Climate Variability and Change Focus Area

The Focus Area Objective:

Understand the role of oceans, ice, land and atmosphere in the climate system and improve predictive capability

Don Anderson

With the help of many others…

16 May 2007

Climate Variability and Change

Component Programs:

- Physical Oceanography
- Cryospheric Science
- Modeling, Analysis and Prediction
  - Cloud Modeling & Analysis Initiative (CMAI)
  - Global Modeling Initiative (GMI) & GEOS-5/DAS
  - Estimating the Circulation & Climate of the Ocean (ECCO-II)
  - GISS/Model
- High End Computing
- **Water and Energy Cycle Study**
- **Atmospheric Composition**
- **Precipitation Science**
- **Carbon and Ecosystems**
- **Solid Earth**

(Water and Energy Cycle Study through Solid Earth: contributing programs)

Observational Assets:

Satellites: **TOPEX, Jason, Quikscat, ICESat, Terra, Aqua, CERES, AMSR, TRMM/TMI, GRACE, CloudSat, CALIPSO, AURA/MLS, OCO, Glory, OSTM, SWOT, Aquarius, MEOSCAT. GPM, NPP, ICESat-n, Sea Ice Thickness mission**

Ground: SHIPS, hydrographic surveys, surface drifters, ARGO buoys, AGAGE, NDAAC, AERONET, MPLNet, NATIVE, SMART-COMMIT, other agency networks

FY07 Budget

Climate Variability and Change Focus Area
FY07 R&A Budget: ~$50M

High End Computing
FY07 Budget: ~$27M

Centers and Leads

Modeling, Analysis and Prediction

- **HQ (Anderson)**
- **GSFC**
  - **GMAO (Rienecker)**
  - **SIVO (Seablom)**
  - **GISS (Hanson)**
- **MSFC (Lapenta)**
- **JPL (Ferraro)**
- **LaRC (Wielicki)**

Physical Oceanography

- **HQ (Lindstrom)**
- **JPL: (Fu, Rodriguez, Lagerloef, Zlotnicki)**
- **GSFC (Hakkinen)**

High End Computing

- **HQ (Lee)**
- **GSFC (Webster)**
- **ARC (Biswas)**

Cryospheric Science

- **HQ (Martin)**
- **GSFC (Abdalati)**

Selected Scientific Accomplishments & Key Results

Cryospheric Sciences

- **ICESat, INSAR, GRACE indicate that ice is changing dramatically in both the Arctic and Antarctic, and on the land and sea**
- **All coupled GCM's predict losses of Arctic sea ice in the next 50-100 years UNDERESTIMATE present-day loss, so the disappearance of Arctic sea ice is likely to come sooner.**

Physical Oceanography:

- **TOPEX/POSEIDON and JASON global sea surface height trend published in the IPCC 2007**
- **Sea surface height calibrated to ocean heat content is used by NOAA to improve hurricane path and intensity forecasts.**
- **Quikscat ocean vector Winds are assimilated into NCEP, ECMWF, and other operational weather-forecast models and providing valuable insight on tropical cyclone location**

Modeling, Analysis and Prediction:

- **GEOS-5 is ESMF compliant and has been released to the community**
- **GISS coupled model contributed to *IPCC AR4***
- **GEOS-4 coupled with GSFC strat-chem contributed to *National ozone assessment***
- **NASA and NOAA jointly developing the Gridpoint Statistical Interpolator (GSI) data assimilation system (JCSDA)**
- **The Modern Era Retrospective-analysis for Research and Applications (MERRA)**
- **Sharing model components between GEOS-5, ModelE, GFDL and CCSM**
- **Advanced ocean data assimilation (GMAO, ECCO); advanced land data assimilation (GMAO)**
- **Developed and implemented coupling between GEOS-5 and WRF for global to regional scale problems—field campaign and satellite validation support**

Future Issues/Opportunities/Challenges

Physical Oceanography and Cryospheric Science

- OSTM launch 2008 - strengthen science team and ties to NOAA
- Aquarius - Revolutionary for physical oceanography, need to strengthen science investment prior to 2010 launch
- Support formulation and development:
  - SWOT: Surface Water and Ocean Topography mission (NRC DP)
  - XOVWM: Extended Ocean Vector Winds
- ICESat-II (Decadal Survey)

Modeling, Analysis and Prediction:

Short-term Climate Prediction:

- Successful forecasts of large anomalies, but need to improve forecasts of smaller anomalies, higher order statistics and uncertainty
- Regional climate impacts require high resolution and greater skill at subseasonal timescales
- Prediction of extreme weather events requires large ensembles
- Need to improve models:
  - Atmospheric models have major deficiencies in moist processes limiting prediction skill, and satellite data assimilation;
  - Ocean models are deficient in surface and interior mixing parameterizations
- Computational resource requirements are significant

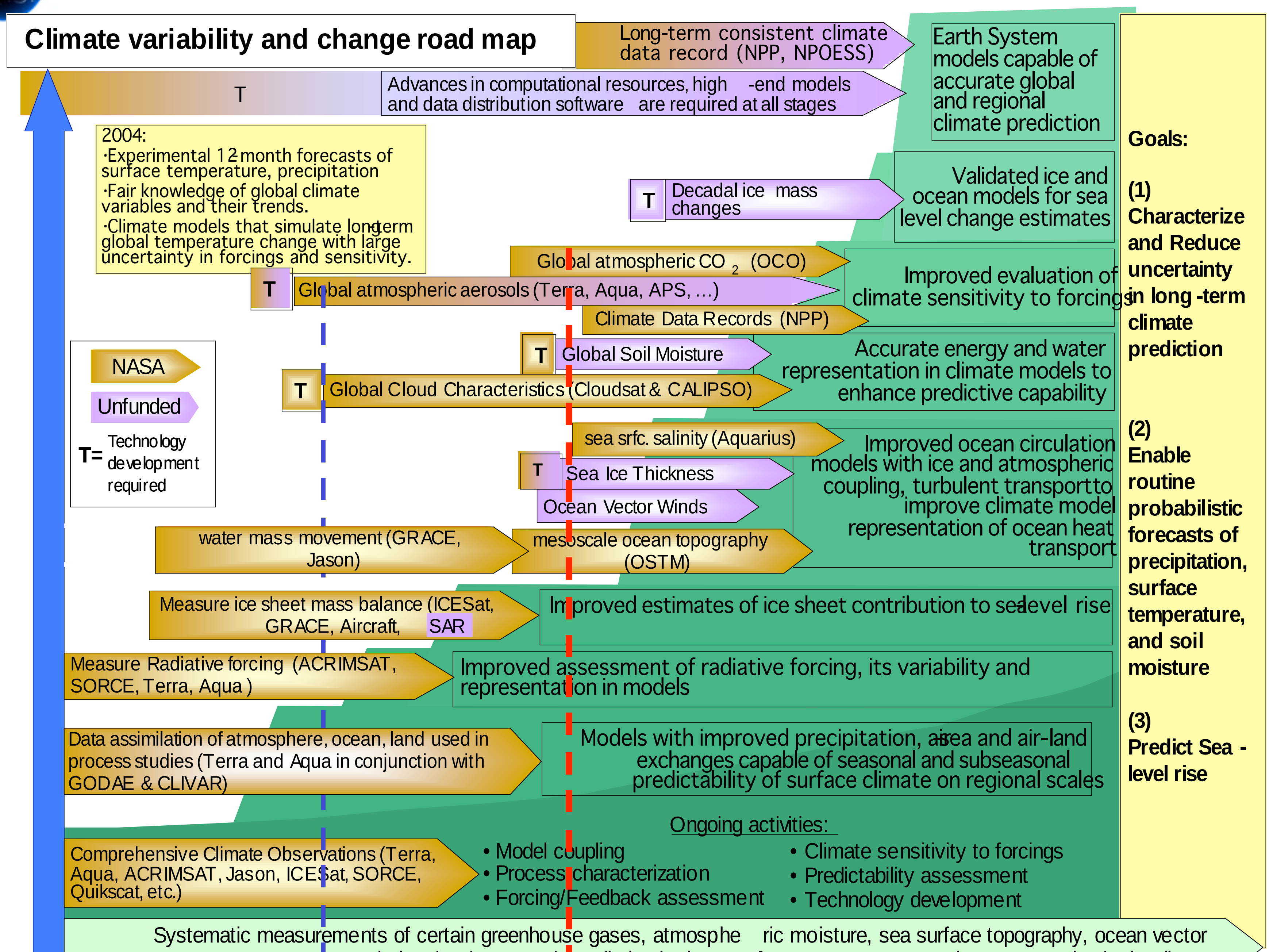
Climate Change:

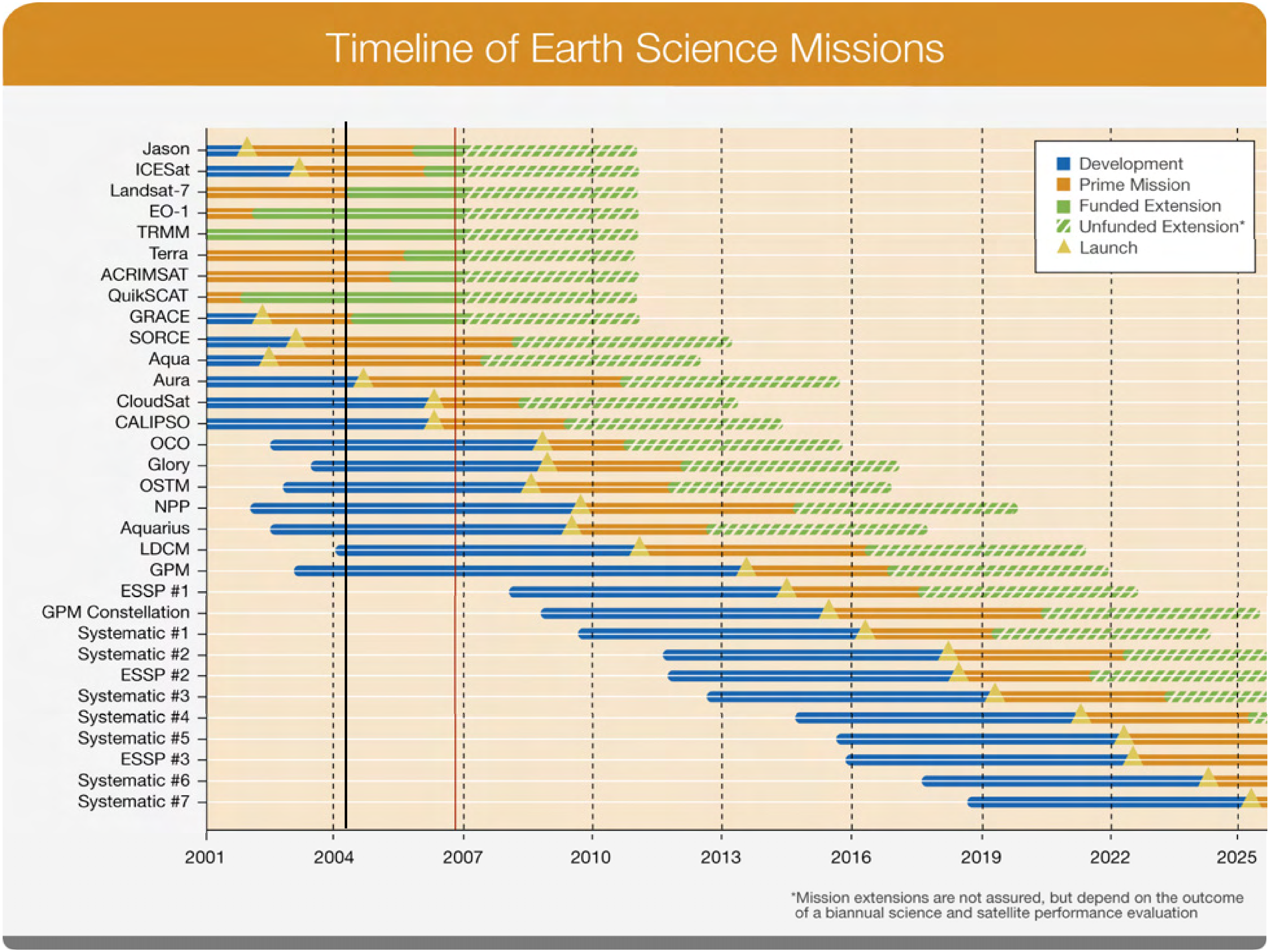
- Climate change models need improved representation of current climate state and variability
- Tension between reducing model biases and increasing model complexity
- Climate models need credible ice sheet models to reduce uncertainty in sea level rise projections
- Need to improve models:
  - Atmospheric models have major deficiencies in moist processes
  - Ocean models are deficient in surface and interior mixing parameterizations

Presentation Outline

- Climate Variability and Change Road Map
- NASA missions supporting the CVCFA
- Observational Contributions/Results
  - Cryosphere Science
  - Physical Oceanography
  - Aerosols
  - Clouds
- Modeling, Analysis and Prediction Program Results
  - Infrastructure
  - Cloud Modeling & Analysis Initiative (CMAI)
  - Global Modeling Initiative (GMI) & GEOS-5/DAS
  - Estimating the Circulation & Climate of the Ocean (ECCO-II)
  - GISS/Model
- The Path Forward

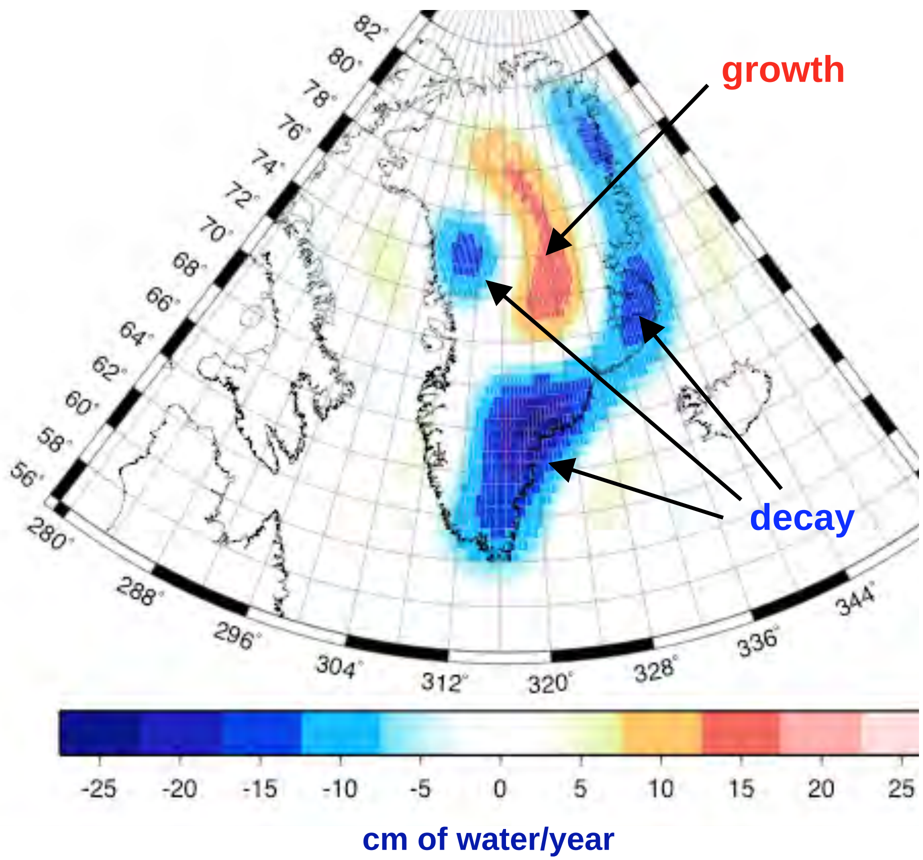
A Time to Reflect……



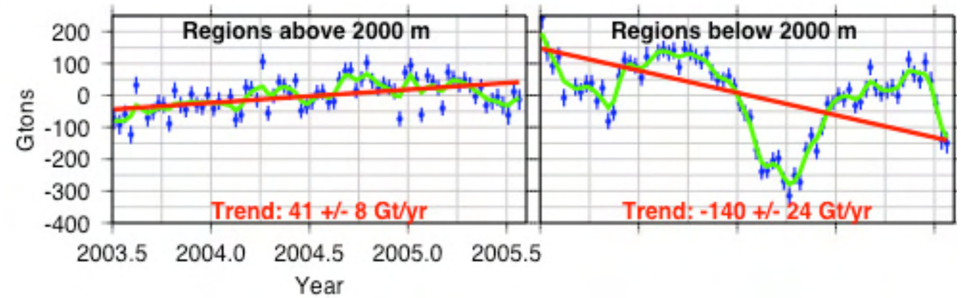

Timeline of Earth Science Missions
Jason
ICESat
Landsat-7
EO-1
TRMM
Terra
ACRIMSAT
QuikSCAT
GRACE
SORCE
Aqua
Aura
CloudSat
CALIPSO
OCO
Glory
OSTM
NPP
Aquarius
LDCM
GPM
ESSP #1
GPM Constellation
Systematic #1
Systematic #2
ESSP #2
Systematic #3
Systematic #4
Systematic #5
ESSP #3
Systematic #6
Systematic #7
2001
2004
2007
2010
2013
2016
2019
2022
2025
Development
Prime Mission
Funded Extension
Unfunded Extension*
Launch
*Mission extensions are not assured, but depend on the outcome of a biannual science and satellite performance evaluation

Greenland Ice Thickness Changes from GRACE

- Spatial signal observed using MASCON solution of GRACE data (Luthcke et al., 2006)
- Melt (in red below) takes place below 2000 m
- Growth (in blue below) takes place above 2000m



Observed annual signal (Luthcke et al., 2006)



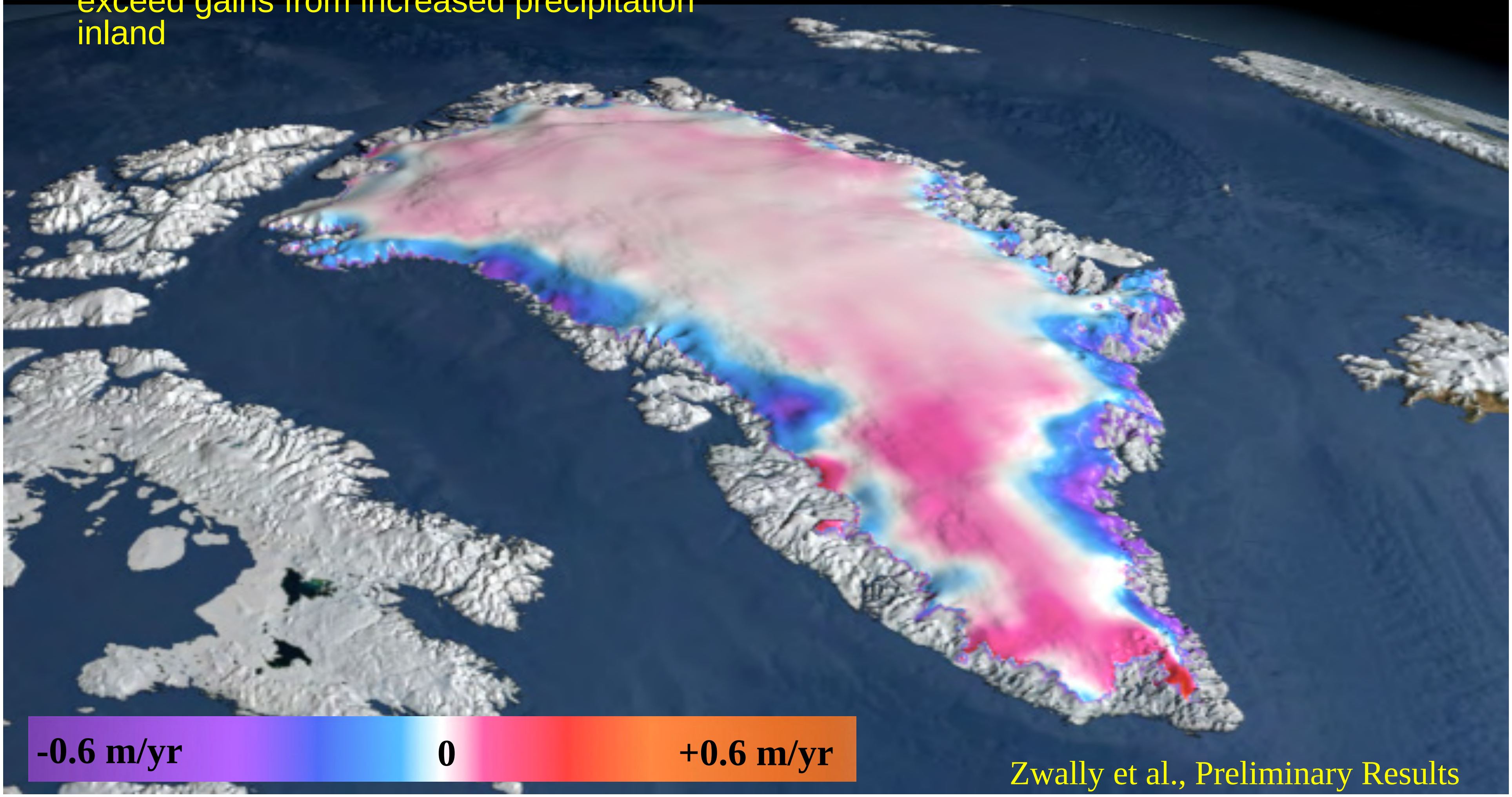
Comparison with results from previous NASA aircraft campaigns and radar altimetry observations in 1990's shows a change from approximate balance to a loss of about 20% of the net input, which is a significant change over a period of less than 10 years. Contribution is approximately 0.3 mm/yr sea level rise (10% of current rate).

Processes of significant ice depletion at the margins, through melting and glacier acceleration, are beginning to dominate the interior growth as climate warming has continued."

Greenland Changes Observed by ICESat

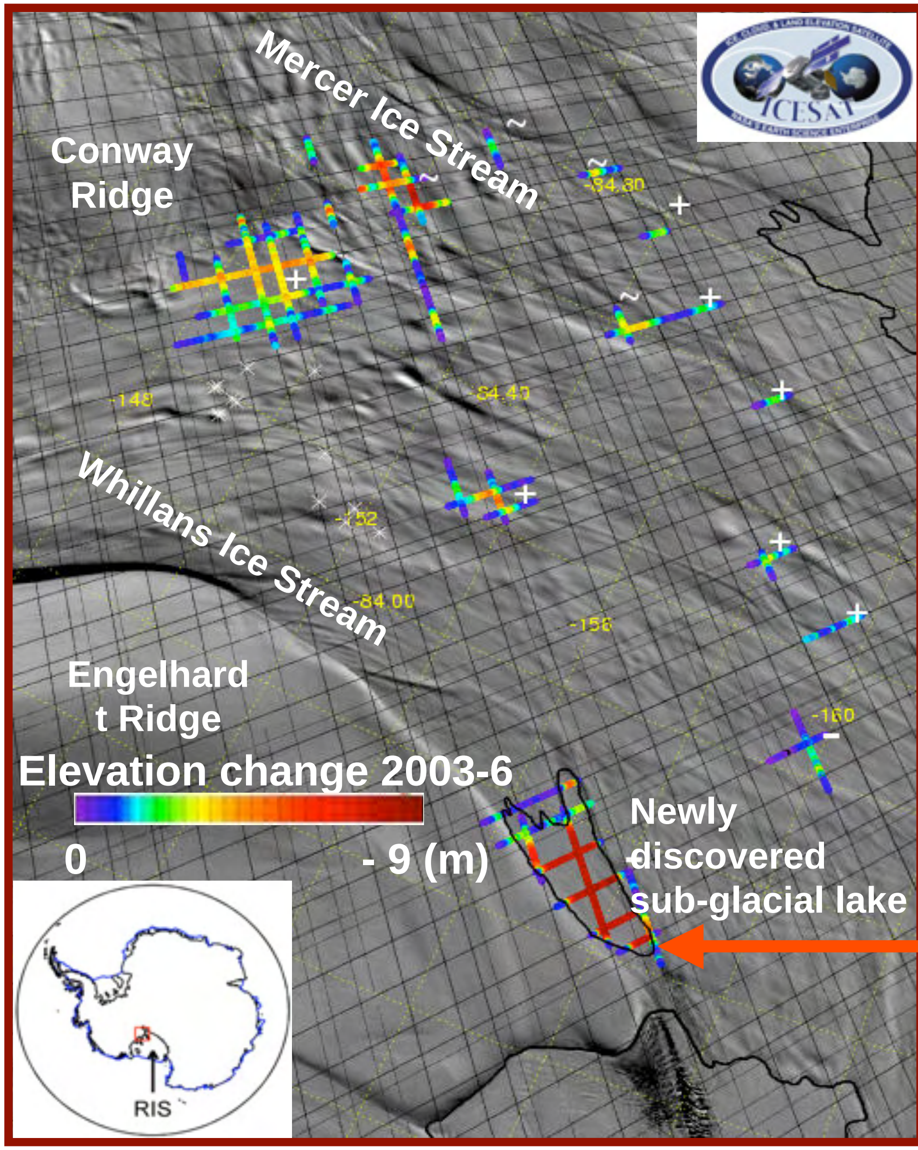
- Enhanced thickening inland and enhanced thinning at edges since the 1990's.
- Mass losses from increased melting near margins and accelerating glacier outflow exceed gains from increased precipitation inland

- Net mass loss of about 100 Gt/yr (0.3 mm/yr sea level rise)
  – consistent with GRACE mascon solutions (Lutchke et al., Science 2006).

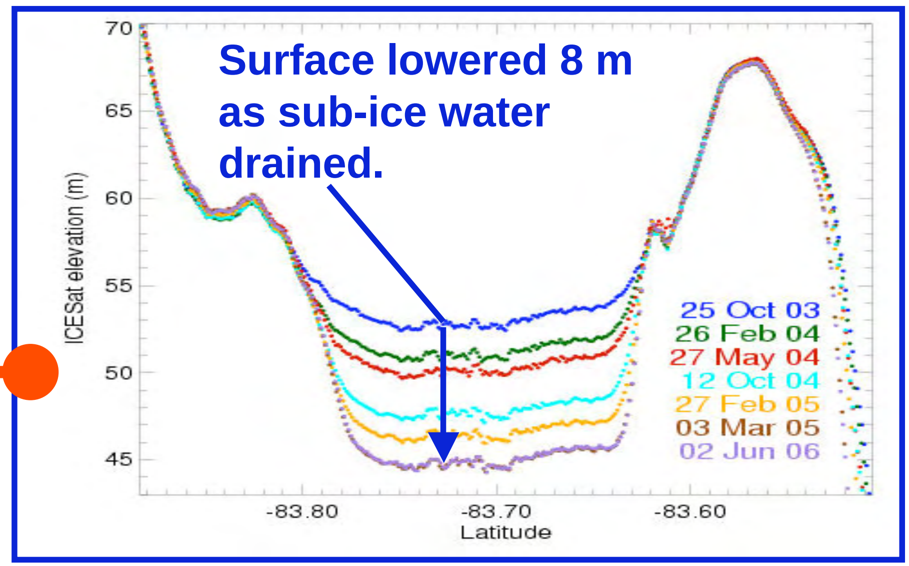


Zwally et al., Preliminary Results

Major ICESat Discovery: Sub-glacial water movement



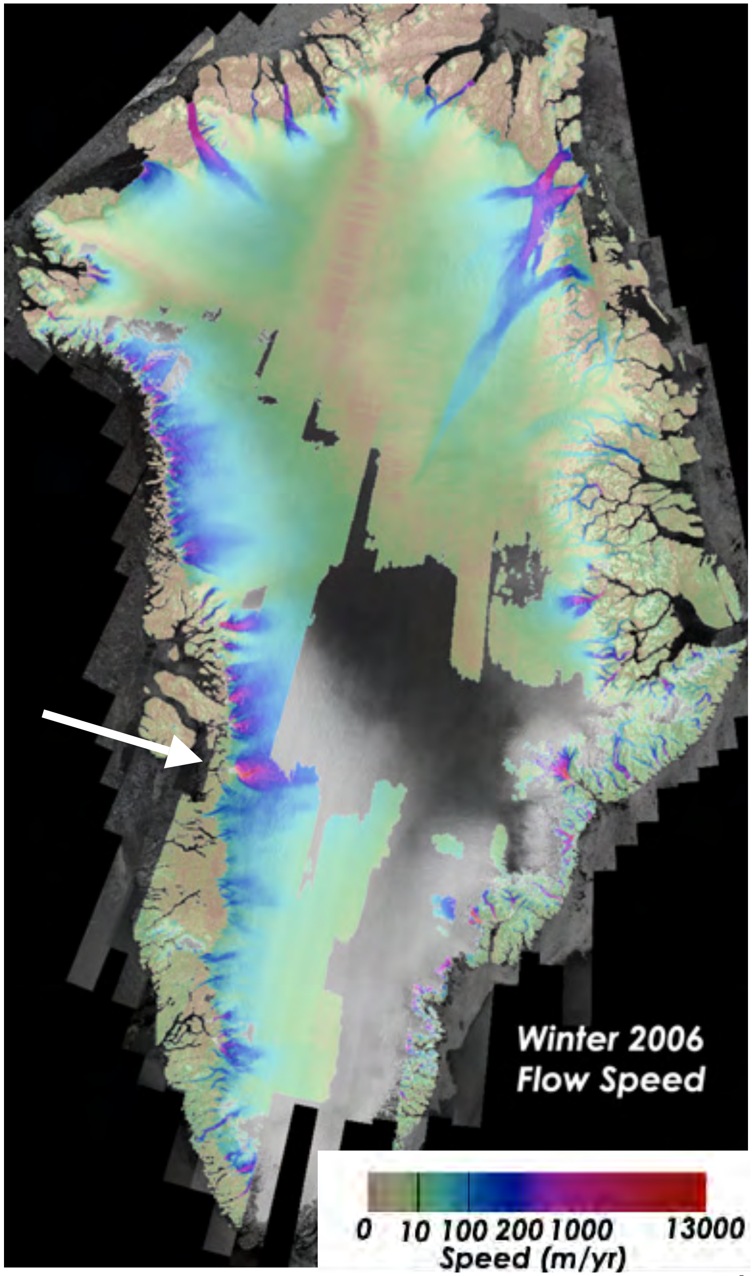
- ❑ Widespread sub-glacial water system beneath West Antarctic ice streams discovered with ICESat laser altimetry.
- ❑ Surfaces inflate as subglacial lakes fill and deflate as they drain. (Lake is about 10-km wide by 40-km long.)
- ❑ ICESat provides new information on sub-glacial processes that affect rates of ice discharge from polar ice sheets.



Fricker et al., Science Online Express, Feb 16, 2007

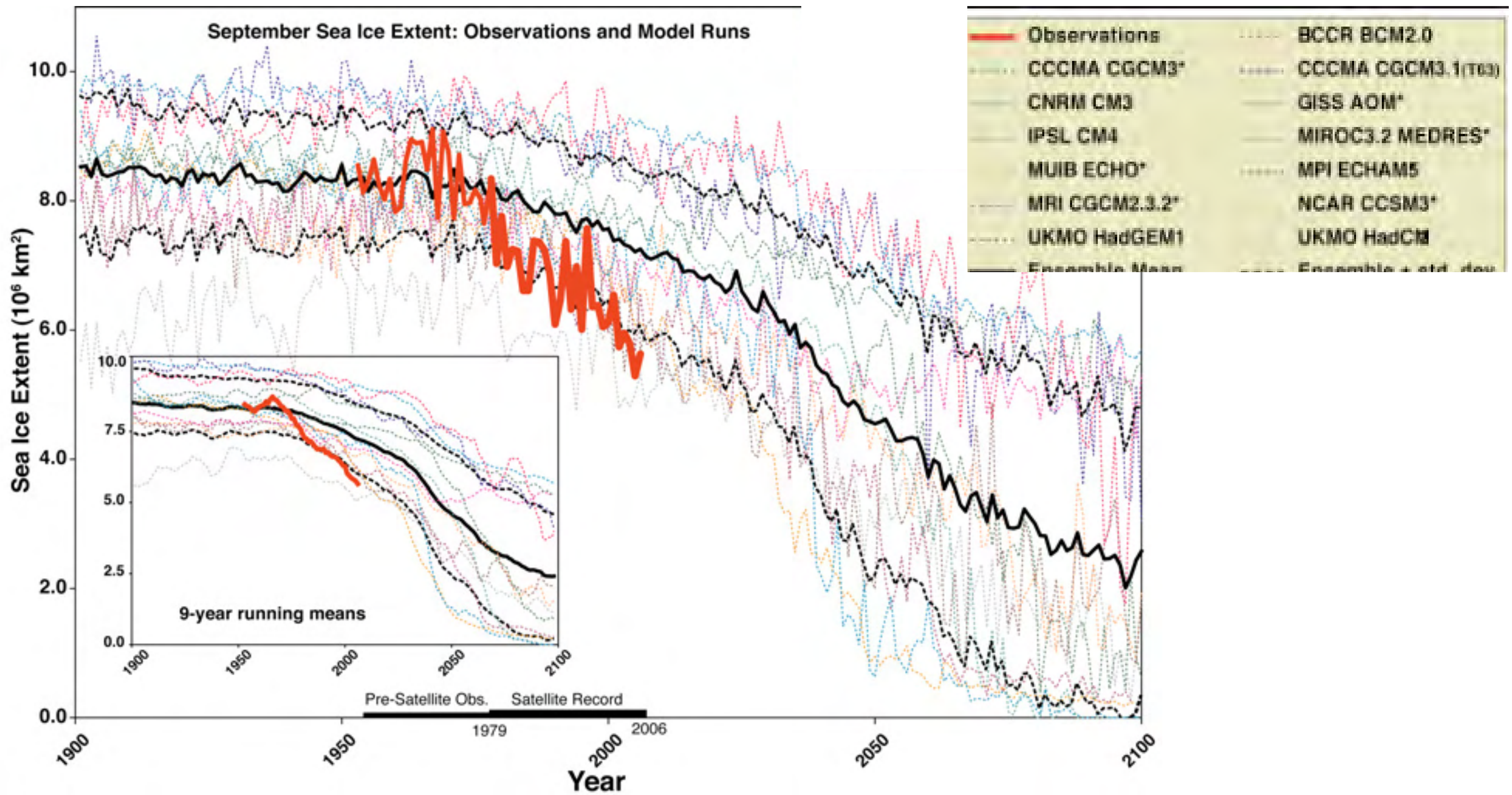
Greenland Changes Observed by INSAR

- **Flow Speeds of the Greenland Glaciers during Winter 2006 from Interferometric SAR (INSAR)**
- **In the past five years, such measurements show that the glaciers have been accelerating**
- **The other interesting factor is that the icecap is mostly surrounded by mountains, so that the outlet glaciers are very narrow**
- **The Jacobshaven glacier (arrow), which produces 50 km^3 of ice per year, is only 6-10 km across**



Courtesy Ian Joughin

Artic Sea Ice Trends: Models versus Reality….



ALL of the models that predict losses of Arctic sea ice in the next 50-100 years UNDERESTIMATE present-day loss, so the disappearance of Arctic sea ice is likely to come sooner. The missing variable that contribute to these underestimates is sea ice thickness for which we are now getting estimates from ICESat.

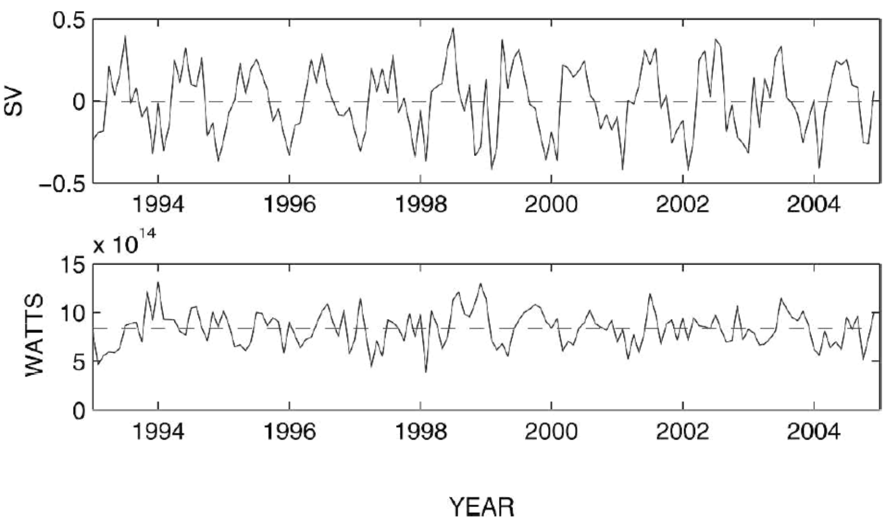
Physical Oceanography: Results from Jason (and TOPEX)

Is the Atlantic Meridional Overturning Circulation changing slowly?

Neither the volume transported by the ocean (top, in million tons/sec), nor the heat carried by ocean waters (bottom, in watts), both in the N. Atlantic, across 26°N, computed top-to-bottom, show any trend in the MOC between 1993 and 2005.

Satellite altimetry and other data constraining numerical ocean models thus contradict previous estimates based on insufficient data.

Volume transported by ocean in N. Atlantic across 26º N (tons x 10^6 s^{-1})



Heat Transported by ocean in N. Atlantic across 26º N (Watts)

C. Wunsch and P. Heimbach, 2006

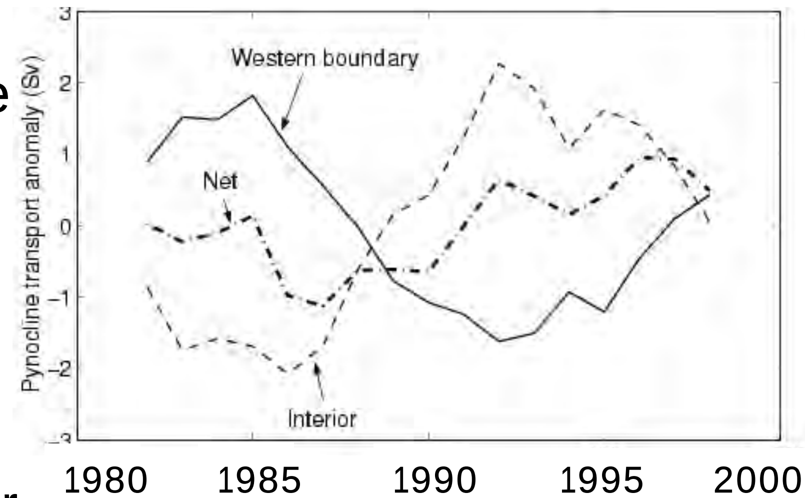
Physical Oceanography:

ERS-2 and TOPEX

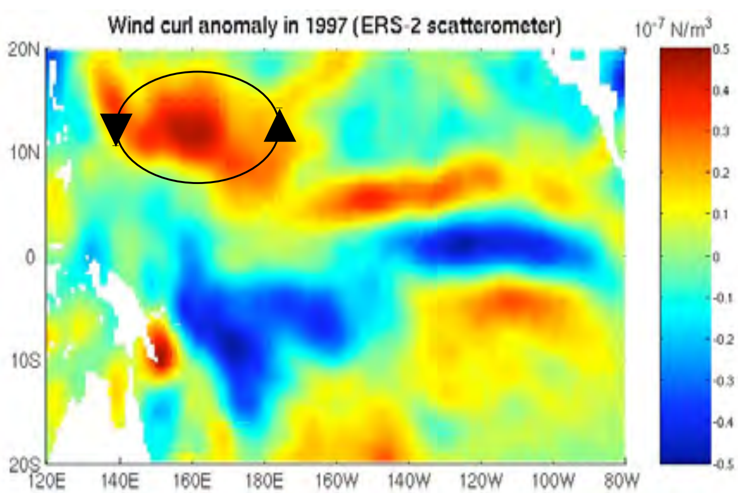
Tropical-subtropical exchange that drive interannual climate variability is out of phase between the ocean interior and the western boundary.

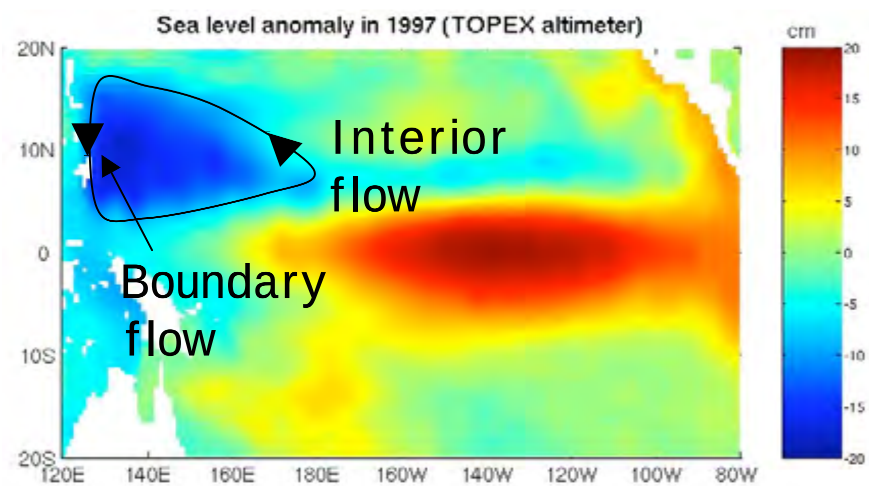
Monitoring the ocean as a whole is critical for understanding climate.

Ocean Mass Transport (@10N)



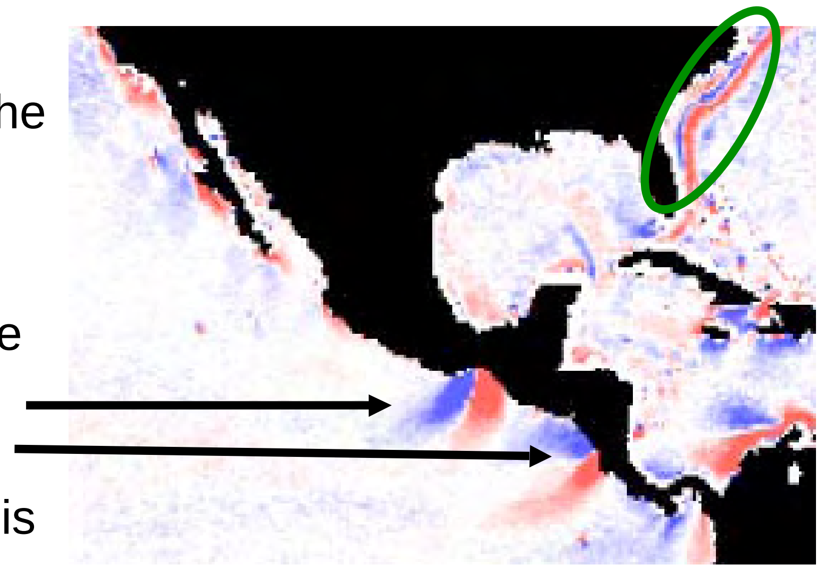
Wind stress anomaly (curl, left) off the equator during El Nino drive anomalous gyre (right)





Physical Oceanography: Results from QUIKSCAT

- QUIKSCAT data revealed persistent (4-year average) small-scale features in the ocean wind curl (Figure) and their relationship to sea surface temperature (SST) gradients.
- The most striking features in the Figure are the Tehuantepec winds, as air crosses narrow passes in central America towards the Pacific, and the curl associated with gradients in SST over the Gulf Stream. This is a small section of a global map, the key advantage of satellite data.
- "Although the intense storms that are responsible for this strong 4-year average curl are intermittent and seasonal, they are important drivers of ocean convection that communicates climate change to the deep ocean" (Chelton et al, 2004)

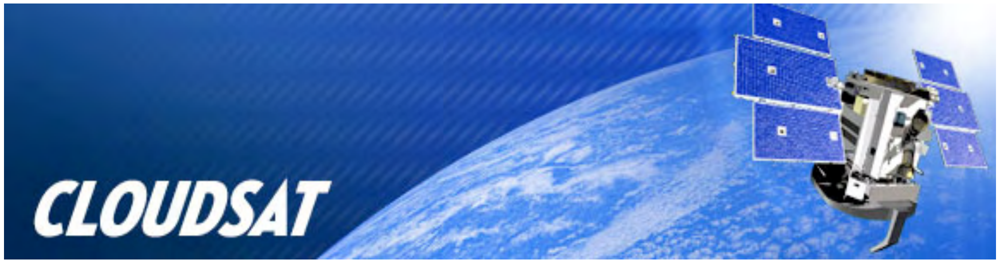


Chelton, Schlax, Freilich and Miliff, 2004, Science 303.

Park, K. A., Cornillon, P., and Codiga, D. L., 2006, J. Geophys. Res. 111.

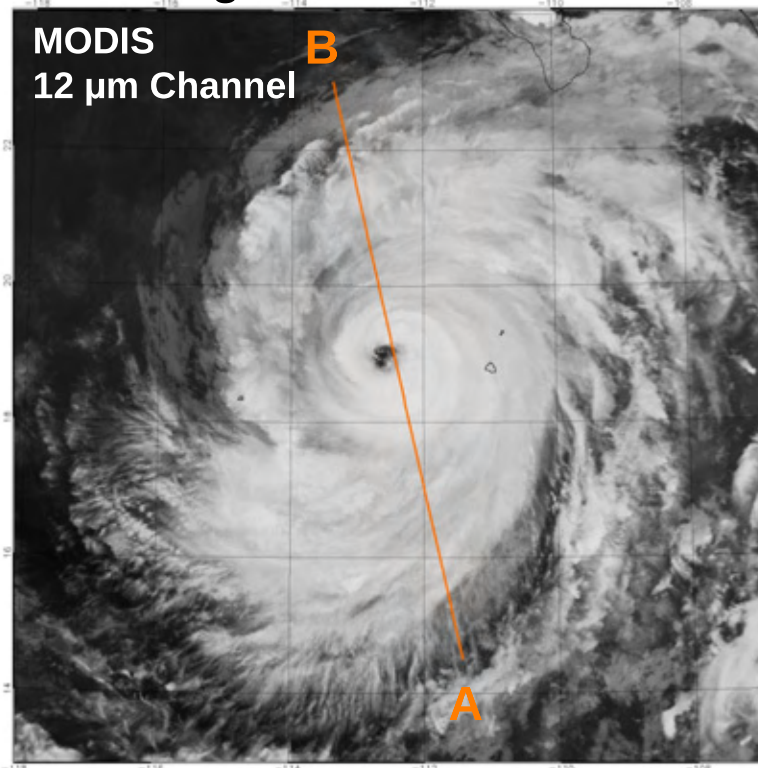
Physical Oceanography: PRODUCTS and 'ASSESSMENT'

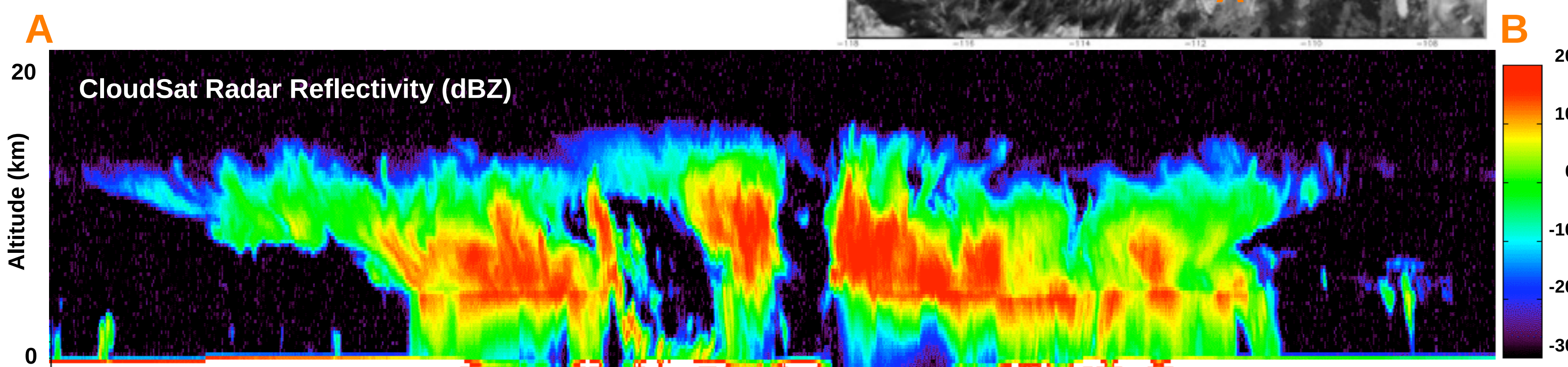
- The published global sea surface height trend from TOPEX/POSEIDON and JASON was used in the IPCC 2007 (5.5, Summary for Policymakers Table 5.3)
- The spatial pattern of those trends has been used in published work to extend the time series of globally-averaged SSH with sparse tide gage data.
- Sea surface height calibrated to ocean heat content is used by NOAA to improve hurricane path and intensity forecasts.
- Quikscat ocean vector Winds are assimilated into NCEP, ECMWF, and other operational weather-forecast models.
- QuikSCAT data have had major operational impact in: a) determining wind warning areas for mid-latitude systems (gale, storm, hurricane force) wind warnings since late 2000. b) determining tropical cyclone 34-knot and 50-knot wind radii. c) tracking the center location of tropical cyclones, including initial identification of their formation.
- Model-assimilated ocean state estimation (ECCO) has been used by many researchers not part of the original ECCO consortium.



Hurricane Ileana
23 August 2006 2100 UTC

- Key CloudSat observations are vertical profiles of:
  - cloud liquid water content
  - cloud ice water content
  - cloud physical & radiative properties
- Furnish data needed to improve model predictions of clouds to increase understanding cloud-climate feedback
- Provide data needed to improve weather forecast models (CloudSat data already being assimilated into Navy's operational weather forecast model)

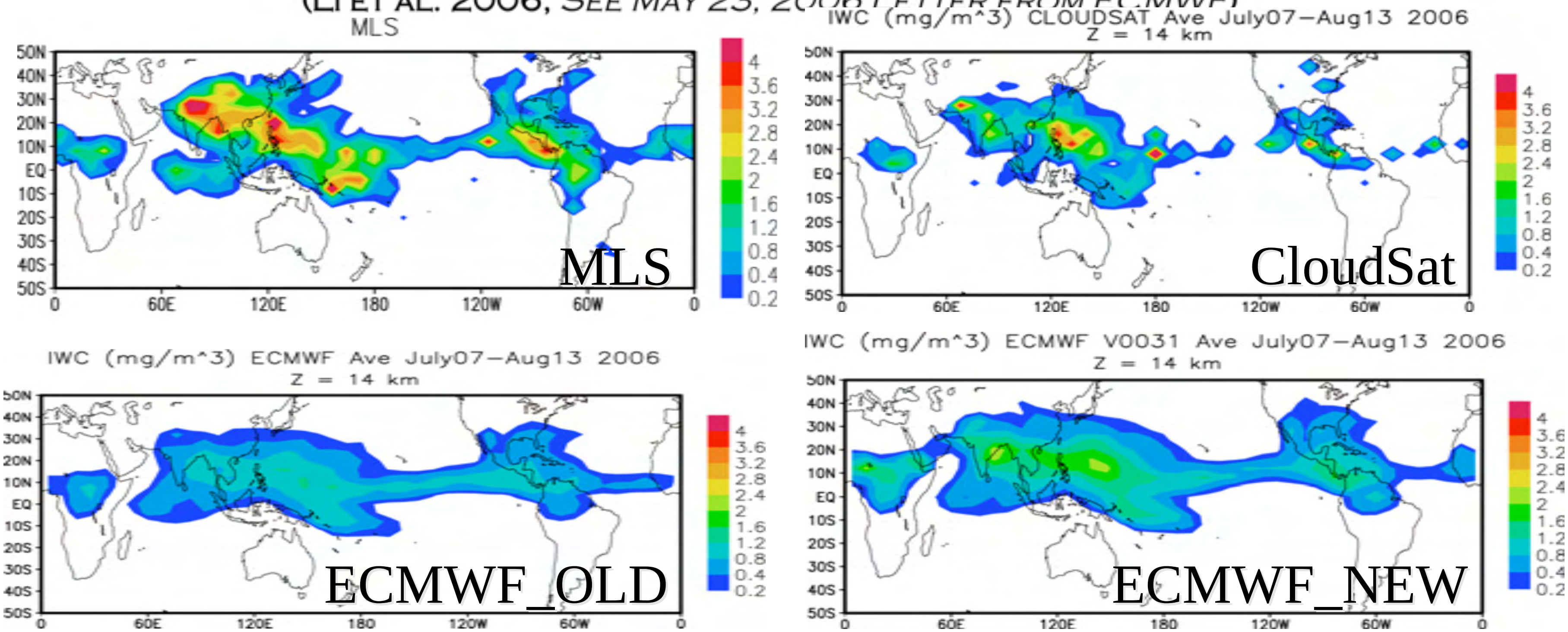




AURA/MLS and CloudSat Ice Water Estimates Help Improve ECMWF Integrated Forecasting System

AURA/MLS, AND NOW CLOUDSAT, CLOUD ICE VALUES ARE BEING USED IN COLLABORATION WITH ECMWF TO REDUCE ERRORS IN THEIR GLOBAL ANALYSIS AND FORECAST SYSTEM

(LI ET AL. 2006; *SEE MAY 23, 2006 LETTER FROM ECMWF*)



The maps above show upper tropospheric cloud ice values from AURA/MLS and CloudSat, as well as from the previous operational version of the ECMWF model and the latest version (Sep 06) whose development benefited from the recent availability of NASA satellite cloud ice data.

Data are all from Jul07-Aug13, 2006 @ ~ 14km

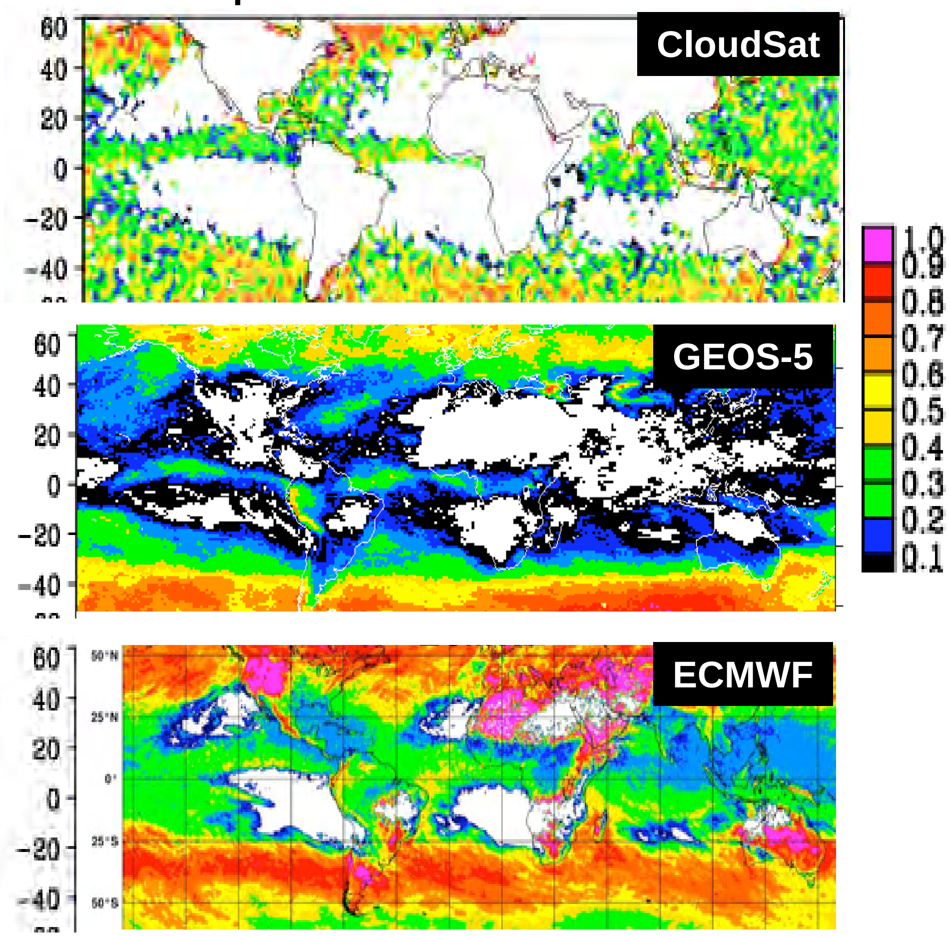
D. Waliser/JPL

Use of CloudSat Products to Assess Simulated Cloud Structures

Global Models

GEOS-5 & ECMWF

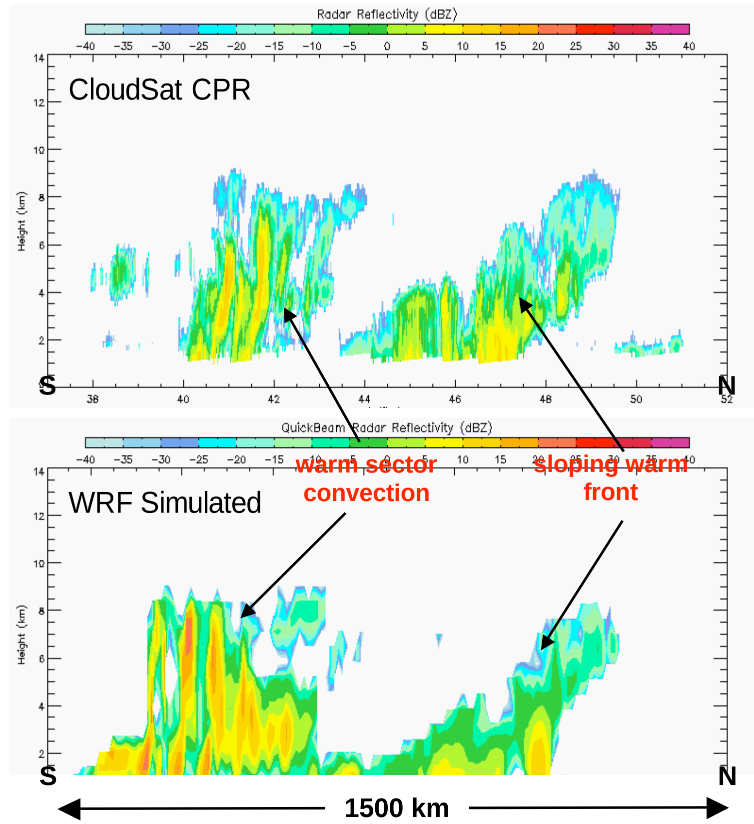
Fraction of precipitating profiles with cloud top between 4.75 to 11 km



Regional Models

WRF

N-S Cross Section of reflectivity through cyclone warm sector 1 March 2007



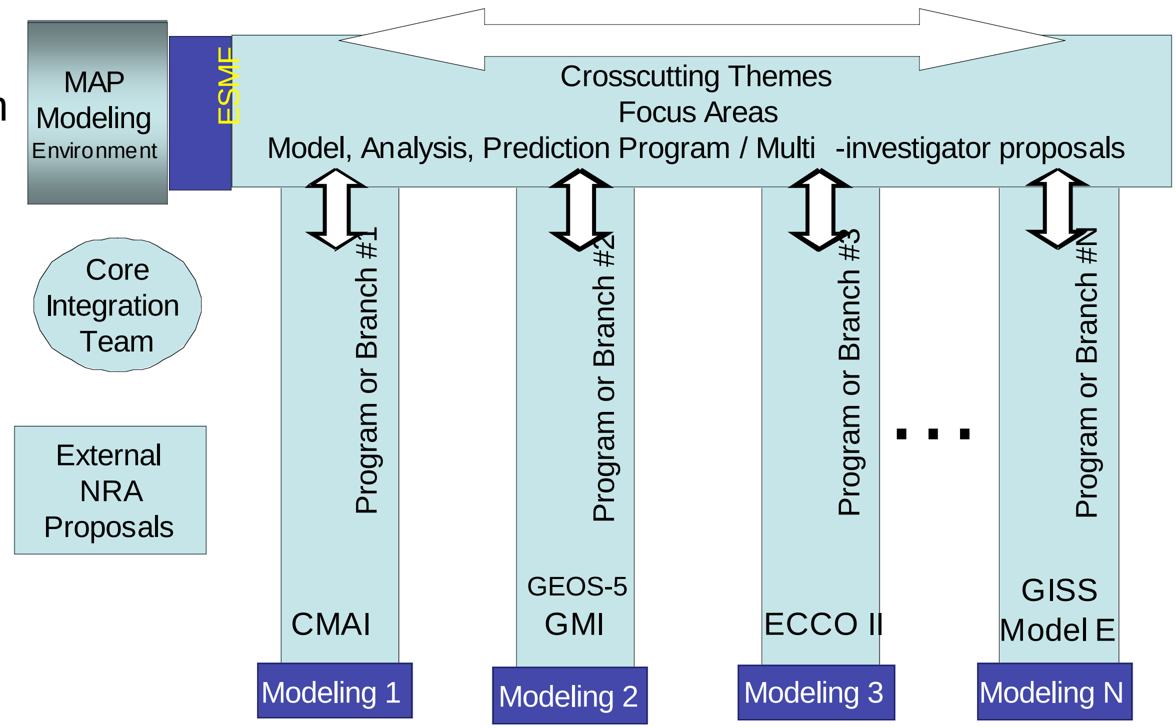
- **QuickBeam CloudSat Radar Simulator applied to WRF**
- **A tool available to the NASA MAP Community**

The Modeling, Analysis, and Prediction Program

Program Goal: Coupling of model elements and relevant observations (ground, in situ, space) toward the development of the NASA Earth SYSTEM model

- **The 'system' includes:**
  - Infrastructure to support system development (ESMF)
  - Visualization
  - Integration
  - Testing
  - Evaluation

- **Program Supports:**
  - Coupled model advances
  - Data assimilation
  - Reanalysis
  - Observing System Simulation Experiment (OSSE) tools Computer/information systems



The Modeling, Analysis, and Prediction Program

NASA models and data assimilation systems allow effective use of satellite observations to make useful analyses and forecasts.

The comprehensive nature of models and assimilation systems provides the means to contribute to satellite mission design.

Motivating Requirements:

- Models are the theoretical summary of our understanding of how nature works
- Each of the Earth Science Focus Areas has prediction as one of its goals.
- Predicting climate variability and change requires comprehensive models that include feedback processes involving the atmosphere, land, ocean and sea-ice, between the climate and biogeochemical and hydrological cycles.
- "**Complete models of the Earth system must be developed along with advanced data assimilation techniques that can incorporate all observations into the model to produce consistent 4D data sets for research and operations." *[Decadal Survey]***

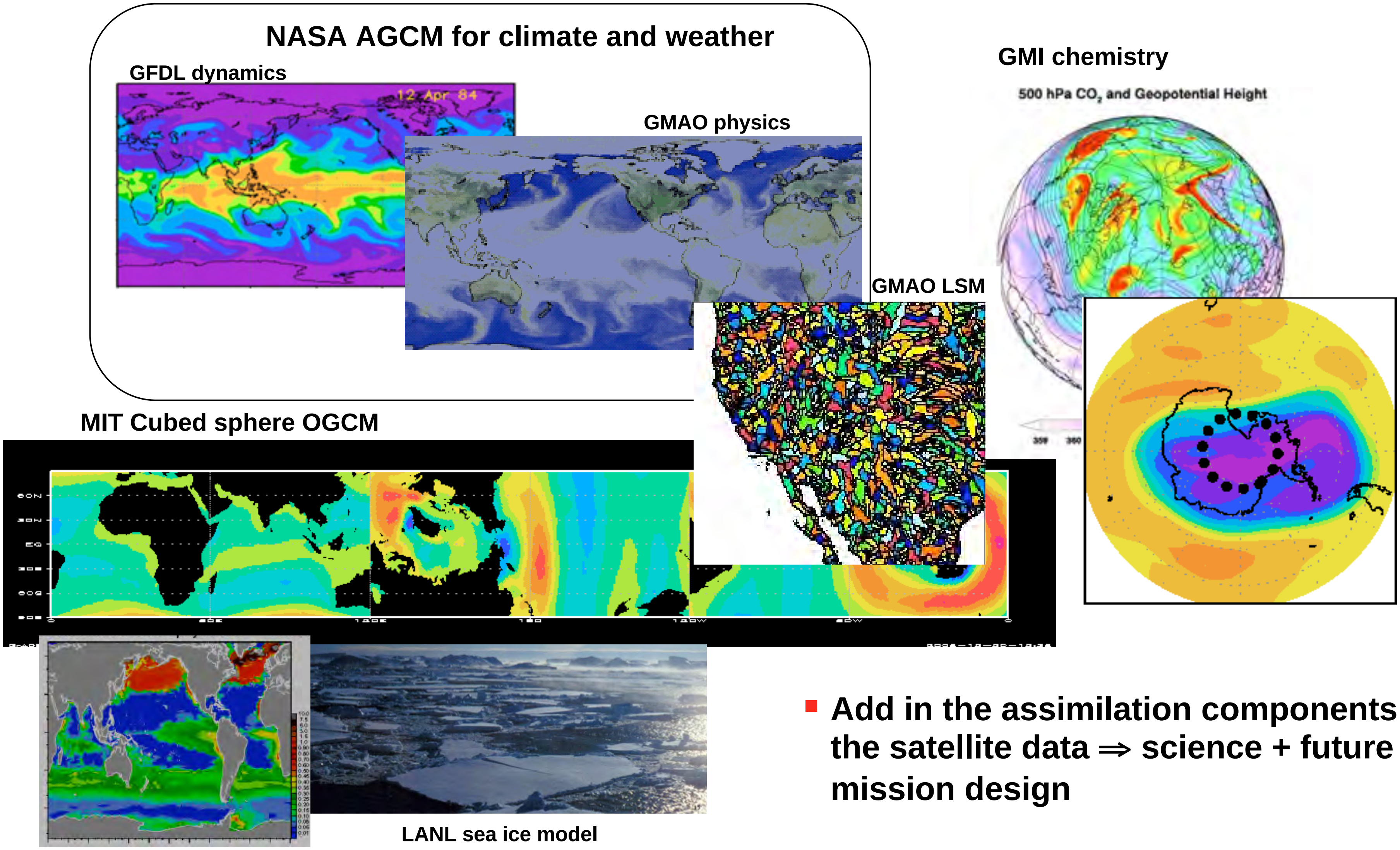
Program goals:

- Create data assimilation capabilities for available diverse data types
- Develop computational modeling capabilities for research focus areas
- **Bring satellite data to bear on model development**
- **Contribute to development of the observing system**
- Participate in national and international scientific assessments

Status:

- Modern models *integrate* components from different sources. The *Earth System Modeling Framework* (ESMF) facilitates that integration and will accelerate model development
- GEOS-5 is the most comprehensive implementation of ESMF to date
- GISS coupled model contributed to *IPCC AR4*
- GEOS-4 coupled with GSFC strat-chem contributed to *National ozone assessment*
- GEOS-5 is coupled to GSFC strat-chem and with GOCART aerosol models
- Model components are being shared, e.g.,
  - GEOS-5 & ModelE share ocean biology;
  - GEOS-5 & ModelE sharing dynamic vegetation dev.
  - GEOS-5 & CCSM share finite volume core;
  - GEOS-5 & GFDL/NCEP CGCMs share MOM4 ocean
- GEOS-5 DAS uses NCEP's GSI, facilitating R2O transition [adjoint tools, MLS ozone, AIRS, MODIS winds]
- GEOS-5 DAS in finalization for *MERRA*
- GEOS-5 and WRF were "coupled" for MAP06 predictions

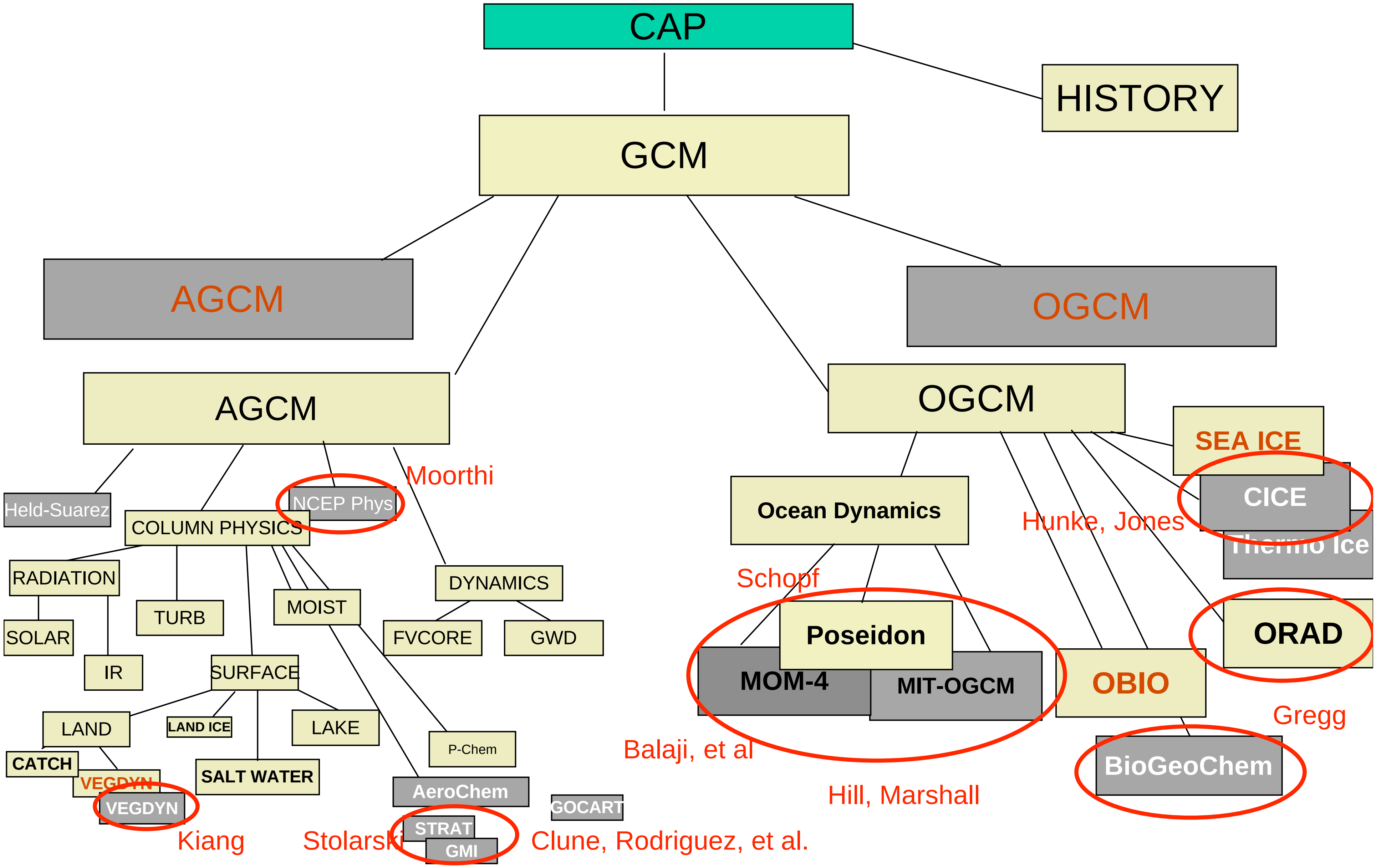
Modern models integrate components from different sources
ESMF accelerates development cycle



GMAO ocean biology

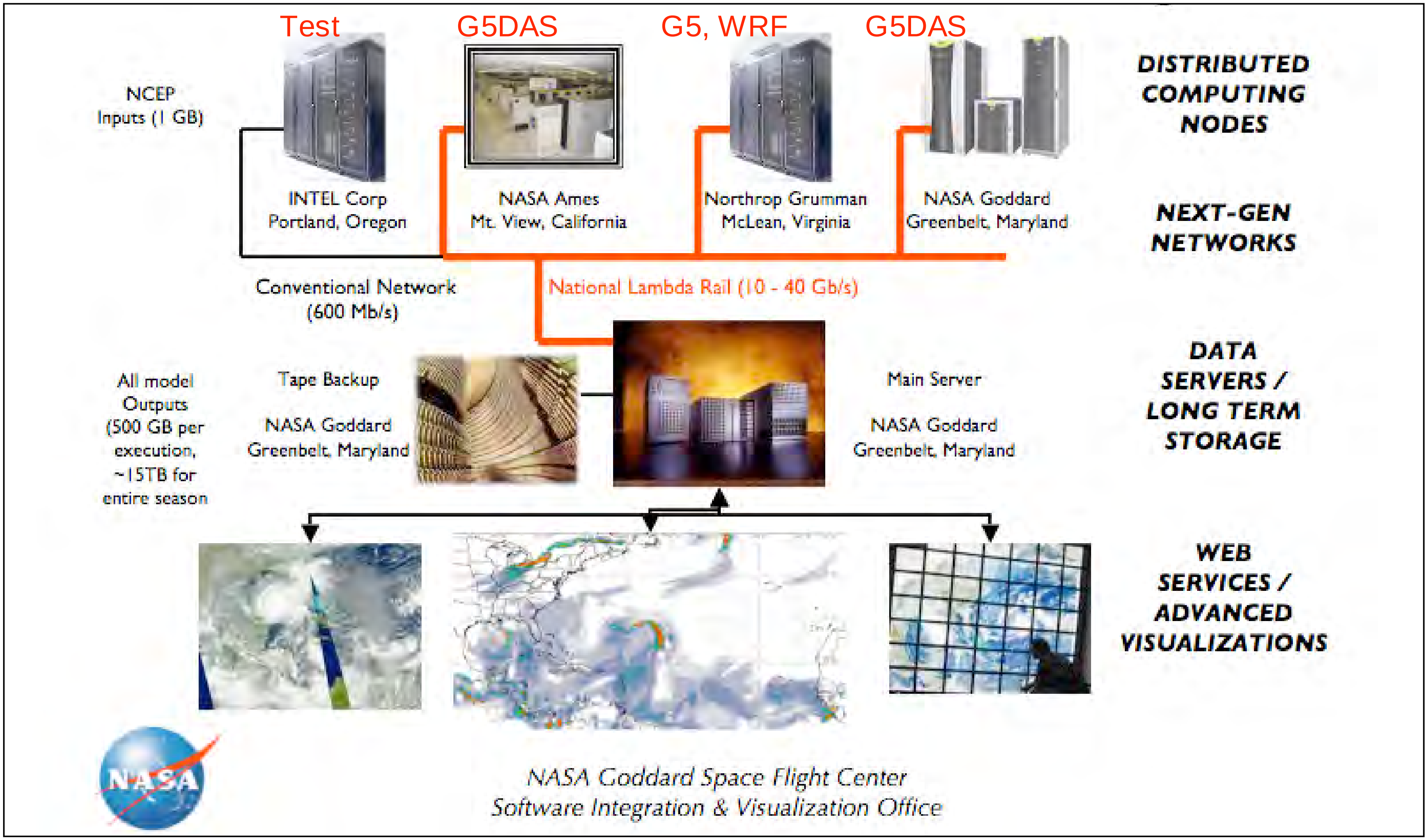
- **Add in the assimilation components and the satellite data ⇒ science + future mission design**
- **DAS: OSSEs, Prediction, Reanalysis**

GEOS-5 GCM
Integrating components for an Earth System Model and Analysis

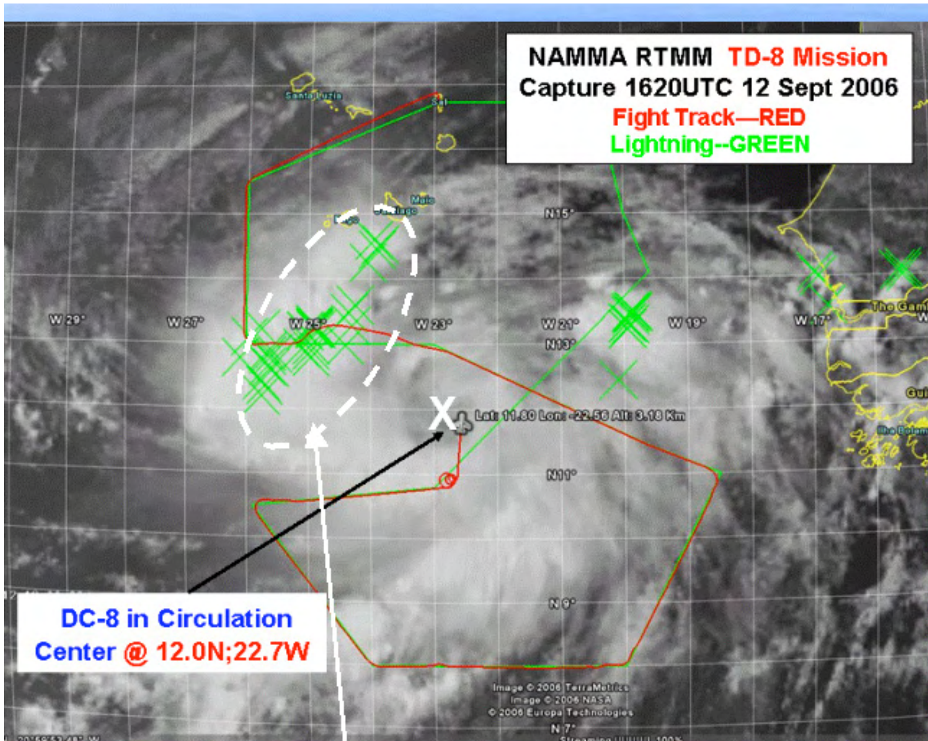


Integrating Weather and Climate Observations, Models, Tools, High-End Computing and NASA Centers

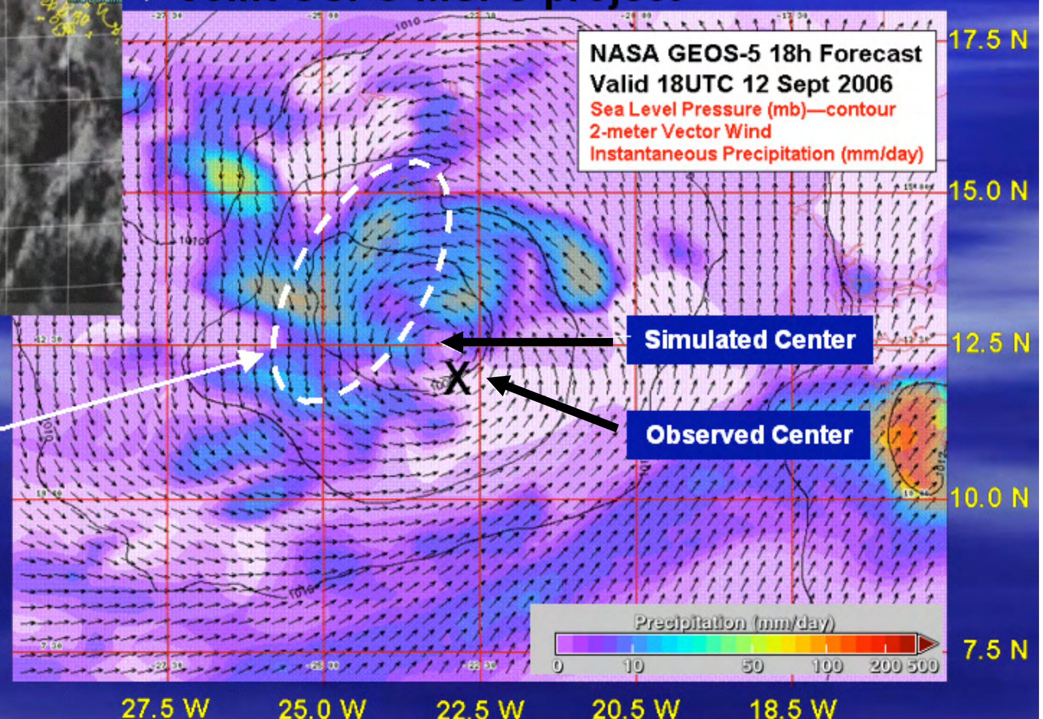
Partnership between GSFC/GISS, JPL, LaRC, MSFC, ARC



MAP Models and Tools in support of NASA Field Campaigns (NAMMA & TC-4)



- NASA GEOS-5 at ¼ degree resolution demonstrates skill in simulating AEW's and tropical depressions during NAMMA
- Provided value-added product to NAMMA Forecast Team
- Joint GSFC-MSFC project



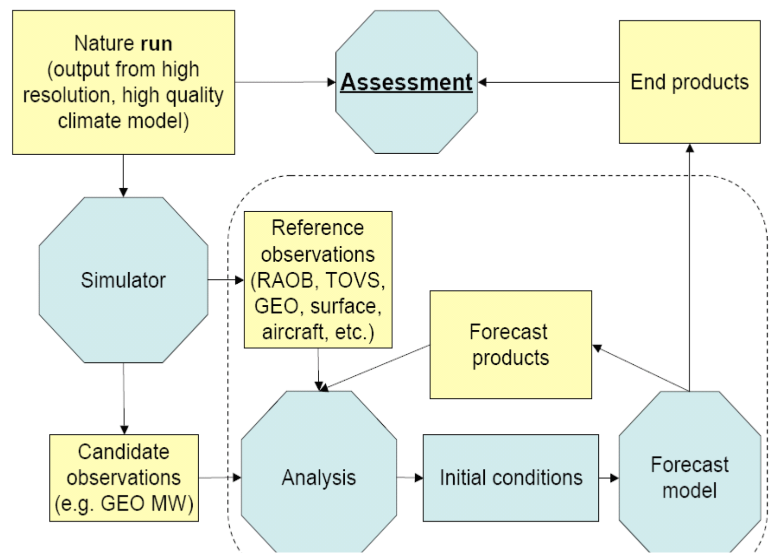
Heaviest Precipitation
NW of Circulation Center

Science Mission Directorate

Observing System Simulation Experiments (OSSE's)

- **Typically aimed at assessing the impact of a *hypothetical* data type on a forecast system**
- **Investment in OSSE's represents a small fraction of overall cost of observing system**
- **Can play a useful role at any phase in the development prior to launch**
- **OSSE capability currently being developed for GEOS-5 and GFS in collaboration between MAP & JCSDA**
- **Application beyond NWP (I.e., land, ocean, seasonal etc.)**

OSSE, conceptual model

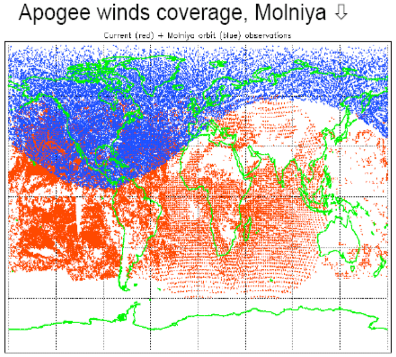


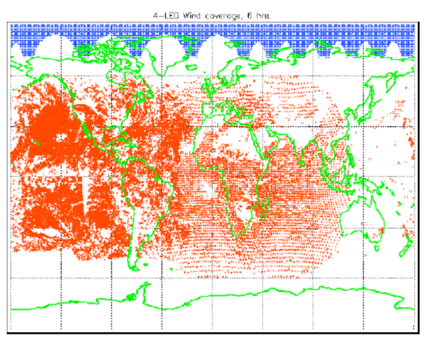
Molniya OSSE

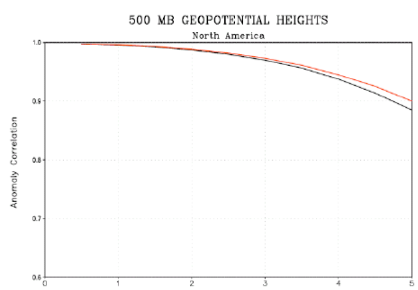
(Observing system simulation experiment)
GEOS-4; Atlas et al.

6-hour winds coverage, 4 LEO's ⇨

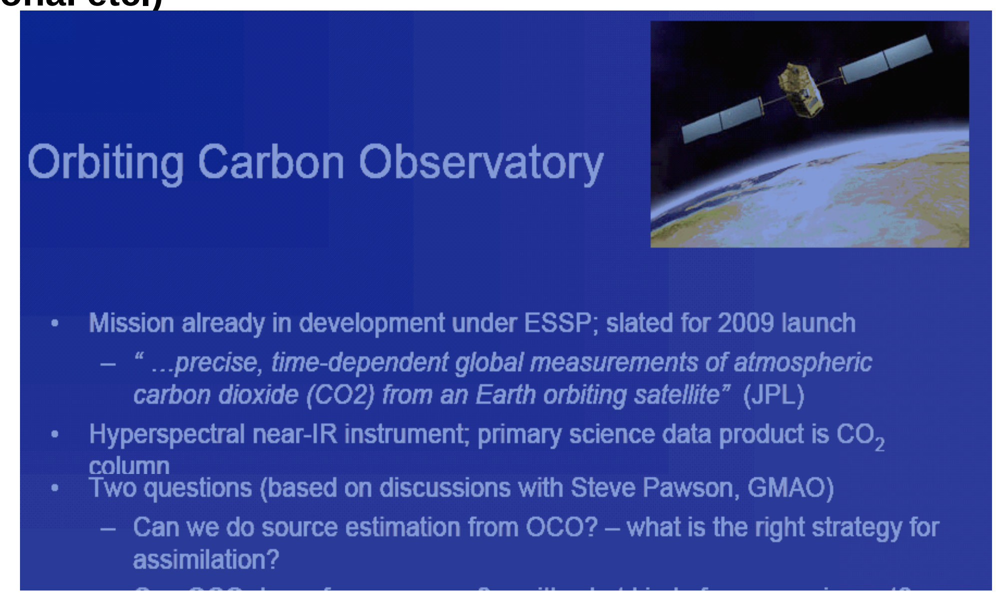
Apogee winds coverage, Molniya ⇩







Forecast improvement over North America, 48 cases ⇨



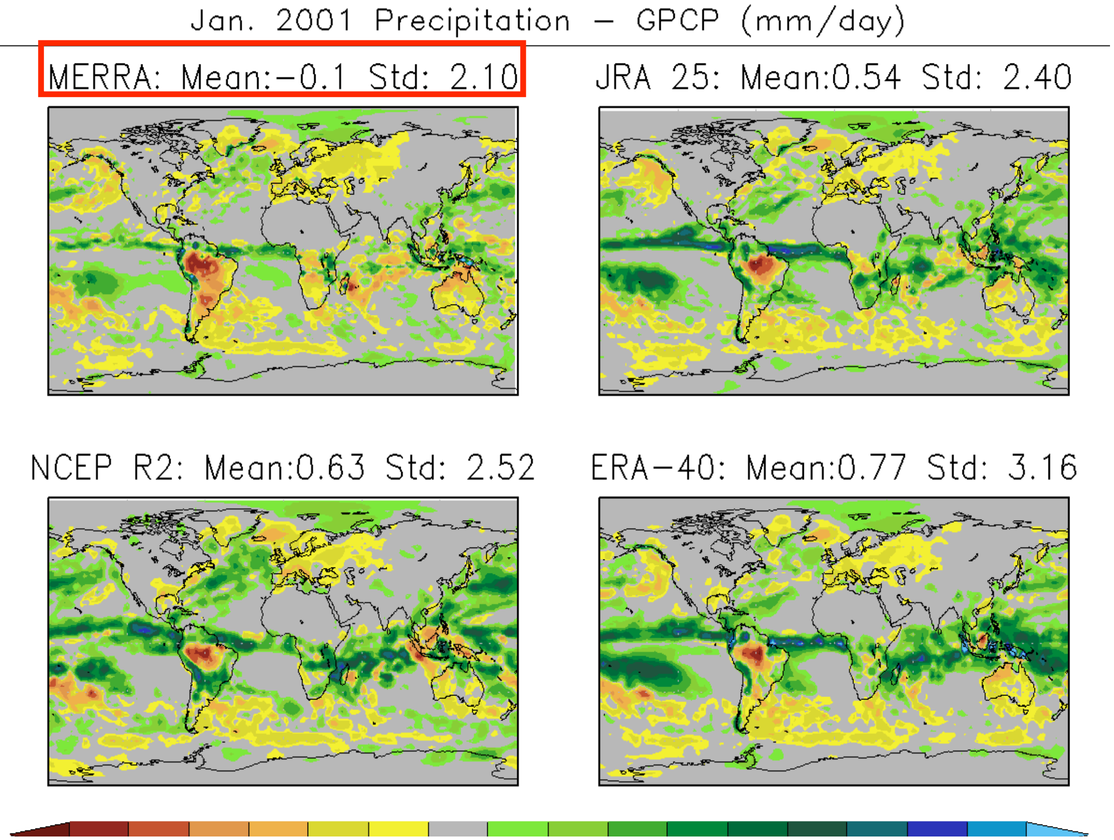
The Modern Era retrospective-analysis for Research and Applications (MERRA)

- **Assimilation of Earth observing system to develop analyses for use in climate studies**
  - **Satellite Era, 1979 – present**
  - **1/2° x 2/3° lat-lon grid**
  - **Begin production July 07**

- **MERRA focus is on improved representation of moist processes**

- **Challenges for climate reanalysis**
  - **Discontinuities associated with time evolving observing system**
  - **Climate model bias**
  - **Uncertainty in reanalysis**

Difference between reanalysis precipitation estimates and GPCP estimates (mm/day) January 2001



Cloud Modeling and Analysis Initiative (CMAI)

NASA satellite observations provide invaluable information to address deficiencies in climate and weather models.

The A-train provides an unprecedented opportunity for the observation and study of cloud properties and behavior.

Motivating Requirements:

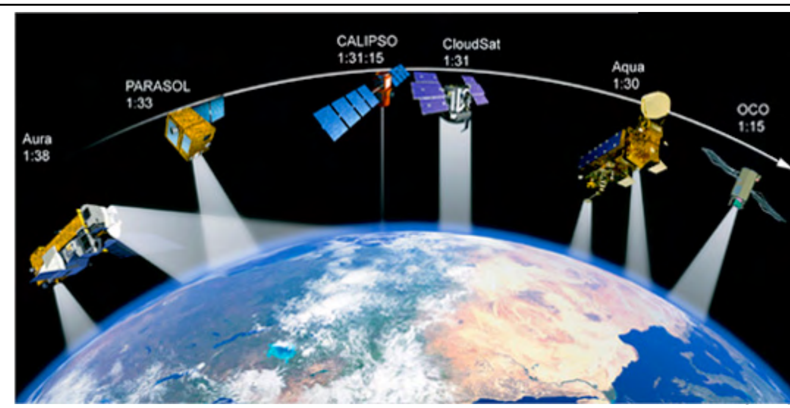
- **Representation of clouds and cloud processes in climate and weather models is one of the central issues driving uncertainty in forecasts**

Status and Path Forward:

- CMAI workshops/meetings held, 20-21 April 2006; MAP ST meeting 7-9 March 2007.
- Three study themes:
  - **The Pacific Cross-Section (PAC) study:** What determines the variability of clouds and convection and what determines the transitions in convective style over the cross-section?
  - **The Cyclone Lifecycle (CYC) study**: What controls the locations of cyclogenesis and cyclolysis and how do cloud processes affect the evolution of these storms?
  - **The Arctic Clouds (ARC) study**: What role do aerosols and phase changes in Arctic clouds play in the formation and evolution of Arctic cloudiness and their effect on the atmospheric moisture budget?
- Model participants:
  - GEOS-5, Model-E, MMF, WRF

Science Questions:

- Cloud formation processes: what is the mass flow rate of vapor-to-condensate for liquid clouds and for ice clouds?
- Precipitation formation processes: what is the mass flow rate of cloud condensate to precipitation form, both rain and snow?
- Cloud lifecycle dynamics: what is the scale dependence of the coupling of atmospheric dynamics with radiation and precipitation by clouds?
- Orographic effects: what are the effects of orography on cloud-precipitation behavior?
- How does the presence of a changing aerosol environment influence cloud and precipitation behavior?



Short-term Climate Prediction

NASA satellite observations characterize variability at seasonal-to-interannual timescales and provide information to initialize and validate forecasts using coupled models.

Satellites are the sole source of Global sea surface temperature, surface winds, surface height, precipitation and soil moisture.

Motivating Requirements:

- El Niño impacts economies worldwide ; yet impacts of such climate anomalies are regional e.g., extreme events (severe storms, prolonged drought)
- Seasonal-to-interannual forecasts - the touchstone and validation for long-term climate prediction (decadal and longer) - improves models by forced confrontation between models and data

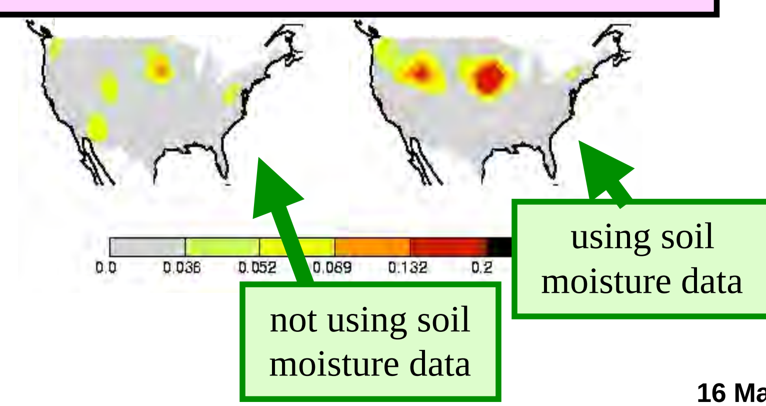
Science Questions:

- What is the predictability of subseasonal to interannual climate forecast skill at all scales - global to regional - MJO, El Niño and other?
- What controls predictability, i.e., what has to be observed?
- How do we realize the theoretical predictability estimated from perfect model simulations?
- What is the impact of global change on seasonal forecast skill? On extreme weather events?

Status:

- GMAO's coupled model forecasts are contributed to national consensus forecasts;
- Advanced ocean data assimilation (GMAO, ECCO); advanced land data assimilation (GMAO)
- GMAO's altimetry assimilation and initialization of soil moisture improve forecast skill, but major breakthroughs are required for further advances; national pathway is multi-model ensemble prediction
- Demonstrated ability to simulate major features in 20th century climate variations - e.g., Great Plains dustbowl, seasonality of precipitation and temperature trends over US.

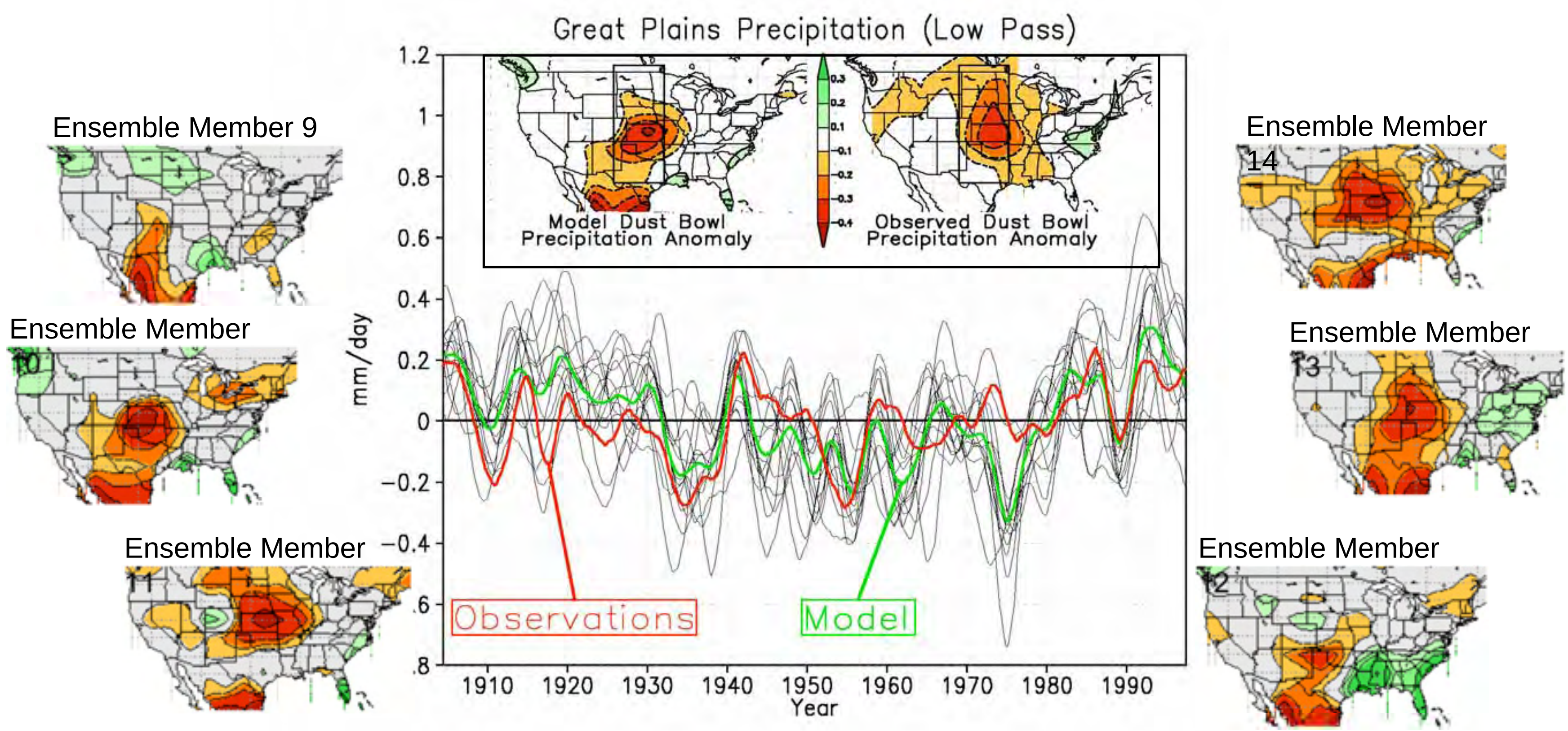
GMAO monthly rainfall forecast skill level (r^2 versus observations)



Modeling Uncertainty - the need for ensembles

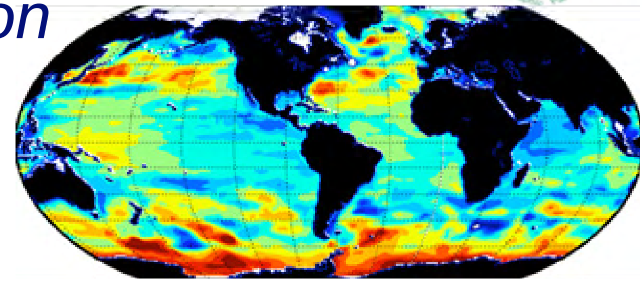
Climate Variability and Chaos: Even large scale circulation patterns are influenced by uncertainties - initial conditions, external factors and unresolved scales

Model simulations of past droughts over the U.S. Great Plains show substantial sensitivity to initial conditions, reflecting the chaotic nature of climate variability.



Summary of 22-23 January 2007 ECCO2 meeting

Overview and Motivation



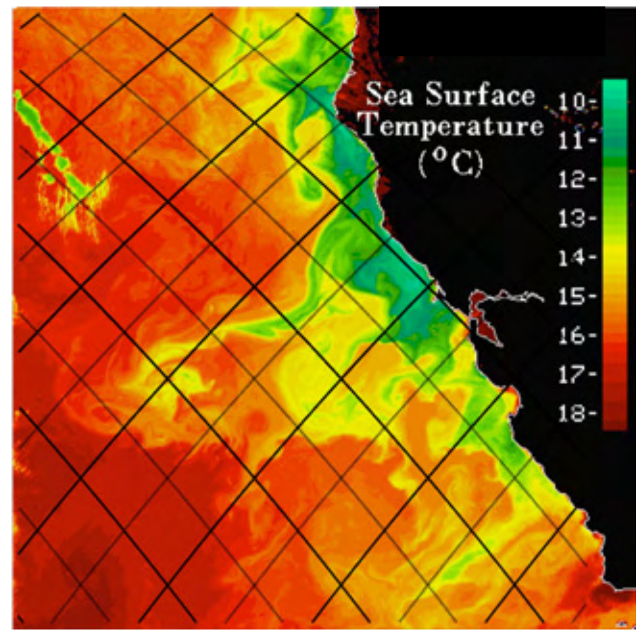
Estimated sea level trend, spatial mean removed (Wunsch, Ponte, and Heimbach, 2007).

ECCO, ECCO-GODAE, ECCO2 (Wunsch, MIT)

The only way to understand the complete, global, time-evolving ocean circulation is to use **all** available data and **all** available theory. ECCO seeks the best possible estimate of the time-evolving ocean circulation, its influence on climate, chemistry, biology, etc., understanding of predictability, and determination of what we do not understand. **A two+ generation problem!**

ECCO2 and NASA satellite missions (Fu, JPL)

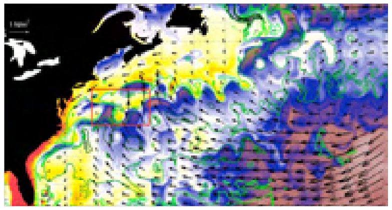
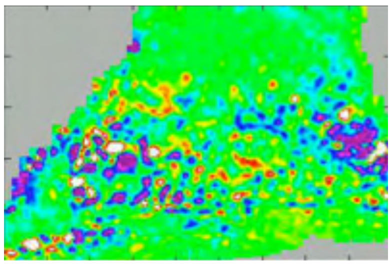
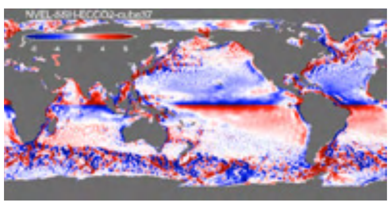
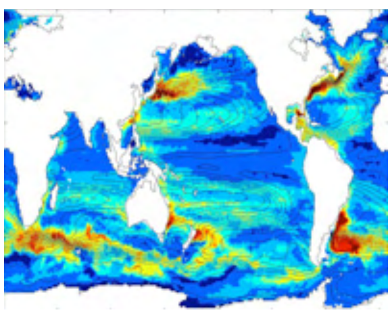
Observations of mesoscale and sub-mesoscale ocean variability are a key requirement for understanding regional and global climate processes. For this reason, wide swath altimetry has been endorsed by the NRC Decadal Survey as a possible new NASA mission. ECCO2 provides a framework for utilizing high-resolution data from existing and future NASA satellite missions.



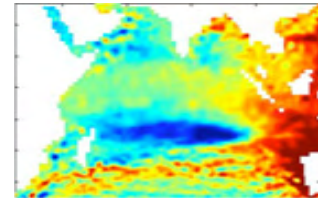
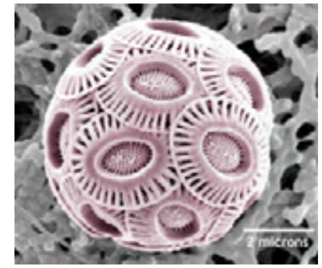
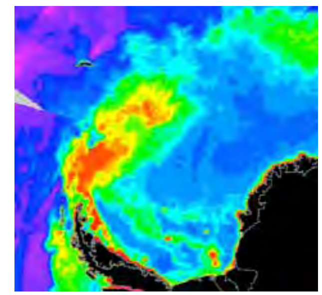
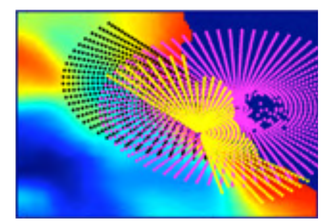
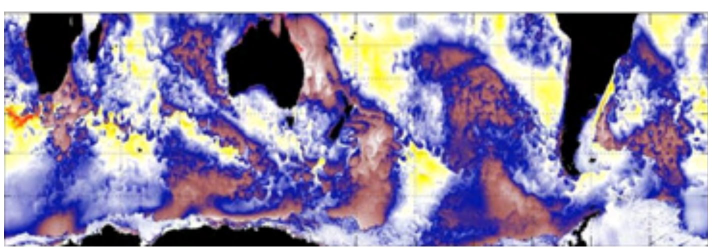
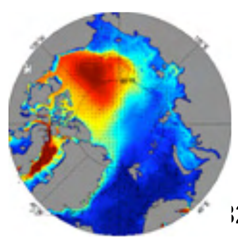
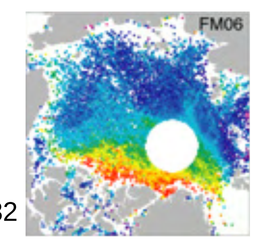
Ground tracks of TOPEX/Jason tandem mission superimposed on satellite imagery of sea surface temperature.

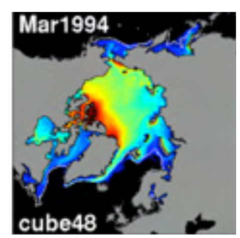
Summary of 22-23 January 2007 ECCO2 meeting

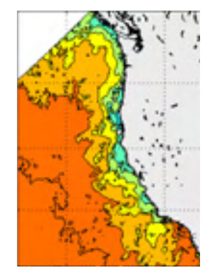
Early User Applications

Subtropical mode water (Maze, MIT)
Eddy propagation velocity (Fu, JPL)
GRACE data constraints (Zlotnicki, JPL)
Errors estimates (Forget, MIT)
Eddy parameterizations (Ferreira, MIT)
Arctic freshwater budget (Condron, WHOI)
Arctic sea ice budget (Kwok, JPL)
Sea ice data/model comparison (Nguyen, JPL)
Carbon cycle modeling (Manizza, MIT)
Eddy variability in Indian Ocean (Lee, JPL)
Darwin project (Hill, MIT)
Southern Ocean (Schodlok, JPL)
MITgcm assimilation efforts (Cornuelle, SIO)
Adjoint assimilation efforts (Edwards, UCSC)

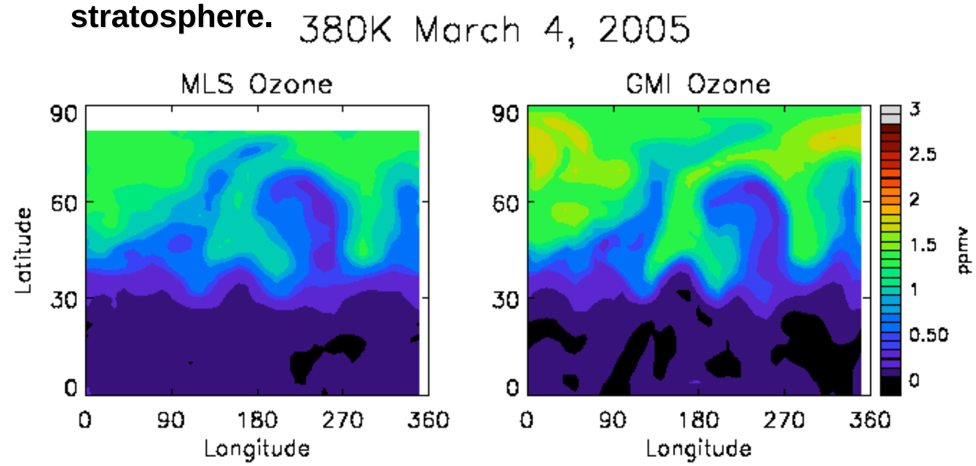


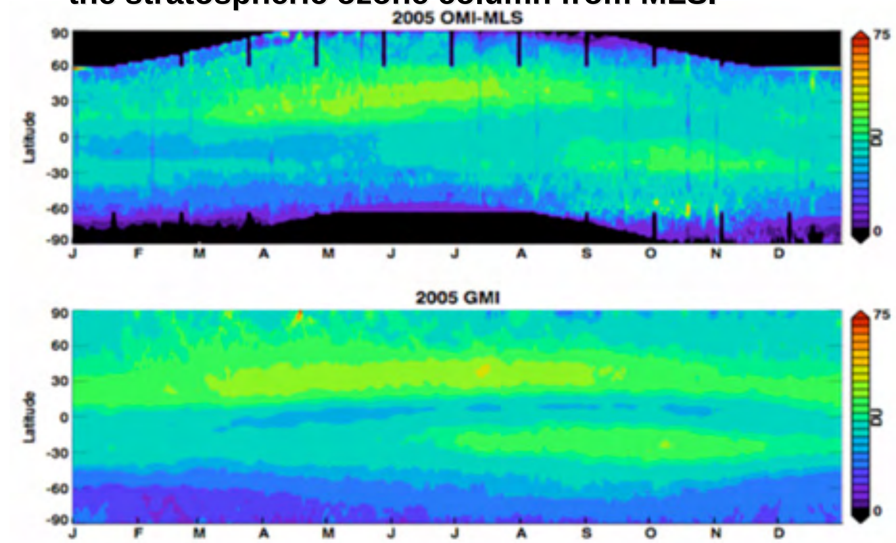
The MAP Global Modeling Initiative (GMI)

- **Integrated a chemical-transport model spanning the surface to the mesopause includes full tropospheric and stratospheric chemistry**
- **GMI algorithms are contributed by different community members, and represent the state of the art in terms of meteorological fields, chemistry, and deposition processes.**
- **Simulations of the Upper Troposphere/Lower Stratosphere region particularly important region for climate simulations.**
- **By incorporating different algorithms into the GMI, the model can test them in comparison to satellite data**
- **These algorithms can then be included with confidence in fully coupled chemistry-climate model.**

GMI simulated ozone reproduces daily features seen by Aura's Microwave Limb Sounder (MLS) in the lower stratosphere.



Difference between the OMI total ozone column and the stratospheric ozone column from MLS.



Science Mission Directorate

Climate Change

Model and Climate Sensitivity to Forcings: Both the Forcing and the Feedbacks still have great uncertainties

Future emphasis will be on an observing system that allows us to monitor trends in both forcings and feedbacks

Motivating Requirements:

- To assess appropriate mitigation/adaptation actions, we must know the climate sensitivity: hence the climate forcings and system response
- For future projections, only models are available: so the models must have the proper sensitivity

Status:

- GISS coupled model (using ModelE AGCM) contributed to IPCC AR4 climate projections
- AR4: Cloud feedback remains the largest uncertainty in climate sensitivity and low clouds dominate the uncertainty.
- AR4: Aerosol indirect effect remains the largest uncertainty in anthropogenic radiative forcing
- AR4: Large uncertainty in projection of Atlantic MOC
- A-train on orbit
- A-train data depot to visualize and explore co-registered CALIPSO, CloudSat, CERES, MODIS, AIRS, MLS, etc under development
- Global energy budget and uncertainty estimates show that ocean temperature estimates are the largest source of uncertainty.
- ASIC^3 multi-agency workshop on ways to achieve satellite instrument calibration for climate change held May 2006.

Science Questions:

- How is the Earth's climate changing?
- What are the primary forcings of the Earth's climate?
- How does climate respond to natural and human forcings?
- What are the consequences of climate change for civilization?
- How well can we predict future climate changes?

ERBS: ERBE/SAGE II

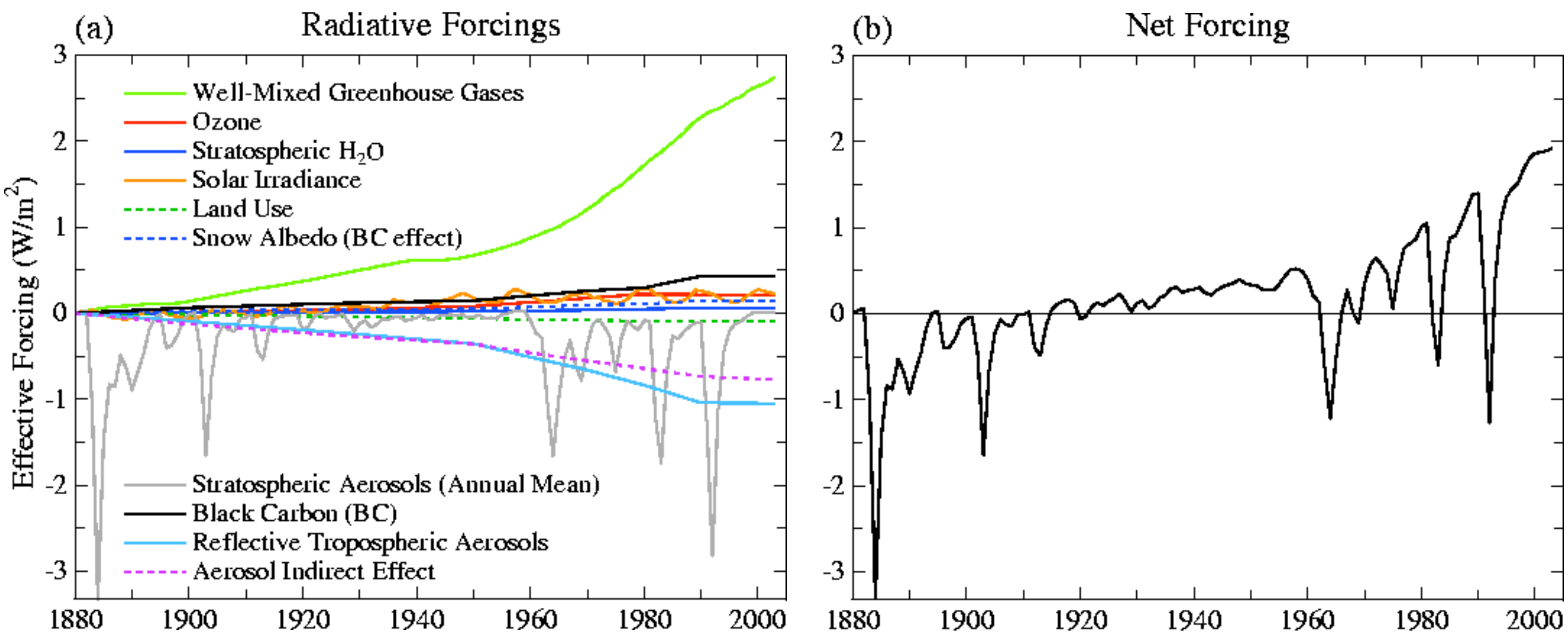
CERES/SAGE III

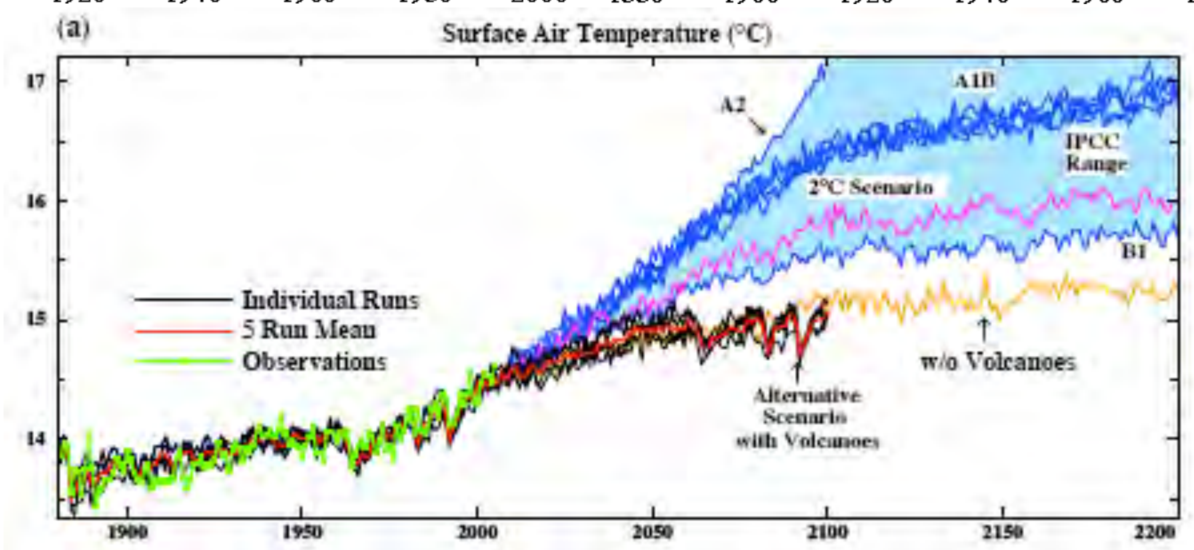
Monitoring of
Radiation Budget,
Aerosols
Ozone
Water Vapor

For over 20 years!

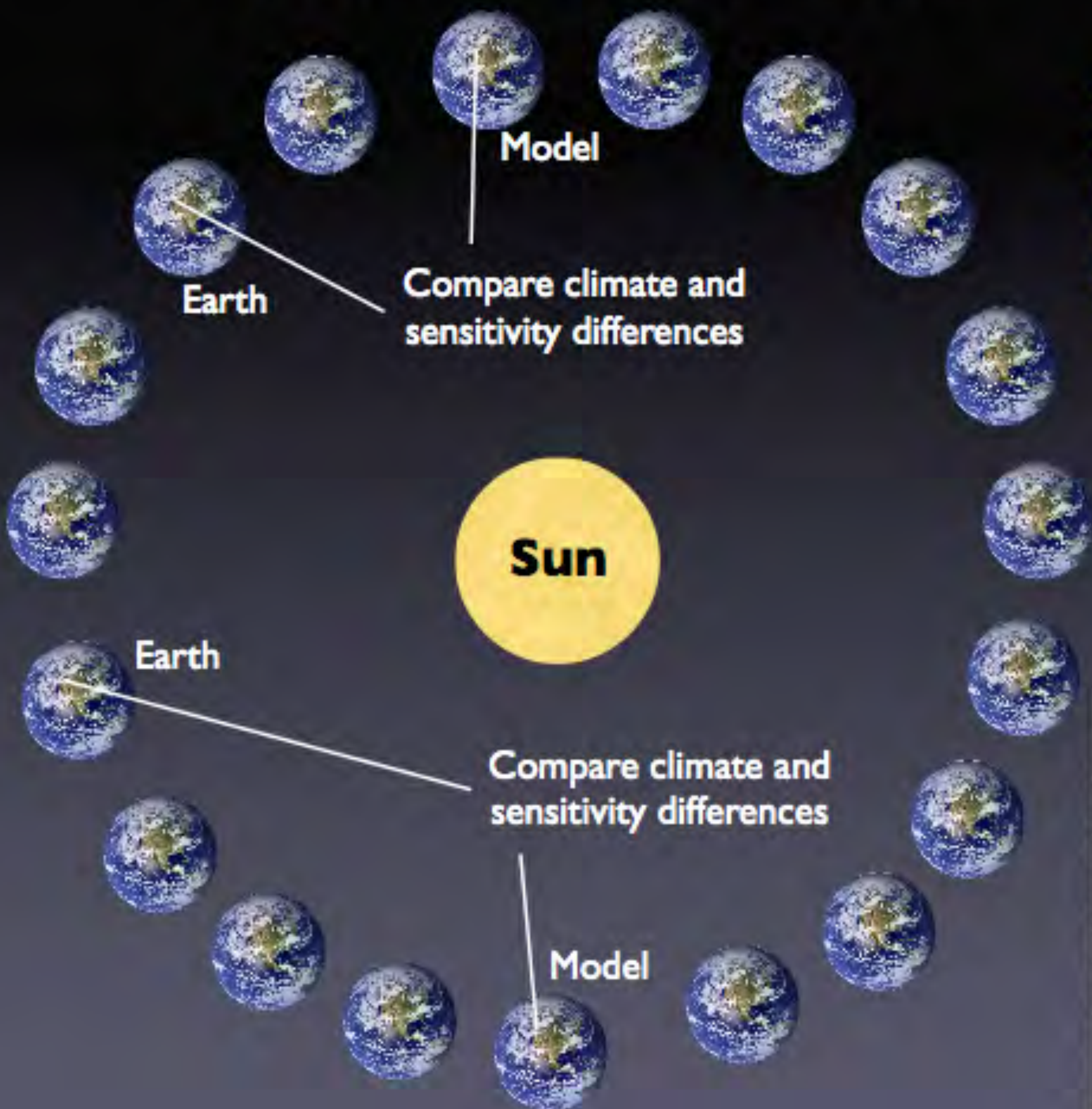
20th Century Forcings used in the GISS ModelE

from Hansen et al. (2005)



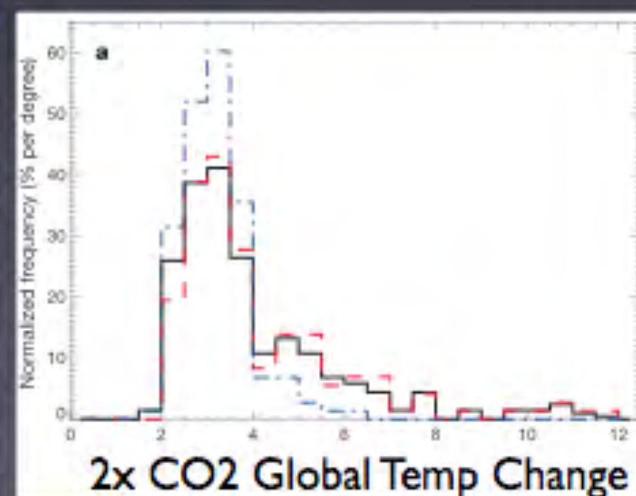


60,000 Earth-Like Planets



climateprediction.net:
constant known physics
vary uncertain physics
Run for normal CO_2
Run for doubled CO_2

Stainforth et al., 2005, Nature



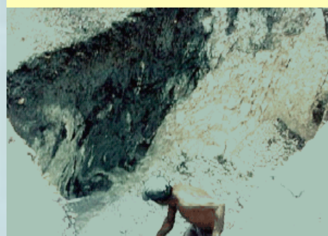
ROSES07: Archeology from Space

Linking the past and the future….

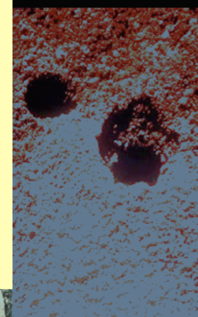
"Plowed fields have replaced forests, domesticated animals have dispersed wildlife. Trees are plowed, mountains smoothed, and swamps drained. There are as many cities as in former years there were dwellings…Everywhere there are buildings, everywhere people, everywhere communities. Proof of this crowding is the density of human beings. We weigh upon the world; its resources hardly suffice to support us. As our needs grow larger, so do our protests that already nature does not sustain us."

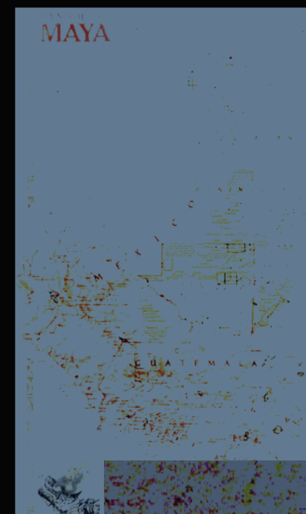
Tertullian 200 AD

Carthage, North Africa



For hundreds of years the Maya depended on the predictable rain cycle.



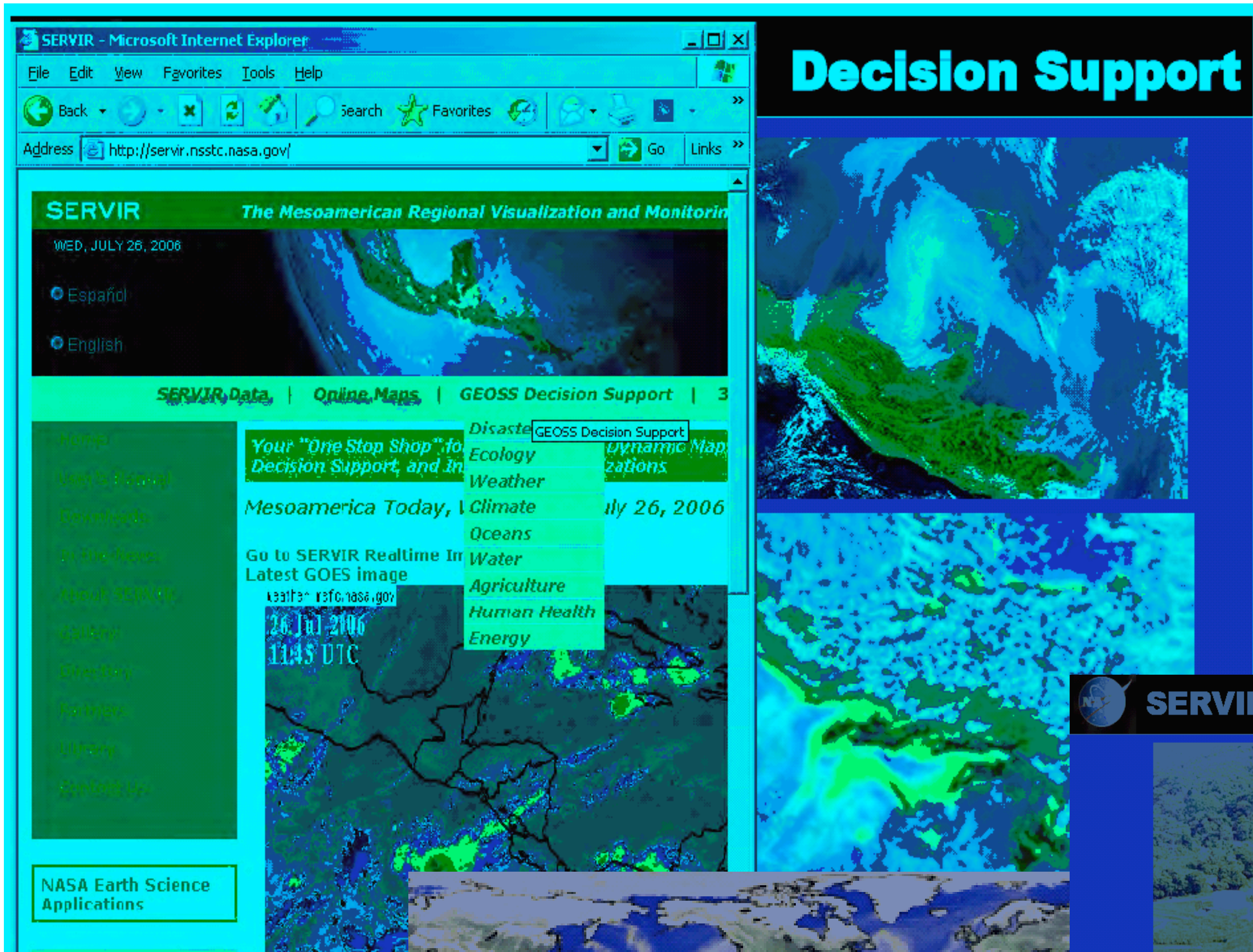


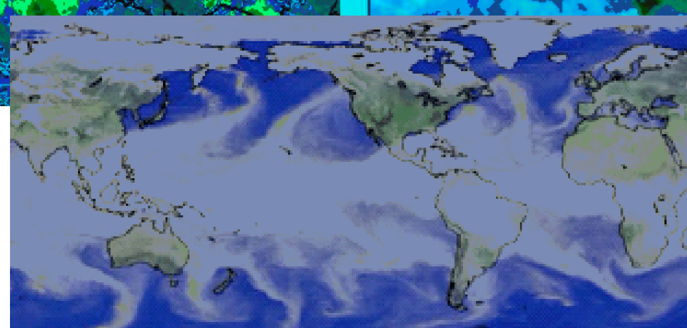
When they filled all of their reservoirs they had an 18-month supply of water.

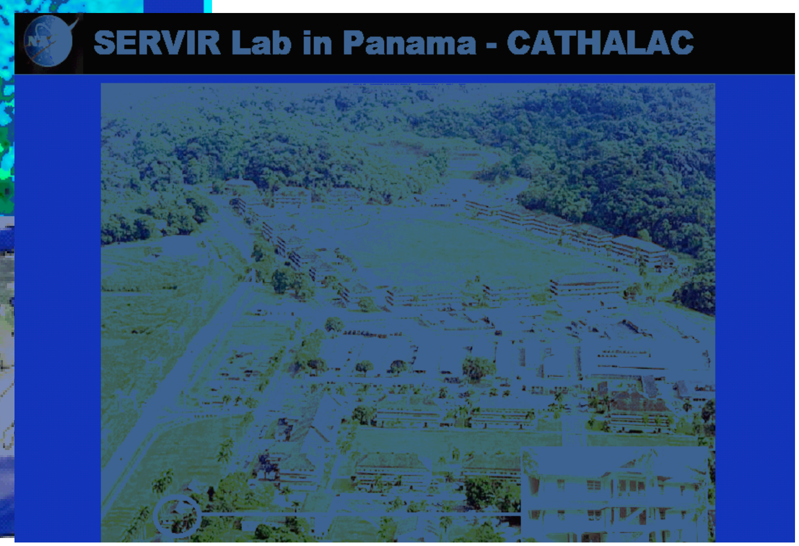
The Greatest Demographic Disaster in Human History

- Over 100 Explanations for the Maya Collapse including:
- Hurricanes
- Overpopulation
- Disease
- Deforestation/Soil Erosion
- Peasant Revolt
- Warfare

The CVCFA and Society: Linking SERVIR & MAP





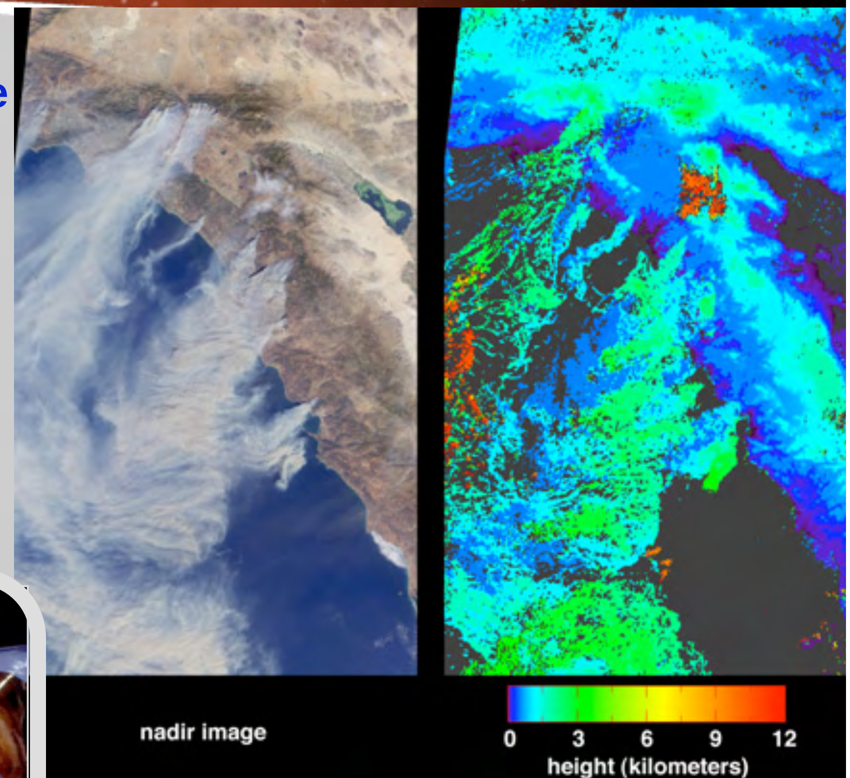


- SERVIR is the Mesoamerican Regional Visualization and Monitoring System
- Building links between the NASA Applied Science Program and MAP weather to climate expertise (MSFC meeting 5/18)
- TC-4: Bringing together multiple disciplines

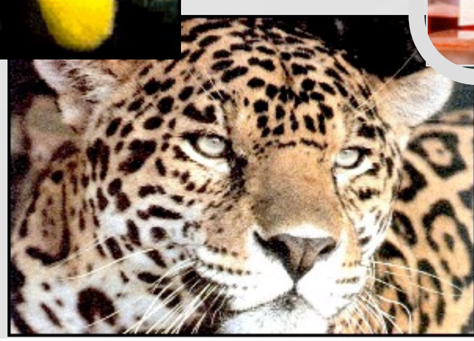
Climate Variability and Change
Research Results Applied to Societal Benefit

Application of NASA Earth-science Research Products for Decision Support in Climate Change

- **Climate Change, Air Quality, and Public Health**
  - **New York Metropolitan Area**
- **Climate Change and Agricultural Efficiency**
  - **State of California**
  - **Costa Rica**
- **Climate Change and Impacts to Water Resources**
  - **California and Globally**
- **Climate Change and Loss of Biodiversity**
  - **Central America**

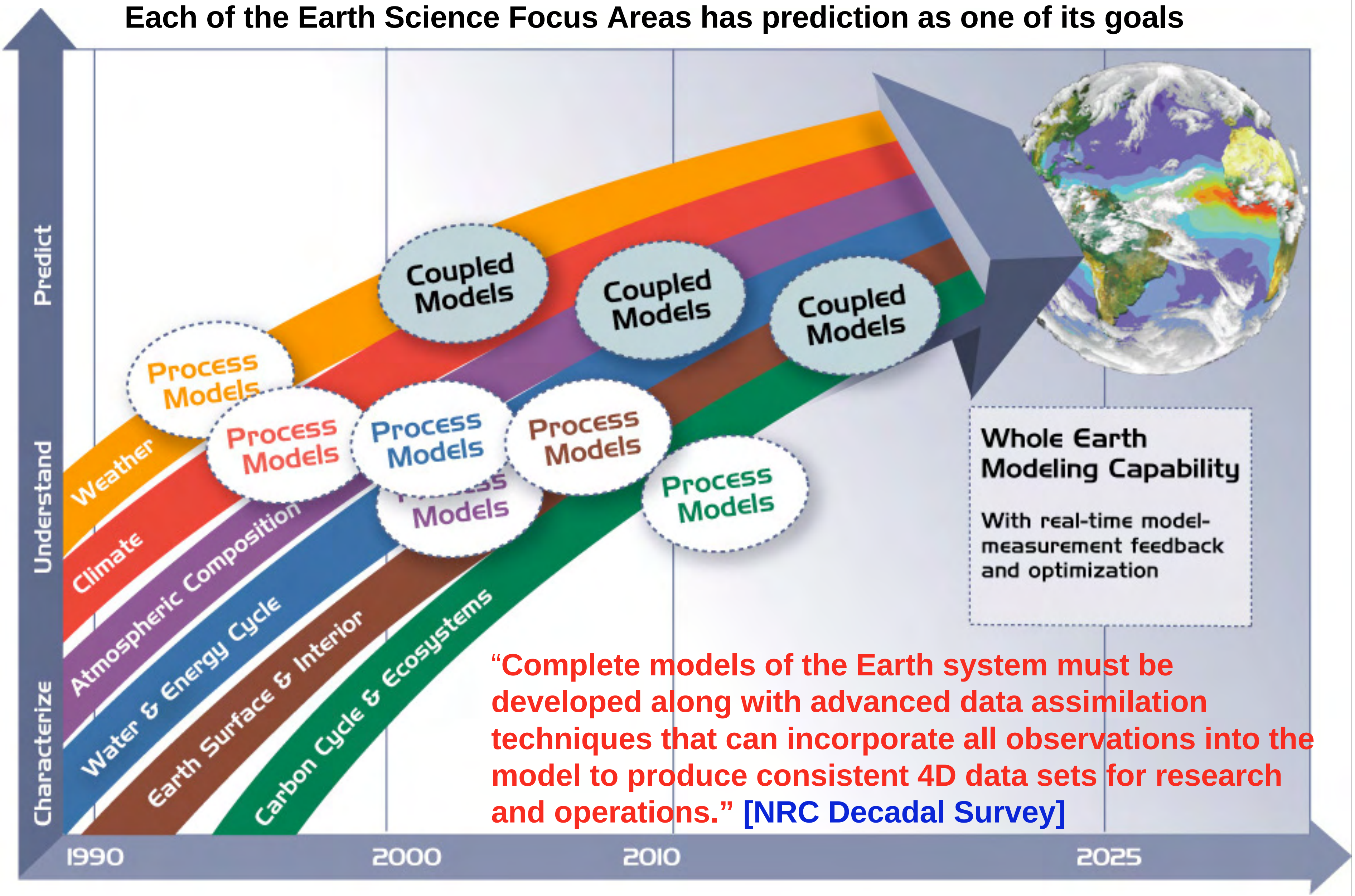


California fires from MODIS October 26, 2003



Earth SYSTEM Modeling

Each of the Earth Science Focus Areas has prediction as one of its goals



"Complete models of the Earth system must be developed along with advanced data assimilation techniques that can incorporate all observations into the model to produce consistent 4D data sets for research and operations." [NRC Decadal Survey]

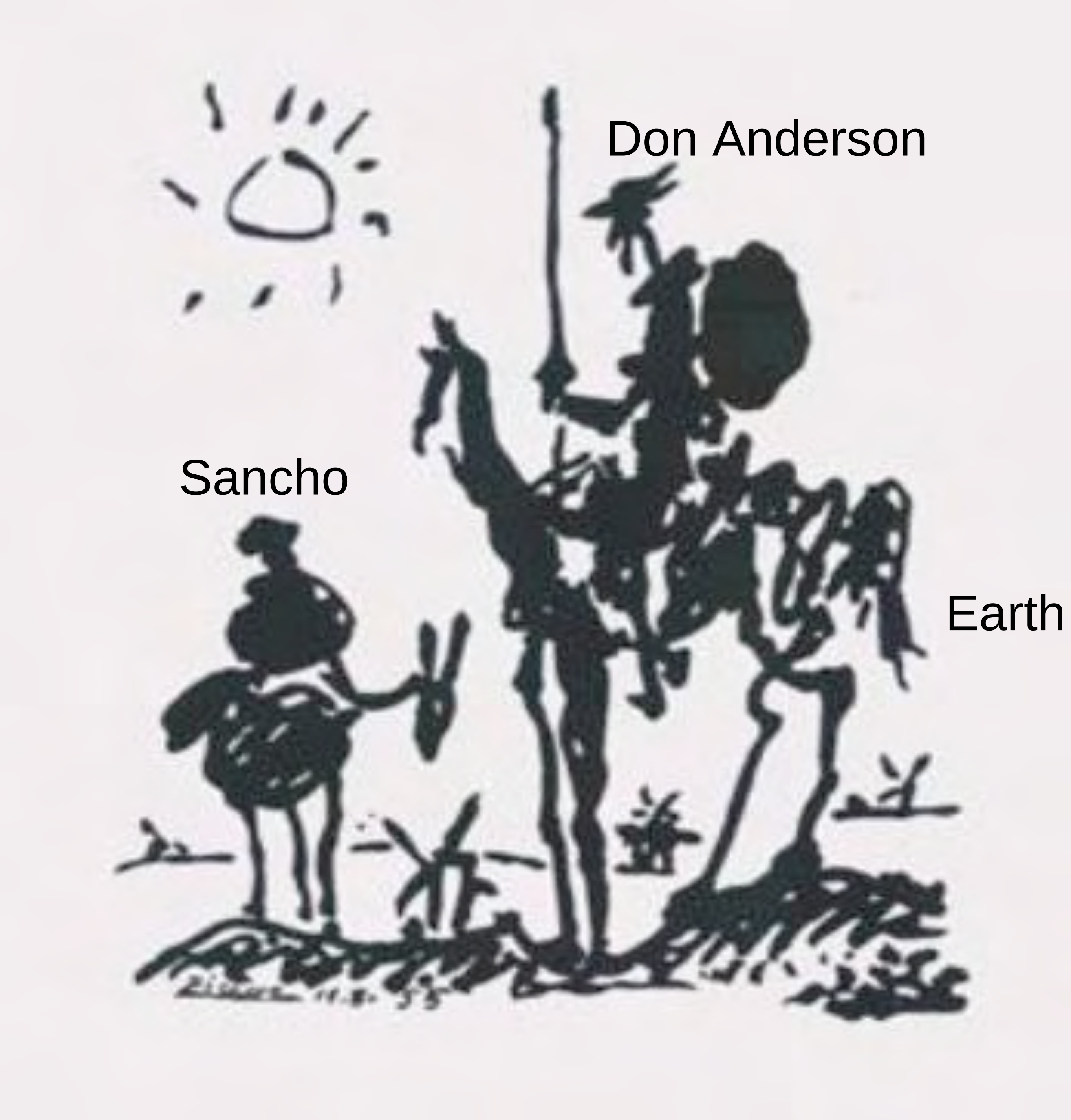
The CCSP Integrated Earth System Analysis (IESA) Initiative

To develop an *earth system analysis capability* that will:

- Improve descriptions of the earth system and understanding how that system works.
- Support evaluations of the fidelity of earth system models and help identify areas where improvements in models and observations will have the greatest benefits.
- Aid in evaluating potential predictability and improving climate forecasts on seasonal-to-decadal time scales.
- Provide state-of-the-art descriptions of the past and present state of the earth system that support the needs of both scientists and end users.

The Bottom Line:

Earth system analyses produced by assimilating diverse observations into state-of-the art models are an essential integrating component in an end-to-end *Earth Observing System.*
Building a capability for an integrated earth system analysis cross-cuts most, if not all, science elements within the CCSP. This effort is

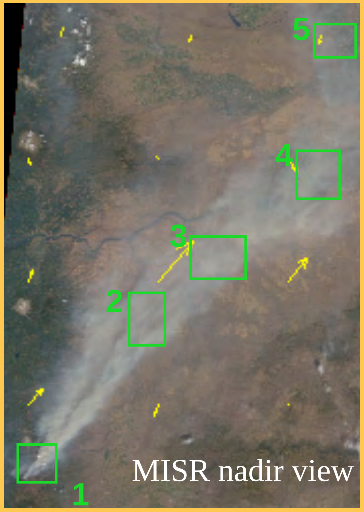


NASA
Earth Science Division

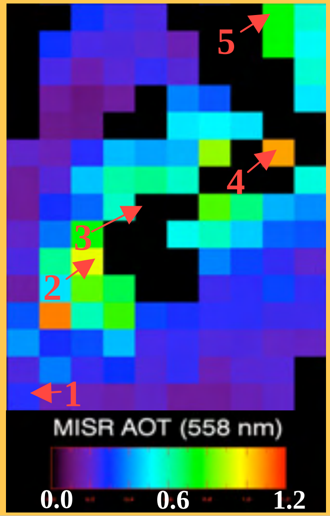
Our Vision

Backup Slides Follow

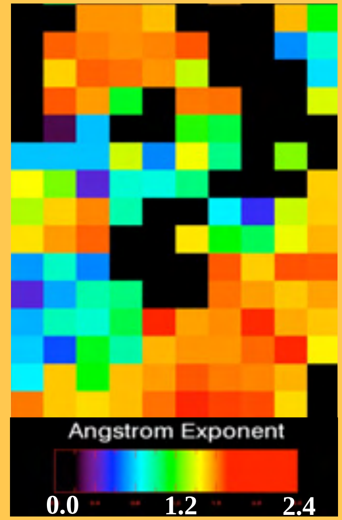
Aerosol Source Plume Physical Characteristics from Space-based Multi-angle Imaging using MISR



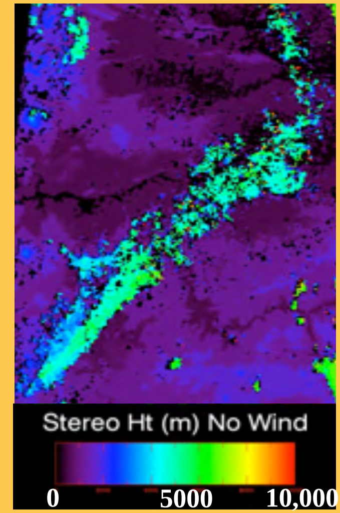
Oregon wildfire Sept 04 2003



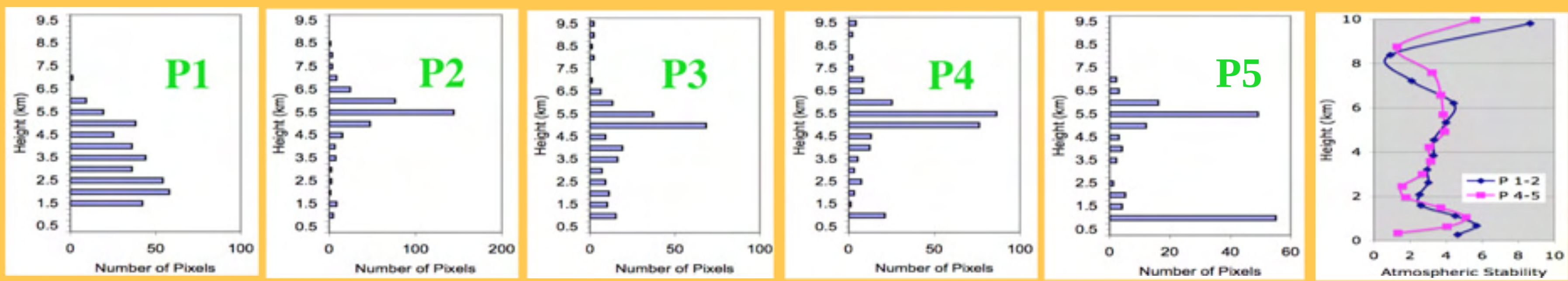
Smoke & bkgd aerosol amount



~Particle Size



Smoke Plume Height



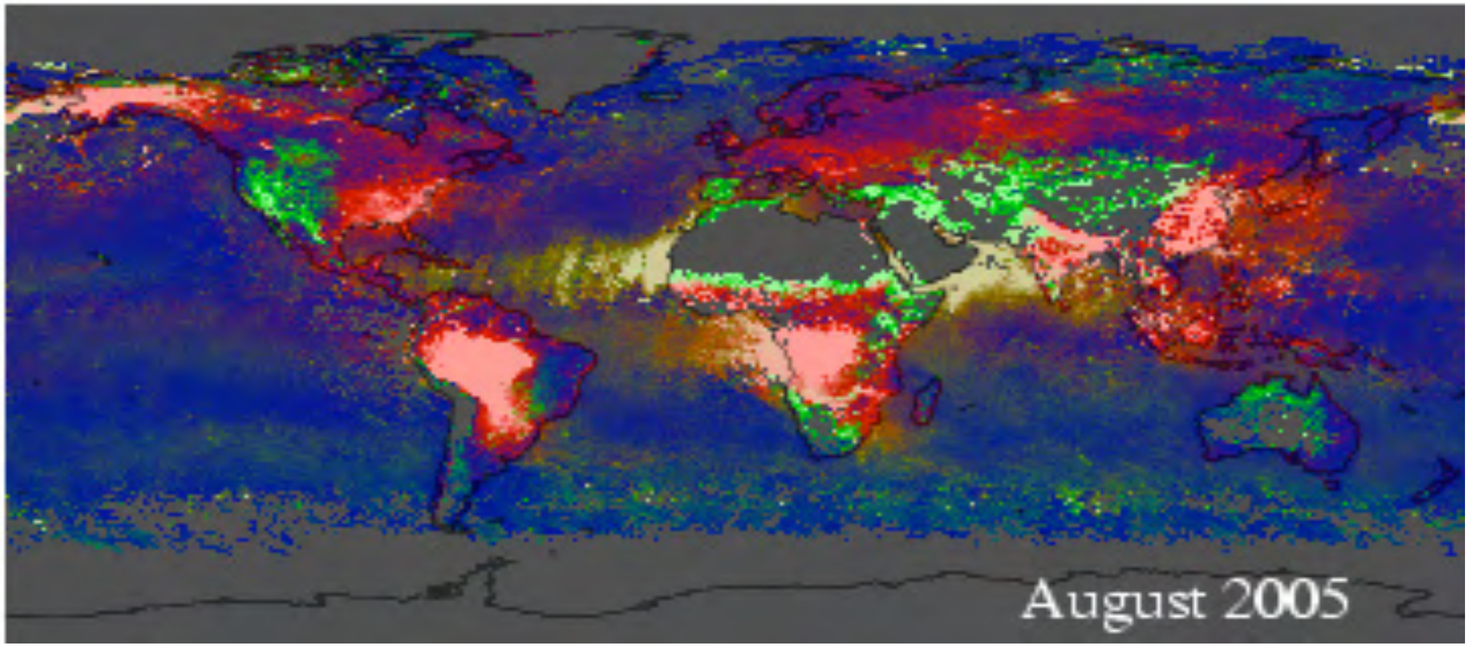
MISR Stereo-Derived Smoke Plume Height histograms for five patches, plus model-derived atmospheric stability profile

- Wildfire smoke plumes tend to concentrate in **layers of high relative atmospheric stability**.
- With sufficient buoyancy from a **fire or volcano**, can they reach **upper levels** in the atmosphere.
- The measurements can be used **directly in models that predict aerosol transport**, or as a guide for **model aerosol vertical distribution** where measurements are absent.

R. Kahn, W-H Li, C. Moroney, D. Diner, J. Martonchik, and E. Fishbein, **JGR 2007**, in press

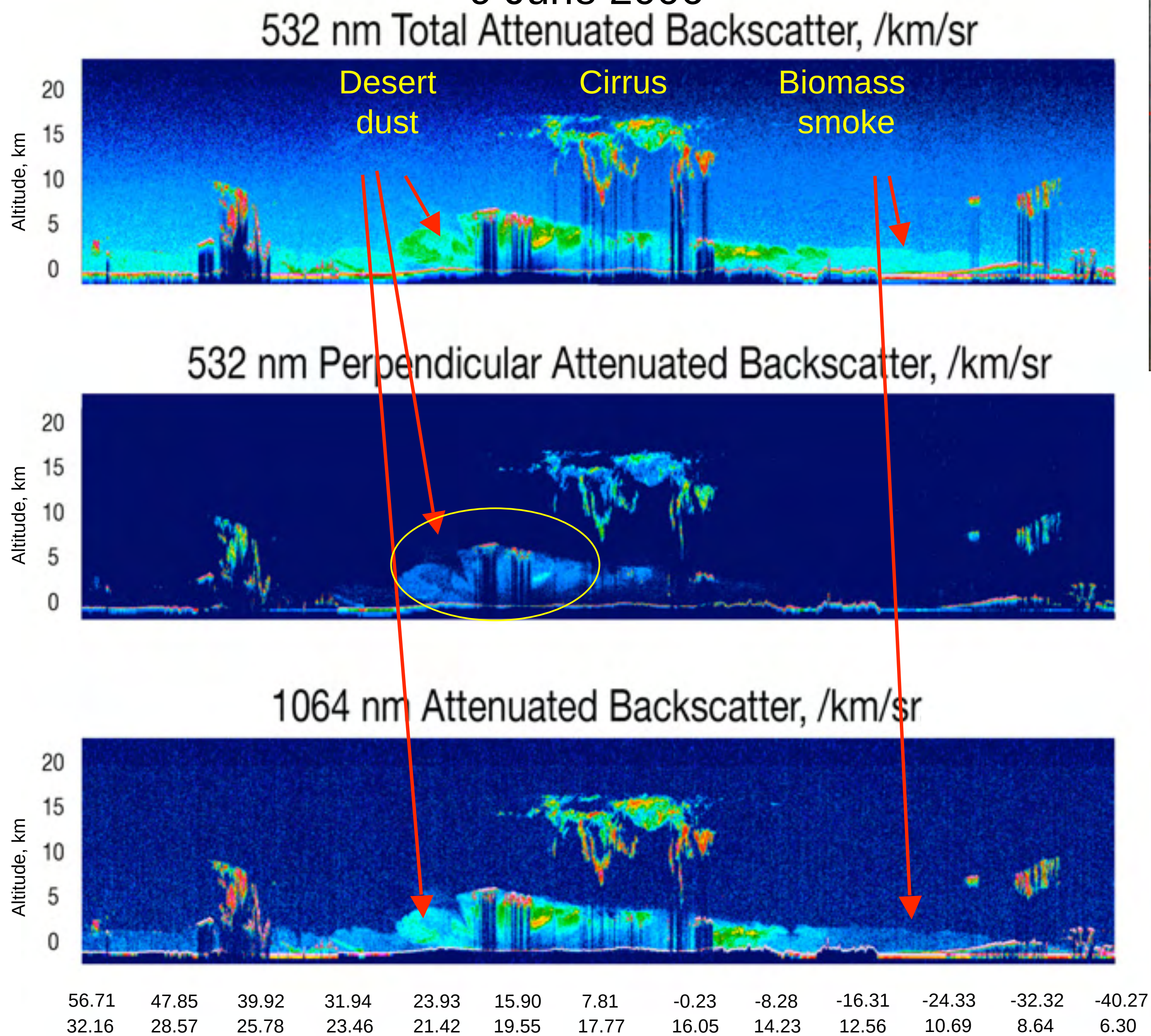
MODIS Aerosol Products View the Global Aerosol System in an Entirely New Way

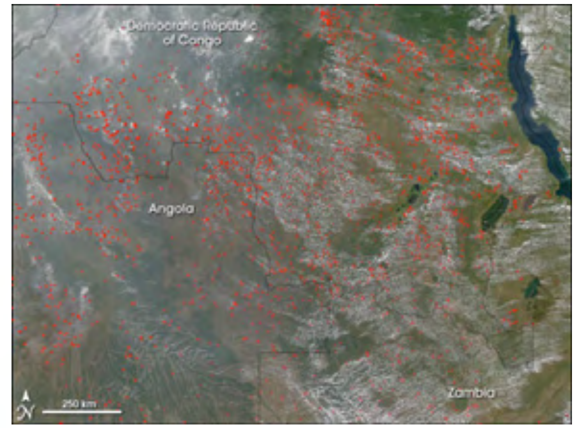
- Quantitatively calculate intercontinental transport of dust (Kaufman et al., 2005) or pollution (Yu et al. in preparation)
- Observationally-based estimate of aerosol direct radiative effect (Remer and Kaufman, 2006; Yu et al., 2006; Bellouin et al.2005; Chung et al., 2005)
- Observationally-based estimate of oceanic aerosol anthropogenic component or direct forcing (Kaufman et al. 2006)
- Tool for operational air quality forecasts (Al Saadi et al. 2005)



CALIPSO Observations – All 3 Lidar Channels

9 June 2006





Fire locations in southern Africa from MODIS 10 June 2006