

# Evolution of Earth System Science: Past Progress and Future Prospects

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# Outline

- ▶ **Introduction**
- ▶ **Past Progress**
  - **Decadal accomplishments**
  - **Personal contributions**
- ▶ **Future Prospects**
  - **Science Challenges & Societal Imperatives**
  - **Opportunities and Challenges**
  - **Lessons Learned and Way Forward**
- ▶ **Discussion**

## Three Decades of Scientific Progress

- ▶ Made significant progress on observing, understanding, and modeling of Earth system.
- ▶ Established major observation networks, in space and on Earth's surface, for atmosphere, oceans and terrestrial systems.
- ▶ Accomplished major advances in development of coupled Earth/climate system models.
- ▶ But, much work remains to be accomplished on all fronts, especially on Earth-Human system interactions.
- ▶ Equally important now is access to scientific knowledge for/by decision makers.

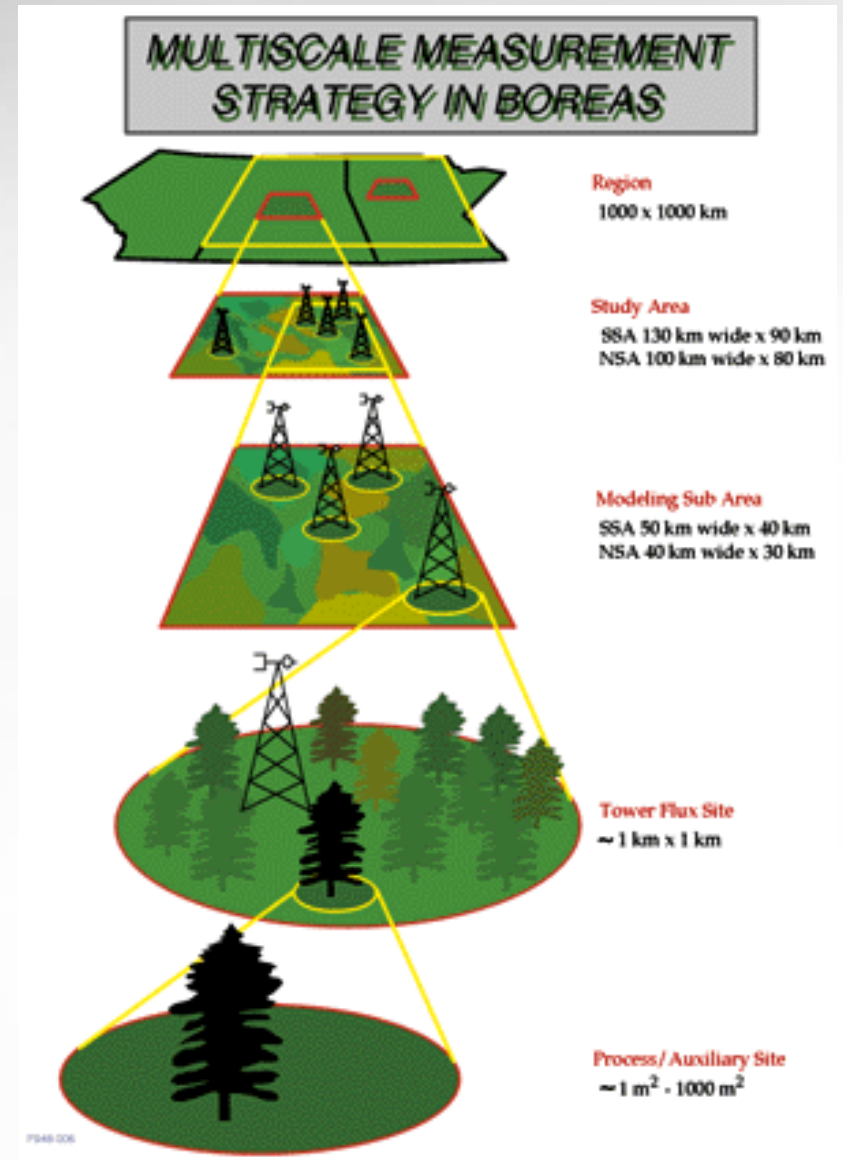
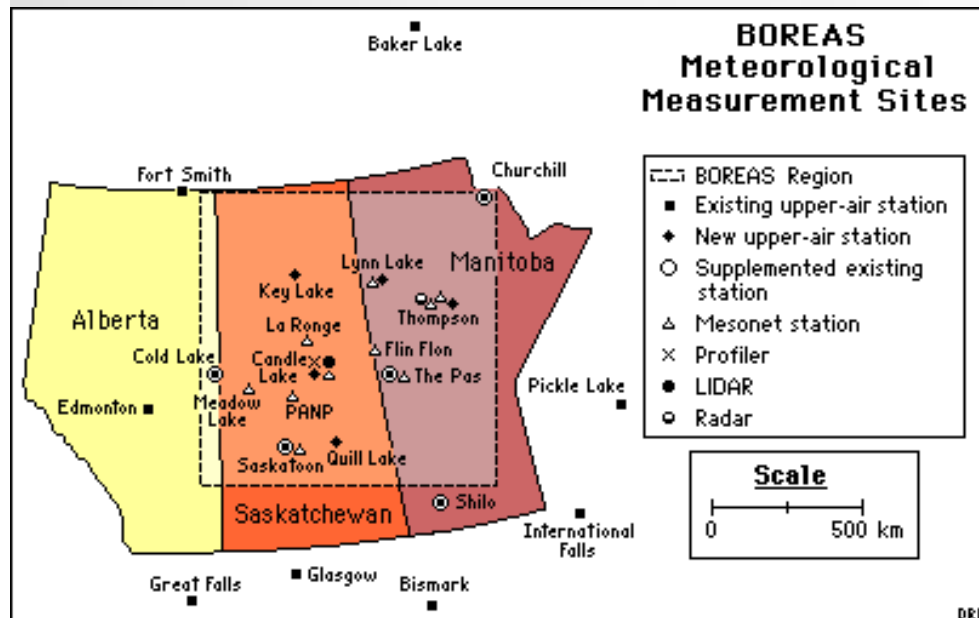
# First Decade

- ▶ Enabled collection and use of multiple observational streams (in situ and remote sensing) that could capture Earth system processes for a wide range of time and space scales.
- ▶ Identified the need for managing quality and quantity of observations, and their stewardship and continuity.
- ▶ Recognized the need for developing coupled Earth system models.
- ▶ Fostered interdisciplinary research, and scientific assessments.
- ▶ Supported educational opportunities for undergraduate, graduate, and post-doctoral students to pursue Earth system science research and teaching.



# Major Field Experiments

**Goal: Improve our understanding of the interactions between the boreal forest biome and the atmosphere, clarifying their roles in global change**



# Personal Research Contribution

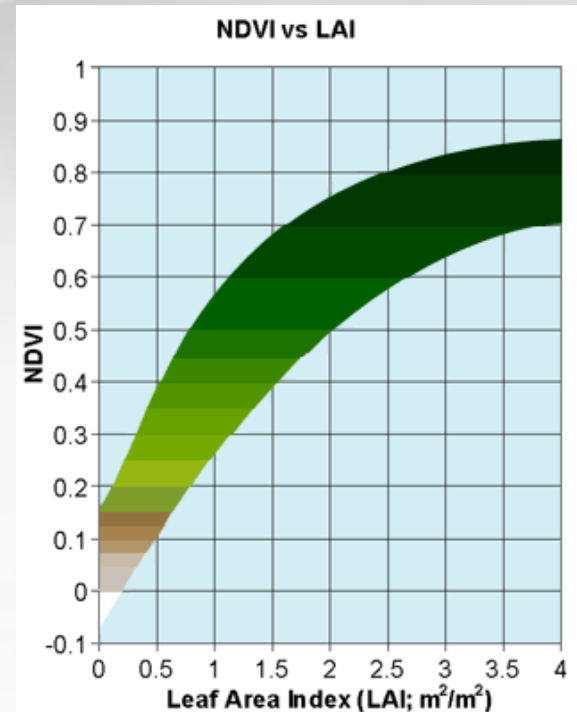
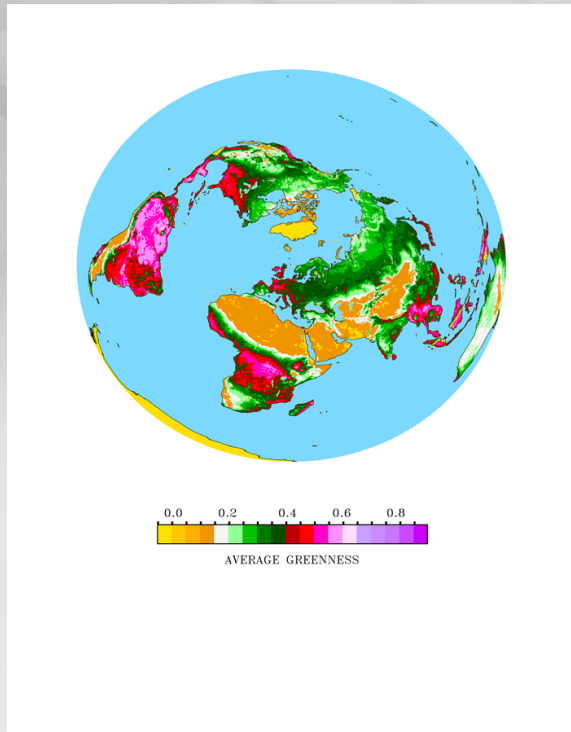


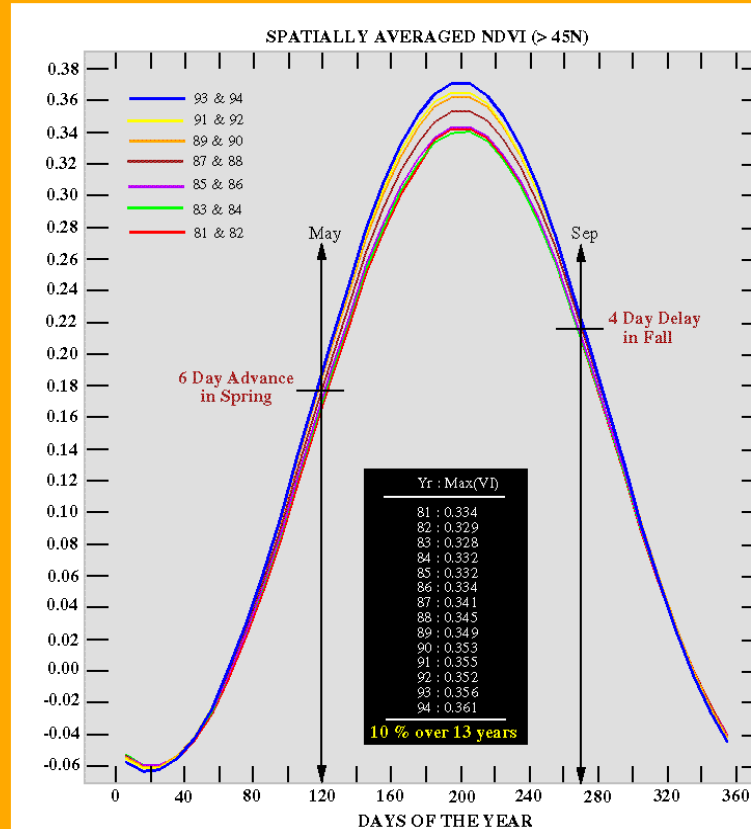
Image credit: Huete et al.

The contrast between red and near-infrared reflectance of vegetation is exploited by the greenness index, NDVI, as  $[(nir-red)/(nir+red)]$ .

NDVI is negative for water bodies and snow, is close to zero for barren areas and gradually increases with leaf area, but saturates in the case of dense vegetation canopies.

# Decadal Analysis of Satellite Data

Analyses of space-based observations for the period 1981 to 1994 revealed -



- NDVI averaged over the peak boreal growing season months of July and August increased by 10%

- The timing of spring green-up advanced by about 6 days.

The satellite data are concordant with an increase in the amplitude of the seasonal cycle of atmospheric CO<sub>2</sub> exceeding 20% since the early 1970s, and an advance in the timing of the draw-down of CO<sub>2</sub> in spring and early summer of up to 7 days (Keeling et al., Nature, 382:146-149, 1996).

Myneni et al. (Nature, 386:698-701, 1997)

## Second Decade

- ▶ **National scientific initiatives such as the US Global Change Research Program supported the research priorities identified during the previous decade.**
- ▶ **Educational programs supported training and development of next generation of scientists, and Earth system science education.**
- ▶ **The National investment for research and education programs grew from several hundred million dollars in late 1980s to more than two billion dollars by late 1990s.**
- ▶ **Major scientific research initiatives sponsored by NSF: Interdisciplinary Global Change Research Centers; DOE: Atmospheric Radiation Measurement Program; NOAA: Climate Change Data and Modeling Centers; and NASA: Earth Observing System and Data Management System Centers and Interdisciplinary Research Program initiatives.**
- ▶ **International scientific research programs such as Earth System Science Partnership, Earth Observing System of Systems emerged with support from scientific community and organizations such as UN, ICSU, etc.**



# Earth System Science



Sun- Earth  
Connection

Climate Variability  
and Change

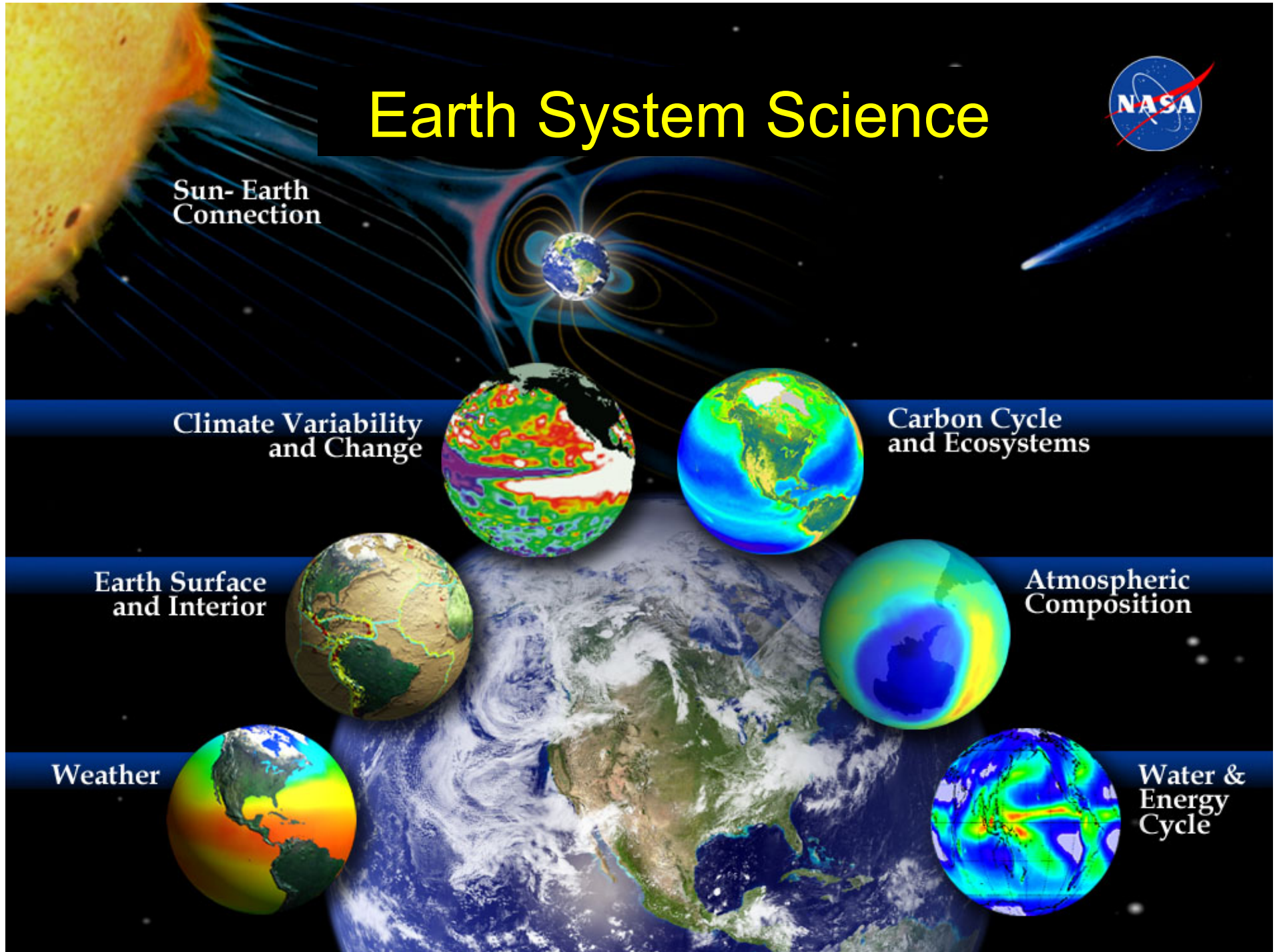
Carbon Cycle  
and Ecosystems

Earth Surface  
and Interior

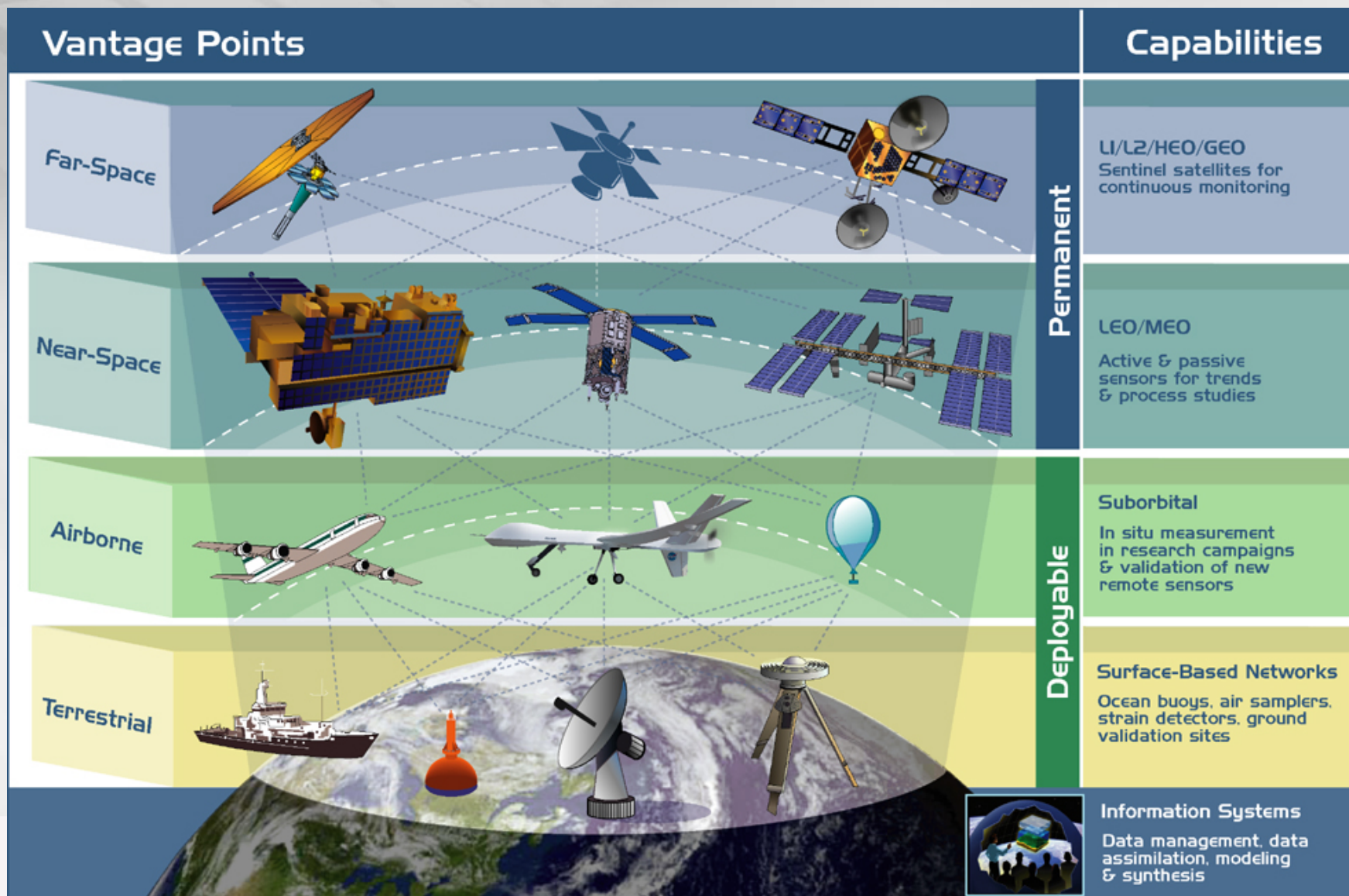
Atmospheric  
Composition

Weather

Water &  
Energy  
Cycle

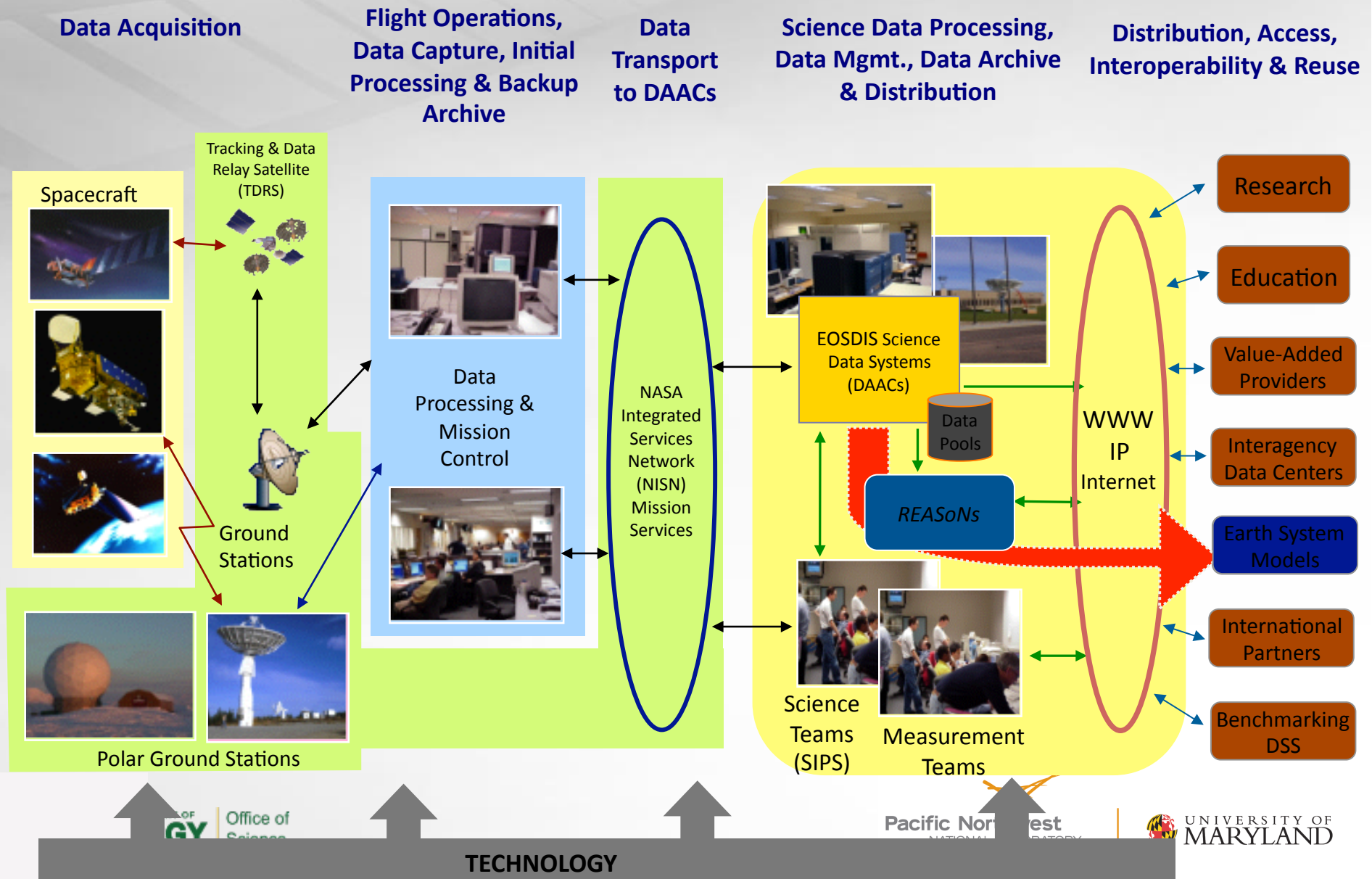


# Global Earth Observing System





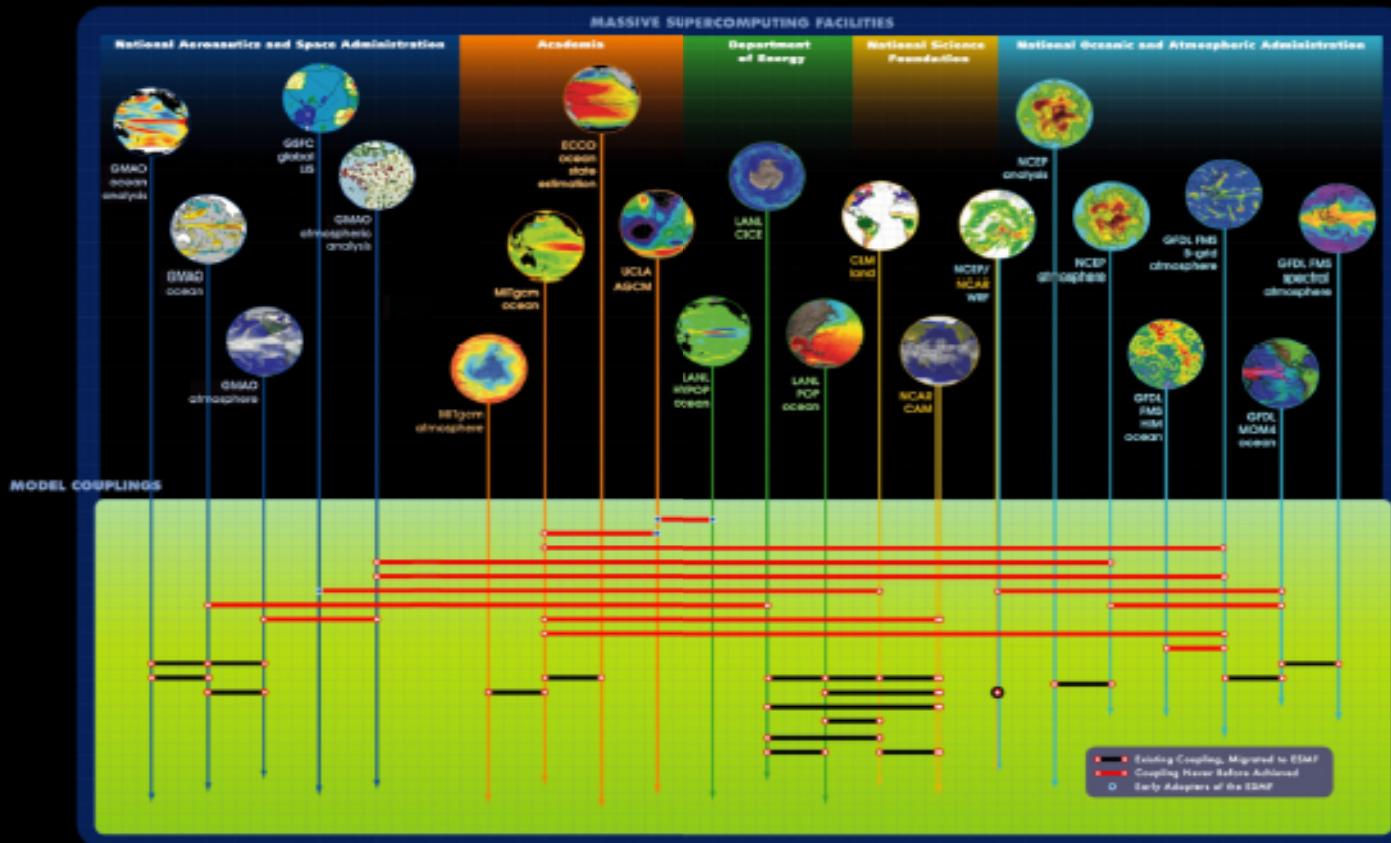
# Data Acquisition, Management and Access



# Earth System Models

## EARTH SYSTEM MODELING FRAMEWORK

MODEL COMPONENTS



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Science

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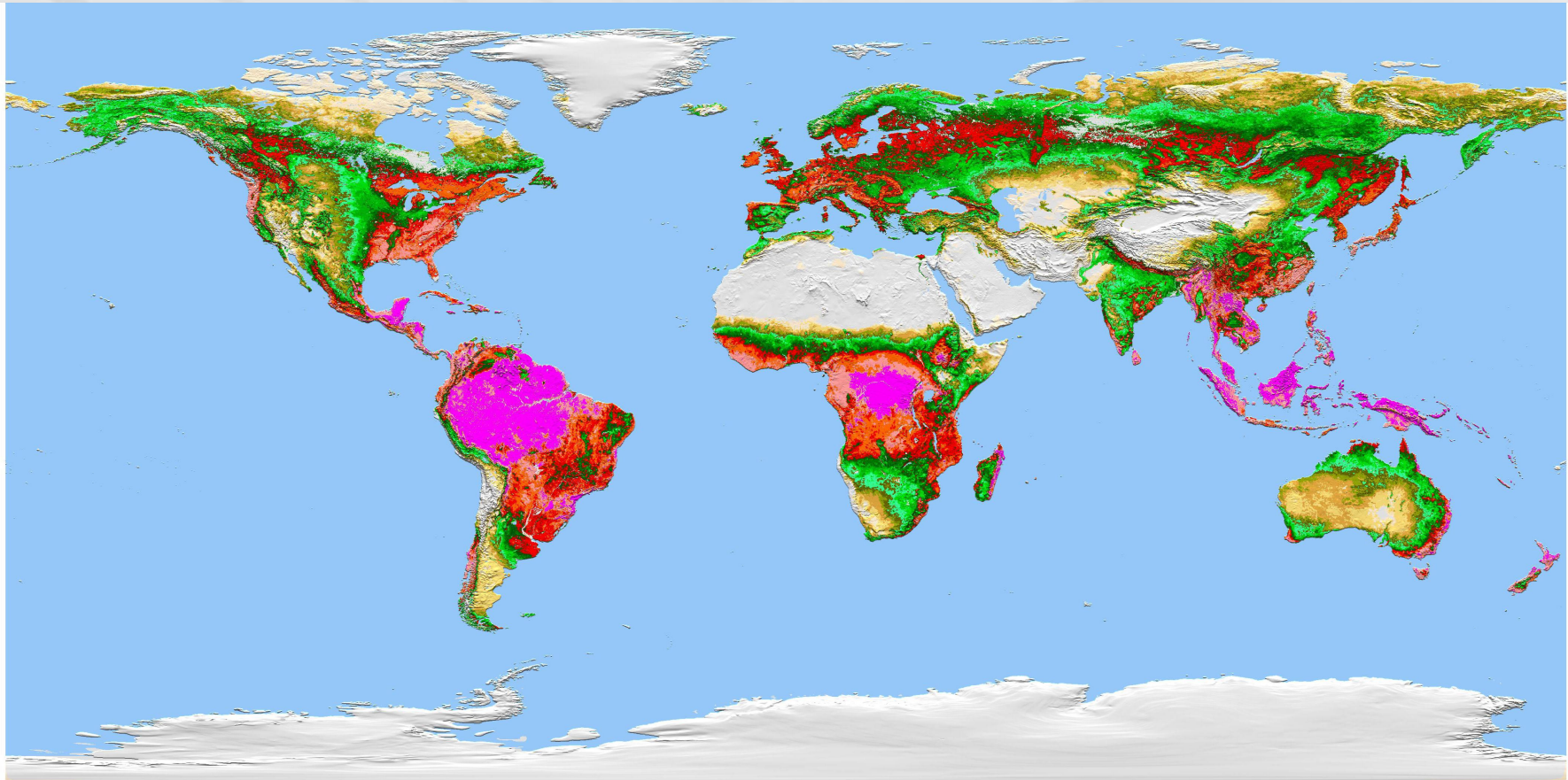
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## Third Decade

- ▶ **Major National and International scientific programs facilitated progress and coordination of observations, research, modeling and assessments at the national and international level.**
- ▶ **National and international debate on future plans and priorities begun earnestly, resulting in major reports such as the Decadal Survey, America Climate Choices, Global Framework for Climate Services, Future Earth, Integrated Framework for Sustained Ocean Observations, etc.**
- ▶ **The National investments for the established research and education programs stayed flat while international investments grew significantly!**

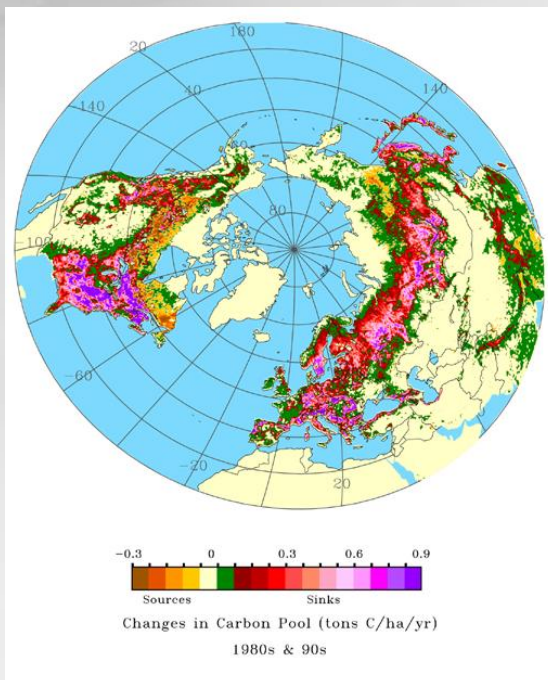
# Routine Production of Global Data Sets



# Study of Terrestrial Ecosystems

To document regional features, the forest woody biomass carbon pools were evaluated for two periods, the early 1980s (1982-86) and late 1990s (1995-99) using a regression model between satellite greenness and forest inventory biomass estimates.

Carbon pool changes were then evaluated as the difference between these two pool estimates, pixel-by-pixel, and quoted on a per year basis.



- The carbon pool in the woody biomass of northern forests (1.5 billion ha) is estimated to be  $61 \pm 20$  Gt C during the late 1990s.

- This is comparable to the TBFRA-2000 reports (80 Gt C), but on 2.5 billion ha of forests and other wooded land.

- The carbon sink estimate for the woody biomass during the 1980s and 1990s is  $0.68 \pm 0.34$  Gt C/yr.

-- This is in the mid-range of estimates by Sedjo for mid-1980s (0.36 Gt C/yr) and TBFRA-2000 for early and mid-1990s (0.81 Gt C/yr).

Myneni et al. (PNAS, 98(26):14784-14789, 2001)

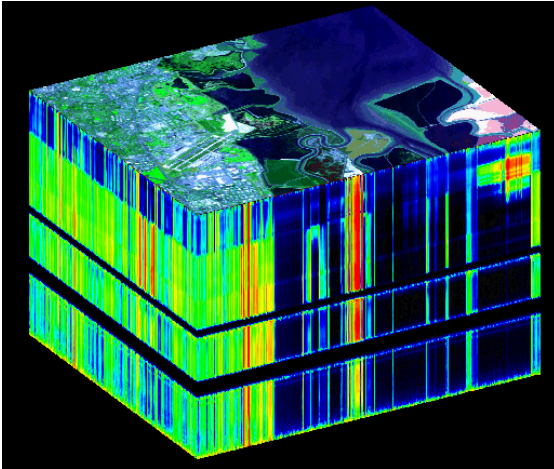
# Remarkable Decades of Technological Breakthroughs

- ▶ Major progress on processing, archive, distribution and visualization of large volumes of data.
- ▶ Access to observations in record time, post acquisition.
- ▶ Real-time availability of observations and information for humanitarian assistance, national services and applications.
- ▶ Innovative applications of observational capabilities beyond their originally conceived use.

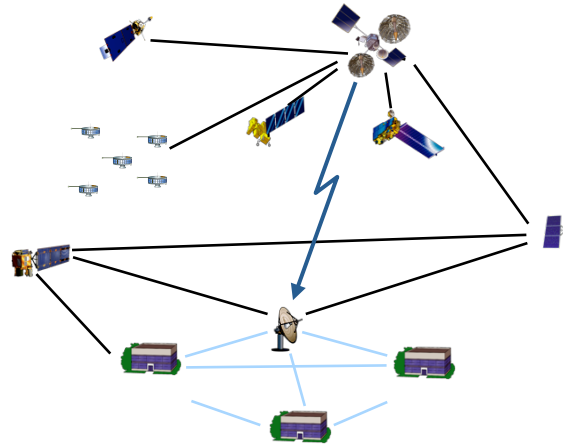


# Enabling Technologies

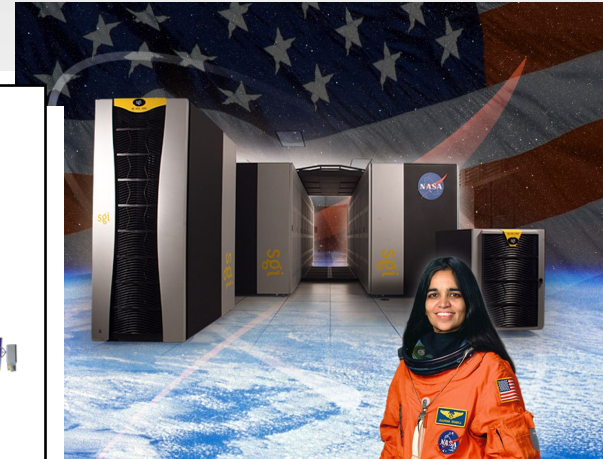
*Earth Science Information Systems of the future will leverage three ongoing technology revolutions:*



Geospatial



Communications

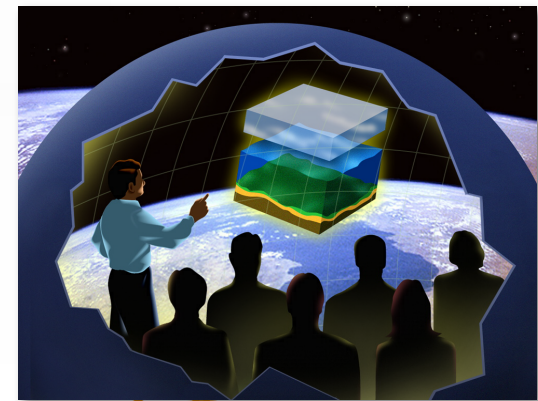
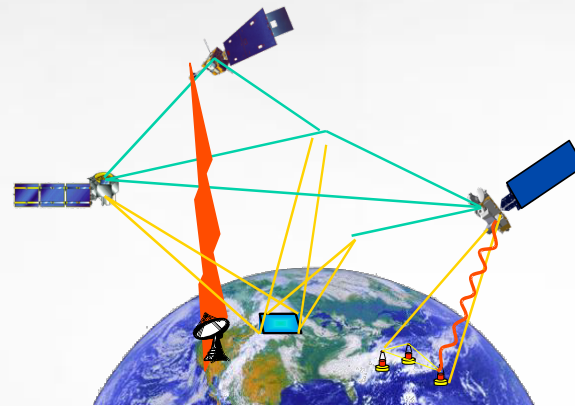


Computing

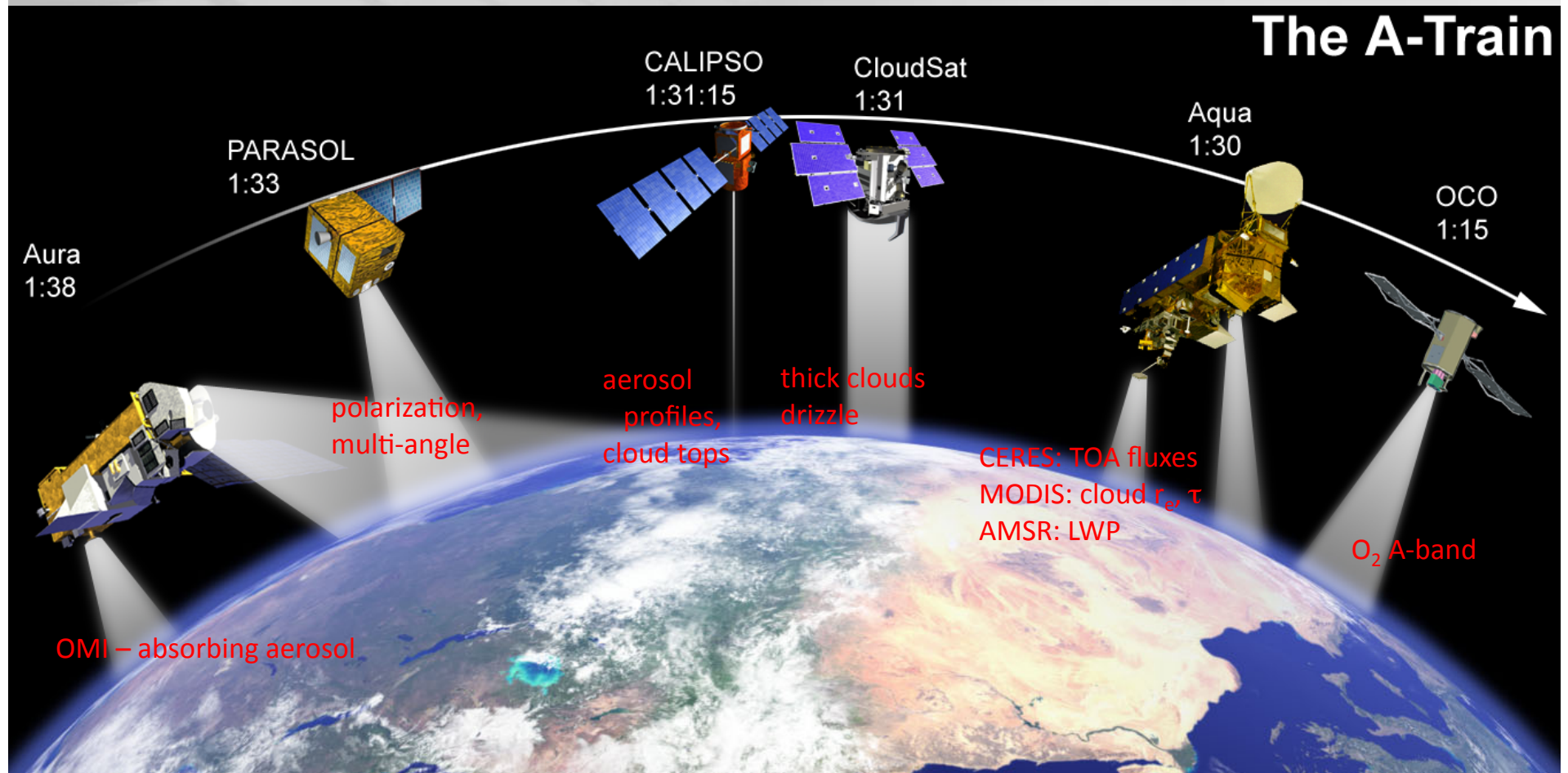
*...To enable seamless, timely, and affordable delivery of Earth science data and information to users.*

# Enabling Technologies

- **Information Synthesis: Distributed, Reconfigurable, Autonomy**
  - **Information Infrastructure: Standards, Formats, Policies**
  - **Access to Knowledge: On-orbit Processing, High Speed Networks**
- 
- **Intelligent Distributed Systems using optical communication, on-board reprogrammable processors, autonomous network control, high density storage, automated data distribution, grid computing and virtual organizations**
- 
- **Information Knowledge Capture through 3-D Visualization, holographic memory, seamlessly linked models, science tools, multi-panel visualization walls**

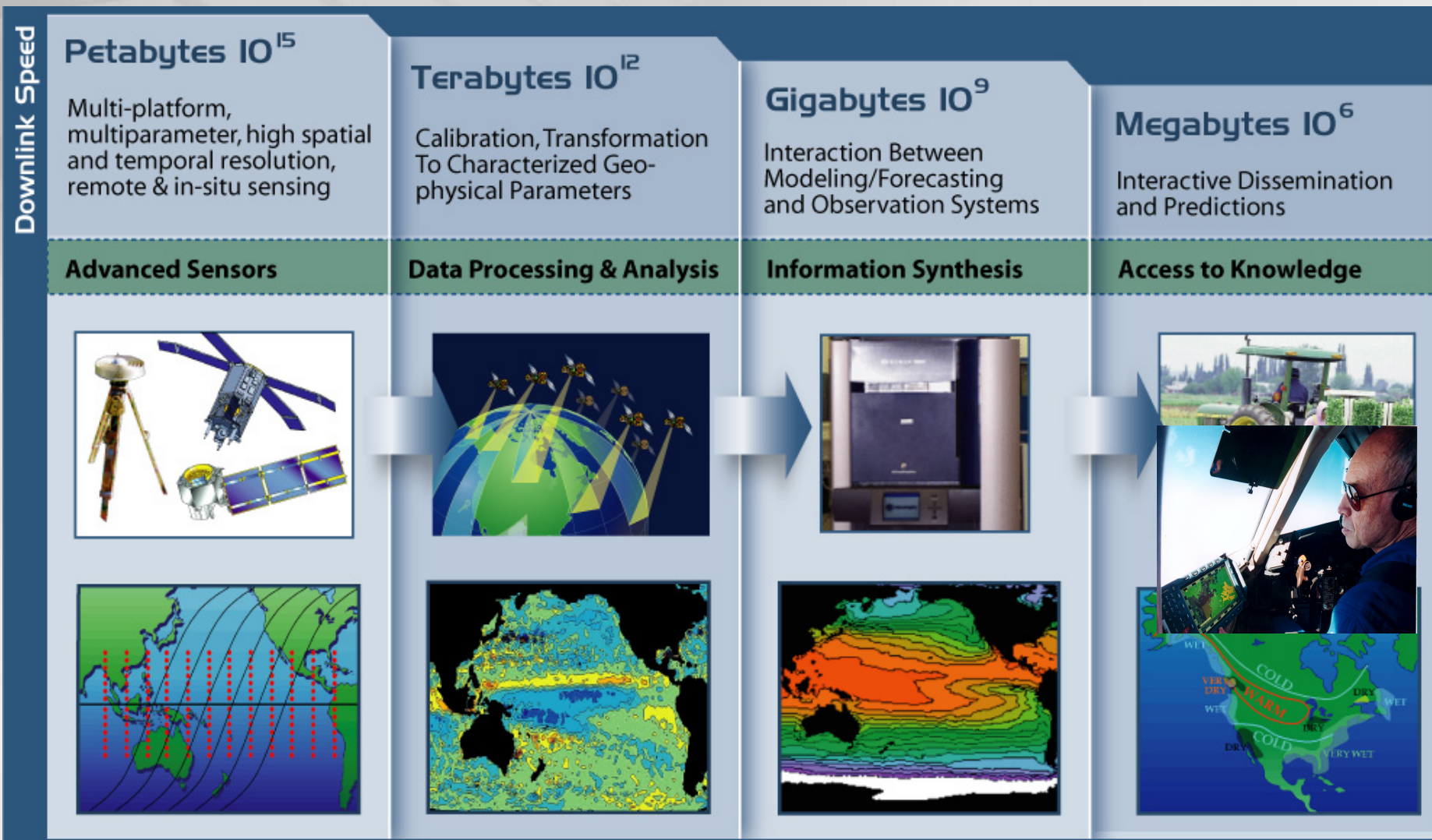


# Earth Observation System A-Train: Aerosol/Clouds/Radiation





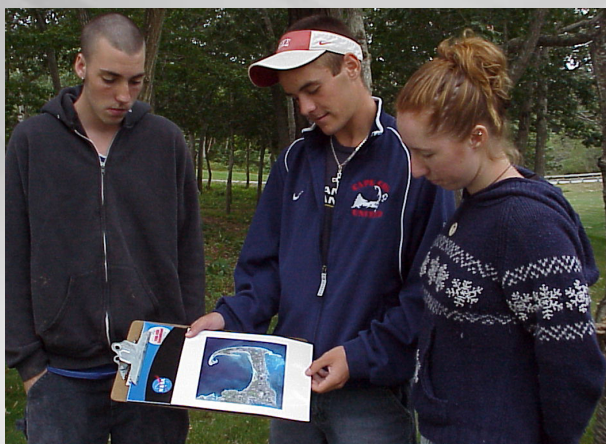
# Turning Observations into Information and Knowledge Products





# Training the Next Generation of Leaders

## Knowledge



## Tools & Facilities



## People



## National & Global





# Evolving International Partnership



## Next Decade(s)

- ▶ **An urgent need for solutions to interrelated challenges of environment, economy, energy and development facing the nations and regions of the world.**
- ▶ **Recognition of a need for science-based information by decision makers, and to engage them in the process of knowledge development.**
- ▶ **Increased complexity of the scientific challenges transcending traditional disciplines of natural and socioeconomic sciences to the fields of engineering, technology and humanities.**
- ▶ **Lack of capacity to accept and act on best available information and knowledge by those nations and regions that need them most.**
- ▶ **Continued tension between science and policy experts, and an urgent need for how to best communicate and build trust among them.**
- ▶ **Attracting the bright minds to pursue their career in these disciplines, but more importantly be willing to think and act beyond their own disciplines, nations and regions towards addressing the global development challenges.**



**These challenges offer many great opportunities for Research Community!**



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The image features a dark blue, semi-transparent globe of the Earth as a background. Overlaid on the globe is a complex, glowing network of thin, light blue lines and numerous small, bright yellow nodes. This network is most dense over the North American continent, where it forms a dense web, and extends across other parts of the world, including Europe and Africa, with varying degrees of density. The overall effect is one of global connectivity and digital infrastructure.

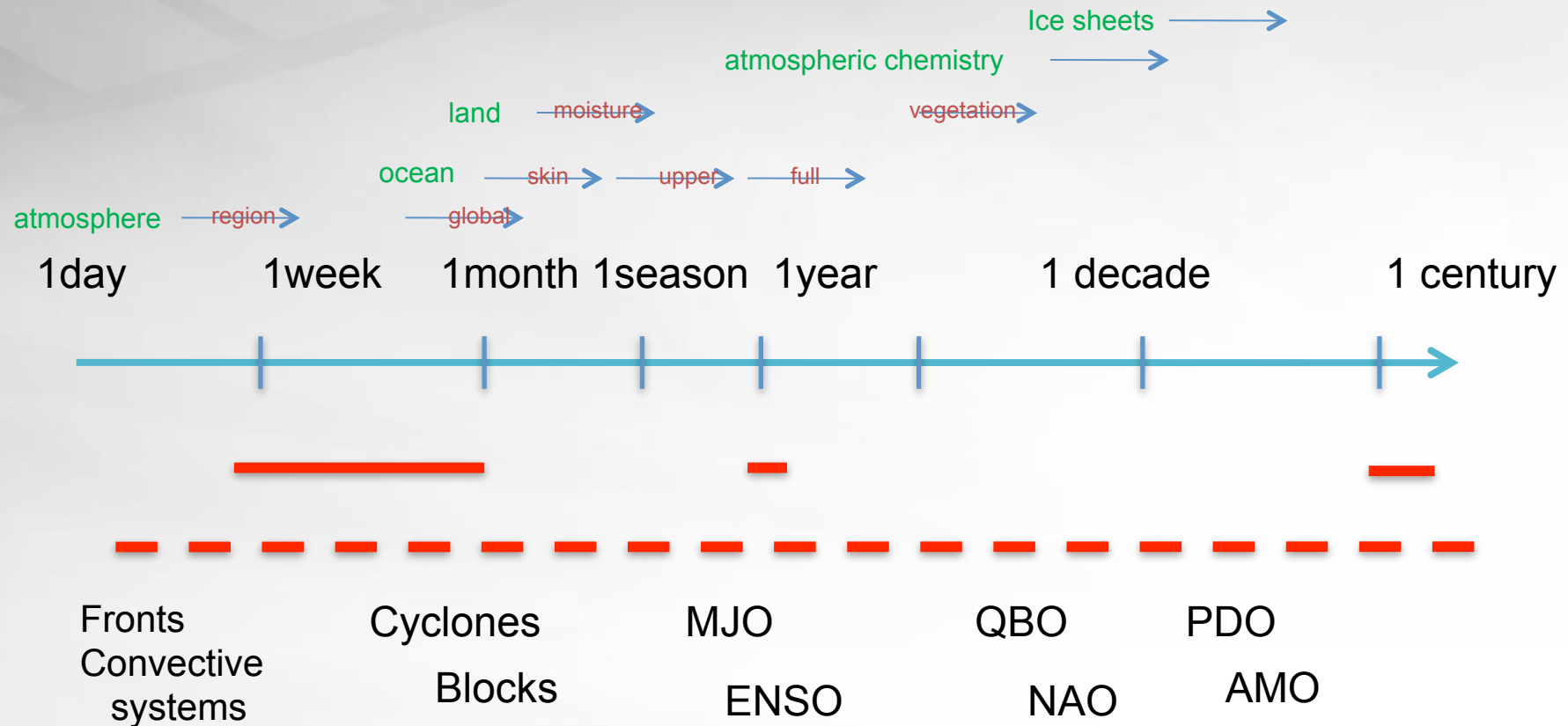
**The nature of the  
challenge/opportunity is  
defined by its global  
scope!**

# International Earth Observing Systems





# The Seamless Prediction of Earth System



The University of Reading



U.S. DEPARTMENT OF  
**ENERGY** | Office of  
Science

  
**Pacific Northwest**  
NATIONAL LABORATORY

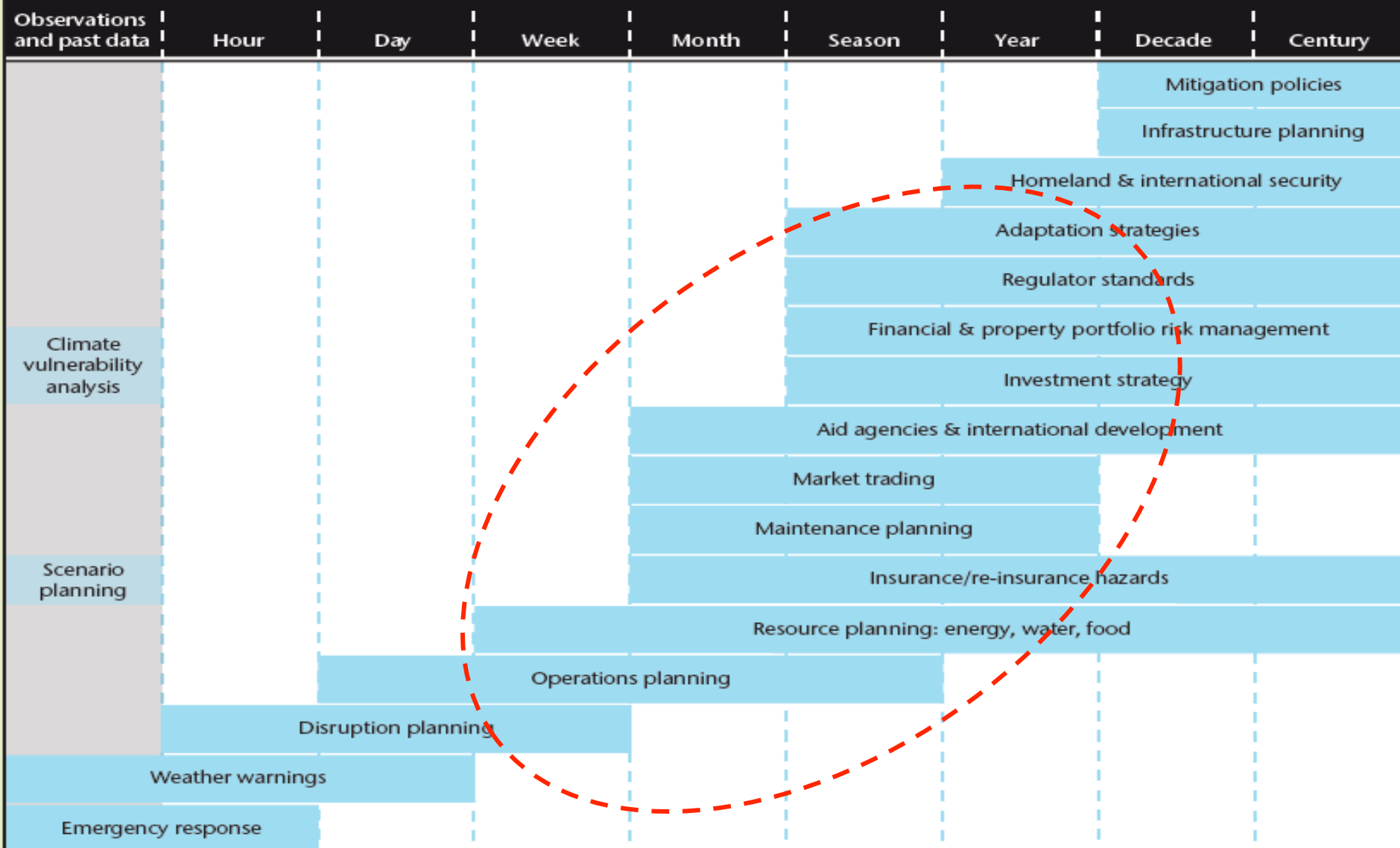
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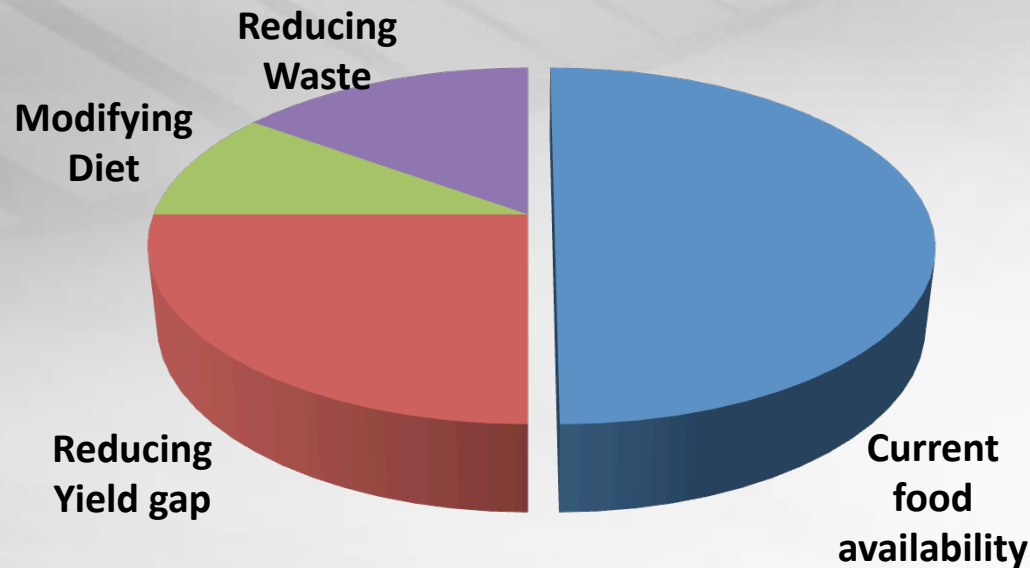
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# Seamless forecasting services

## Forecast lead-time

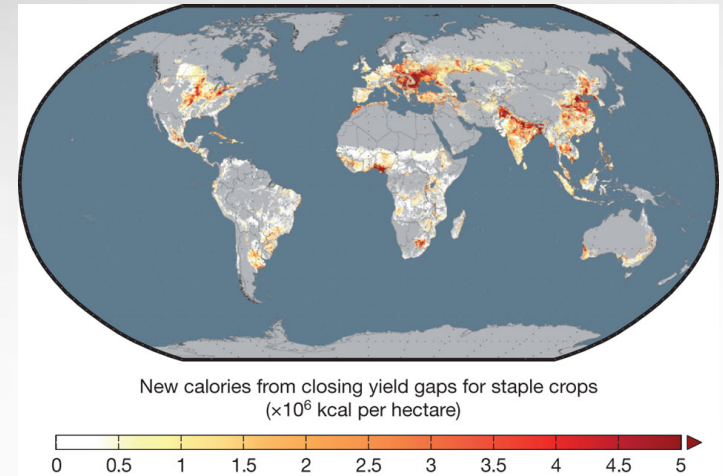


# Offering Solutions- Food, Society & Environment

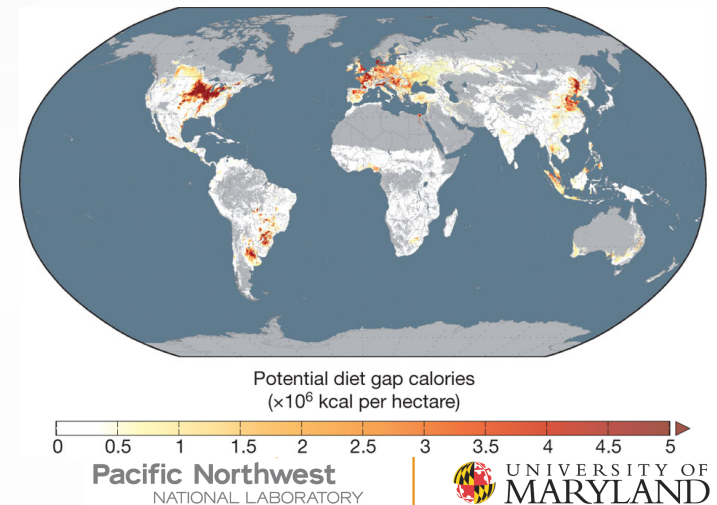


- **Trade-offs and synergies:**
  - Improve food availability
  - Improve livelihoods
  - Improve economics
  - Improve environmental conditions

## Reducing yield gap.



## Reducing the diet gap.



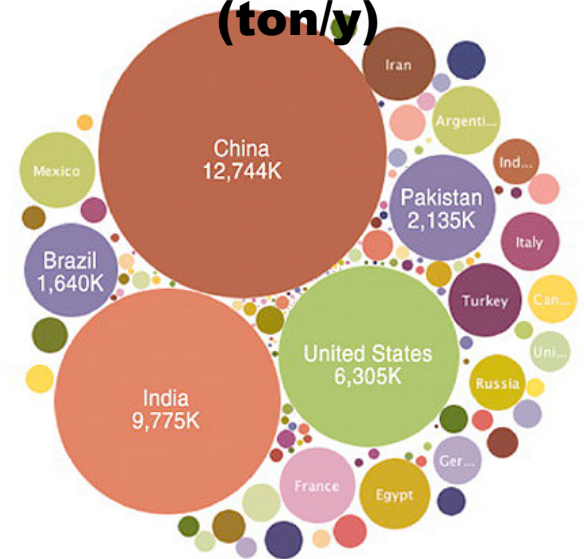


## Multiple Benefits of Addressing Climate, Human Health and Food Security Together

A bubble chart showing the distribution of countries by their percentage of the world population. The bubbles are arranged in a circular pattern, with the size of each bubble representing the percentage of the world population. The largest bubbles are for Bangladesh (10.6%) and India (8.3%). Other countries shown include Nigeria, China, Pakistan, and many others.

Country	Population (K)
India	814
China	684
Bangladesh	159
Russia	159
Indonesia	89.1
Viet Nam	58.7
Nigeria	69.4
Pakistan	90.6
Ethiopia	90.6

**Crop production  
increase – wheat  
+rice+maize+soy  
(ton/y)**



## Lessons Learned

- ▶ Forging personal and professional networks and networking.
- ▶ Mobilizing professional science, education, engineering and technology communities.
- ▶ Establishing new networks and capabilities, as required.
- ▶ Developing and supporting common/shared priorities.
- ▶ Engaging these communities in every steps for; 1) planning and priority setting; 2) advocacy and communication; 3) implementation,...
- ▶ Focusing primarily on doing the science right!
- ▶ Attending to communication and advocacy as needs emerged, reactively not proactively.
- ▶ Focusing on future plans and priorities too far down the road.

# Way Forward

- ▶ Agreeing on a our science plans and priorities that; 1) attract the interest and support of science community; 2) appeals to the stakeholders and users for the resulting information and knowledge; garners support of public and sponsoring agencies.
- ▶ Developing a compelling science, education and communication strategy focused on Earth-human system
- ▶ Building the required new partnerships and networks that transcend current ones to include humans, engineering and technology.
- ▶ Mobilizing resources and funding beyond traditional sources.
- ▶ ....

# Opportunities and Challenges

- ▶ A solution-based approach to research on societal challenges, e.g. environment, energy, economy and development.
- ▶ Seamless approach to Human-Earth systems research, modeling, prediction and assessment.
- ▶ Forging the required partnerships to develop and deliver “action oriented” information for decision making.
- ▶ Maintaining and evolving the current Earth observing and information systems, together with required modeling capabilities.
- ▶ Training the next generation of leaders for progress and continuity.
- ▶ These all can/should benefit from significant investments in global development.

# Thank you.