Understanding Global Change from Data

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Global Change:
A Defining Issue of our Era

What is Global Change?

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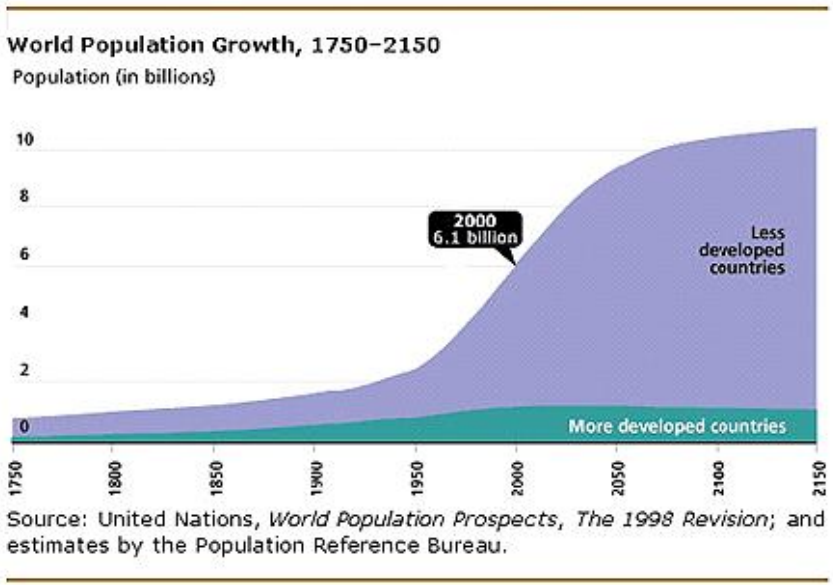

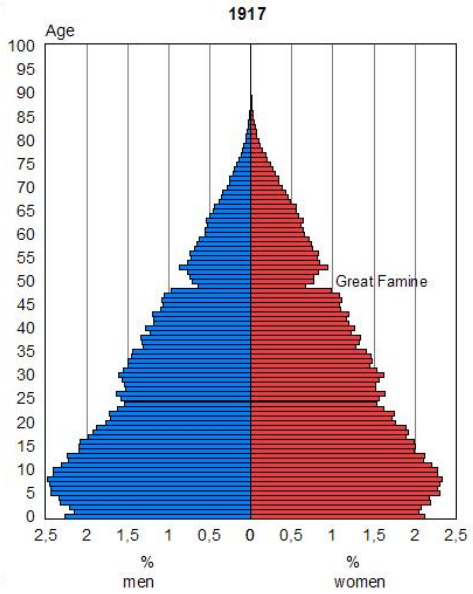

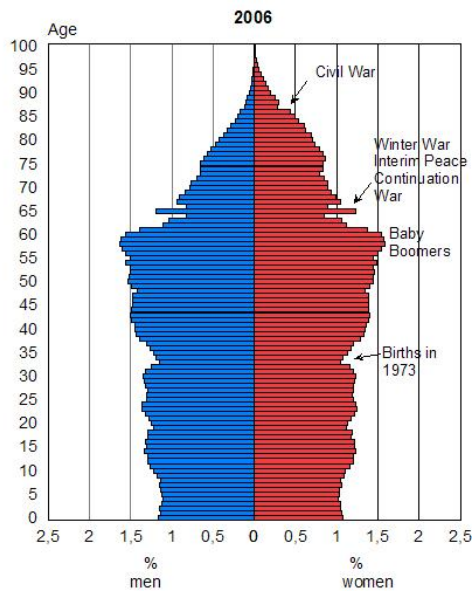

Population Growth & Demographic Shifts

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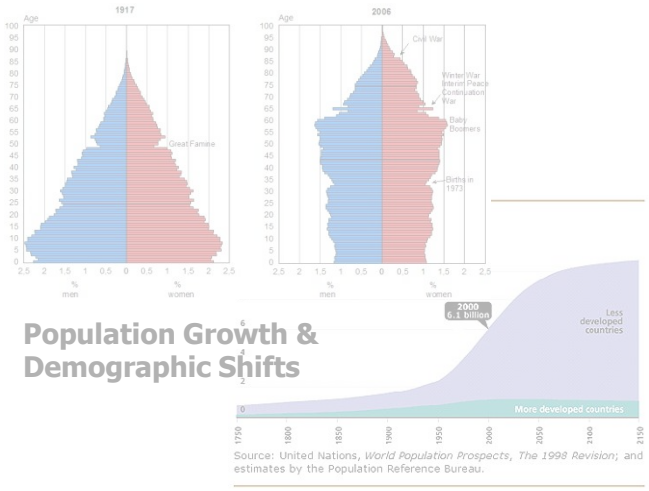

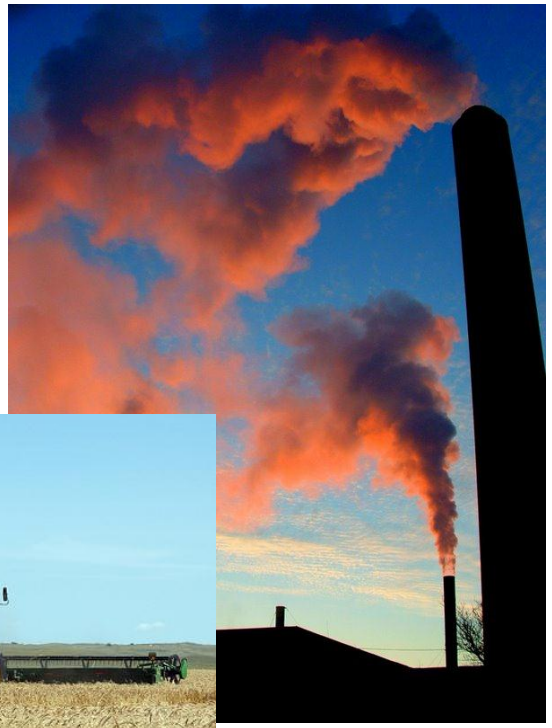

Industrialization & Modernization

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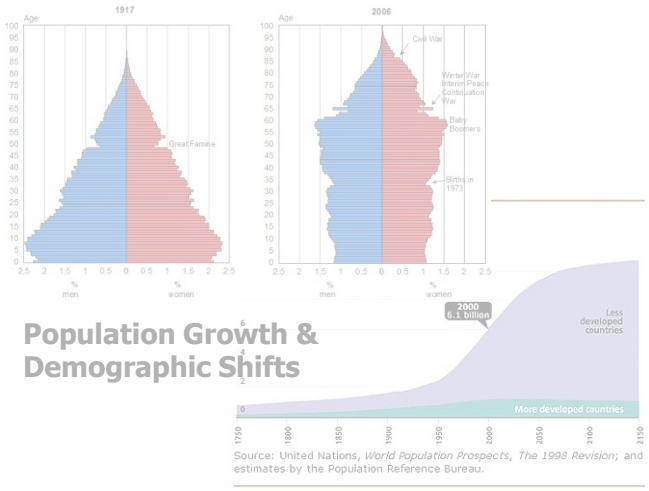

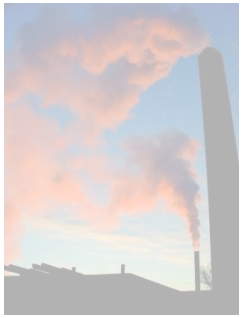

Industrialization &
Modernization

Land Use Change

Urbanization

Land Coversion

Deforestation

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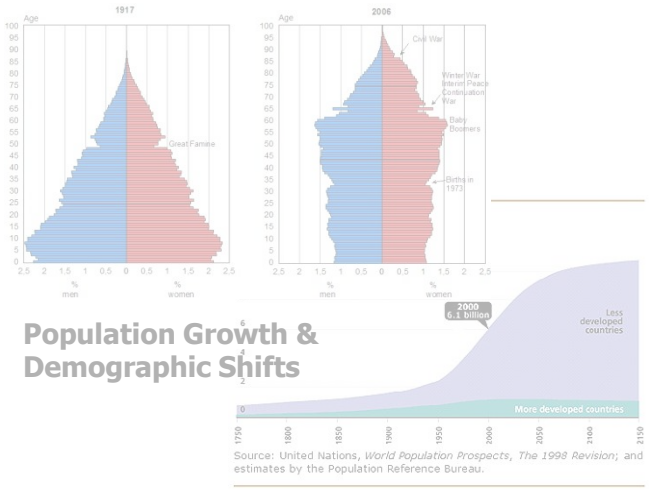
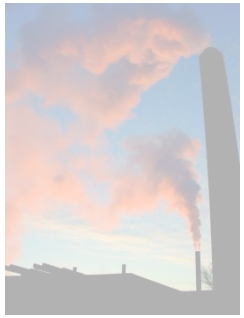


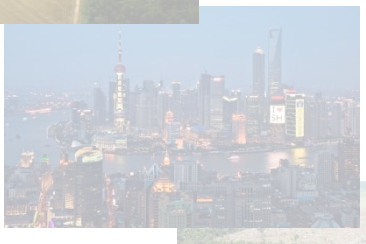
Source: United Nations, *World Population Prospects, The 1998 Revision*; and estimates by the Population Reference Bureau.

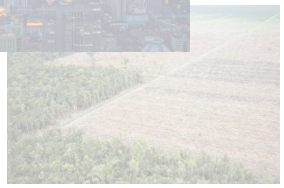
Population Growth & Demographic Shifts



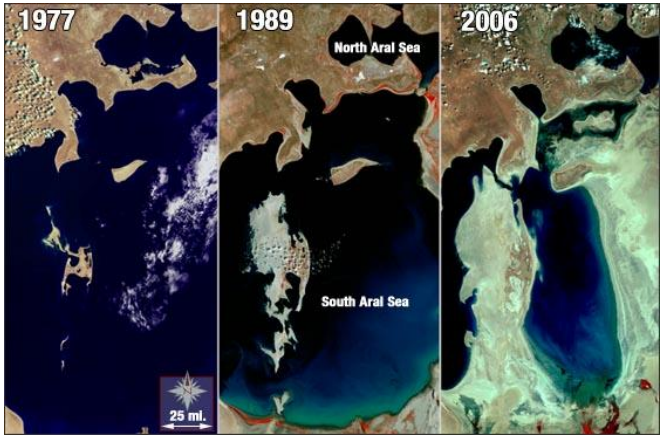
Industrialization & Modernization

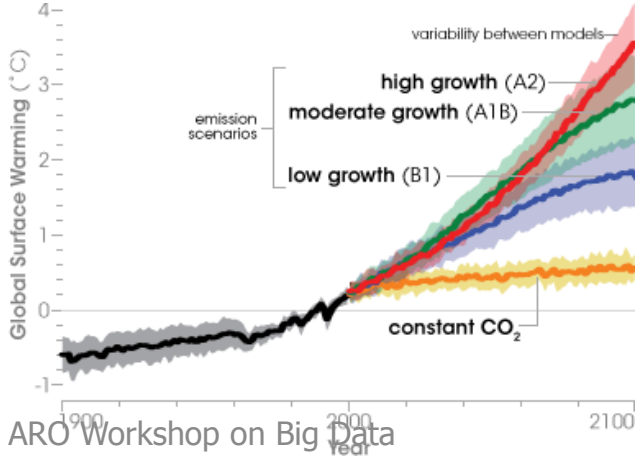
Land Use Change





Climate Change





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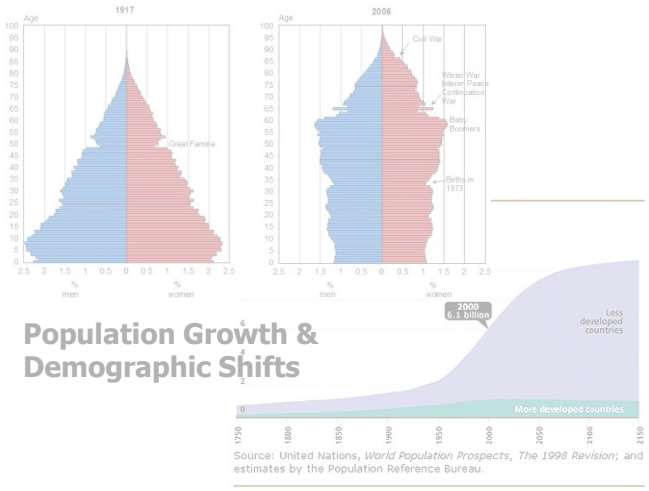

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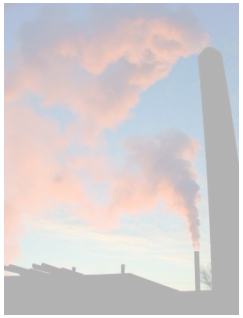

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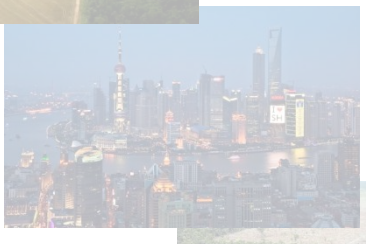

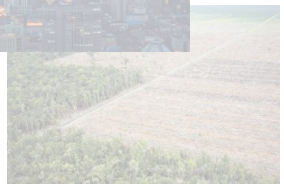

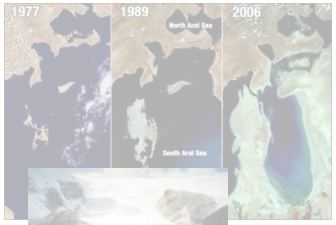

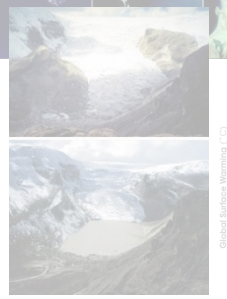

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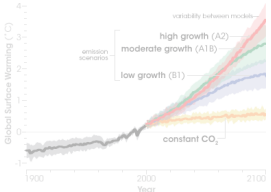

Biodiversity Loss & Natural Disasters

Monoculture

Ocean Acidification

Destruction of Wetlands

Cyclones

Fires

Drought

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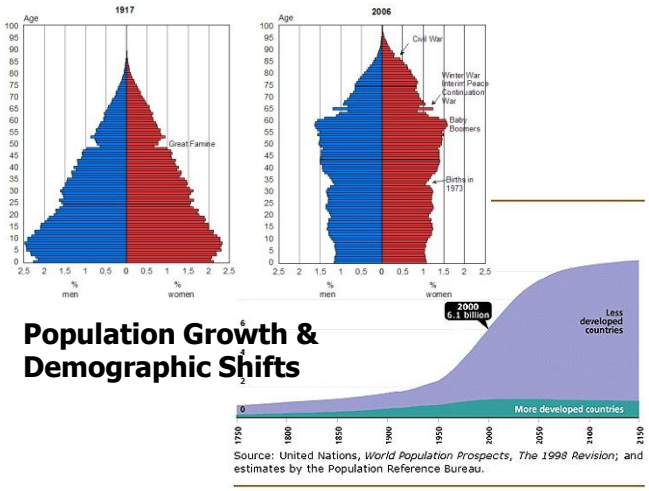

Population Growth & Demographic Shifts

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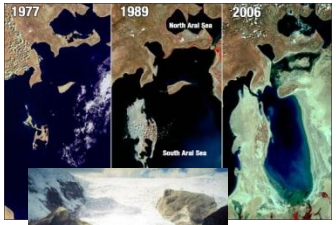
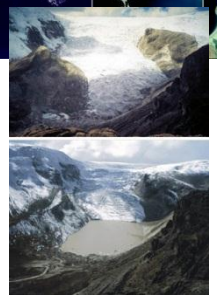
Land Use Change

THIS IS GLOBAL CHANGE





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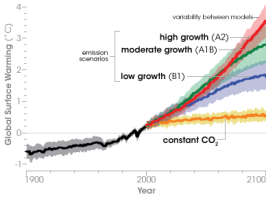
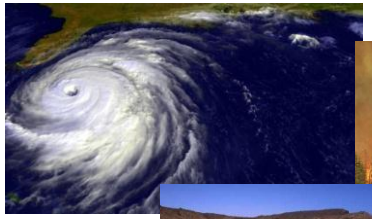


Biodiversity Loss



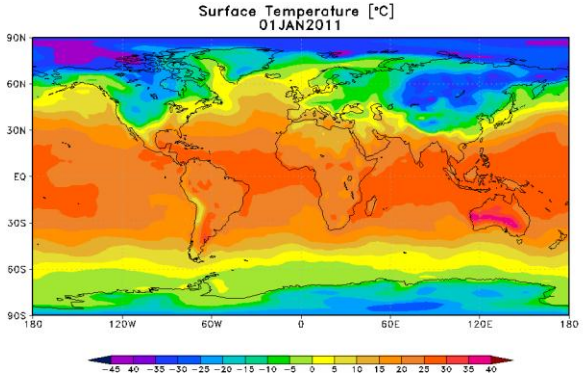
Natural Disasters

Responding to Societal Needs

- Where is population growth putting pressure on urban infrastructure and natural resources?
- What is the interplay between the global climate system, local ecosystems and natural disasters?
- How does increased biofuel production impact crop patterns and food availability?
- How do changing oceans affect the atmosphere and land climate?
- What are the major feedback mechanisms among eco-climatic processes?

Transformation: Data-Poor to Data-Rich

- Satellite Data
  - Spectral Reflectance
  - Elevation Models
  - Nighttime Lights
  - Aerosols
- Oceanographic Data
  - Temperature
  - Salinity
  - Circulation
- Climate Models
- Reanalysis Data
- River Discharge
- Agricultural Statistics
- Population Data
- Air Quality
- …



"The **future of science** depends […] on **cleverness being applied to data** for their own sake, complementing scientific hypotheses as a basis for exploring today's information cornucopia."

(Nature, September 2008)

Global Change is a Big Data Problem

- Scale and nature of the data offer numerous challenges and opportunities for research in the computational analysis of large datasets.
- Data-driven discovery methods hold great promise for advancing our understanding of the climate and ecosystem processes contributing to global change.
- Advances are of scientific importance and societal relevance.

"data-intensive science [is] so different that it is worth distinguishing [it] … as a new, fourth paradigm for scientific exploration." – Jim Gray

Active Research Projects

- GOPHER: Global Observatory for Planetary Health and Resources

  Project Aim: Monitoring of global ecosystem for changes in land cover, land use, etc.

PLANETARY SKIN

- NSF Expeditions: Understanding Climate Change – A Data Driven Approach

  Project Aim: Develop novel data analysis methods to help improve understanding and prediction of climate change

NSF Expeditions in Computing

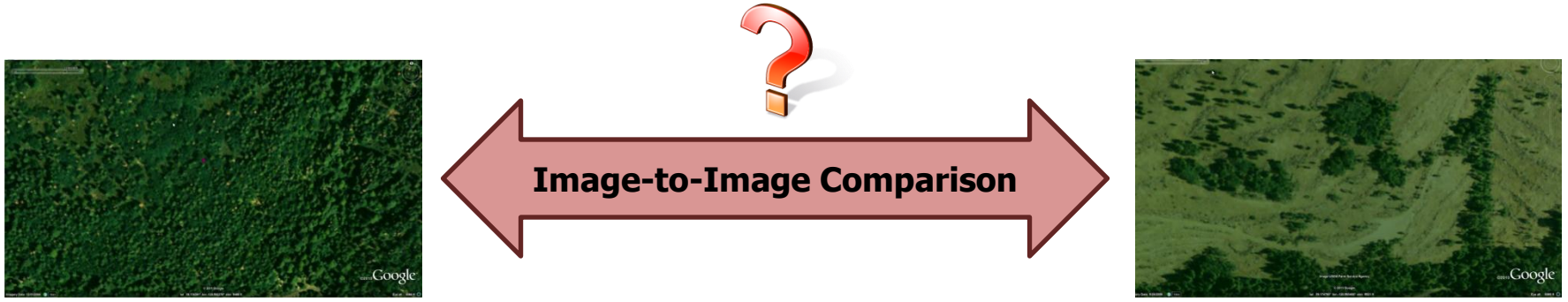
GOPHER: Ecosystem Monitoring

What is the current state of the global **forest ecosystems** and how are they changing as a result of logging and natural disasters?

How are the demands of a growing population affecting **agriculture**, e.g., creation of new farmland, changings in cropping patterns, conversion to biofuels, etc.?

How is **urbanization** affecting the surrounding ecosystem resources and water supply?

Traditional Approach for Change Detection



- Requires high-quality imagery
  - Available infrequently
- Requires high resolution
  - No global coverage
- Requires training data
  - Must be created manually
  - Labor-intensive, time-consuming, expensive

→ Studies are limited to small regions and unable to identify change point or rate of change

Alternate Approach: Spatio-Temporal

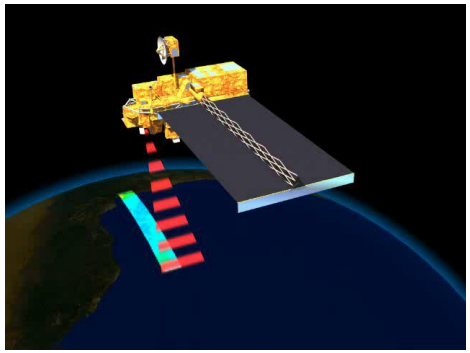
Multi-Spectral Data

- Provides global coverage daily
- (Relatively) coarse resolution
- Sometimes poor quality
  - Noisy
  - Missing Data

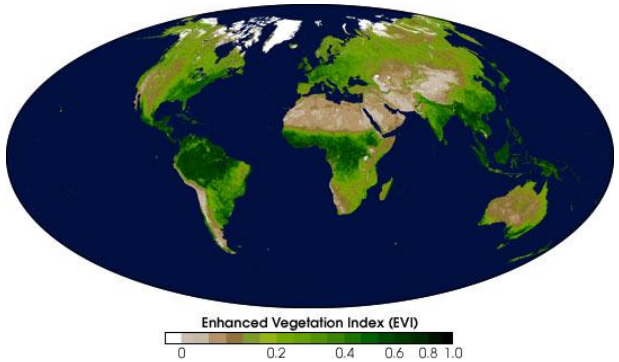
Trade-Off

lower spatial resolution vs. higher frequency, increased coverage

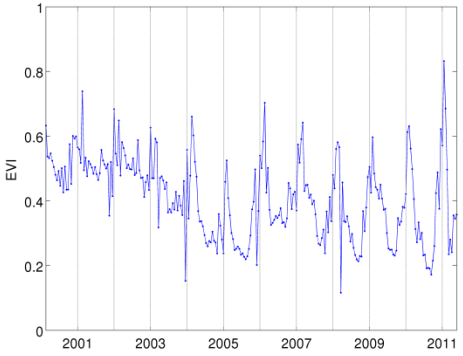
→ opportunities and challenges for **spatio-temporal data mining**



MODIS instrument on NASA Aqua/Terra Satellites

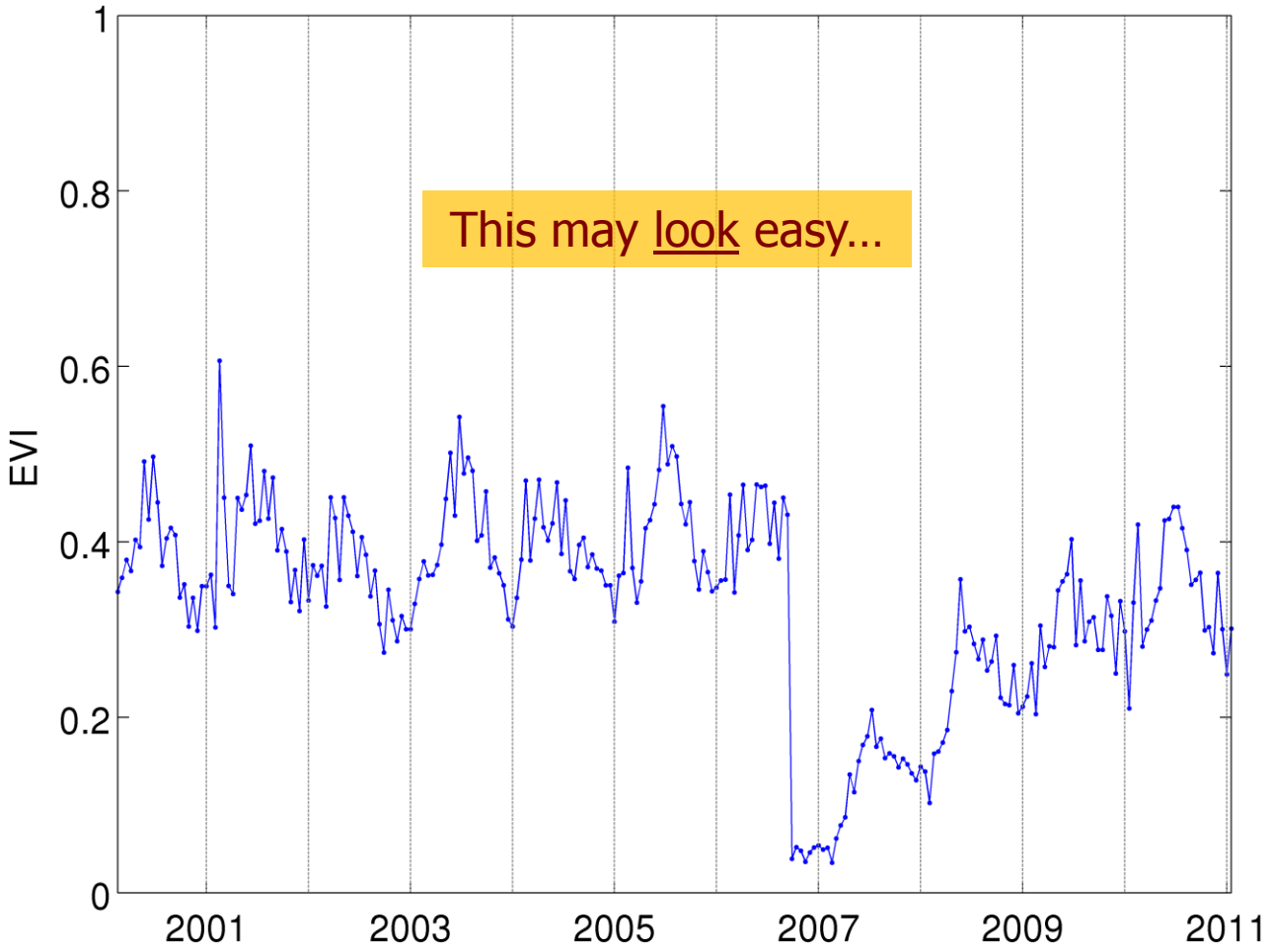


A **vegetation index** measures the surface "greenness" – proxy for total biomass



This vegetation **time series** captures temporal dynamics

Time Series Change Detection



Time Series Change Detection

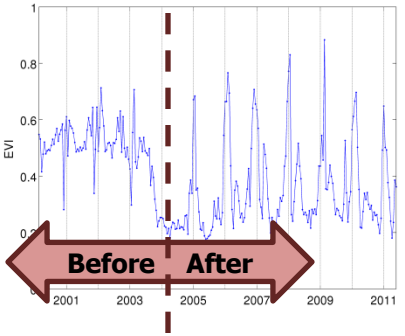
…but there are two billion time series
…and every one is different!

Novel Change Detection Techniques

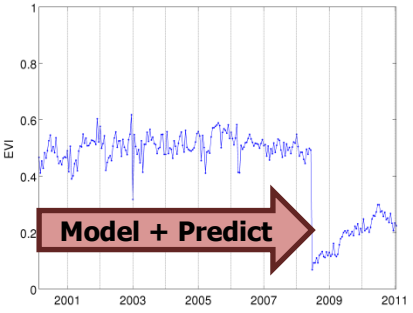
Current methods are **not adequate** to address these challenges. We focus on developing algorithms that are:

- **Robust** to missing data, noise and outliers
- Able to automatically **characterize** different types of **changes**
- Capable of **incremental** update and (near) **real-time** detection
- Aware of spatial **context**

Segmentation Approaches:
Divide time series into pieces and determine if a change occurred

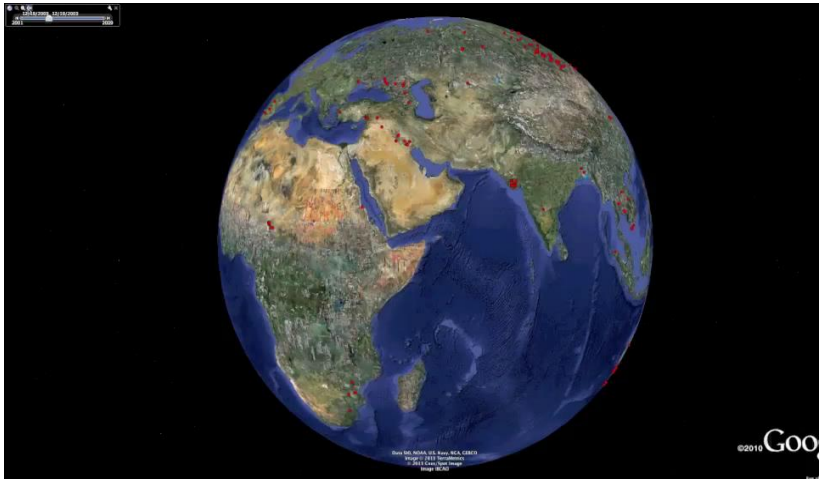


Prediction-Based Methods:
Build model of the "normal" behavior and predict, measure deviation



ALERTS: Automated Land change Evaluation, Reporting and Tracking System

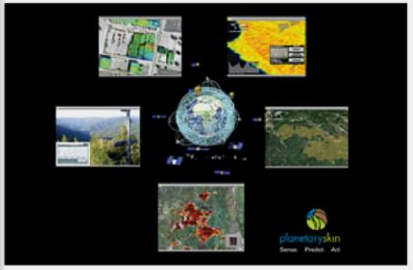
- **Planetary Information System** for interactive investigation of ecosystem disturbances discovered by GOPHER
  - Forest Fires
  - Deforestation
  - Droughts
  - Urbanization
  - …
- Helps quantify **carbon impact** of changes, understand the relationship between climate variability and human activity
- Provides **ubiquitous web-based access** to changes occurring across the globe, creating public awareness



TIME The 50 Best Inventions of 2009

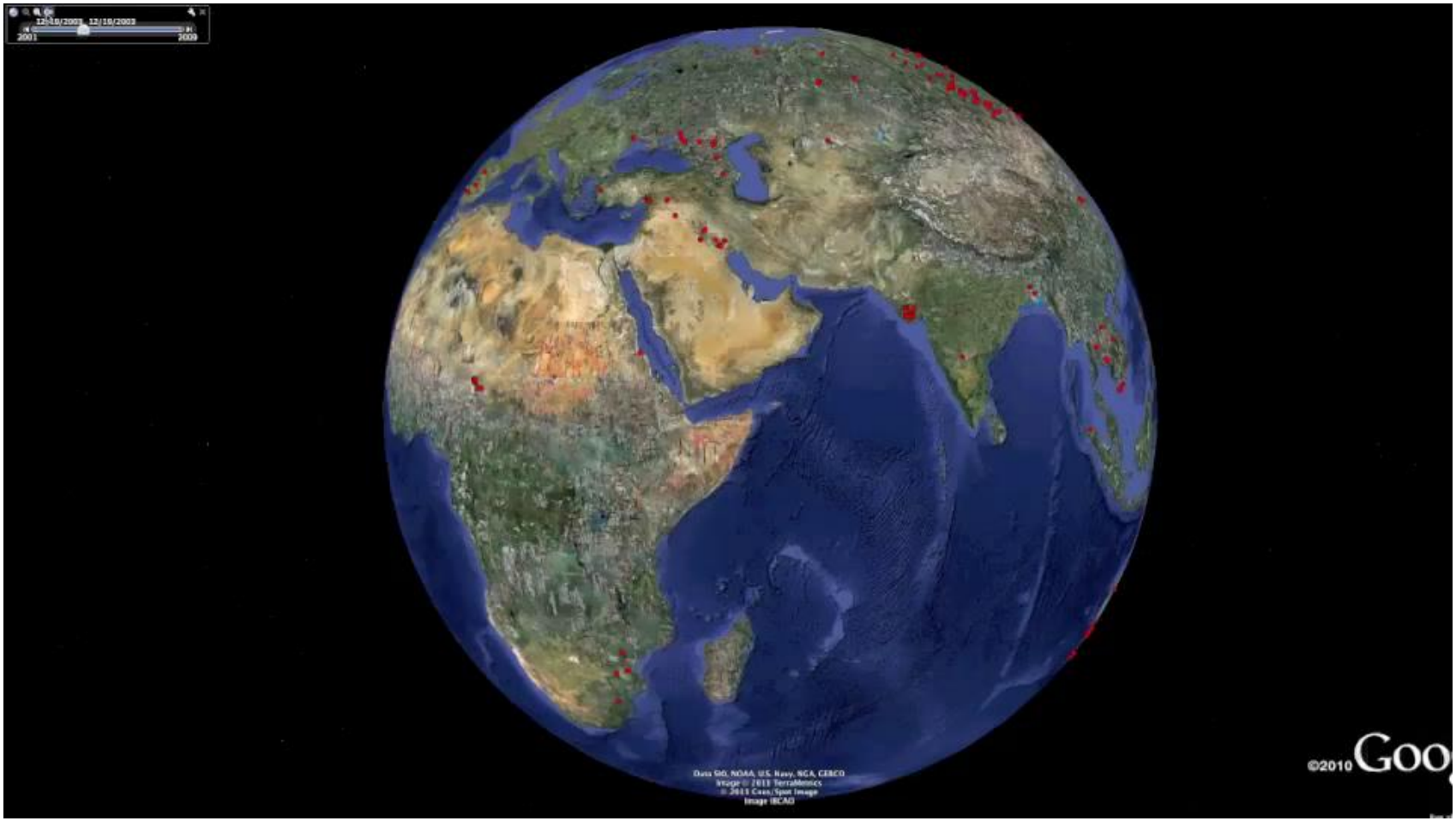
The 50 Best Inventions of 2009 > The Best Inventions

The Planetary Skin



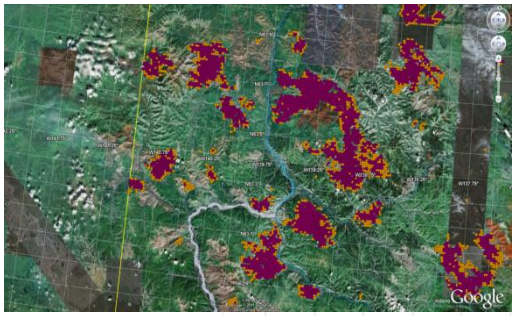
What happens to Earth when a forest is razed or energy use soars? We don't know because environmental data are collected by isolated sources, making it impossible to see the whole picture. With the theory that you can't manage what you can't measure, NASA and Cisco have teamed up to develop Planetary Skin, a global "nervous system" that will integrate land-, sea-, air- and space-based sensors, helping the public and private sectors make decisions to prevent and adapt to climate change. The pilot project — a prototype is due by 2010 — will track how much carbon is held by rain forests and where.

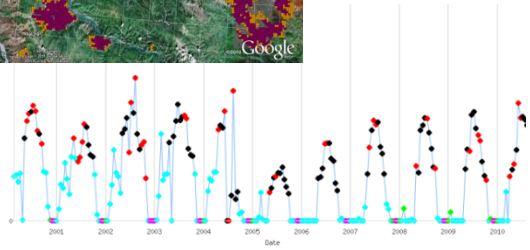
Global Change Points



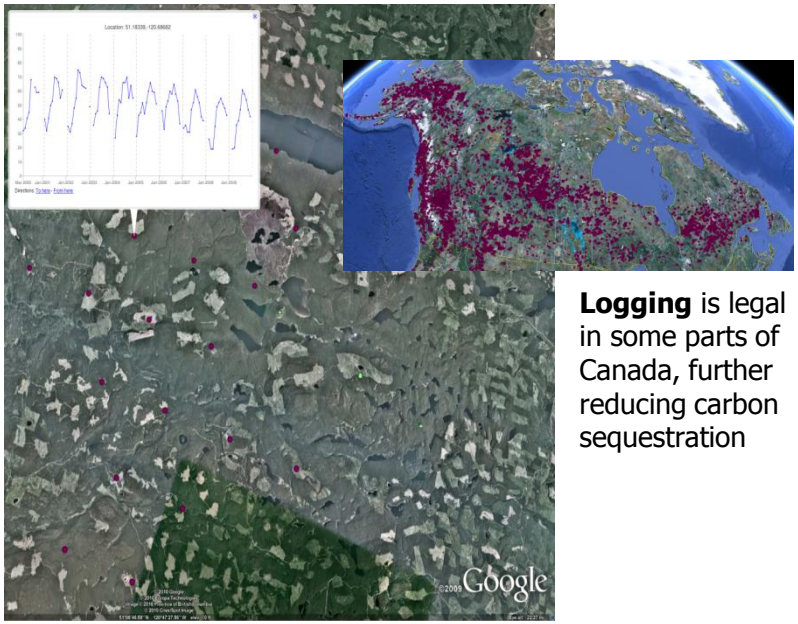
Northern Hemisphere Changes

Illustrative Examples

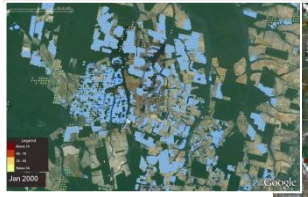


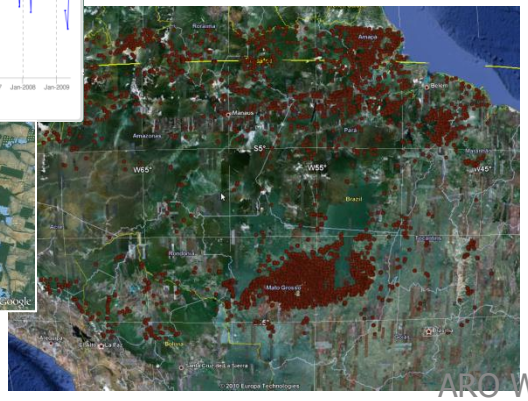


Large **forest fires in Canada** have converted the forests from a sink into source of carbon in the atmosphere.

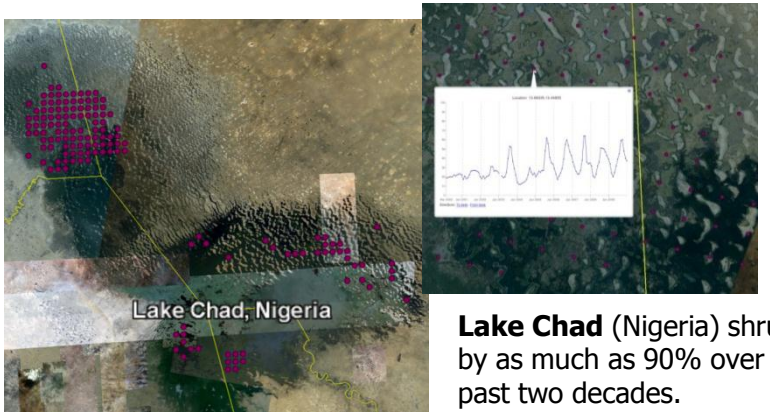


Logging is legal in some parts of Canada, further reducing carbon sequestration



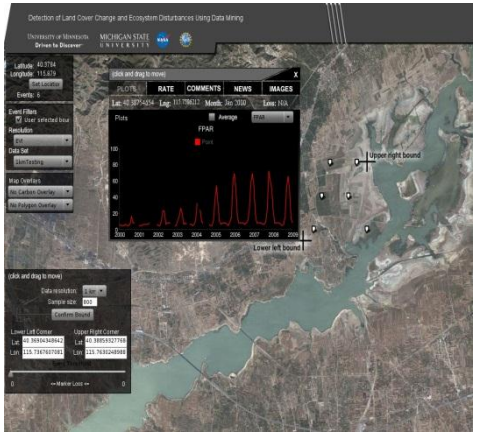


Brazil Accounts for almost 50% of all humid **tropical forest clearing**, nearly 4 times that of the next highest country.

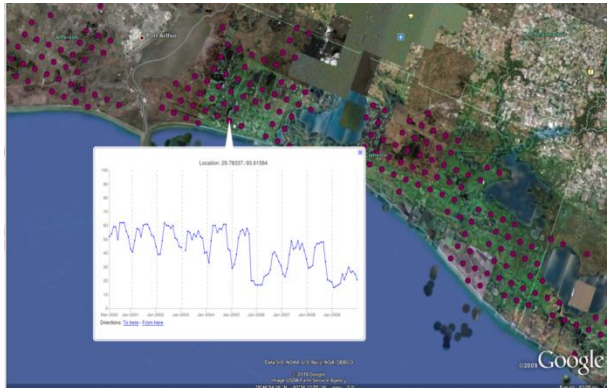


Lake Chad (Nigeria) shrunk by as much as 90% over the past two decades.

Illustrative Examples

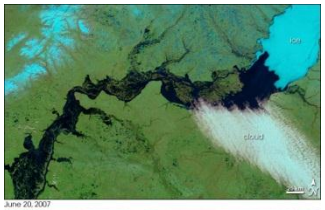


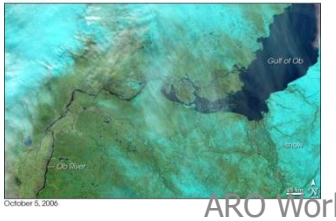
Examples of **afforestation** can be seen in several areas around the world, including this region near **Beijing** (China) where new trees have been planted to prevent dust storms and erosion.

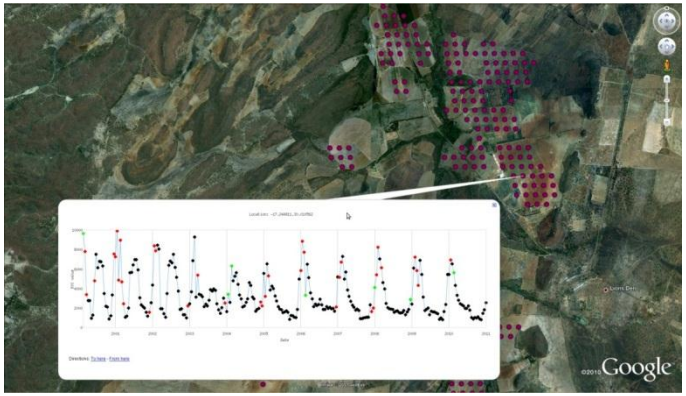


Hurricane Katrina caused significant damage and vegetation loss along the US Gulf Coast.

One winter the **Ob River** caused massive **flooding** due to freezing of the Bay of Ob / Kara Sea.







Political conflict and the ensuing "land reform" resulted in wide-spread **farm abandonment** and loss of productivity in **Zimbabwe** between 2004 and 2008.

Impact on REDD+

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Monitoring forests

Seeing the world for the trees

An international deal on deforestation makes it ever more important to measure the Earth's woodlands

Dec 16th 2010 | CANCÚN | from the print edition

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"The [Peru] government needs to spend more than $100m a year on high-resolution satellite pictures of its billions of trees.
But … a computing facility developed by the Planetary Skin Institute (PSI) … might help cut that budget."

"ALERTS, which was launched at Cancún, uses … **data-mining** algorithms developed at the **University of Minnesota** and a lot of computing power … to spot places where land use changed."

(The Economist 12/16/2010)

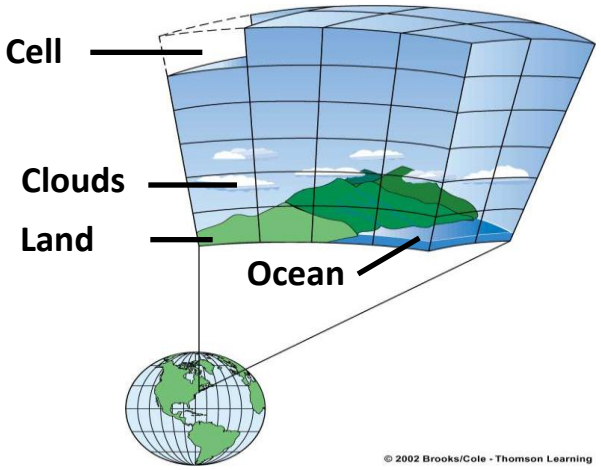
Understanding Climate Change: A Data Driven Approach

- 5-year / $10M NSF Expeditions in Computing

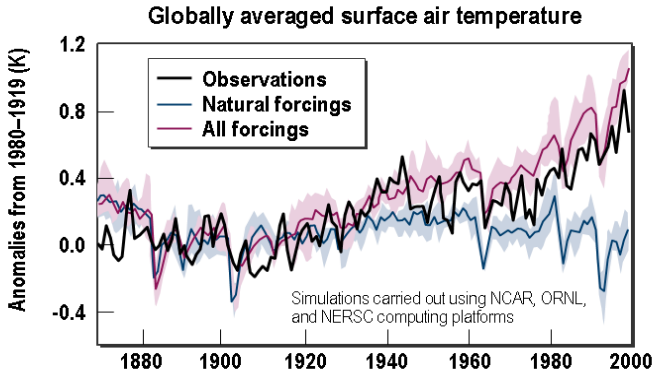
- Team led by UMN, consists of 15 senior personnel and ~50 students and post-docs

- Developing state of the art computational methods to address research questions in climate sciences

Understanding of Climate change is Limited



Much of what we know is derived from computer simulations of **general circulation models** (mathematical equations describing the physical processes involved in climate)



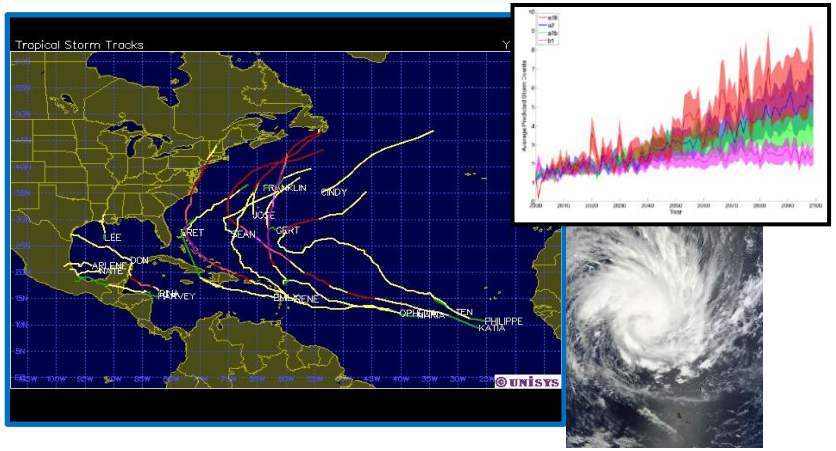
Physics-based models are essential but not adequate

- Relatively reliable for projections at global scale for smooth fields such as temperature, pressure
- Less reliable for variables that are crucial for impact assessment such as regional precipitation, extremes

"The sad truth of climate science is that the most crucial information is the least reliable" (Nature, 2010)

Expeditions Project Highlights

Hurricane Intensity Prediction and Land-Fall Modeling



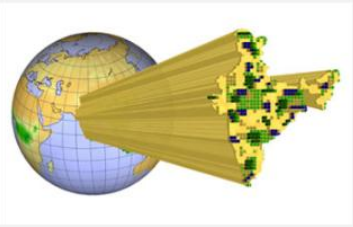
Climate Extremes and Uncertainty

National Science Foundation
WHERE DISCOVERIES BEGIN

Press Release 11-266

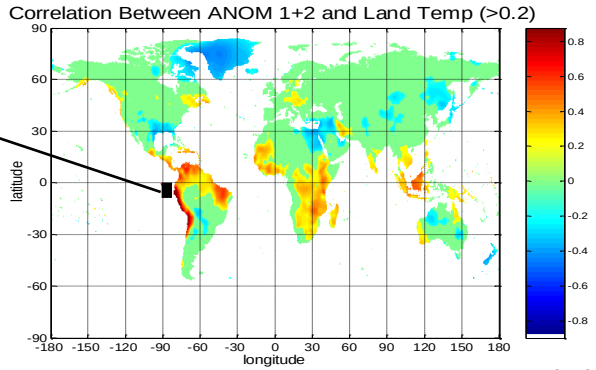
Journal Piece Reveals New Data-driven Methods for Understanding Climate Change

Geographical variability of rainfall extremes in India enhances interpretation of climate change data

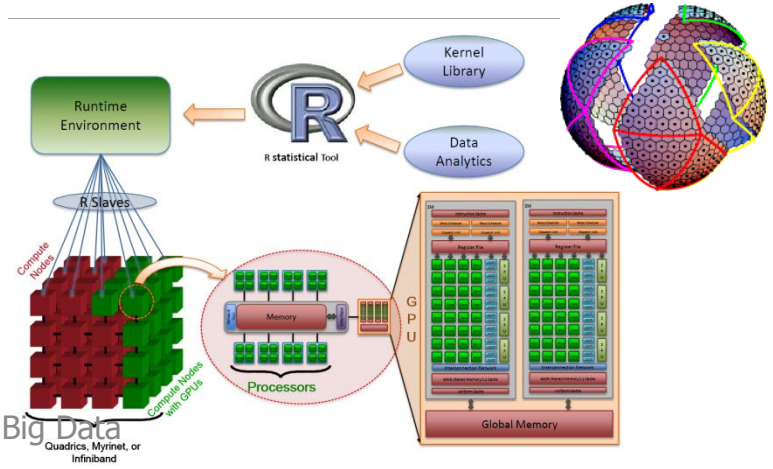


Understanding Climate Change: A Data Driven Approach is a NSF Expedition in Computing program.

Teleconnections & Sparse Predictive Modeling



High-Performance Data Analytics



Thank You! Questions?

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PLANETARY SKIN

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