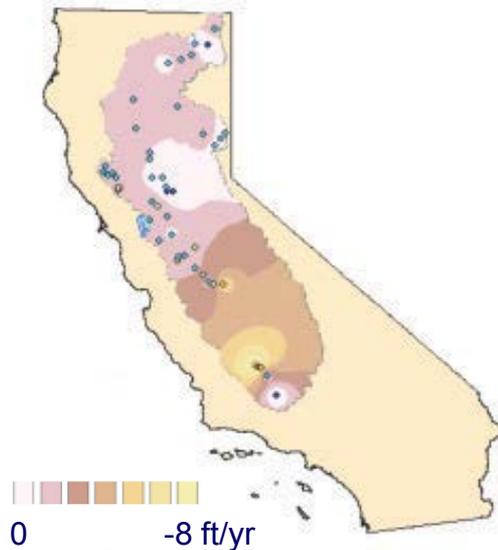
# Gravity Recovery and Climate Experiment (GRACE)



Depletion of groundwater in northwestern India between 2002 and 2008

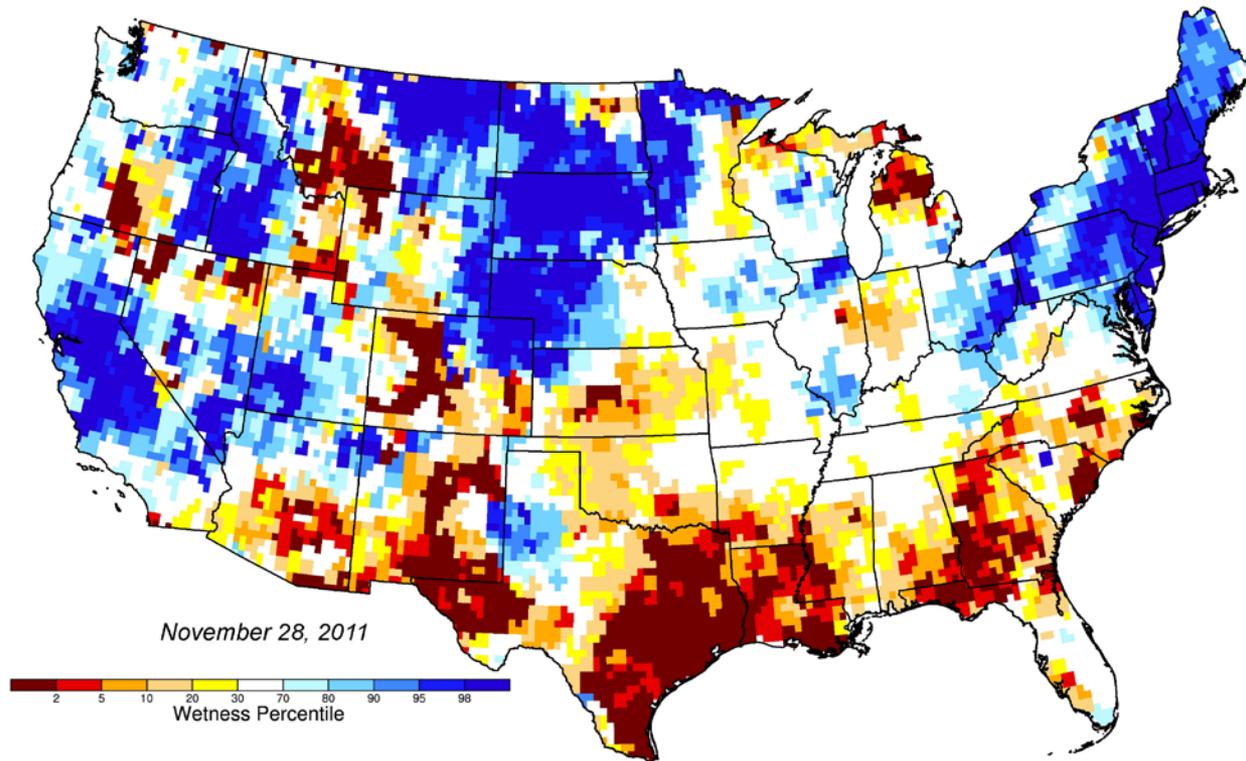


Groundwater withdrawals as a percentage of groundwater recharge Rodell (2009)



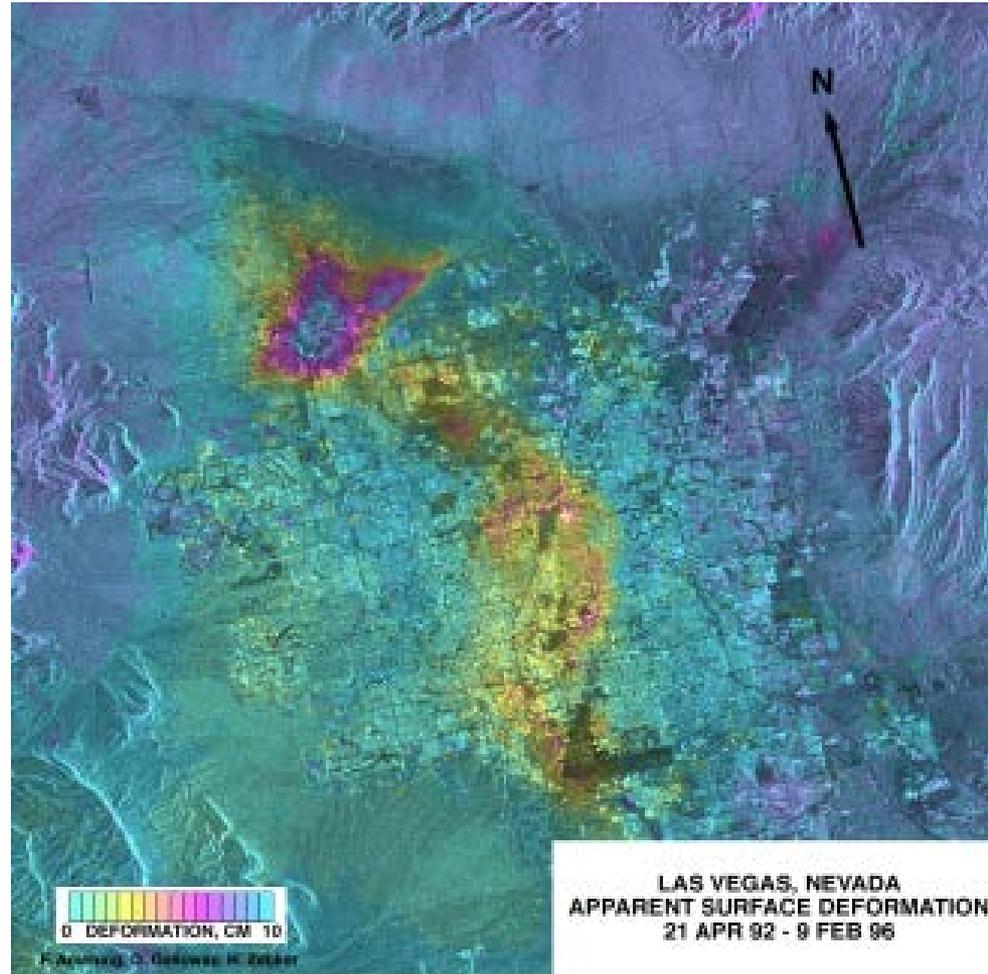
Groundwater storage changes in the Sacramento-San Joaquin River Basins (University Of California Center for Hydrologic Modeling )

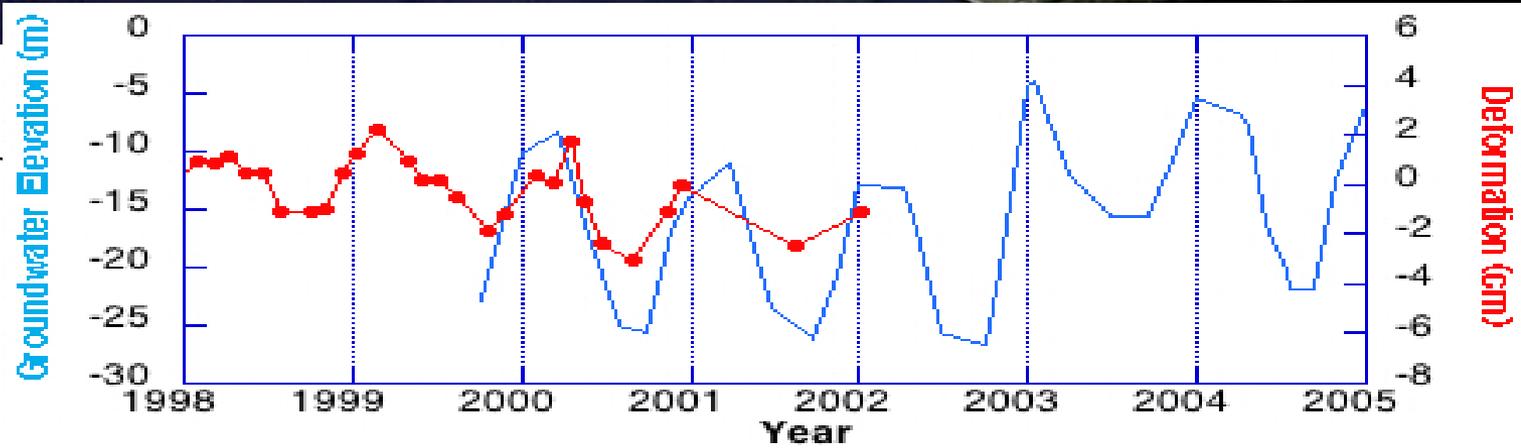
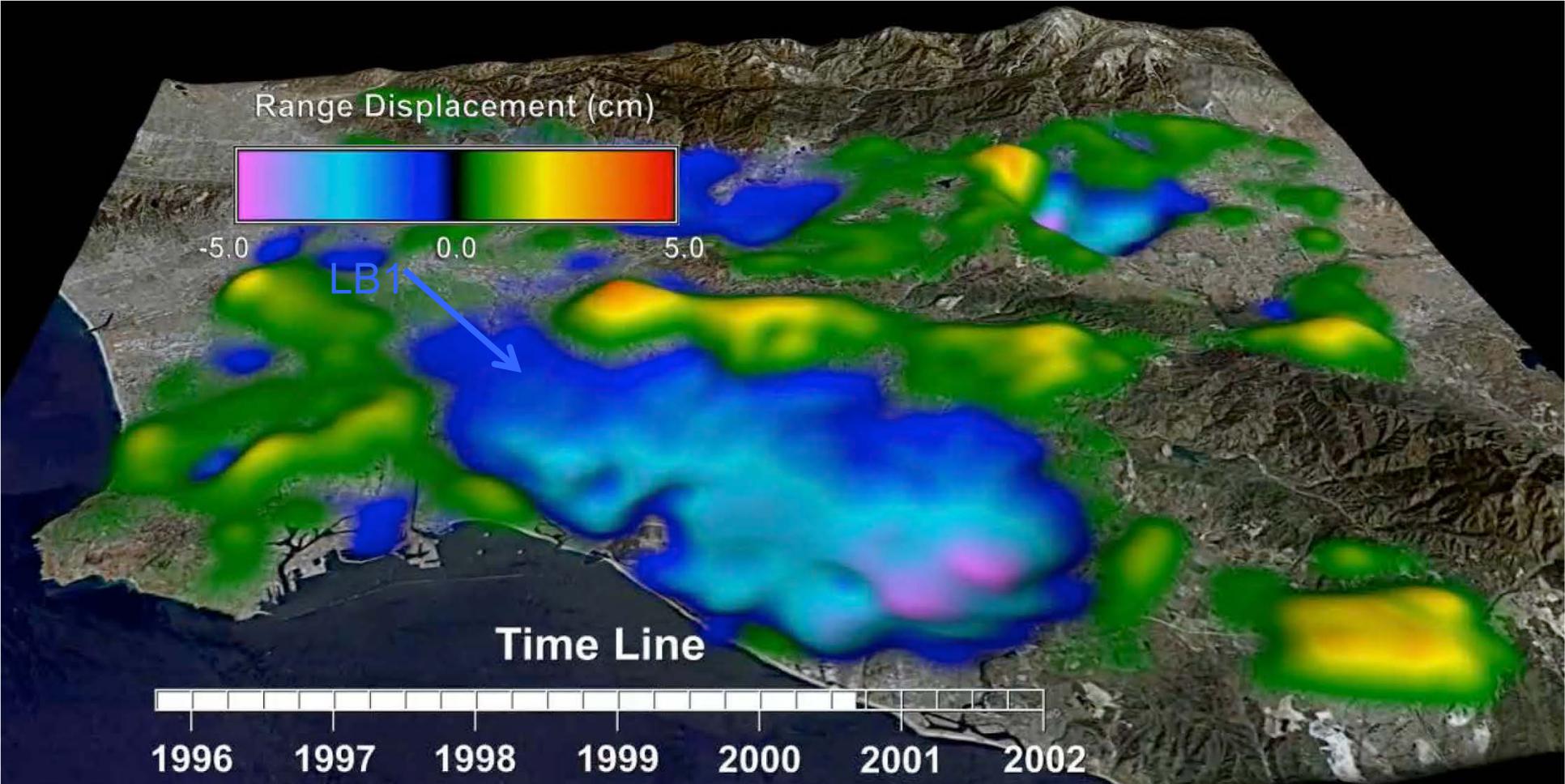
# GRACE Helps Monitor U.S. Drought



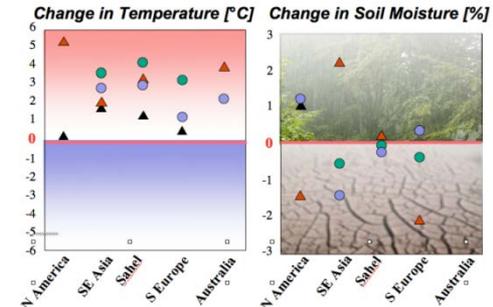
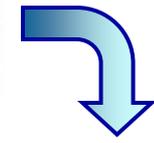
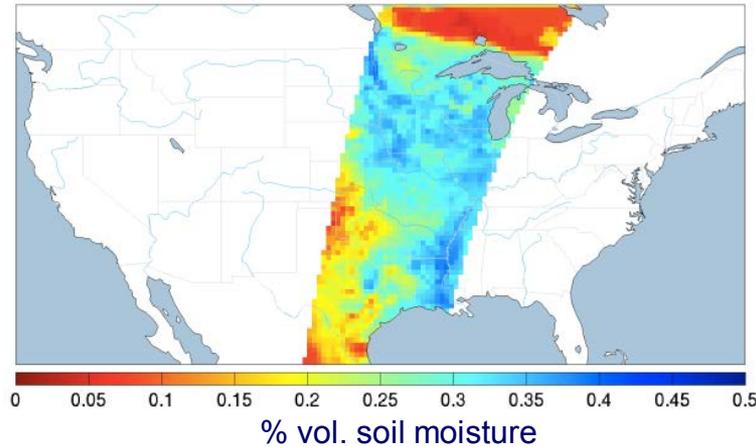
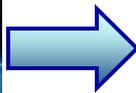
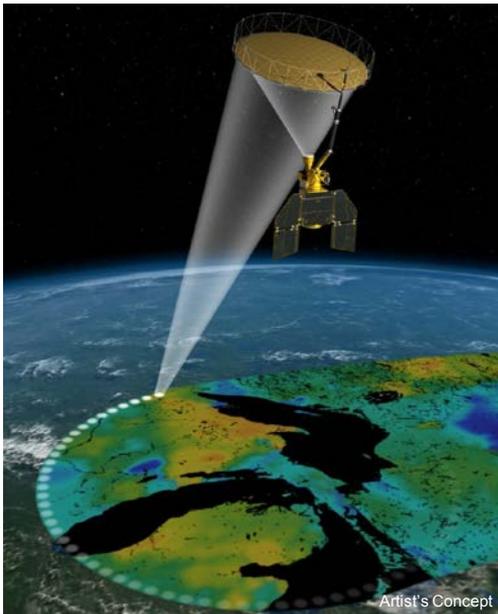
New groundwater and soil moisture drought indicator maps produced by NASA are available on the National Drought Mitigation Center's website. They currently show unusually low groundwater storage levels in Texas. The maps use an 11-division scale, with blues showing wetter-than-normal conditions and a yellow-to-red spectrum showing drier-than-normal conditions. Image credit: NASA/National Drought Mitigation Center

# Las Vegas InSAR Data



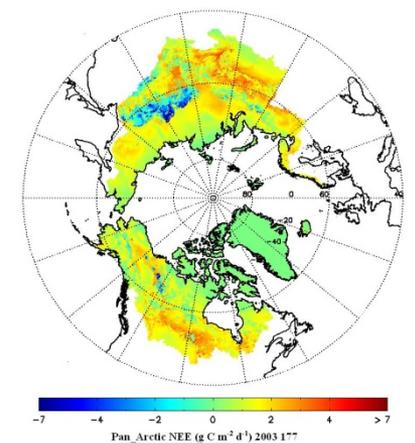
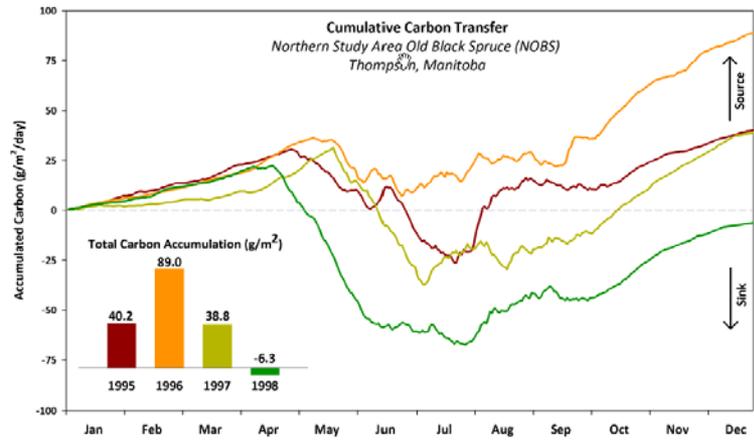


# Soil Moisture Active and Passive (SMAP)

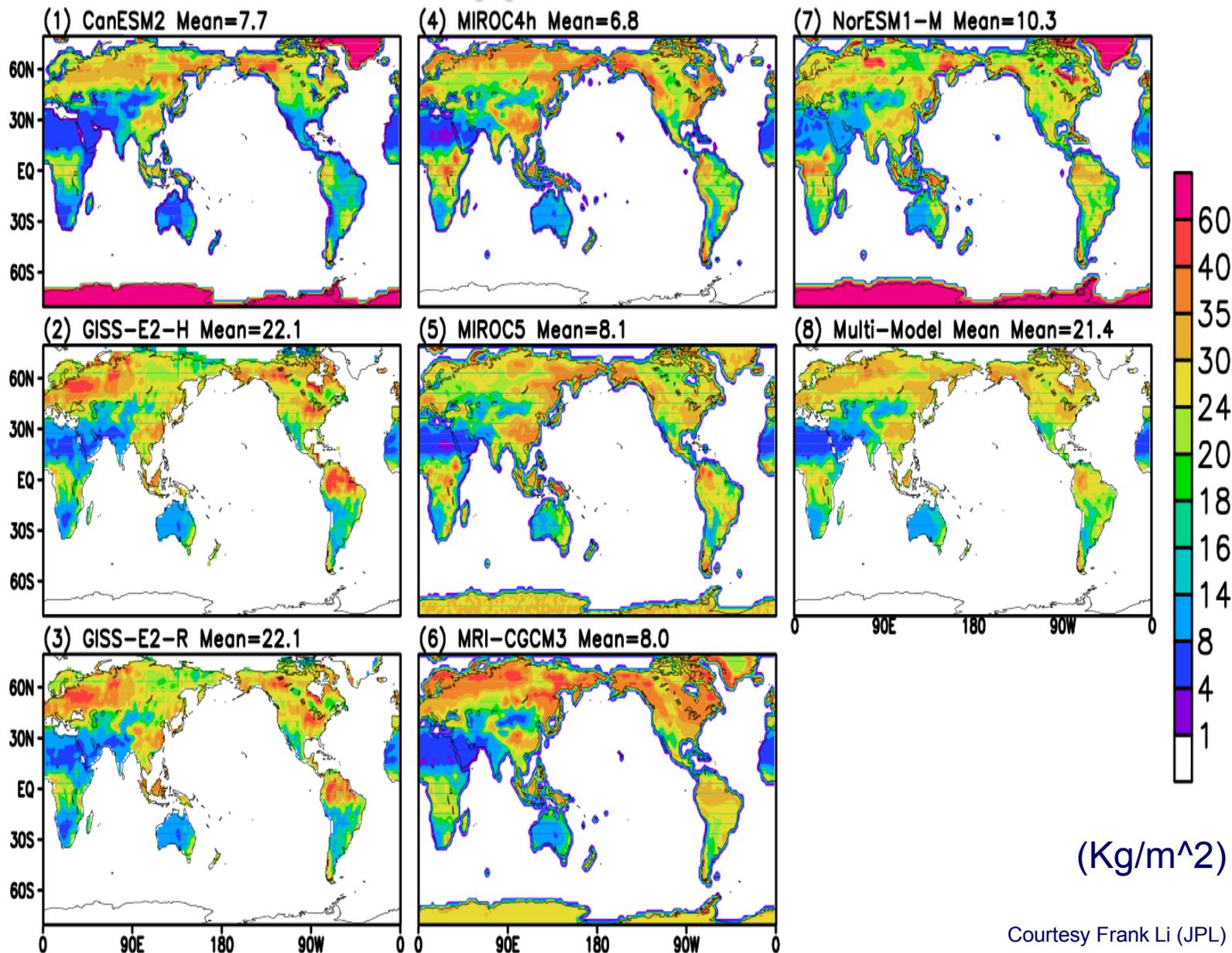


Improved climate models

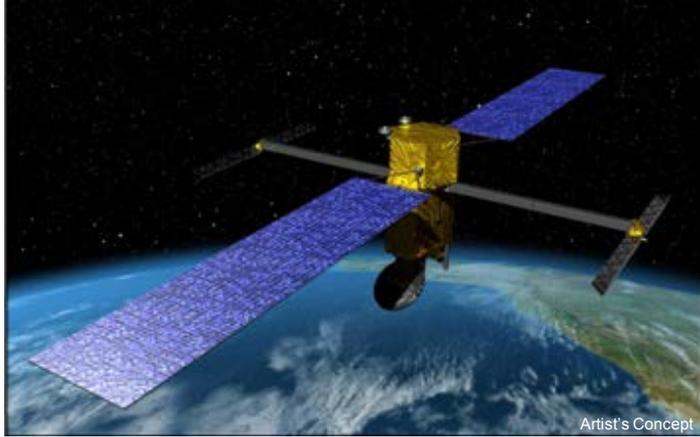
SMAP will use a rotating 6-m deployable mesh antenna shared by an L-band radar (JPL) & radiometer (GSFC) to map soil moisture and freeze/thaw state with 10 km resolution every 3 days



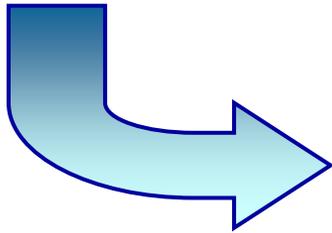
# CMIP5 Present Day (1970-2005) Annual Mean Moisture in Upper 10cm of Soil Column



# Surface Water and Ocean Topography (SWOT)\*



Artist's Concept



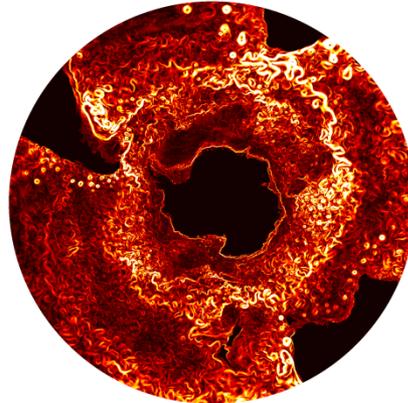
The proposed SWOT mission would use a Ka-band interferometric SAR with 2 swaths, 60 km each to characterize the ocean circulation at a spatial resolution of 10 km and provide a global inventory of terrestrial water bodies.



\*Proposed Mission

CENTRE NATIONAL D'ÉTUDES SPATIALES

Pre-decisional – for Planning and Discussion Purposes Only

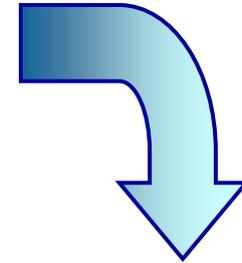


Mesoscale Ocean Circulation



Fresh Water Storage  
And Discharge

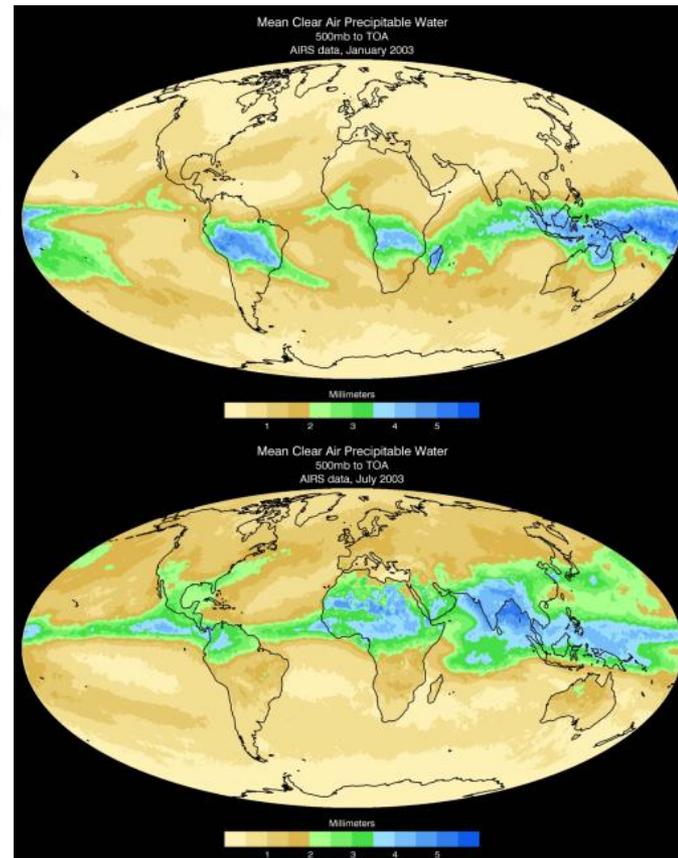
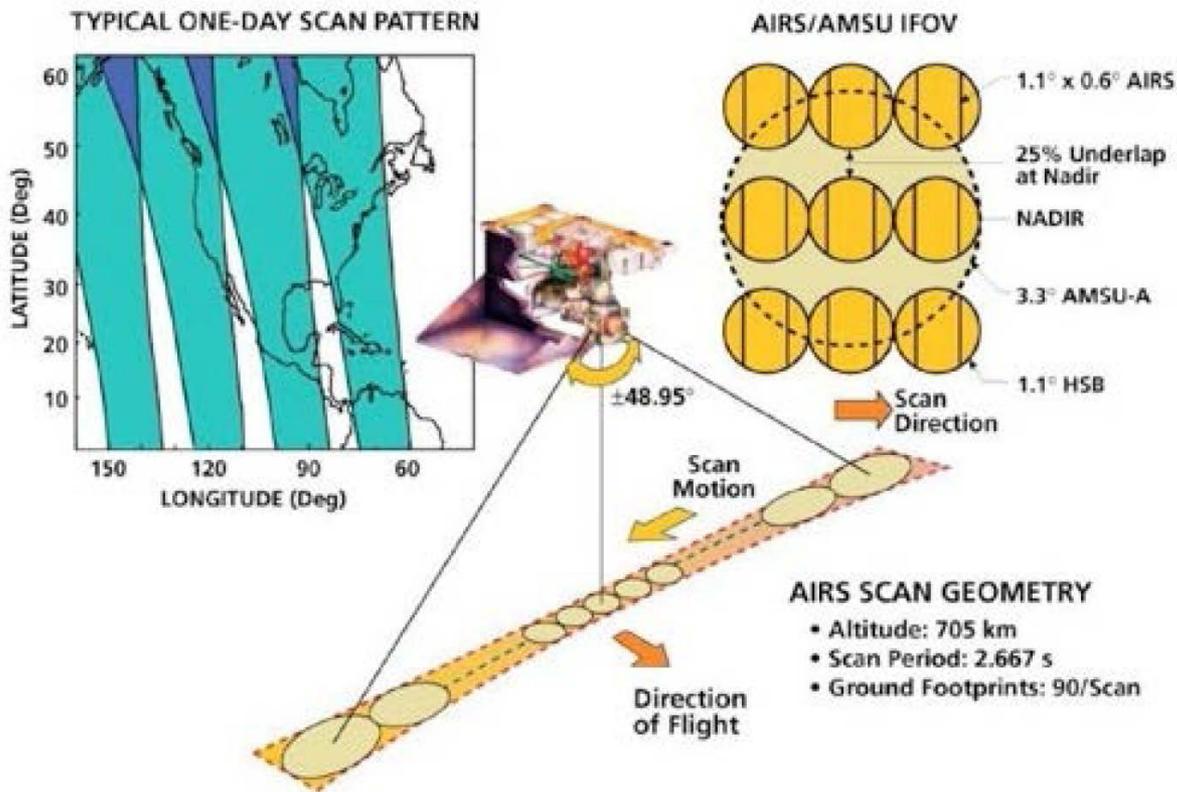
SWOT\* measurements would be critical to determining surface water availability, flooding potential, and the ocean's capacity to absorb heat and carbon from the atmosphere.



Courtesy Doug Alsdorf

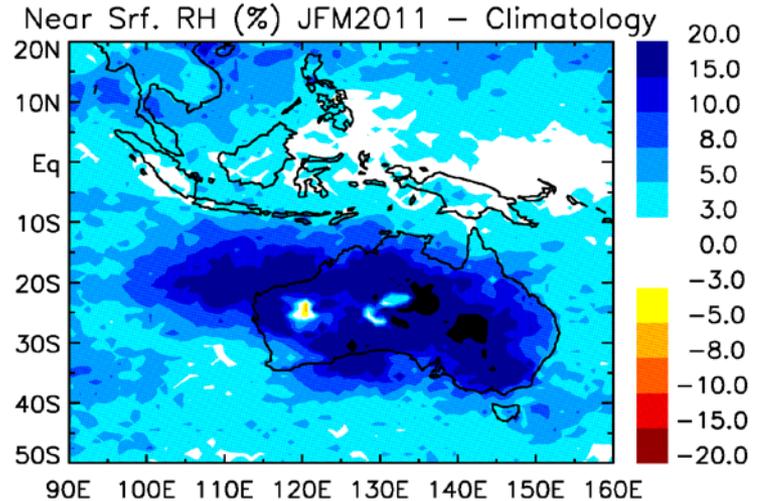
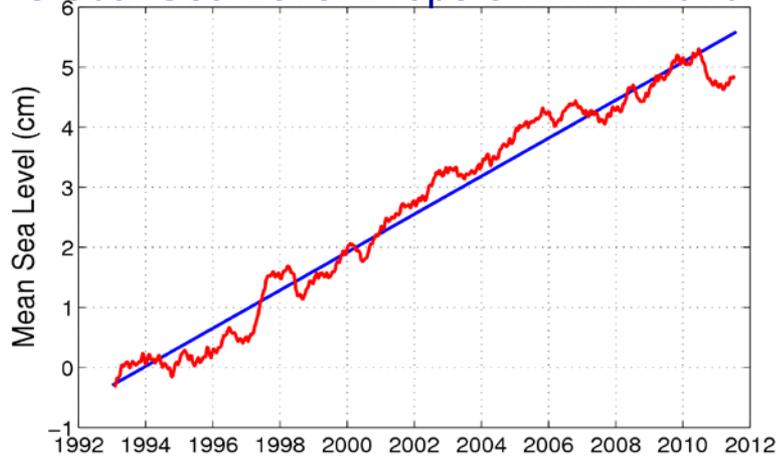
LRD: 2019

# Atmospheric Infrared Sounder (AIRS)

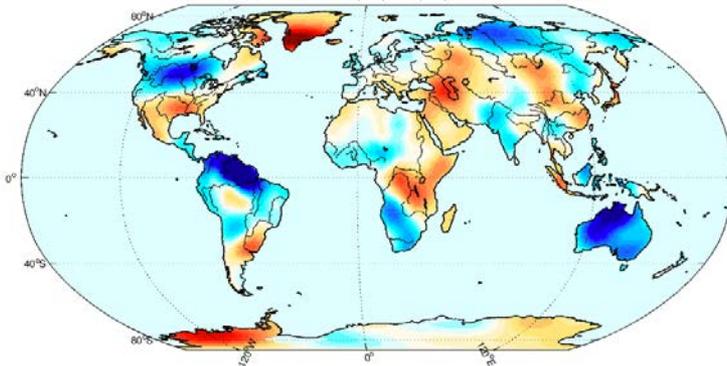


# Closing the Water Budget

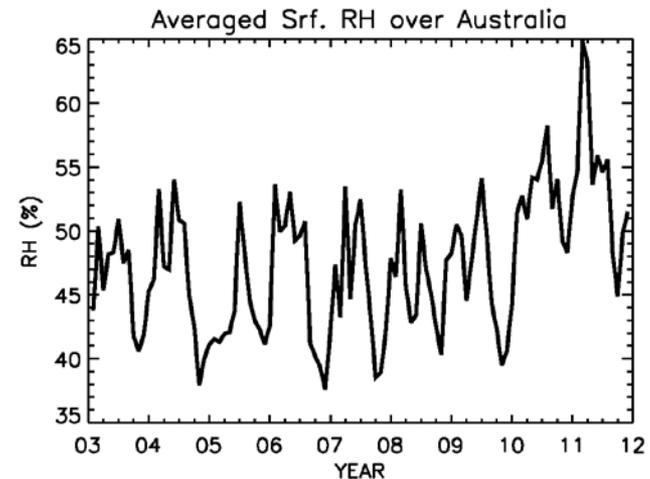
Global Sea Level Drops 5 mm in 2010



GRACE Shows Change in Water from March 2010 to March 2011

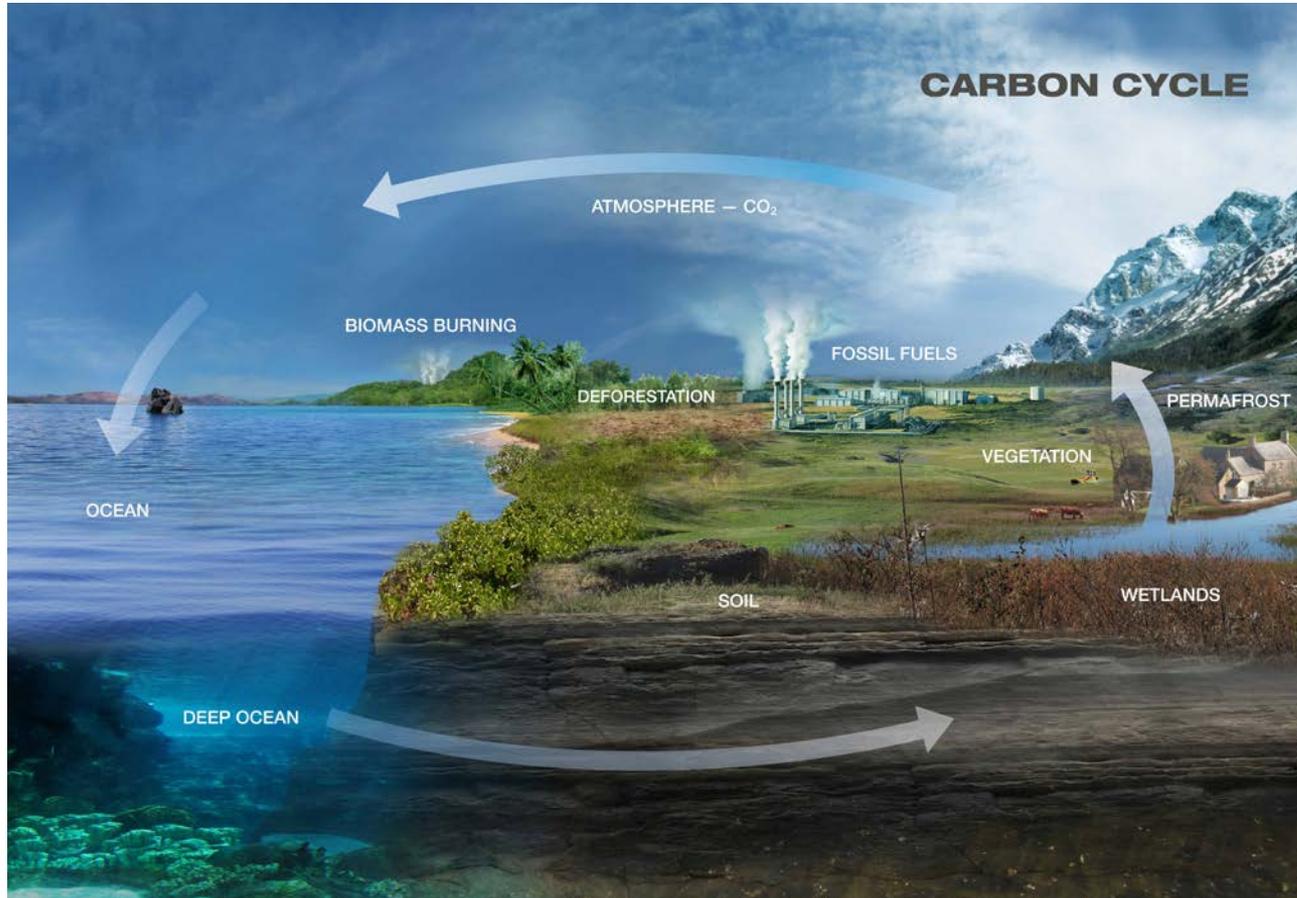


Mass in centimeters of water thickness  
From Boening et al., submitted



Courtesy Joao Teixeira

# Carbon Cycle



**Spectrometers**  
CO<sub>2</sub>, CO, Methane

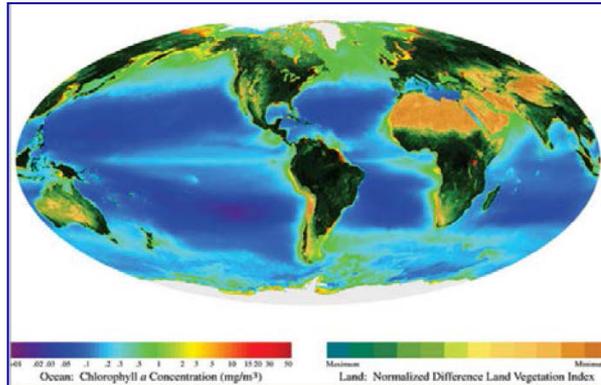
**RADAR**  
Freeze/Thaw  
Biomass

**Lidar**  
Vegetation Structure

**Optical**  
Land Cover Change  
Ocean Color

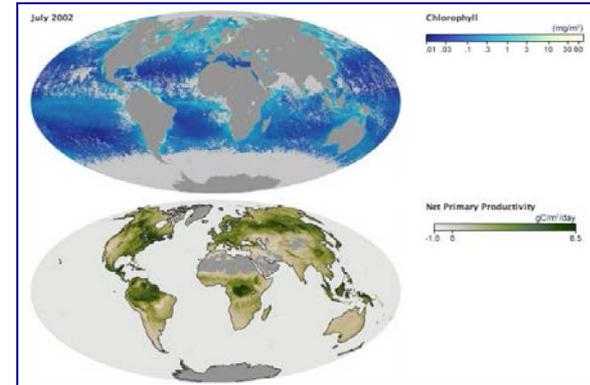
# Optical Data Sets

Sea-viewing Wide Field-of-view Sensor  
(SeaWiFS)



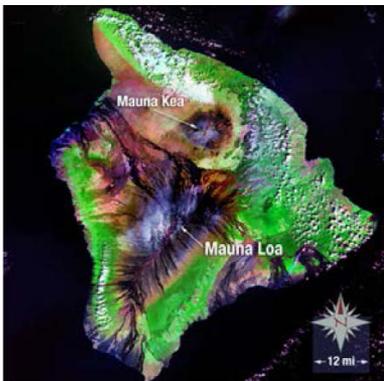
<http://oceancolor.gsfc.nasa.gov/SeaWiFS/>

Moderate Resolution Imaging Spectroradiometer



<http://earthobservatory.nasa.gov/>

Landsat



<http://landsat.gsfc.nasa.gov>

Multi-angle Imaging SpectroRadiometer  
(MISR)



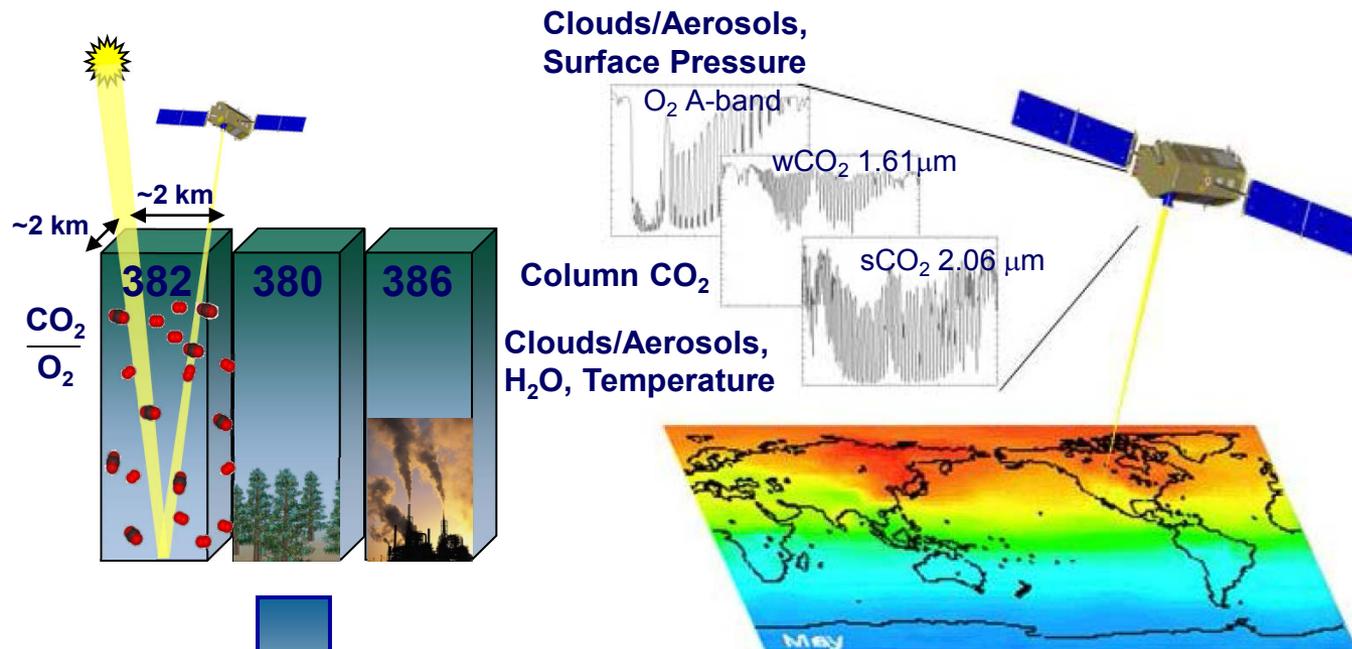
<http://www-misr.jpl.nasa.gov>

Visible/Infrared Imager Radiometer Suite (VIIRS)  
Instrument aboard Suomi NPP

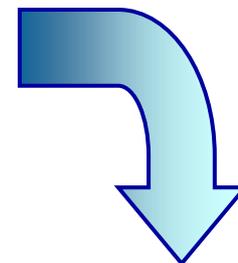


<http://www.spaceflightnow.com>

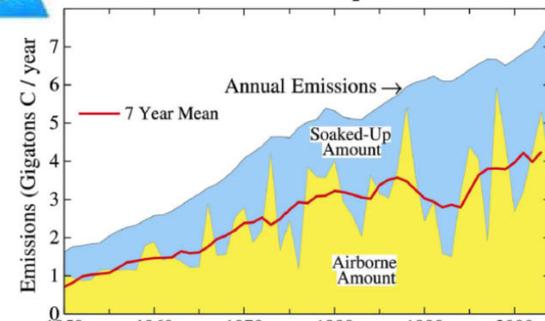
# Orbiting Carbon Observatory (OCO-2)



Only ~58% of the >200 Gt C humans have added to the atmosphere since 1958 is staying in the atmosphere



Global Fossil Fuel CO<sub>2</sub> Emissions

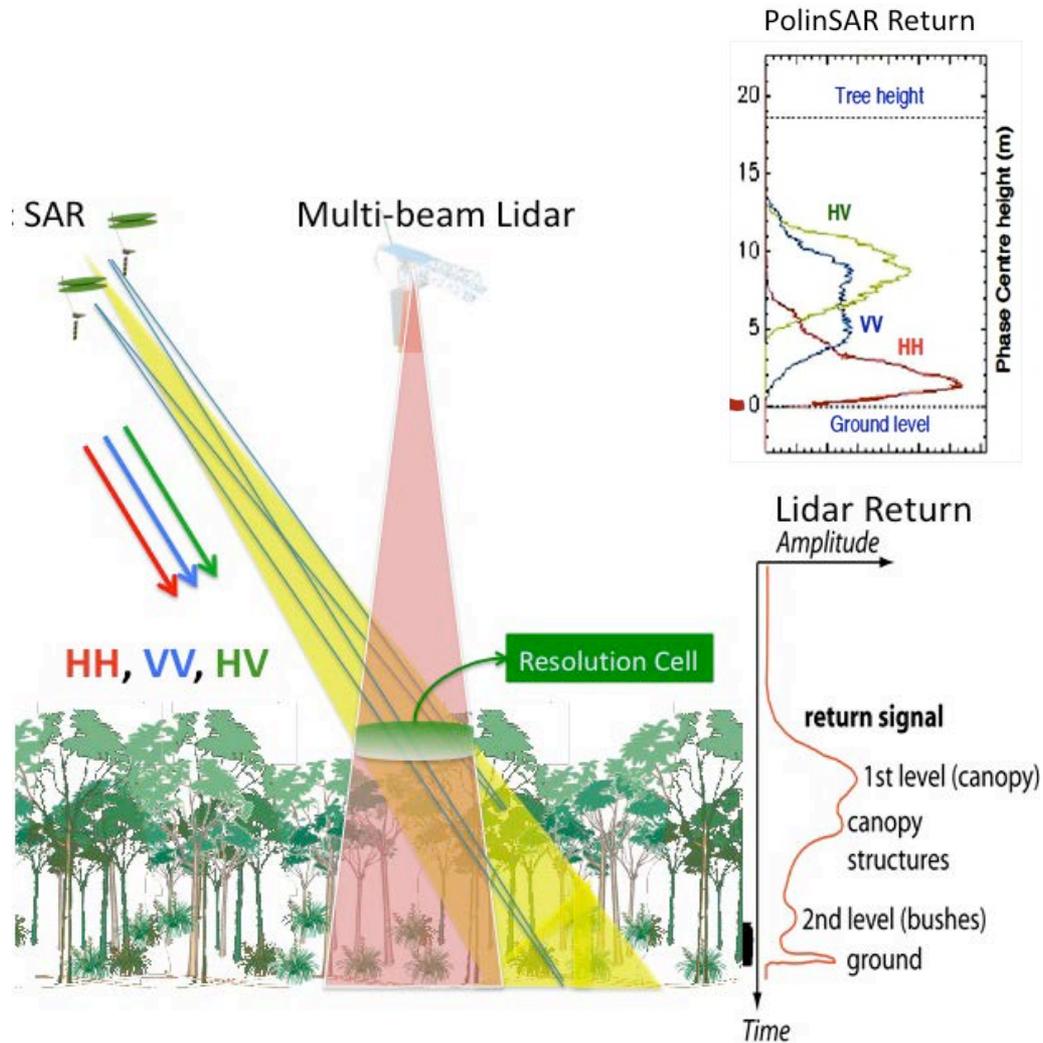


Global fossil fuel CO<sub>2</sub> emissions with division into portions that remain airborne or are soaked up by the ocean and land.

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

OCO will measure reflected sunlight with 3 bore-sighted, high resolution grating spectrometers with enough precision (1–2 ppm) to resolve sources and sinks of CO<sub>2</sub> at a scale of 1000 km

# Forest Structure and Biomass

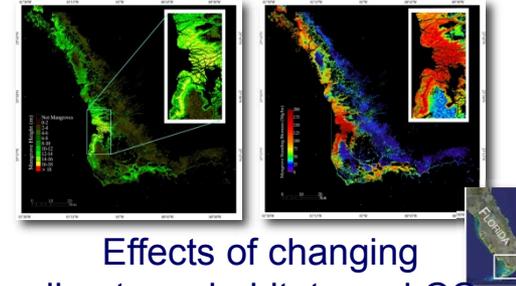
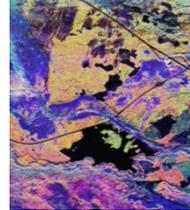


# Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)\*



DESDynI is a proposed interferometric L-band synthetic aperture radar (InSAR)

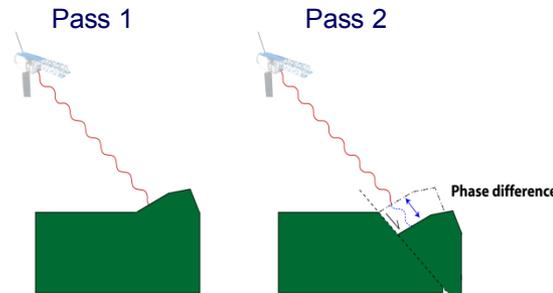
## Polarimetric SAR



Effects of changing climate on habitats and CO<sub>2</sub>

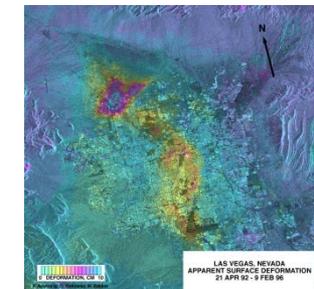
## Biomass Vegetation Structure

## Repeat Pass InSAR



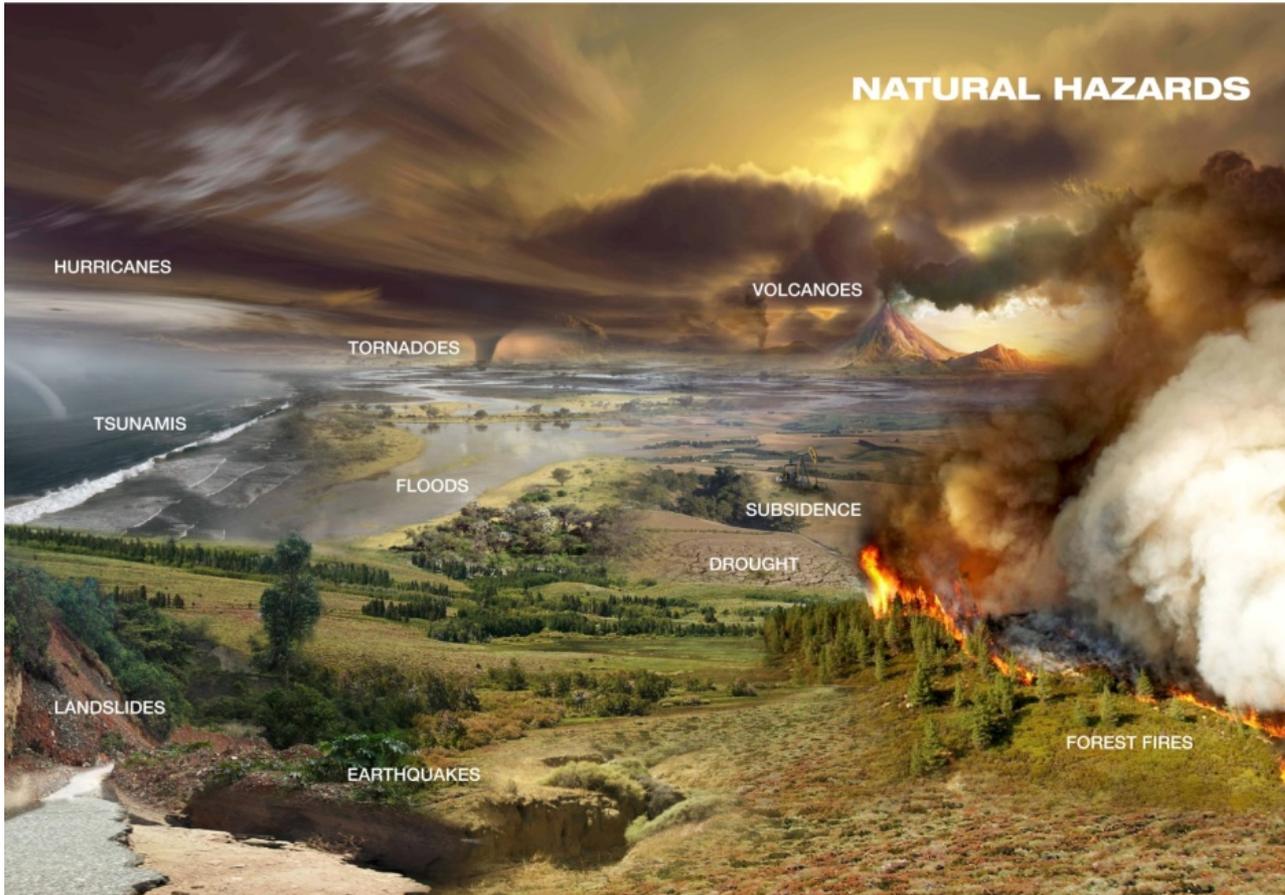
Ice sheet dynamics  
Vegetation Disturbance  
Changes in Earth's Surface

Response of ice sheets to climate change & sea level rise



Natural Hazards  
Water Resource Management

# Natural Hazards



## GRAVITY

Displacement

## RADARS

Surface deformation, subsidence, vector winds, tsunami modeling, ocean heat content

## RADIOMETERS

Soil moisture, sea ice, clouds, water vapor, salinity

## SPECTROMETERS

Soil properties, land surface volcanic emissions, temperature, hazardous gases

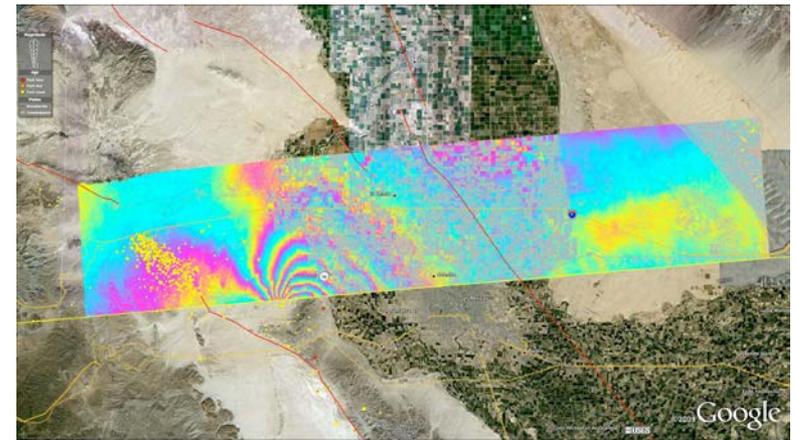
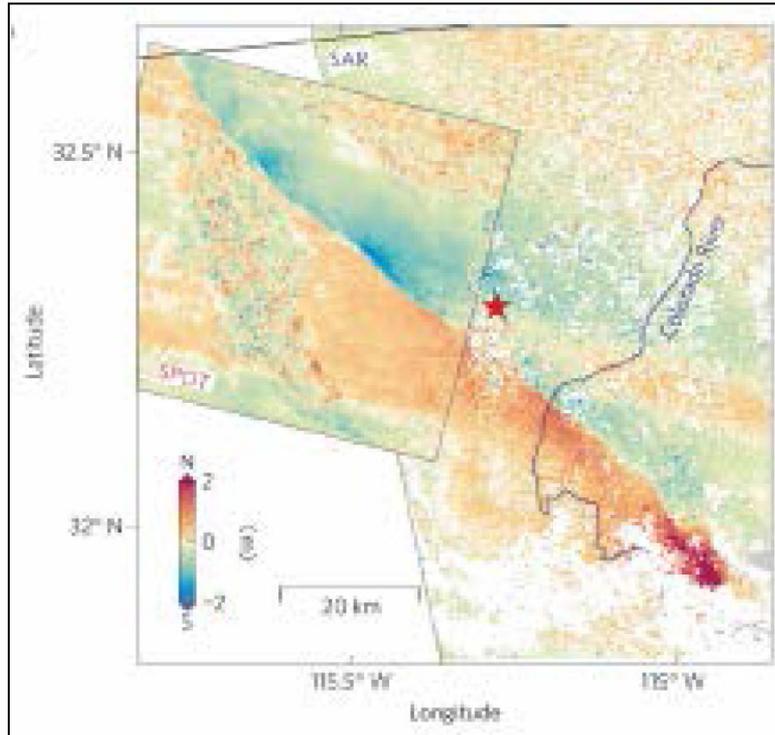
## Lidar

Topography, hazardous gases

## GPS

Surface motion

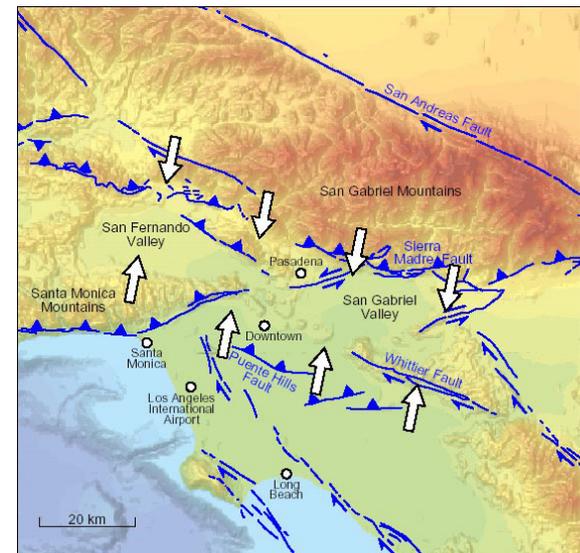
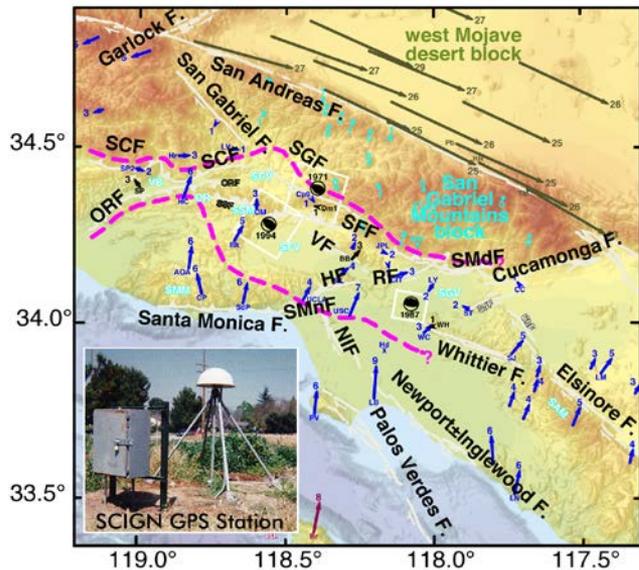
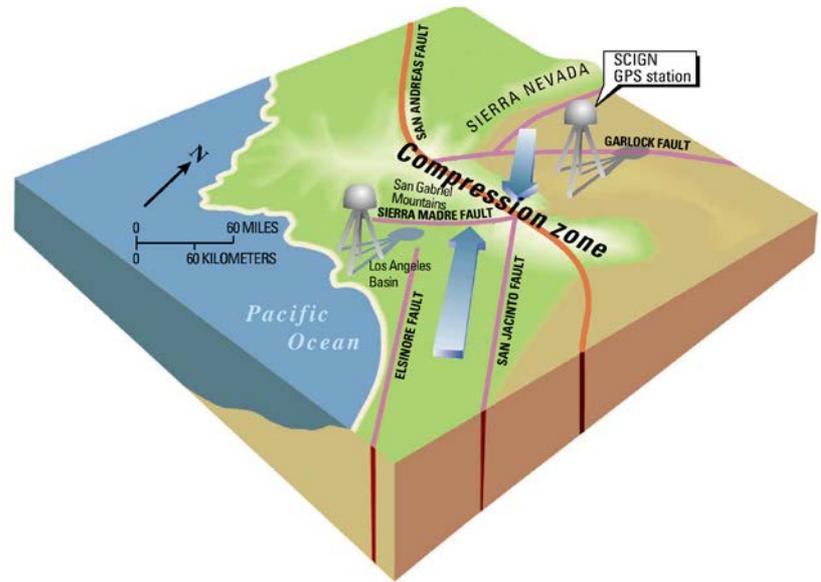
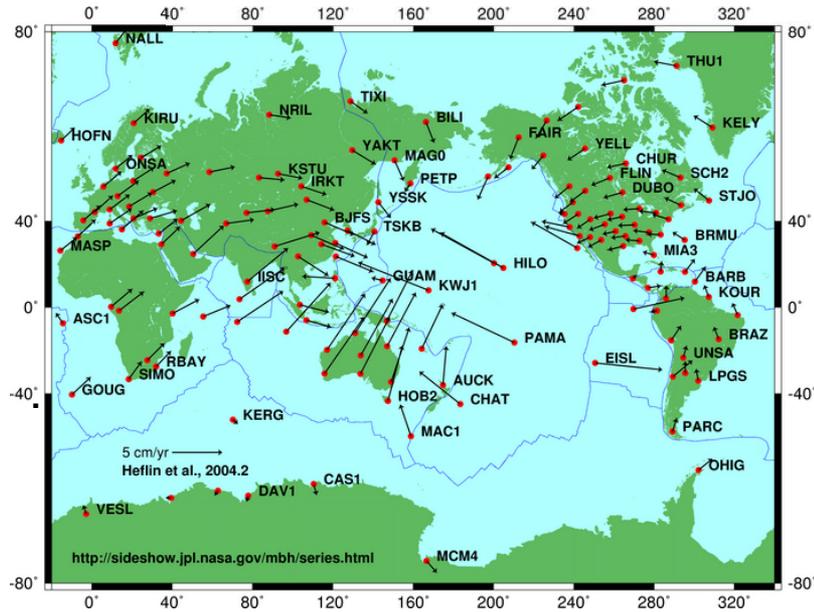
# InSAR Measurements of Fault Motions



Magnitude 7.2 earthquake April 4, 2010

InSAR and optical images were used to determine surface displacements caused by the April 10, 2010 magnitude 7.2 earthquake of Baja California in Mexico  
(Wei et al., Nature Geoscience, 2011)

# GPS Measurements of Plate Motion



Argus, et al., 2005

# Access to Earthquake and Volcano Data

**main**

**new event**

**news**

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**apply for access**

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## WELCOME TO THE SUPERSITES

**New Event** [Van, Turkey, earthquake of 23 October 2011](#)

The Supersites have data for the study of natural hazards in geologically active regions, including information from Synthetic Aperture Radar (SAR), GPS crustal deformation measurements, and earthquakes. The data are provided in the spirit of GEO, ESA, NASA and the National Science Foundation (NSF), that easy access to Earth science data will promote their use and advance scientific research, ultimately leading to reduced loss of life from natural hazards.

Click on a site in the map below, or see the regions listed below in Geohazard Supersites and Geohazard Natural Laboratories.

**GROUP ON EARTH OBSERVATIONS**

**esa**

**JAXA**

**NASA**

**DLR**

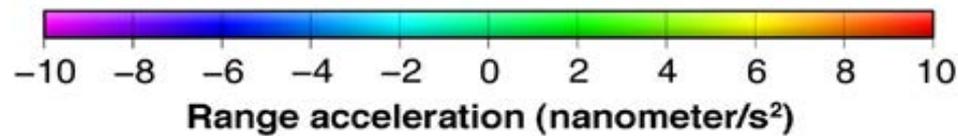
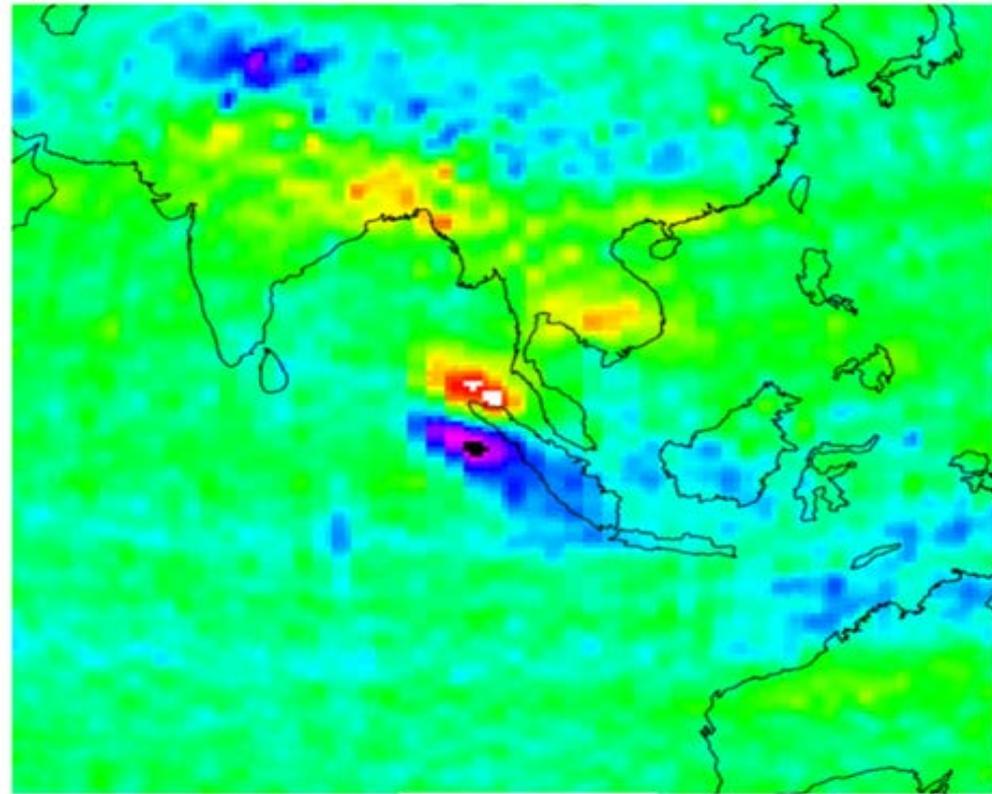
**NSF**

**UNAVCO**

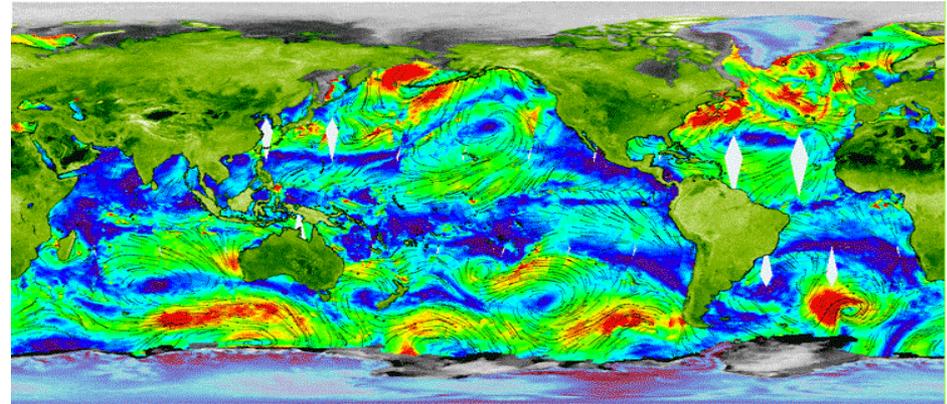
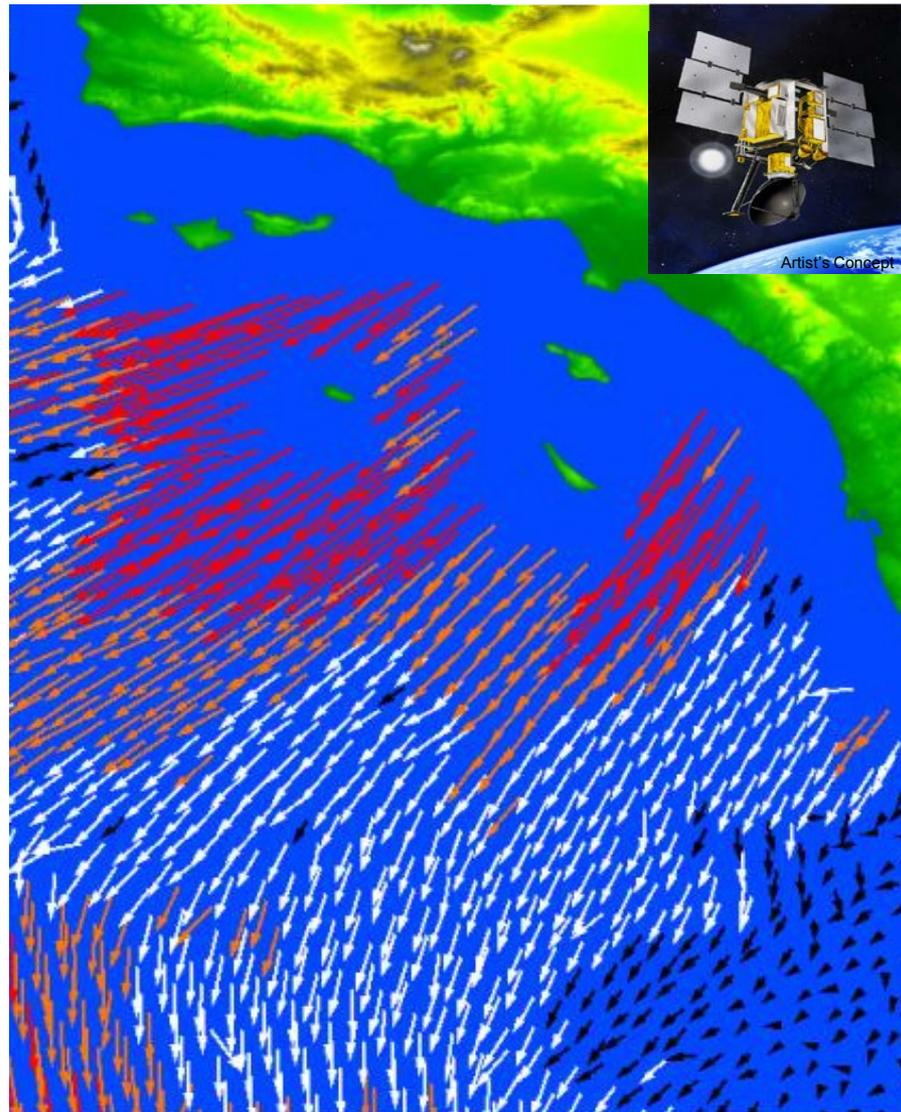
**EPOS**

<http://supersites.earthobservations.org/main.php>

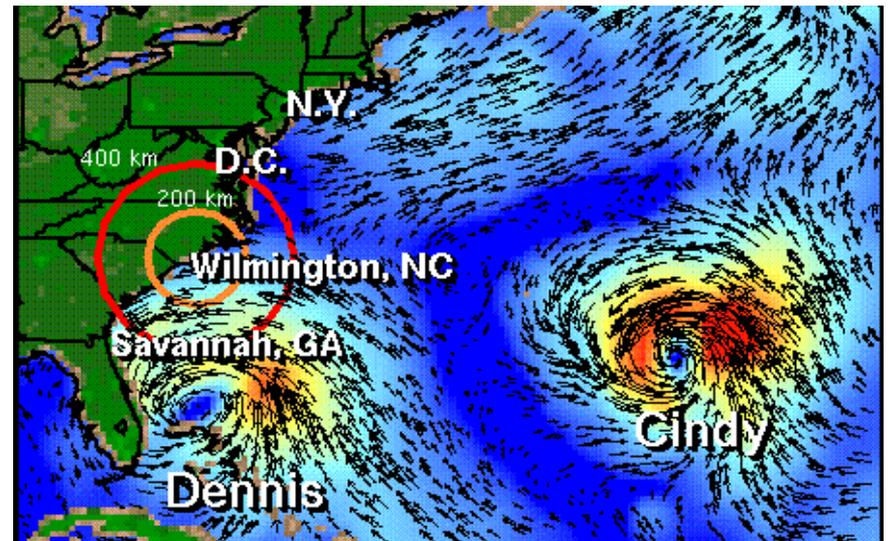
# Sumatra Earthquake Seen by GRACE



# Ocean Vector Winds



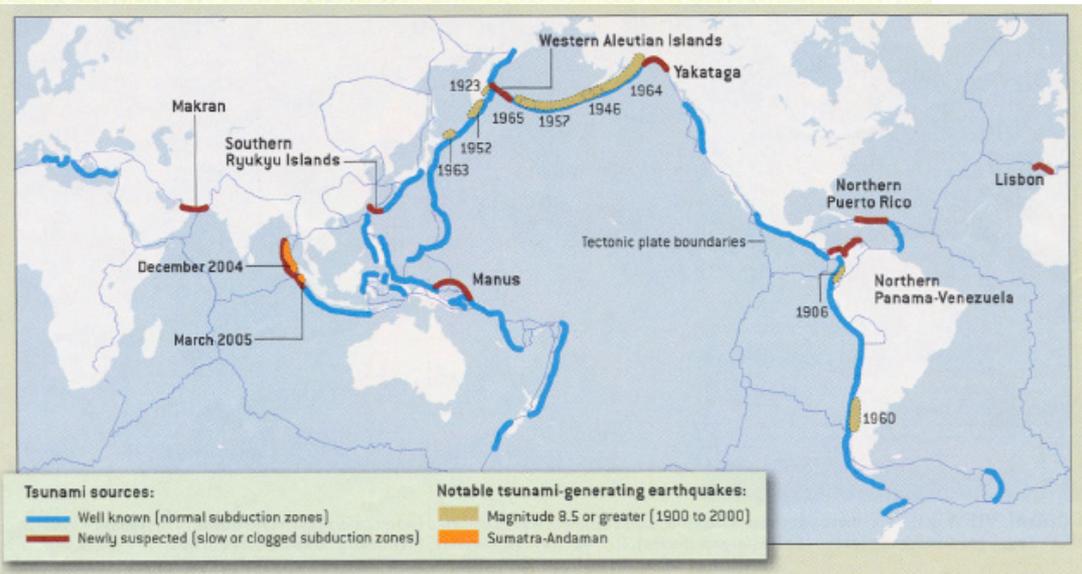
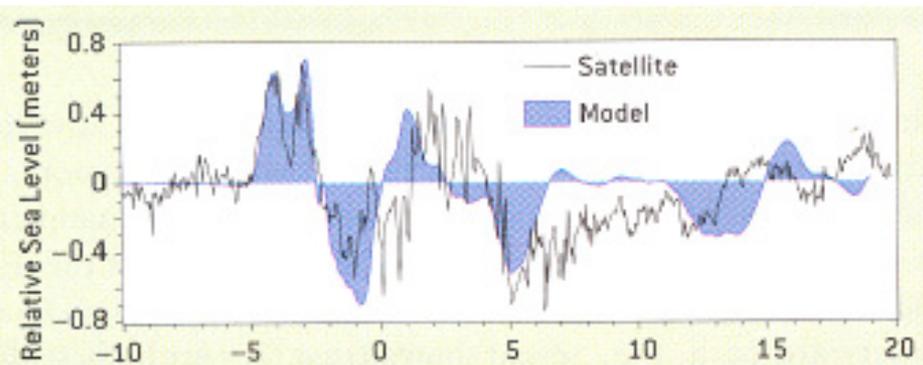
The oceans store more heat in their uppermost 3 meters than the entire atmosphere



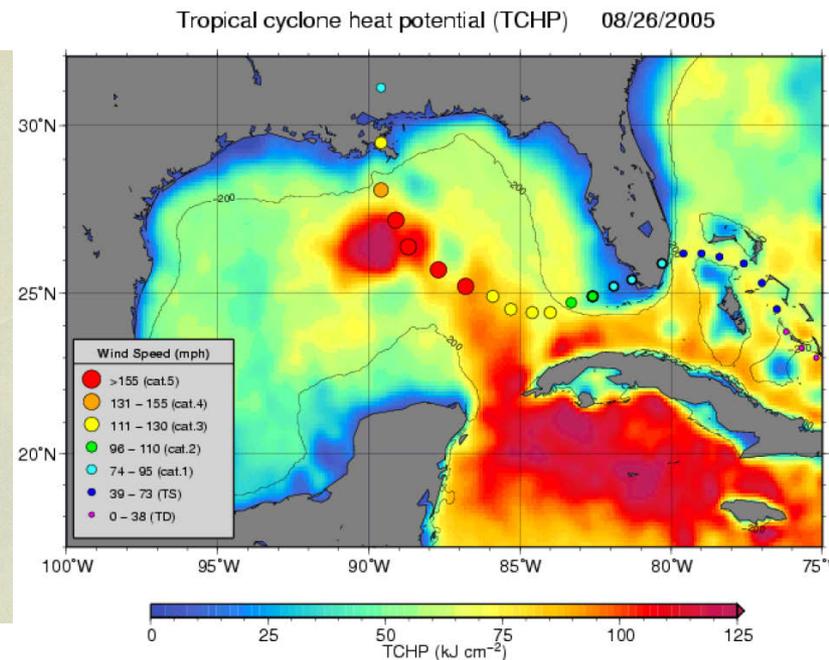
SeaWinds can improve hurricane predictions saving up to \$40 million per event

< 4 m/s    4-6 m/s    4-6 m/s    >8 m/s=15.5kn

# Altimeter Applications



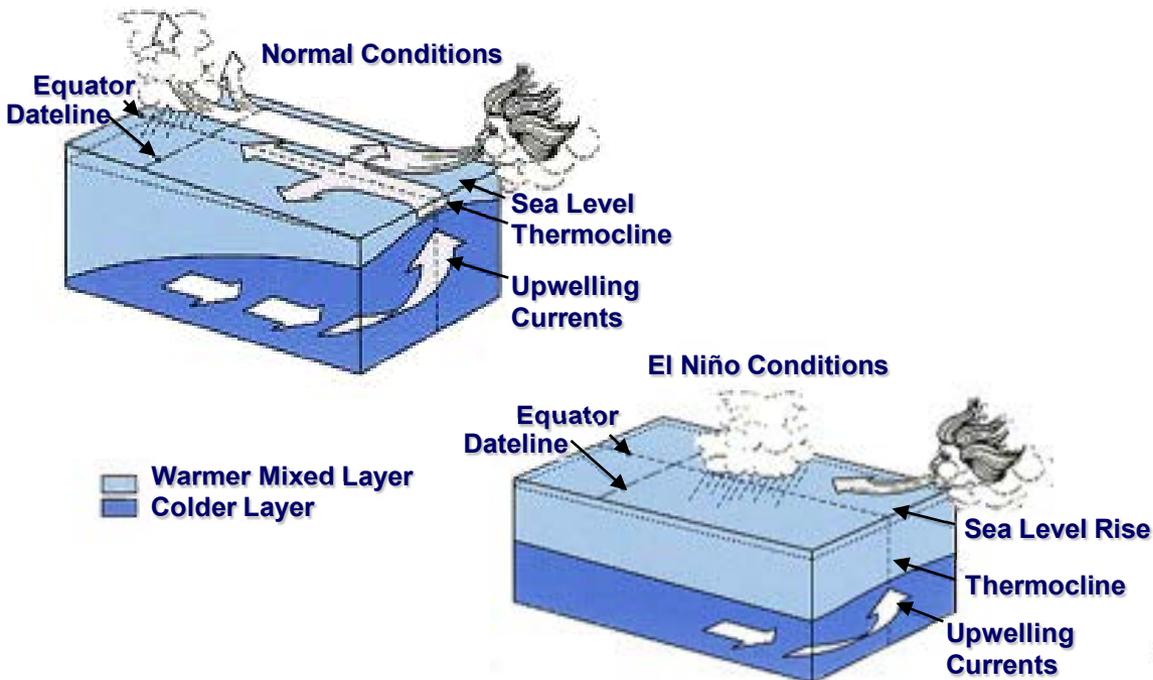
Scientific American, January, 2006



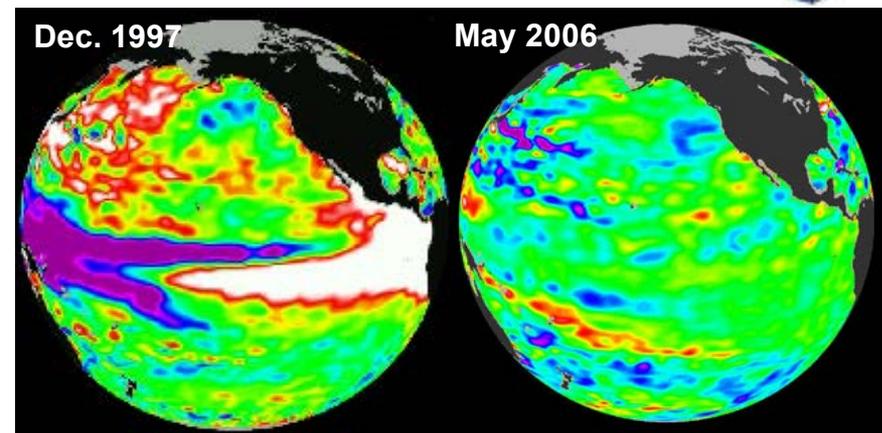
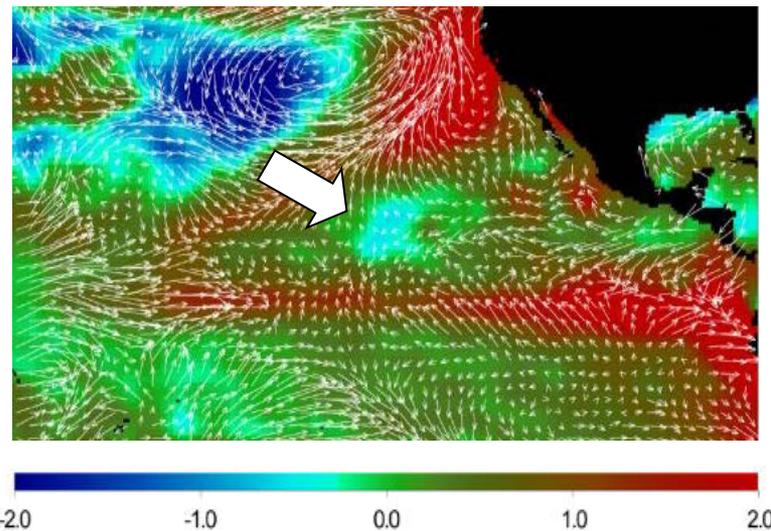
G. Goni and J. Trinanes, NOAA/AOML

**Topex/Jason data were used to validate models of tsunamis wave heights in the open ocean and for hurricane intensity forecasts**

# Predictions of Regional Impacts



Scatterometers show weakening trade winds

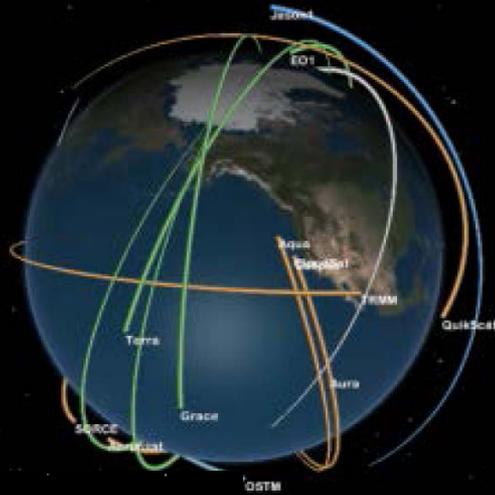


Altimeters show increase in sea surface height



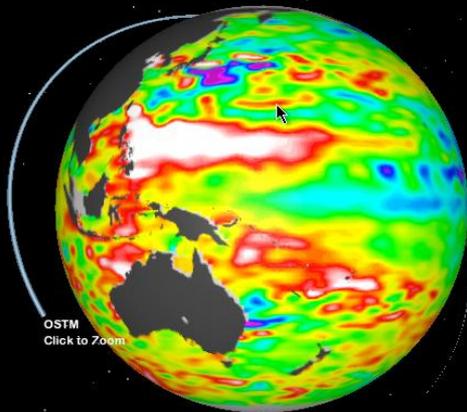
El Niño forecasts are worth \$320 million to the agricultural industry

# Eyes on the Earth



OSTM Elevation from Mean Sea Level  
November 10 - November 20, 2008

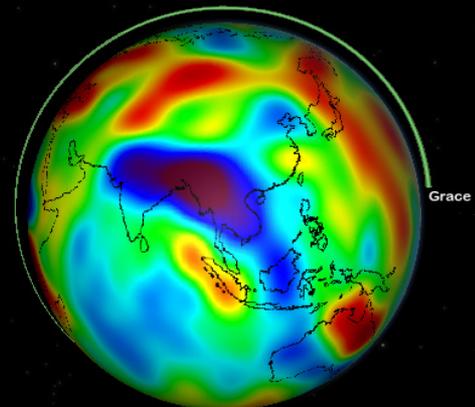
GRACE Gravity Field Map  
March, 2010



129 millimeters  
mm from Mean Sea Level

-180 -90 0 90 180

21° 1' 24" S Lat.  
160° 43' 13" W Lon.



cm of equiv water

-15 -10 -5 0 5 10 15

<http://climate.nasa.gov>

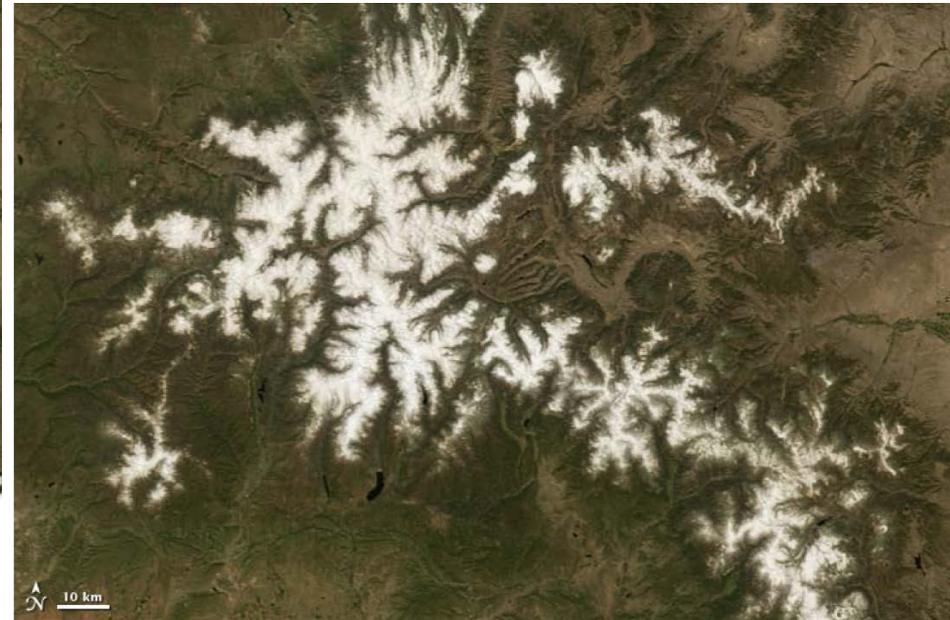
# EARTHNOW iPhone App



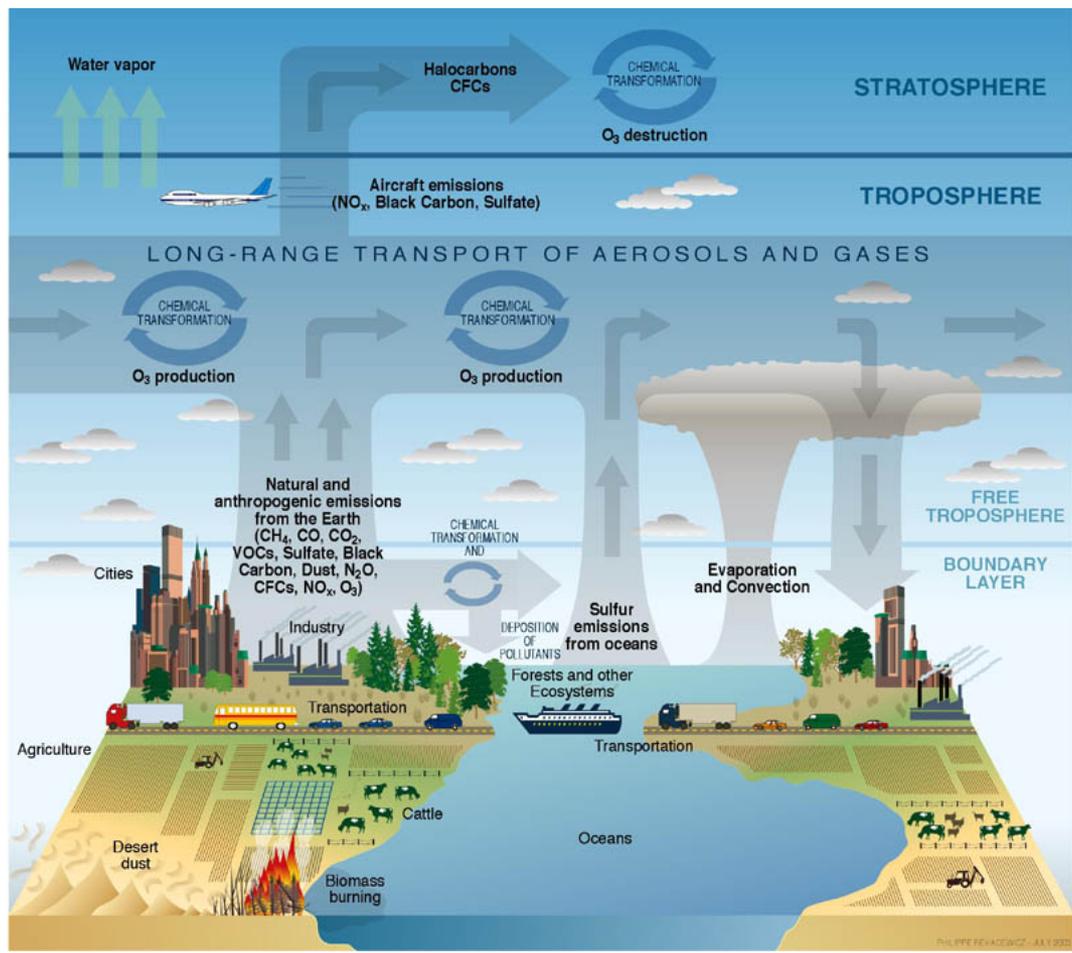
Copyright 2012 California Institute of Technology.  
Government sponsorship acknowledged.

**Back-up**

# Dust Accelerates Snow Melt in San Juan Mountains

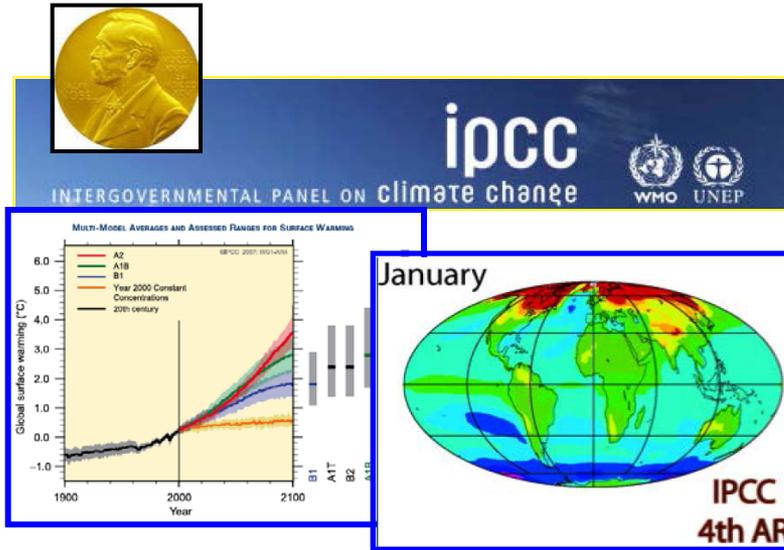


The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured the left image on May 18, 2009, and the right image on May 31, 2008.

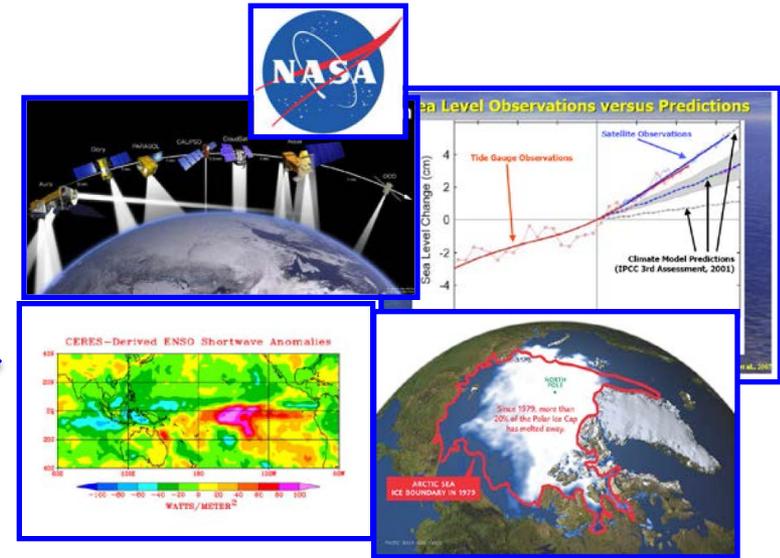


02.23.2011 <<http://en.wikivisual.com/index.php/Air>>

# NASA and CMIP/IPCC: Better Linkage



How to bring as much observational scrutiny as possible to the IPCC process?



How to best utilize the wealth of NASA Earth observations for the IPCC process?

# ESG Gateway: Side-by-Side Archive with CMIP

**Earth System Grid**  
Home Data Account About Contact Us Login

ESG Gateway hosted by the Program for Climate Model Diagnosis and Intercomparison

Search:  for:  Search

To conduct a search, select a category from the pull down menu and/or enter free text into the text box.

**Search Categories**

- Project
  - > CMIP5
  - > TAMIP2
  - > gfdl\_test
  - > obs4MIPS
- + Institute
- + Model
- + Experiment
- + Frequency
- + Product
- + Realm
- + Variable
- + Ensemble

**Welcome to PCMDI**

**PCMDI**

The Program for Climate Model Diagnosis and Intercomparison was established in 1989 at the Lawrence Livermore National Laboratory located in the San Francisco Bay Area. Our staff includes research scientists, computer scientists, and administrative personnel.

The PCMDI mission is to develop improved methods and tools for the diagnosis and intercomparison of general circulation models (GCMs) to simulate the global climate. The need for innovative analysis and interpretation of climate simulations is apparent, as increasingly more complex models are developed, while the disagreements among these simulations are increasing. To improve our understanding of climate system behavior and to improve the quality of climate model simulations, we must be able to account for the differences between the various GCMs for simulation.

**obs4MIPS Project**

**Status of the CMIP5 Archive**

6/3/2011: CNRM-CERFACS decadal hindcast/forecast datasets are available for all realms but sea-ice (10 members already available for all realms ocean, only 3 so far for realms land/atmos/landIce).  
6/25/2011: PCMDI CMIP5 data server is back online. The INM-CM3.0 datasets are available.  
7/7/2011: NCC datasets are now available to all users.  
7/19/2011: PCMDI data server will be down for maintenance on 7/20 17:00 PST. It is expected back online 7/20 17:00 PST.  
7/20/2011: PCMDI data server is back online.  
7/20/2011: Because of a processing fault affecting the MOHC rcp85 data from 2080 onwards, this data has been withdrawn from the archive. They expect to provide us with corrected data in a matter of days at which time a new version of these datasets will be published.  
9/7/2011 - 9/9/2011: The BADC ESGF system will be unavailable from September 7th and 8th. As a precaution you should consider "At Risk" on Friday September 9th.

**ESG Gateway hosted at the NASA Jet Propulsion Laboratory**

Search:  for:  Search Start Over

To conduct a search, select a category from the pull down menu and/or enter free text into the text box.

Please note that the NASA datasets accessible through this gateway are provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. These are not standard NASA satellite instrument products. They may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 models. Community feedback to improve and validate the dataset for modeling usage is appreciated.

**Search Categories**

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**AIRS (Atmospheric Infrared Sounder)**

**AIRS Data Catalog at ESG**  
Documentation: Air Temperature  
Documentation: Specific Humidity  
AIRS Home at NASA/JPL

**AMSR-E (Advanced Microwave Scanning Radiometer - EOS)**

**AMSR-E Data Catalog at ESG**  
Documentation  
AMSR-E Home at NSIDC

**AVISO**

**AVISO Data Catalog at ESG**  
Documentation: Sea Surface Height (SSH)  
AVISO Home

**MLS (Microwave Limb Sounder)**

**MLS Data Catalog at ESG**  
Documentation: Specific Humidity  
Documentation: Air Temperature  
MLS Home at NASA/JPL

**MODIS (Moderate Resolution Imaging Spectroradiometer)**

**MODIS Data Catalog at ESG**  
Documentation  
MODIS Home

**TES (Tropospheric Emission Spectrometer)**

**TES Data Catalog at ESG**  
Documentation: Ozone  
TES Home at NASA/JPL

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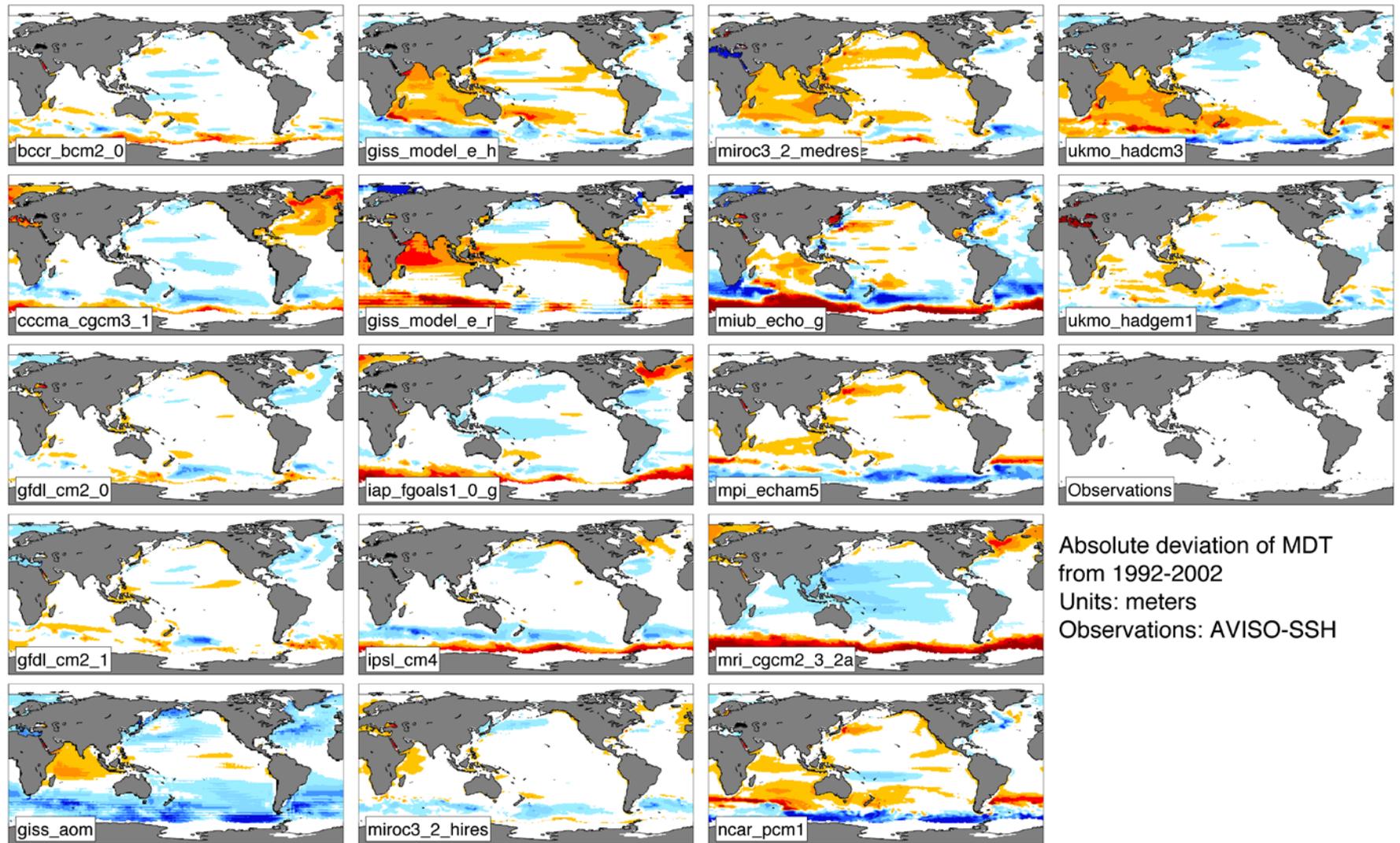
**ESG Federation**

- PCMDI Gateway
- BADC Gateway
- DKRZ Gateway
- NASA JPL Gateway
- NCAR Gateway
- NCI Gateway
- ORNL Gateway
- NERSC Gateway



# CMIP3 Sea Level vs TOPEX/JASON

Mean dynamic topography (GCMs 1992-2002); Obs: Maximenko et al. [2005]) Absolute values (each field has zero mean)

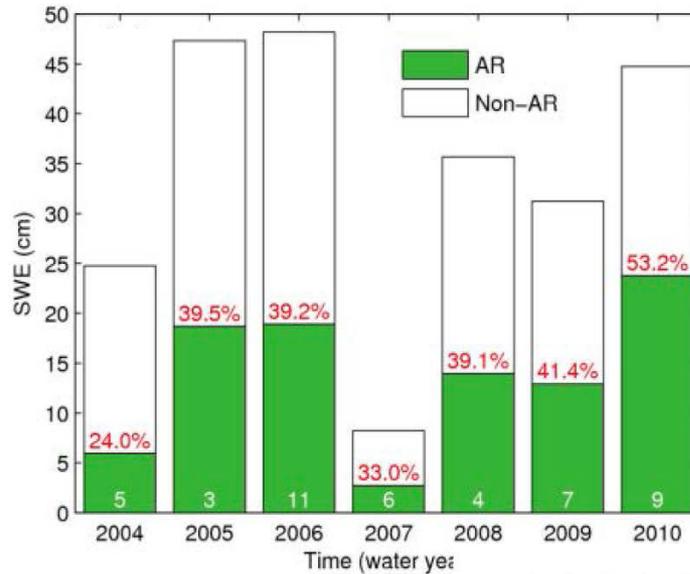
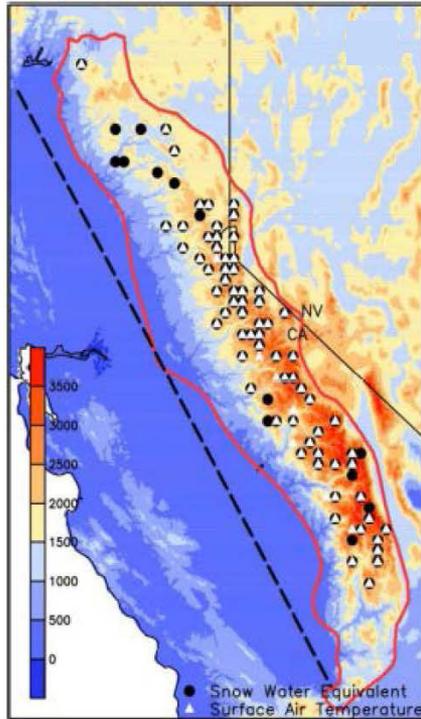


Absolute deviation of MDT from 1992-2002  
Units: meters  
Observations: AVISO-SSH



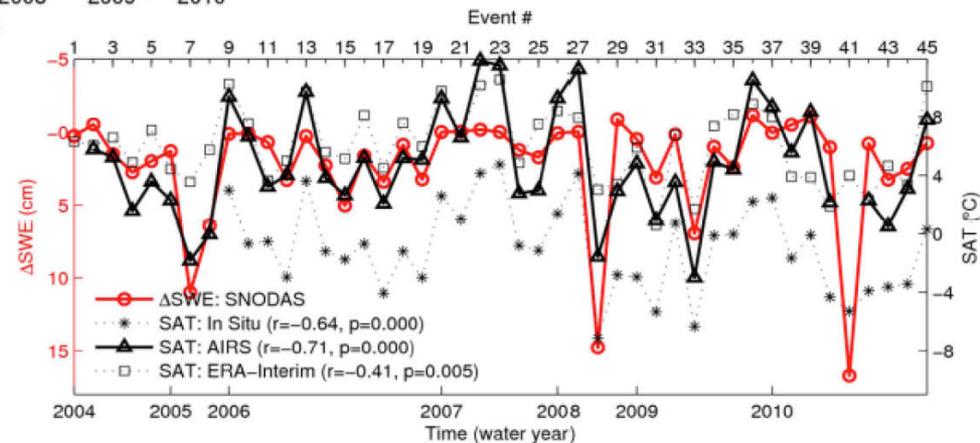
Courtesy F. Landerer (JPL)

# Atmospheric Rivers and Wintertime Extreme Precipitation Events

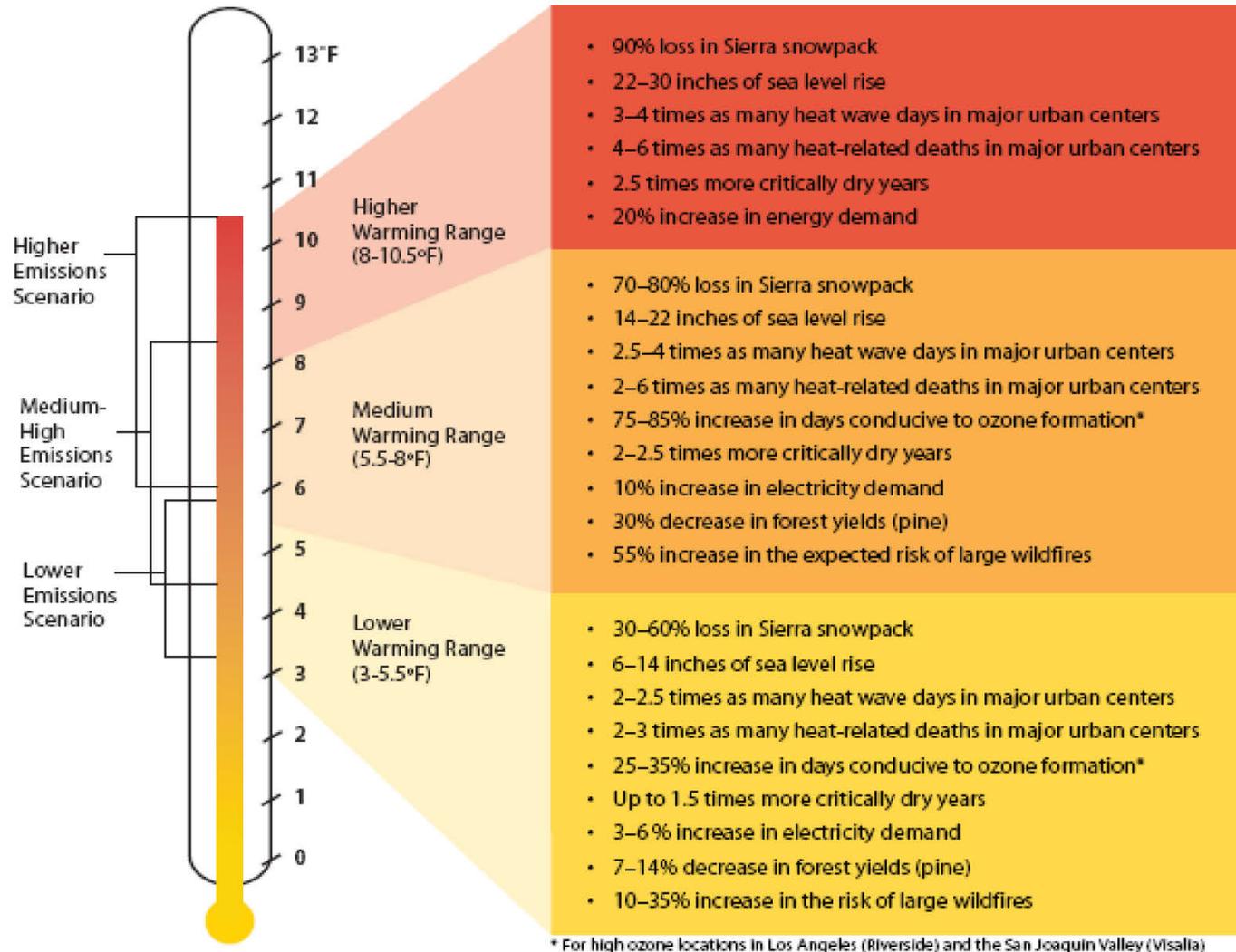


Atmospheric rivers (AR) on average generate ~4 times daily snow water equivalent (SWE) accumulation of non-AR storms.

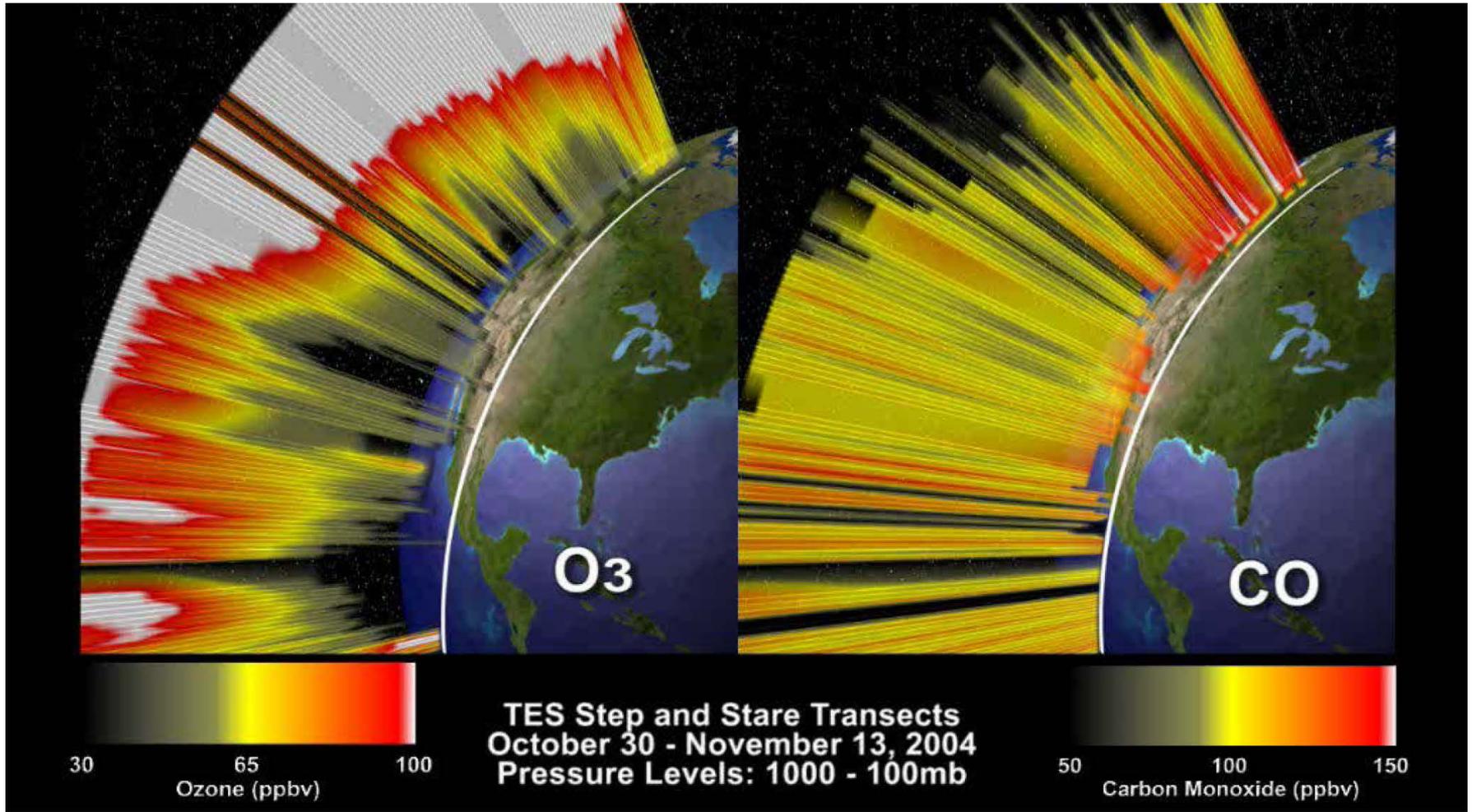
Sierra snowfall (red) is better correlated with surface air temperature (SAT) from AIRS (thick black) than weather models (black boxes).



# Summary of Projected Global Warming Impact, 2070-2099 (as compared with 1961-1990)



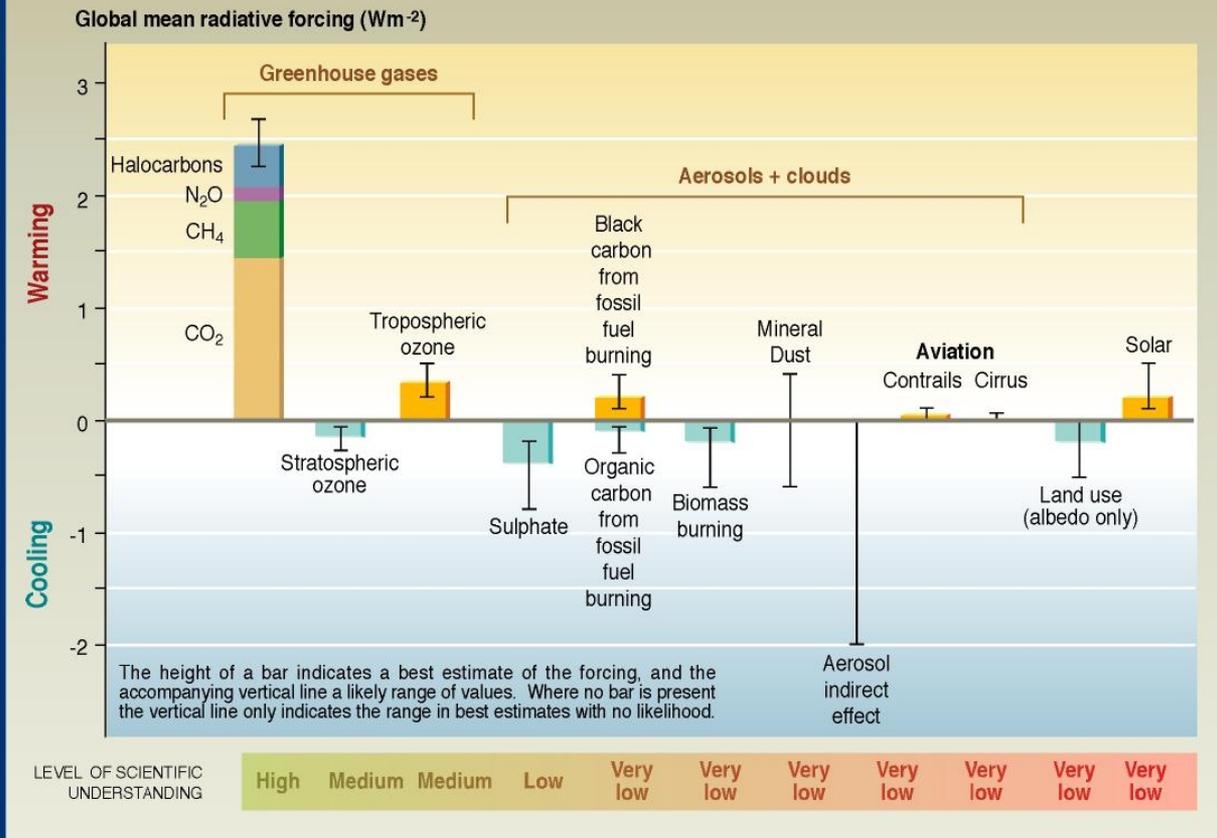
# Thermal Emission Spectroscopy Atmospheric O<sub>3</sub> and CO Measurements



**TES: Houston/AVE 2004 Campaign**

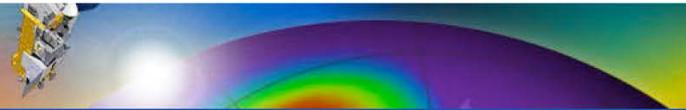
**TES on AURA  
(2004-Present)**

# Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750



SYR - FIGURE 2-2

# Microwave Limb Sounder

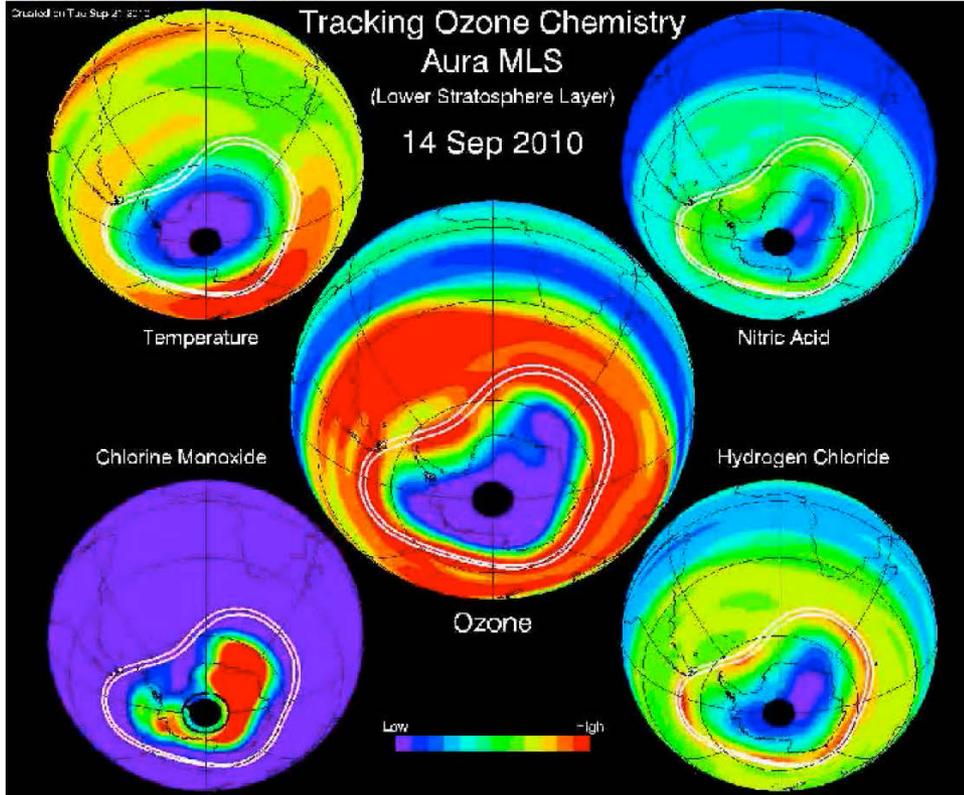


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    - HCN
    - HNO3
    - HO2
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This animation: Aura MLS SH 2010



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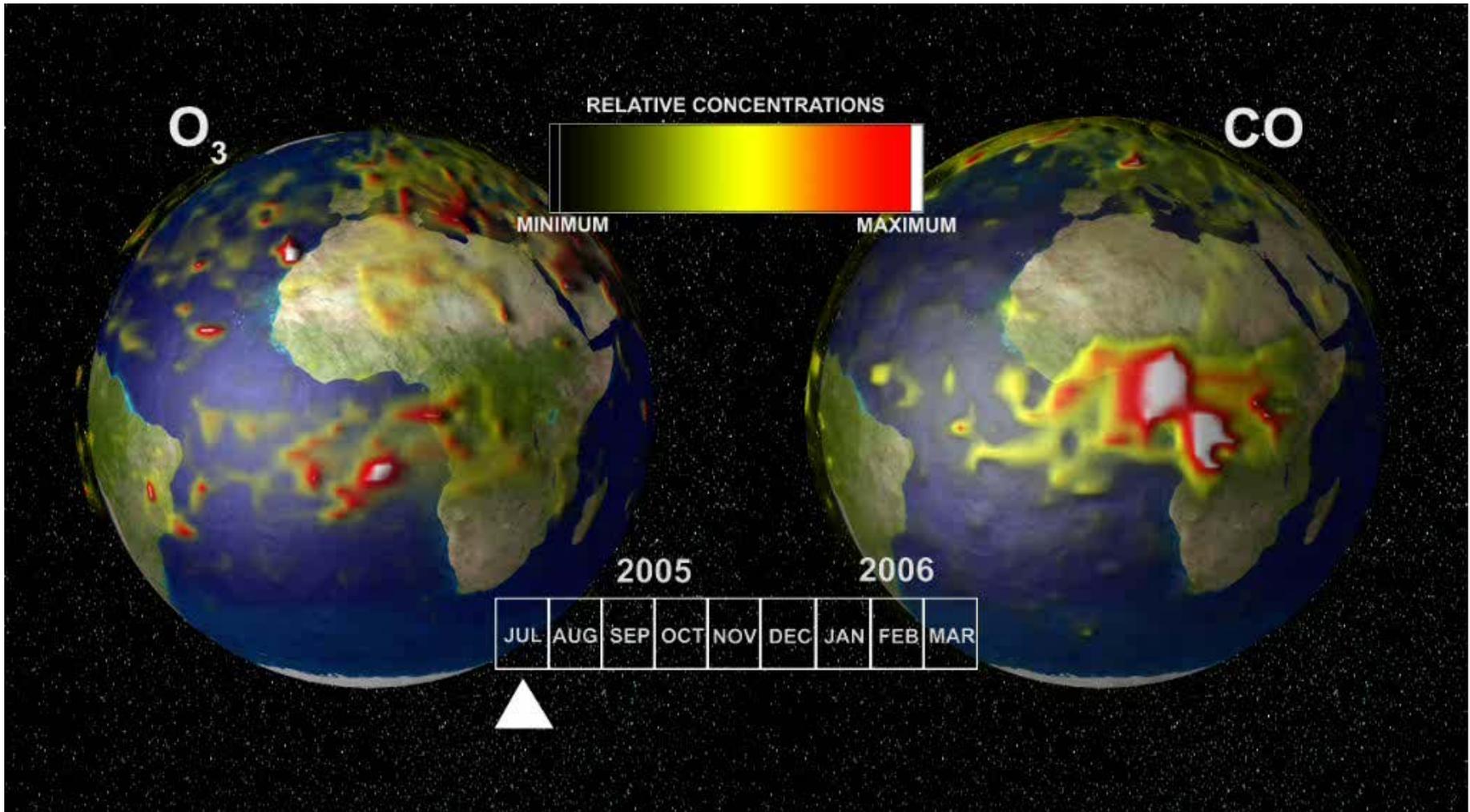
Season

(All search fields are mandatory)

### Technical Information

- [MLS Animation Technical Information](#)
- [MLS-MIPAS Animation Technical Information](#)

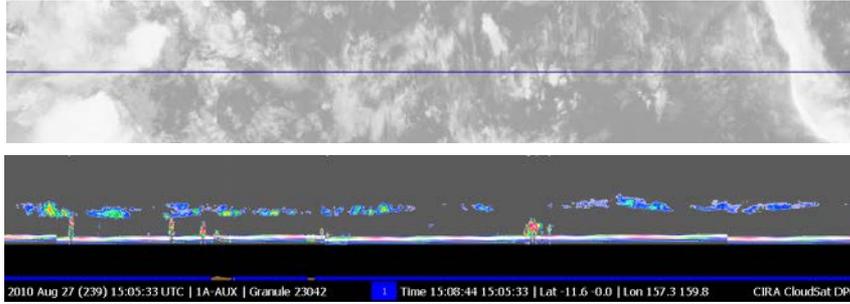
# Tropospheric Emission Spectrometer



High level clouds: 20,000 feet (6,000 meters) cirrus clouds are composed of ice crystals



What we see from the ground



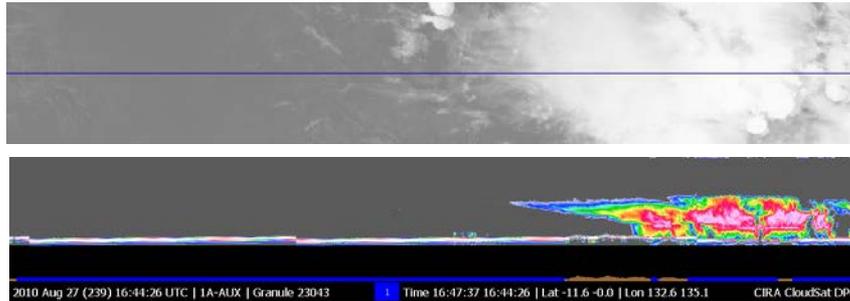
What MODIS Sees)

What CloudSat Sees

Vertically developed cumulonimbus clouds grow to heights in excess of 39,000 feet (12,000 meters) and are a mixture of water droplets and ice crystals



What we see from the ground



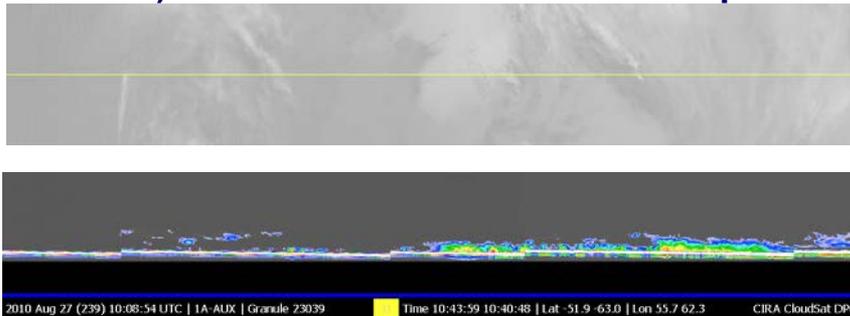
What MODIS Sees)

What CloudSat Sees

Low-level—6,500 feet (2,000 meters)—stratus clouds can be accompanied by light to moderate precip



What we see from the ground



What MODIS Sees)

What CloudSat Sees