

# Future Challenges:

## Monitoring and Prediction of the Earth's Climate

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CLIVAR 2004 conference



The climate is changing: It is likely to continue to change!  
Regardless of the success of mitigation actions:

**We need a comprehensive information system to:**

- Observe and track the climate changes and forcings as they occur.
- Analyze global products (with models)
- Understand the changes and their origins
- Validate and improve models
- Initialize models; predict future developments
- Assess impacts regionally: on environment, human activities and sectors such as agriculture, energy, fisheries, water resources, etc.

**Such a system will be invaluable regardless of**

In the future what kind of a climate information system might we have?

Major technological advances occurring now!

Observations: exciting new satellites and instruments,  
in situ (e.g. McPhaden et al. session 1)

Computers: e.g., Earth Simulator- many TFlops

Assimilation:

- atmosphere (Simmons et al., this session)
- ocean (Stammer et al., this session)
- coupled ??

Modeling:

- Earth system at high resolution (few km globally) (Matsuno et al., this session)



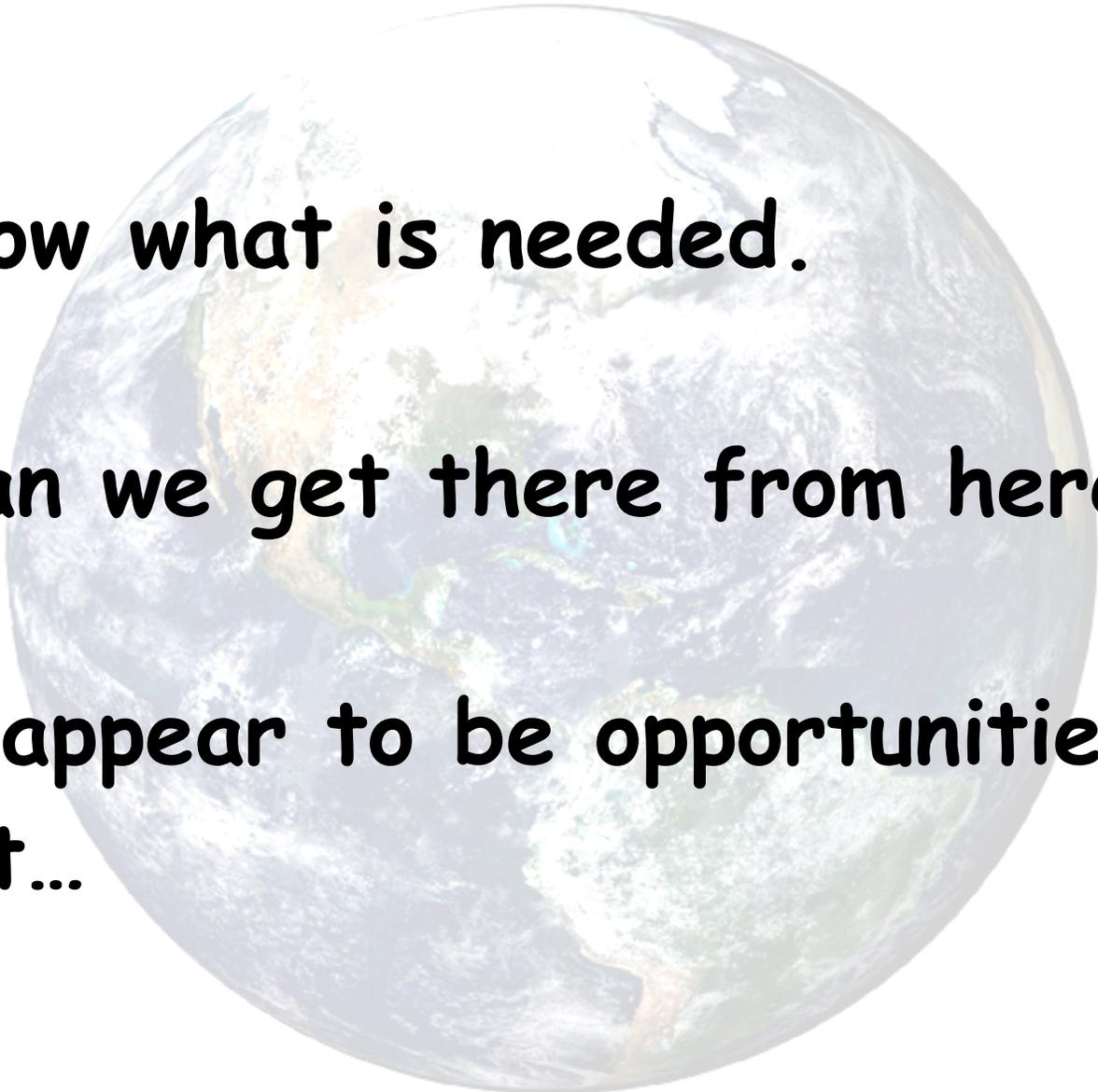
## Major technological advances occurring now!

But they do not make for a climate observing system.

### Some Issues:

- Developing observations for climate
  - satellites change and drift in orbit
- Establishing climate data records
- Handling screeds of data
- Stewardship and archival of data
- Access to data
- Reanalysis of observations
- Developing new parameterizations





**We know what is needed.**

**How can we get there from here?**

**There appear to be opportunities,  
but...**



## Climate Data Records are needed.

- Most observations are instrument and platform dependent
- Observations must be of **known** quality.
- Preferably the quality is high
- However consistency and continuity are vital
- Calibration is essential
- Analysis and integrated assessment of observations is a vital part of the system
- Uncertainty or error analysis

We need some **benchmark** observations:  
absolute accuracy, independent of instrument  
and platform.

## Satellite Radio Occultation Temperatures

Radio occultation measurements are robust to changes in satellites and instrumentation on satellites: gives temperatures above 6 km.

"If we had had RO during the '80s and '90s there would not have been this huge controversy over the MSU temperature record." R. Anthes 2003

Advantages: Measurement: excellent long term stability, all weather

Good vertical resolution ~100 m

Global, fairly uniform, coverage

Diurnal cycle coverage

Millions of observations (beats down noise)

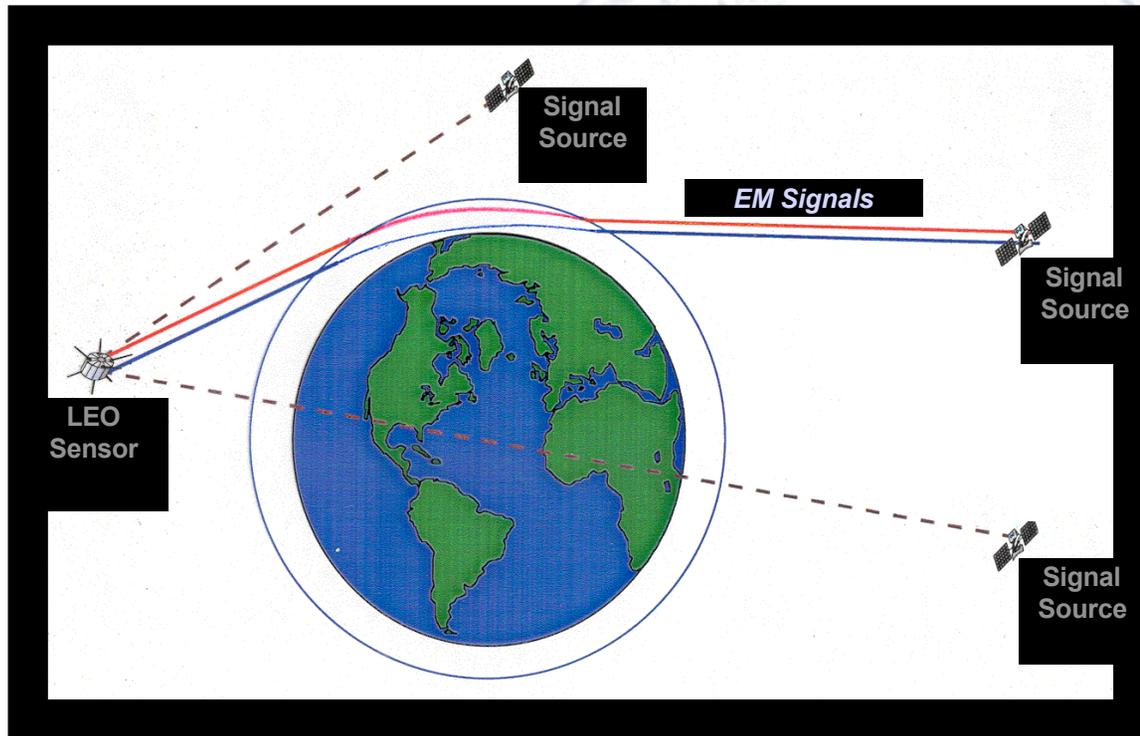
Can calibrate, validate, and combine with IR and MSU sensors

Horizontal representativeness of ~200-300 km: excellent for climate

Disadvantages:

Measures time delay: refractive index, depends on T and moisture

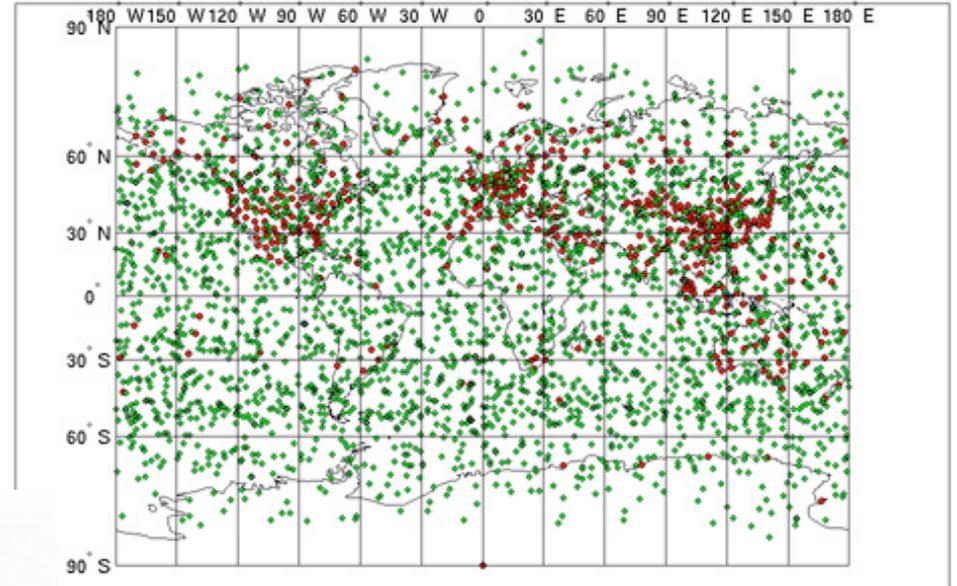
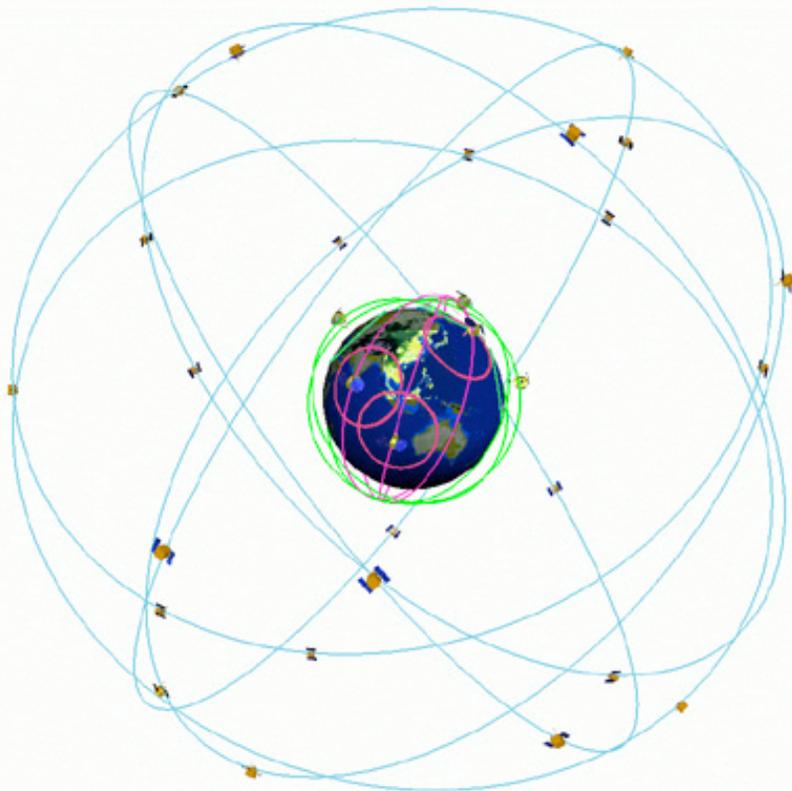
# GPS Radio Occultation Methods: How they work



- Exploit extinction and/or refraction of electromagnetic signals along limb paths
- Signal is **retarded** or **bent** by atmosphere giving a phase or Doppler shift that is measured very accurately with signal amplitude by the GPS receiver aboard the low-Earth orbiting satellites

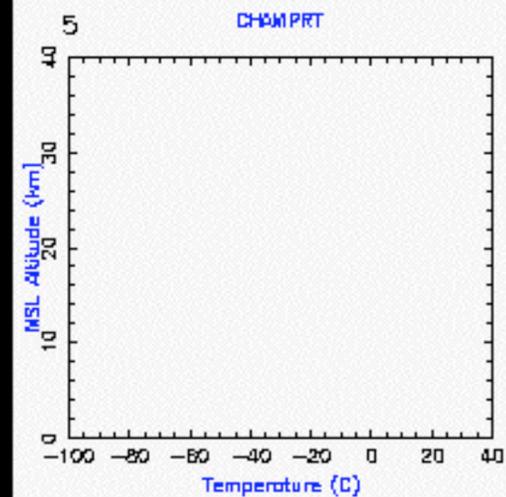
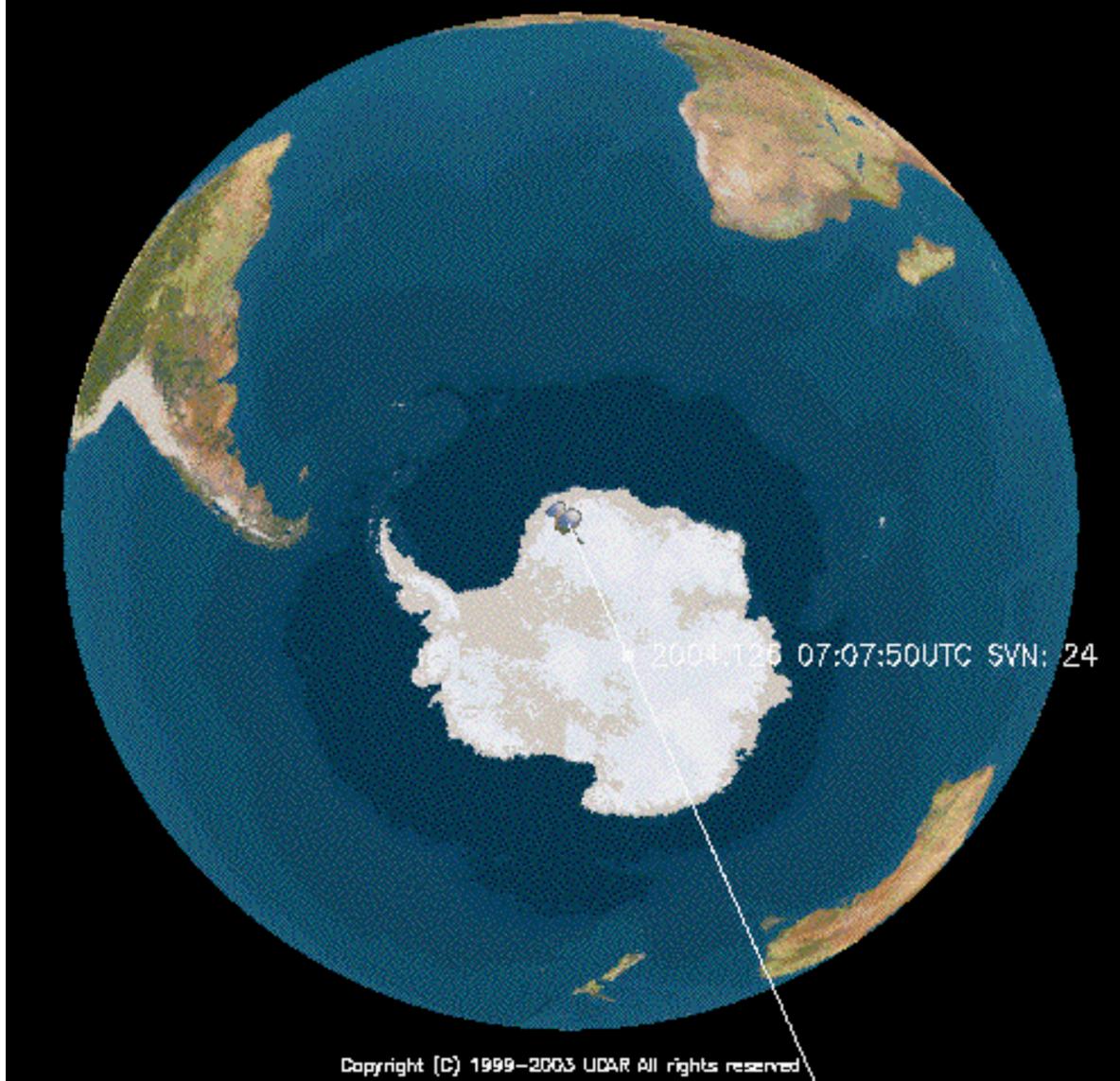
# GPS Radio Occultation

Constellation of GPS satellites (outer) and low earth orbiters which use occultation to make soundings as they rise and set.



Current global coverage of instruments launched via radiosondes each day (in red) with the expected coverage from the 6 satellite COSMIC network in a 24-hour period (in green) in 2005.

5 Last 5 occultations (champprt) at 2004.126.14.48.59



Live acquisition  
of GPS  
soundings from  
CHAMP via the  
UCAR web site.



NCAR

We need a much better baseline of high quality soundings approaching absolute accuracy:

## “Reference sonde” network

- temperature (3 thermister, redundant, radiation adj.)
- water vapor (chilled mirror?) :Operational sondes not responsive for humidity below about  $-20^{\circ}\text{C}$
- ozone, other sensors

▶▶ Calibrates satellite-based measurements

▶▶ Anchors analyses

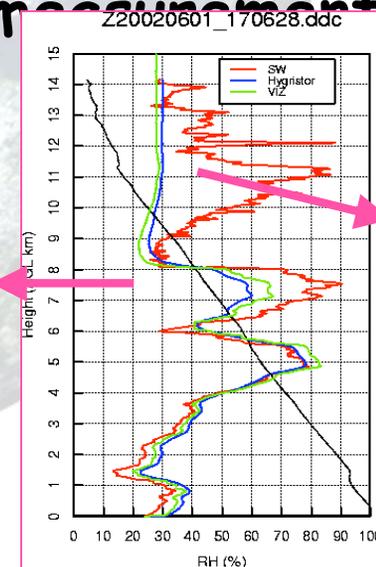
▶▶ Provides continuity

Viz and Vaisala  
vs prototype

ref. sonde

Wang et al.

Slow  
response



No  
response



NCAR

Domain	Essential Climate Variables
<b>Atmospheric</b> (over land, sea and ice)	<p><b>Surface:</b> Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapor.</p> <p><b>Upper-air:</b> Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapor, Cloud properties.</p> <p><b>Composition:</b> Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties.</p>
<b>Oceanic</b>	<p><b>Surface:</b> Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean color (for biological activity), Carbon dioxide partial pressure.</p> <p><b>Sub-surface:</b> Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.</p>
<b>Terrestrial</b>	<p>River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance.</p>



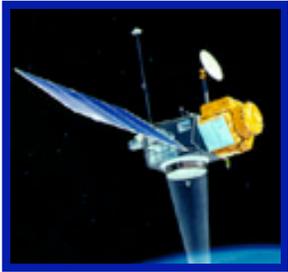
## A vision for the future

### Atmosphere:

#### Includes (not complete):

- ✓ Hourly precipitation: intensity, frequency, amount: from gauges, remote sensing rates (radar, satellite: GPM?).
- ✓ Few regular radiosonde stations
- ✓ Sparse network of ~40 "reference sondes" for satellite calibration and climate monitoring, and UT water vapor plus ozone and other constituents
- ✓ Co-located with regular sondes to give full temporal sampling
- ✓ GPS RO (COSMIC+) for temperatures above 500 mb
- ✓ IR and microwave soundings (T and water vapor)
- ✓ Ground based GPS column water vapor network  
continuous in time (Suomi Net plus)





## A vision for the future

### Ocean



✓ A backbone of expanded ARGO array of floats with multiple sensors

✓ Satellite based:

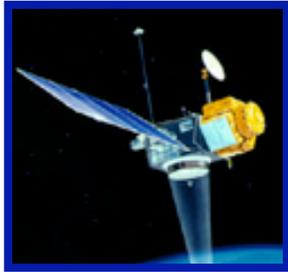
- ✓ Altimetry
- ✓ Scatterometry
- ✓ Ocean color
- ✓ Salinity
- ✓ Precipitation
- ✓ SST
- ✓ Some surface fluxes

✓ Moored buoys

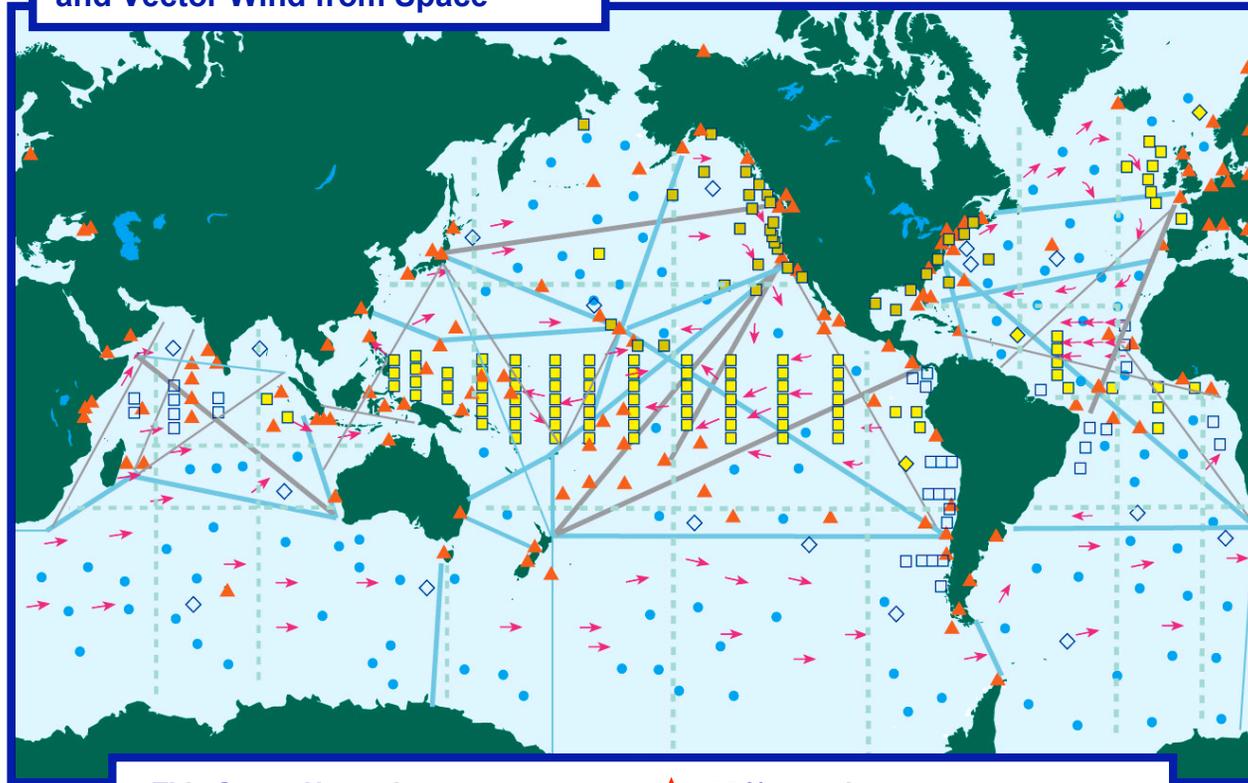
✓ XBTs



# This builds upon the proposed initial ocean observing system



Sea Surface Temperature, Height, and Vector Wind from Space



- |                                    |                                      |
|------------------------------------|--------------------------------------|
| Tide Gauge Network                 | ▲ 45 % complete                      |
| 3°x3° Argo Profiling Float Array   | ● 15% complete                       |
| 5°x5° Surface Drifting Buoy Array  | ➔ 35 % complete                      |
| Moored Buoy                        | ■ Existing    □ Planned              |
| Ocean Reference Station            | ◆ Existing    ◇ Planned              |
| High Resolution XBT and Flux Line  | — Existing    — Planned              |
| Frequently Repeated XBT Line       | — Existing    — Planned              |
| Carbon Inventory & Deep Ocean Line | — Existing    — Planned              |
|                                    | ■ Survey 1.5 lines/year, 50 % funded |

## A vision for the future:

### Land and carbon

Need enhancements in several areas via remote sensing and in situ

### **Key variables:**

River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance.

*DNA Micro-Arrays*



*Chem-Lab on a chip*



*Minirhizotron Array*



*Micro-weather Stations*



*Multiparameter Soil Probes*



# Instrumenting the Environment



*Vapor Detector*



*E-nose*



*Smart Sensor Web*



*Automated E-tongue*



*Organism Tracking & Sensing*

# Remote sensing: changes in landscape



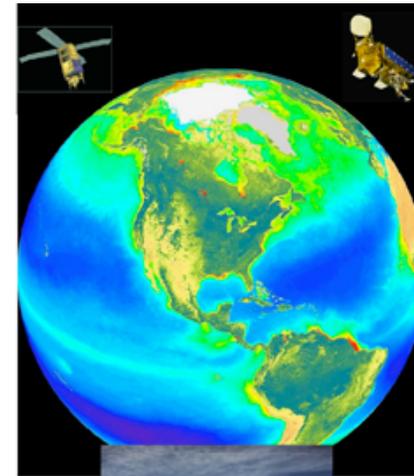
SPOT 5 image of Iguazu, Brazil - September 2002

# The Carbon System

The **sources** and **sinks** and **controlling processes** will only be determined within an **integrated** approach where point-wise *in situ* surface measurements can be scaled up using global satellite datasets and models, **and then constrained and verified by atmospheric CO<sub>2</sub> concentration measurements.**

## Approach

- Remote Sensing
- ↓
- Aircraft Surveys
- ↓
- Trans-basin Sections
- ↓
- VOS Surface Observations
- ↓
- Time-series sites and Moorings
- ↓
- Process Studies



## Scale

- Global
- ↓
- Ocean Basin
- ↓
- Regional
- ↓
- 1 km<sup>2</sup>
- ↓
- 1 m<sup>2</sup>

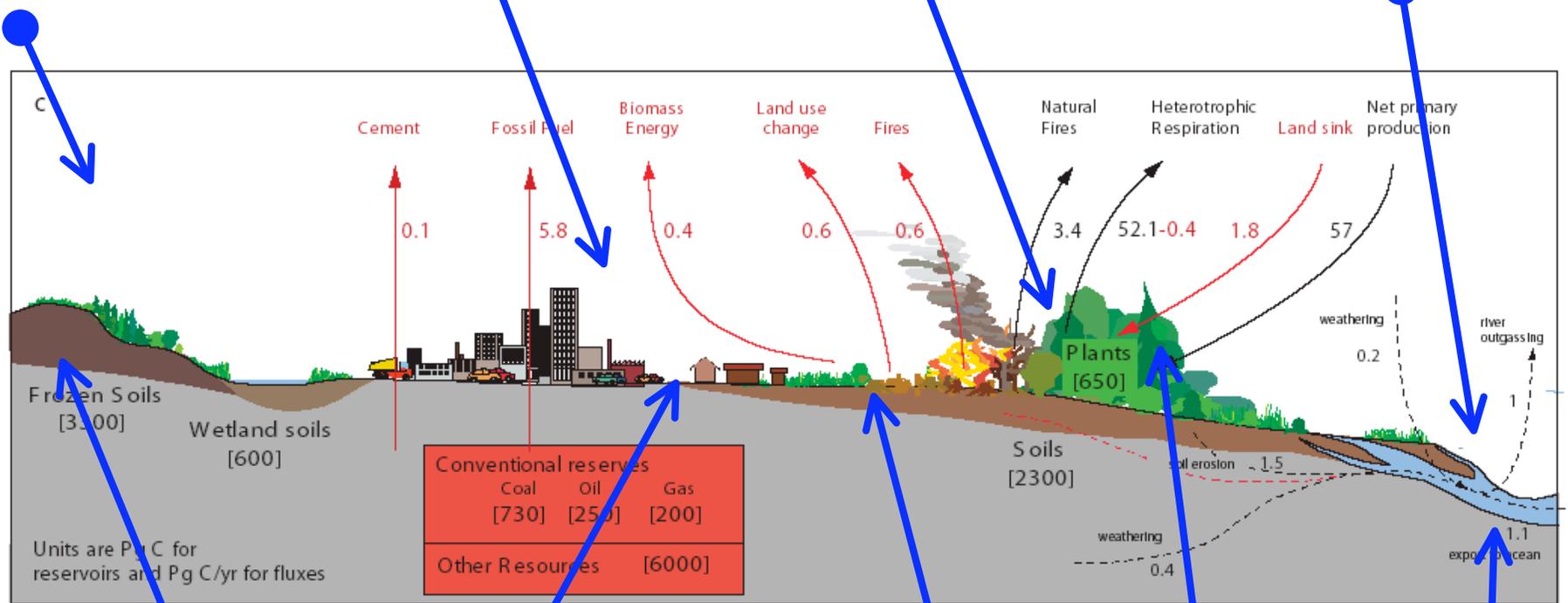
# Surface Fluxes

Atmospheric column  $CO_2$  concentration measured from satellites

Global satellite observations complement in situ observations

Land-atmosphere  $CO_2$  flux measured via eddy covariance flux network

Air-sea fluxes of ocean  $pCO_2$  from ships and buoys



Carbon storage in sediments of reservoirs, lakes

Carbon storage in anthropogenic pools, primarily wood products

Soil carbon inventories

Forest biomass inventories

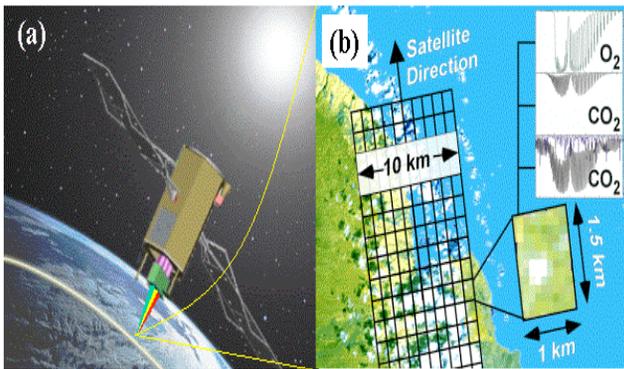
Land Pools

Ocean Pools

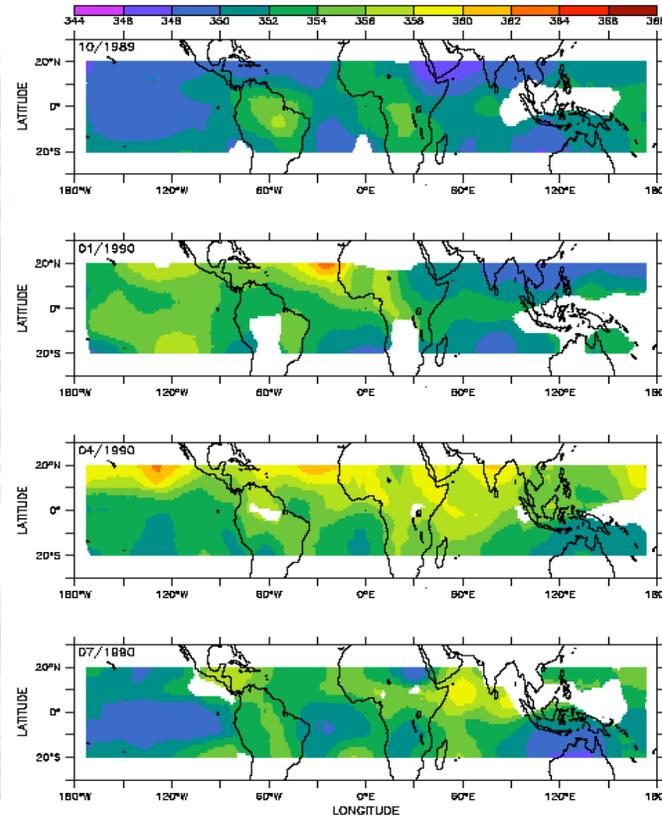
# Space based measurements of Atmospheric CO<sub>2</sub>

- Advantage of dense, repetitive coverage
- Column integrated sampling
- IR and NIR sensors

2007 : OCO NIR passive

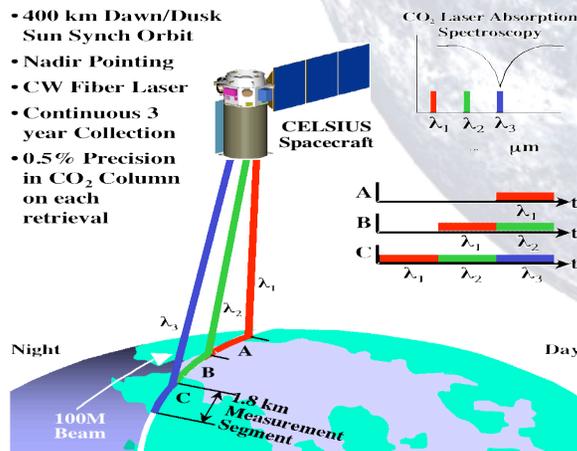


Present: IR HiRs (Below),  
IASI, AIRS  
NIR : SCIAMACHY-Glint



## Future : NIR active

- 400 km Dawn/Dusk Sun Synch Orbit
- Nadir Pointing
- CW Fiber Laser
- Continuous 3 year Collection
- 0.5% Precision in CO<sub>2</sub> Column on each retrieval



Need more comprehensive climate observations:

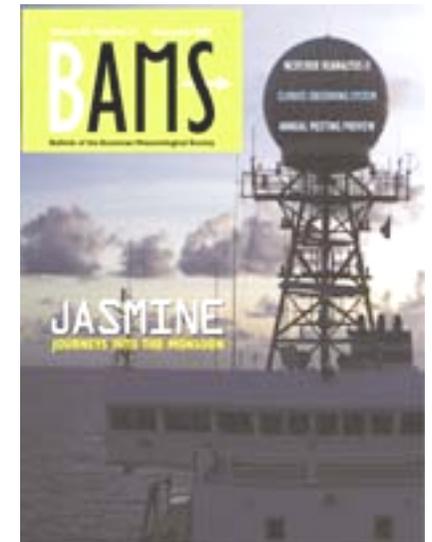
## THE NEED FOR A SYSTEMS APPROACH TO CLIMATE OBSERVATIONS

BY KEVIN E. TRENBERTH, THOMAS R. KARL, AND THOMAS W. SPENCE

Because climate is changing, we need to determine how and why. How do we best track and provide useful information of sufficient quality on climate?

*Bulletin of the American Meteorological Society:*

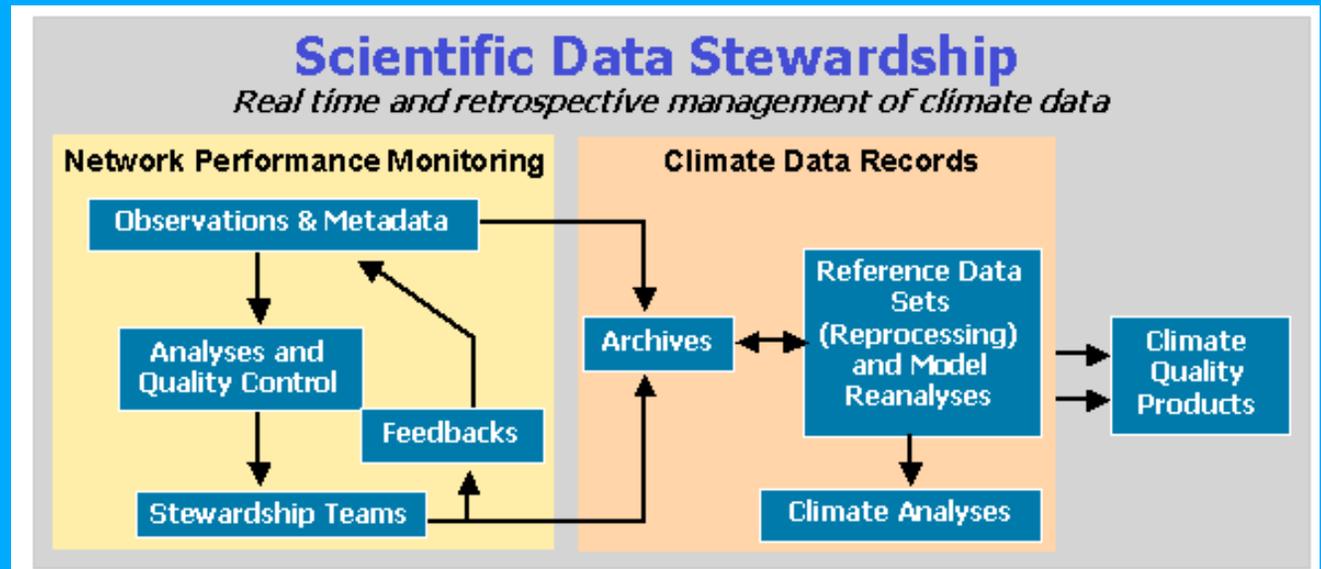
November 2002, **83**, 1593-1602



**Observing system** means a comprehensive approach, including

- **Climate observations** from both space-based and in situ platforms taken in ways that address climate needs and adhere to the ten principles outlined by the NRC (1999).
- A **global telecommunications network** and satellite data telemetry capacity to enable data and products to be disseminated.
- A climate observations **analysis** capability that produces global and regional analyses of products for the atmosphere, oceans, land surface and hydrology, and the cryosphere.
- **Four dimensional data assimilation** capabilities that process the multivariate data in a physically consistent framework to enable production of the analyses: for the atmosphere and oceans, land surface etc.
- **Global climate models** that encompass all parts of the climate system and which are utilized in data assimilation and in making ensemble predictions.
- A climate observations **oversight and monitoring center** that tracks the performance of observations, the gathering of the data, and the processing system. This center must have **resources** and influence to fix problems and be a prominent climate voice when observational systems are established, such as for weather purposes or in establishing requirements for instruments on satellites.

**Stewardship**  
of the data is  
needed:



**Essential infrastructure has to be established to ensure the integrity and continuity of the observations, their analysis into products, and links to modeling and research activities.**

Needed: a central facility with oversight of the **health of the observing system** and resources and authority to build and sustain a climate observing system operating under the guideline principles.

# Reprocessing and Reanalysis

Given the continuing improvement in our understanding of climate observations and the need for long time series, reprocessing is a hallmark of every climate observing system.

NOAA Climate and Global Change WG report,  
April 1-3 2003.

## Ongoing Analysis of the Climate System: A Workshop Report



August 18-20, 2003  
Boulder, CO  
Sponsored by NOAA, NASA & NSF

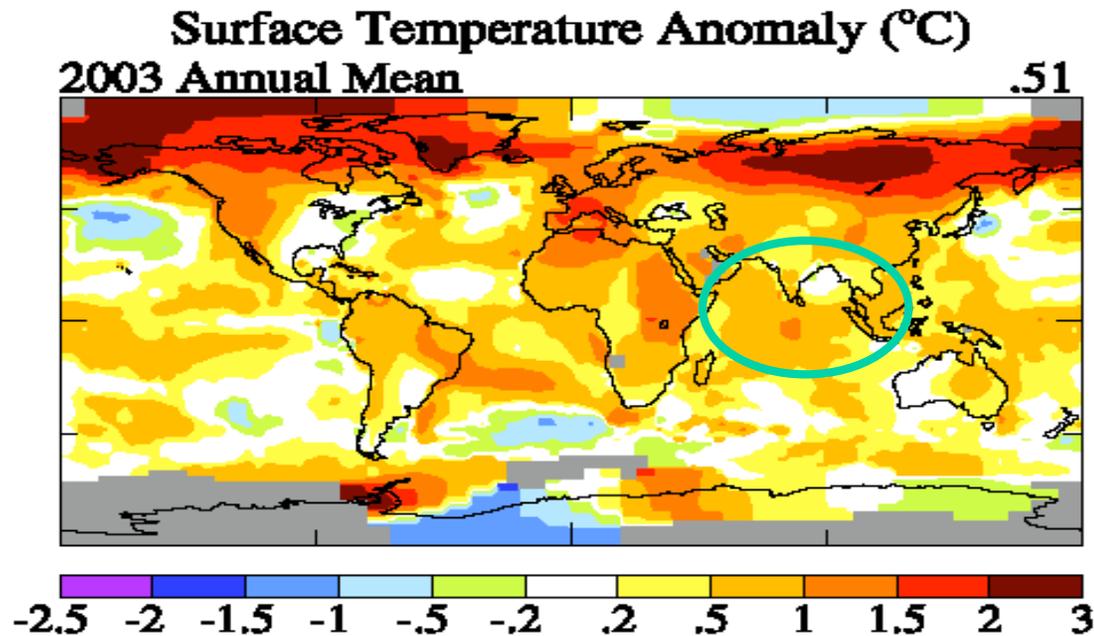
# Attribution

One area of major growth should be developing the ability to not only **track** climate anomalies but also to **attribute** them on multiple time scales to:

- external forcings (solar, volcanoes, atmospheric composition)
- internal forcings (e.g., ENSO, SSTs and ocean heat content, soil moisture anomalies, state of vegetation, sea ice)
- natural variability (essentially unpredictable)

This requires an **operational numerical experimentation program running ensembles of**

# Global increases in SST are not uniform. Why?



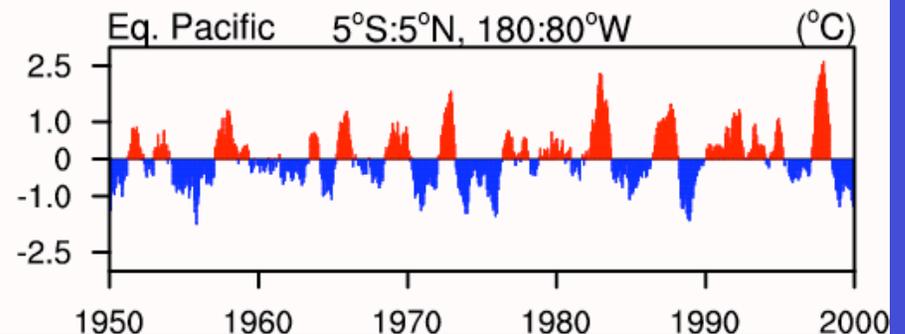
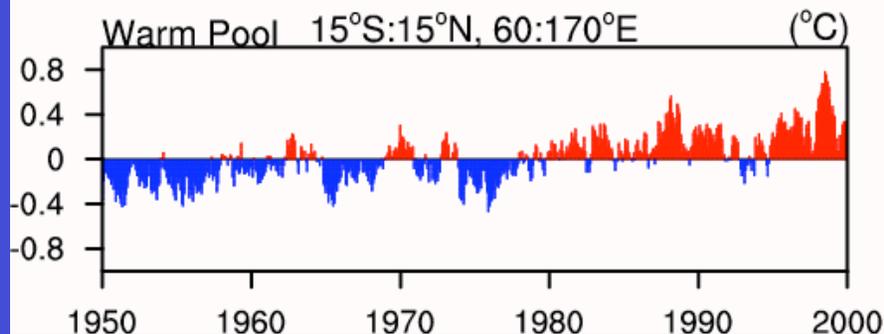
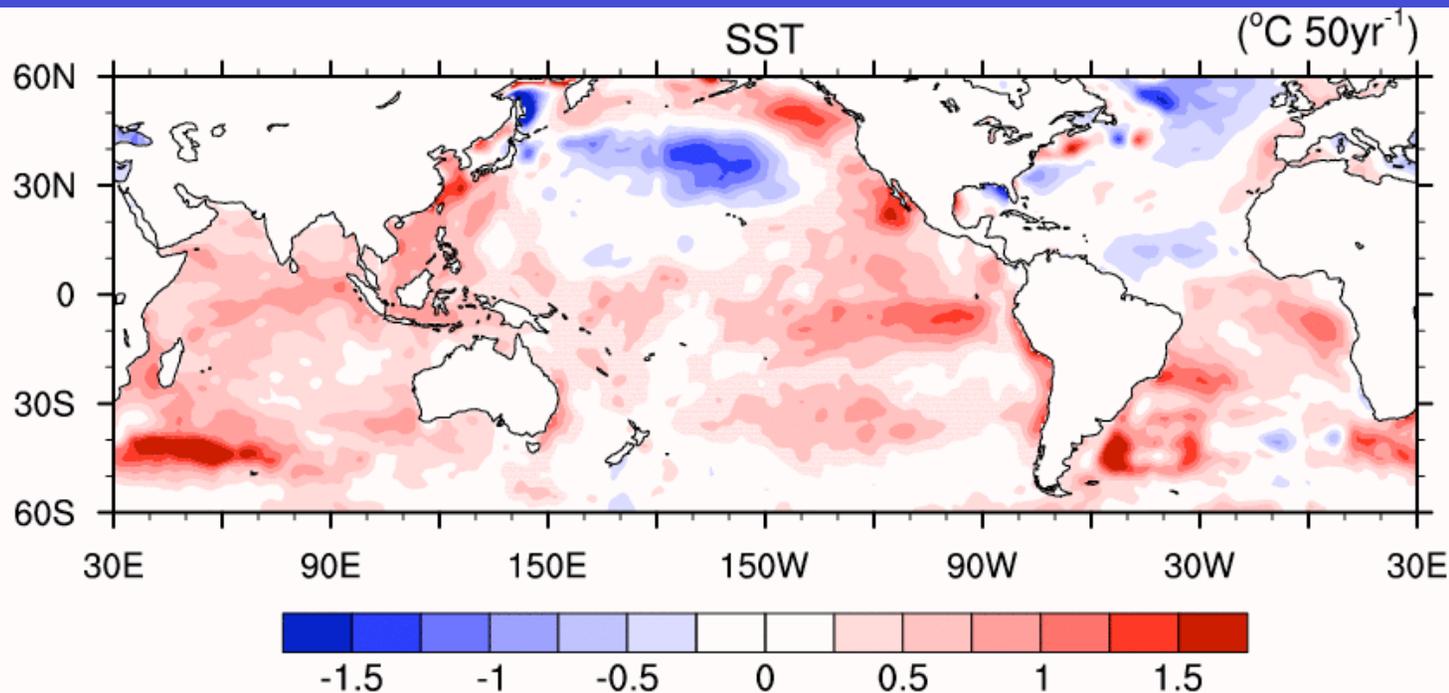
INDIAN OCEAN  
WARMING

relative to 1951-80  
mean

GISS

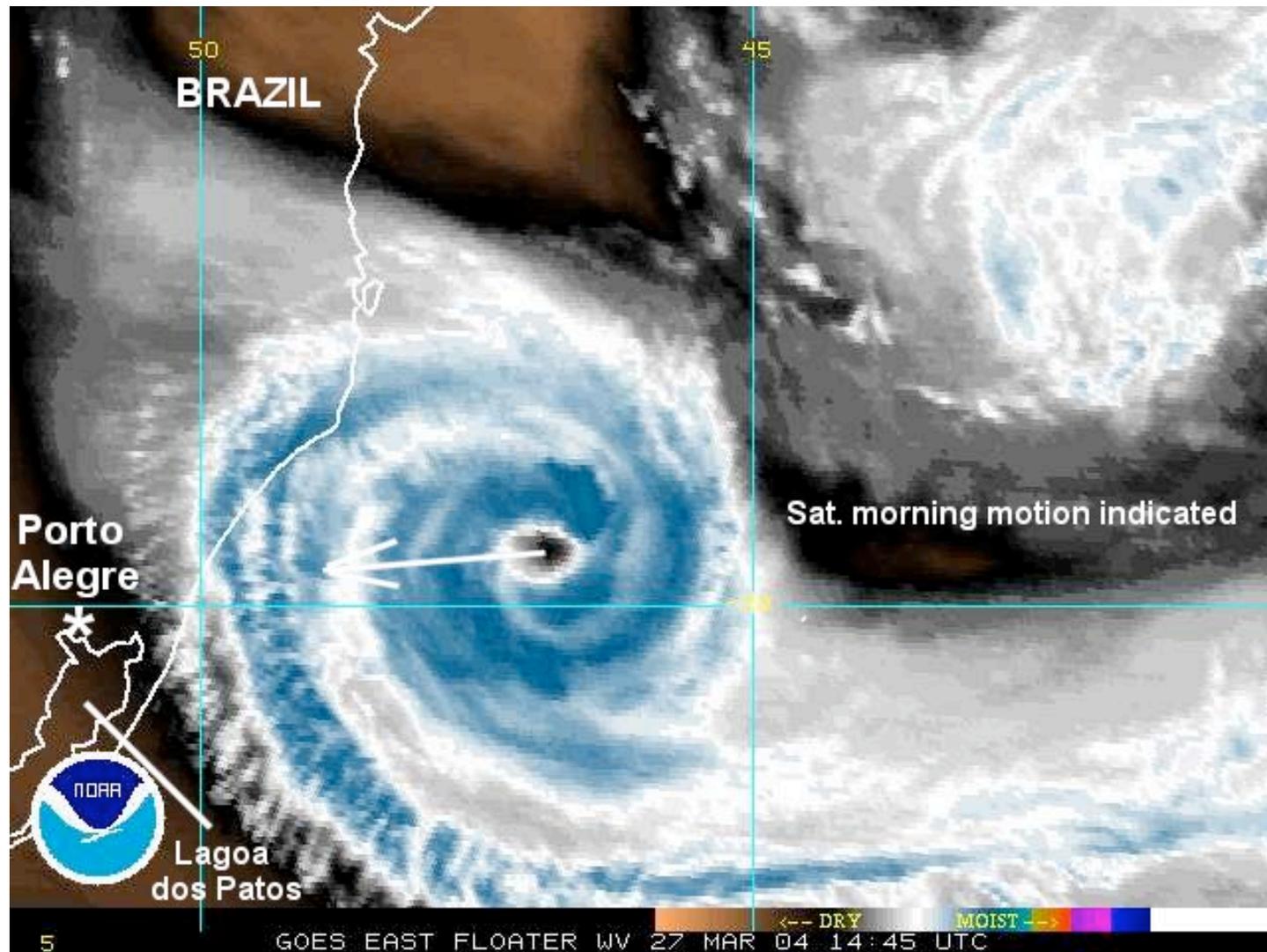
- ❖ Coupling with atmosphere
- ❖ Tropical Indian Ocean has warmed to be competitive as warmest part of global ocean.
- ❖ Tropical Pacific gets relief owing to ENSO?
- ❖ Deeper mixing in Atlantic, THC.

Relates to ocean uptake of heat, heat content & transport.  
This pattern is NOT well simulated by coupled models!



*Trends 1950-1999. Time series of monthly SST anomalies over the equatorial Indian and western Pacific Oceans (lower left) and eastern equatorial Pacific Ocean (lower right). Courtesy J. Hurrell et al. 2004.*

First observed hurricane in the South Atlantic?  
Is it natural variability or a changing climate?



"Catarina", 27 March 2004 14:45 UTC

## Models have improved

### Several atmospheric models can simulate major changes:

- the Sub-Saharan African drought beginning in the 1960s, (e.g. Giannini et al 2003)
- the “Dust Bowl” era in North America in the 1930s, (e.g. Schubert et al 2004)
- trends in the North Atlantic Oscillation, (e.g. Hurrell et al 2004)
- other large-scale persistent droughts (e.g. Hoerling and Kumar 2003)
- ENSO effects

given the global SSTs.

Can coupled models predict these evolutions? (Not so far). But there is hope that they will improve.

In any case models should show some skill simply based on the current state, **when** it becomes well known and properly assimilated into models:



The challenge is to better determine:

- 1) how the **climate** system is changing
- 2) how the **forcings** are changing
- 3) how these **relate** to each other
- 4) what they mean for the immediate and more distant **future**
- 5) seamless **predictions** on multiple time scales
- 6) **attribution** of anomalies to causes
- 7) how to use this information for informed planning and **decision making**
- 8) how to **manage** the data and reanalyze it routinely
- 9) how to **disseminate** products around the world
- 10) how to **interact** with users and stakeholders and add regional value



# Earth Observing Summit

31 July 2003 Washington DC



## G8 Proposal:

Focused on need for observations but really with a vision for an Earth Information System.

Implies need for analysis and reanalysis: indeed a complete system.

Implementation being developed: a system of systems to be implemented in next 10 years. Plan endorsed by 47 nations in April 2003.



*Science*, Vol 304, Issue 5671, 661 , 30 April 2004

## EARTH OBSERVATION:

### Summit Pledges Global Data Sharing

Dennis Normile, TOKYO—

Representatives from 47 nations have endorsed a 10-year plan to **share** Earth-observation data, identify **gaps** in observational efforts, and come up with ways to fill them.

The idea behind the **Global Earth Observation System of Systems**, is straightforward: Dozens of observational systems are now generating reams of data that could be far more powerful if they were **combined** and **widely disseminated**. But achieving that goal means overcoming major technical and political hurdles.



# Global Earth Observations

## Discipline Specific View

## Whole System View

<p><b>Atmospheric Observations</b></p>				
<p><b>Data Systems</b></p>				
<p><b>Ocean Observations</b></p>				
<p><b>Space Observations</b></p>				
<p><b>Technology Development</b></p>	<p><b>Innovations</b> Breakthrough</p>	<p><b>Efficiencies</b> Cost</p>	<p><b>Mass</b> Productions</p>	

**Breakthrough**  
**Innovations**  
**Efficiencies** Cost  
Mass Productions

20<sup>th</sup> Century

21<sup>st</sup> Century

**OBSERVING SYSTEM TIMELINE**





# GEOSS--- Eliminating the Stove Pipe Observing Systems to Create a “System of Systems”



## Global Observing Systems

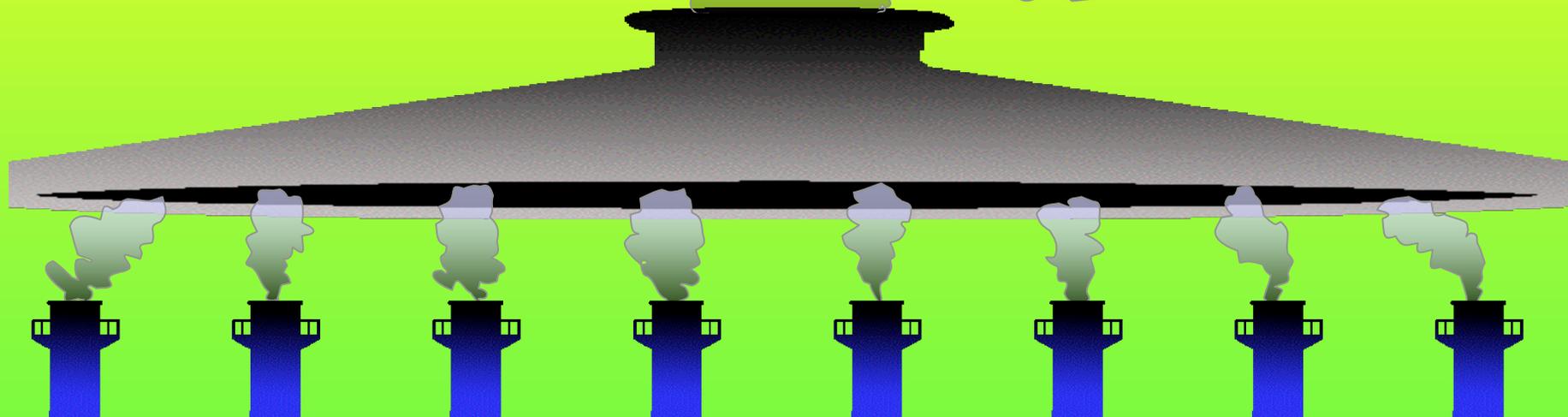
GCOS  
 GOOS  
 GTOS  
 WHYCOS  
 World Weather  
 IGBP  
 IOOS  
 CEOS  
 IGOS, etc.

## National Observing Systems

Satellites  
 Surface Obs.  
 Radar  
 Aircraft  
 Ocean Observations  
 Paleo-data

## Private Sector Observing Systems

Satellites  
 Mesonets  
 Lightning  
 Commercial Aircraft



Climate

Ocean Resources

Disasters

Energy

Health

Agriculture

Ecosystem

Water Resources



# Optimizing Operational Observing Systems For Multiple Users



## 21st Century Vision

### Immature

Scientific Data Stewardship

New Observing Systems

Estimated Data Quality Statistics

*Integrated with Similar Observing Systems*

Data Quality Statistics

Scientific Data Stewardship

Monte Carlo Experiments  
Model Simulations

Enhancement of Existing Systems

### Mostly Mature

#### Trade Space

#### Demand Criteria

- Usefulness of Existing Observations
- Capacity & demand
- Dual use potential
- State of models for data utilization
- Perceived impact of resulting data

#### Implementation Criteria

- Cost to implement
- Readiness
- Operating cost
- Well defined measurement principles
- Probability of successful implementation
- Extensibility to improvements
- Timeliness of data & information

#### Strategic Criteria

- Existing infrastructure to support data stewardship
- Potential for transition from research to operations
- Cost sharing & partnerships
- Commitment and stability of sponsors
- Easy access to data
- Absence of potential impediments to data use
- Breadth and readiness of user communities
- Capacity building opportunities

Today

Tomorrow

Today

# WCRP COPEs

**Coordinated  
Observation &  
Prediction of the  
Earth  
System**



# Climate is global.

## COPEs will:

- Provide a framework for ensuring collaboration among nations and synergy across projects and activities
- Build new tools to describe and analyze climate variability and change, and their combined effects
- Assess why these effects are occurring
- Build improved and more comprehensive climate system models
- Make climate predictions of greater utility from weeks to centuries and on global to regional scales
- Enable improved climate change assessments:
  - On effects of humans
  - Changes in extremes
  - Impacts on water resources



