

20th and 21st Century Climate Change: Climate Modeling, Societal Impacts, and Environmental Justice

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Agriculture in a Changing Climate across Scales:
Broadening Participation in Research and Decision-Making

August 25-28, 2014



NCAR



U.S. DEPARTMENT OF
ENERGY

Office of Science

Overview

- Brief history of climate modeling
- Brief discussion of computational methods
- Environmental Justice connected to climate change
- Behind the scenes White House origin of the U. S. Global Change Research Program (USGCRP)
- The future of the USGCRP and National Climate Assessment

The next two NASA satellite videos give insight to how the climate is changing and the interaction of vegetation on the carbon cycle.

Credit to the NASA Aqua instrument:
Tom Pagano and colleagues at JPL



Mauna Loa, Hawaii
(MLO)

The atmospheric carbon dioxide and vegetation connection!

The Climate and Earth System Modeling Story

Laws of Physics, Chemistry, and Biology

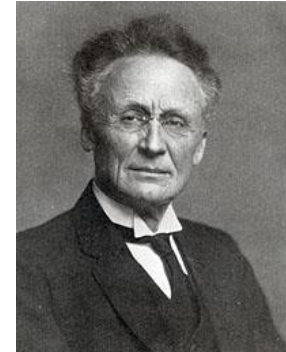
- Equations govern the dynamics of atmosphere, ocean, vegetation, and sea ice
- Equations put into a form that can be solved on modern computer systems
- Physical processes such as precipitation, radiation (solar and terrestrial), vegetation, boundary transfers of heat, momentum, and moisture at earth's surface are included
- Forcings: GHGs, Volcanic, Solar variations

Mathematical equations (known since 1904)

Eqs. of Momentum

$$\frac{du}{dt} - \left(f + u \frac{\tan \phi}{a} \right) v = -\frac{1}{a \cos \phi} \frac{1}{\rho} \frac{\partial p}{\partial \lambda} + F_\lambda$$

$$\frac{dv}{dt} + \left(f + u \frac{\tan \phi}{a} \right) u = -\frac{1}{\rho a} \frac{\partial p}{\partial \phi} + F_\phi$$



Hydrostatic

$$g = -\frac{1}{\rho} \frac{\partial p}{\partial z}$$

Conservation of mass

$$\frac{\partial \rho}{\partial t} = -\frac{1}{a \cos \phi} \left[\frac{\partial}{\partial \lambda}(\rho u) + \frac{\partial}{\partial \phi}(\rho v \cos \phi) \right] - \frac{\partial}{\partial z}(\rho w)$$



First law of thermodynamics

$$C_p \frac{dT}{dt} - \frac{1}{\rho} \frac{dp}{dt} = Q$$

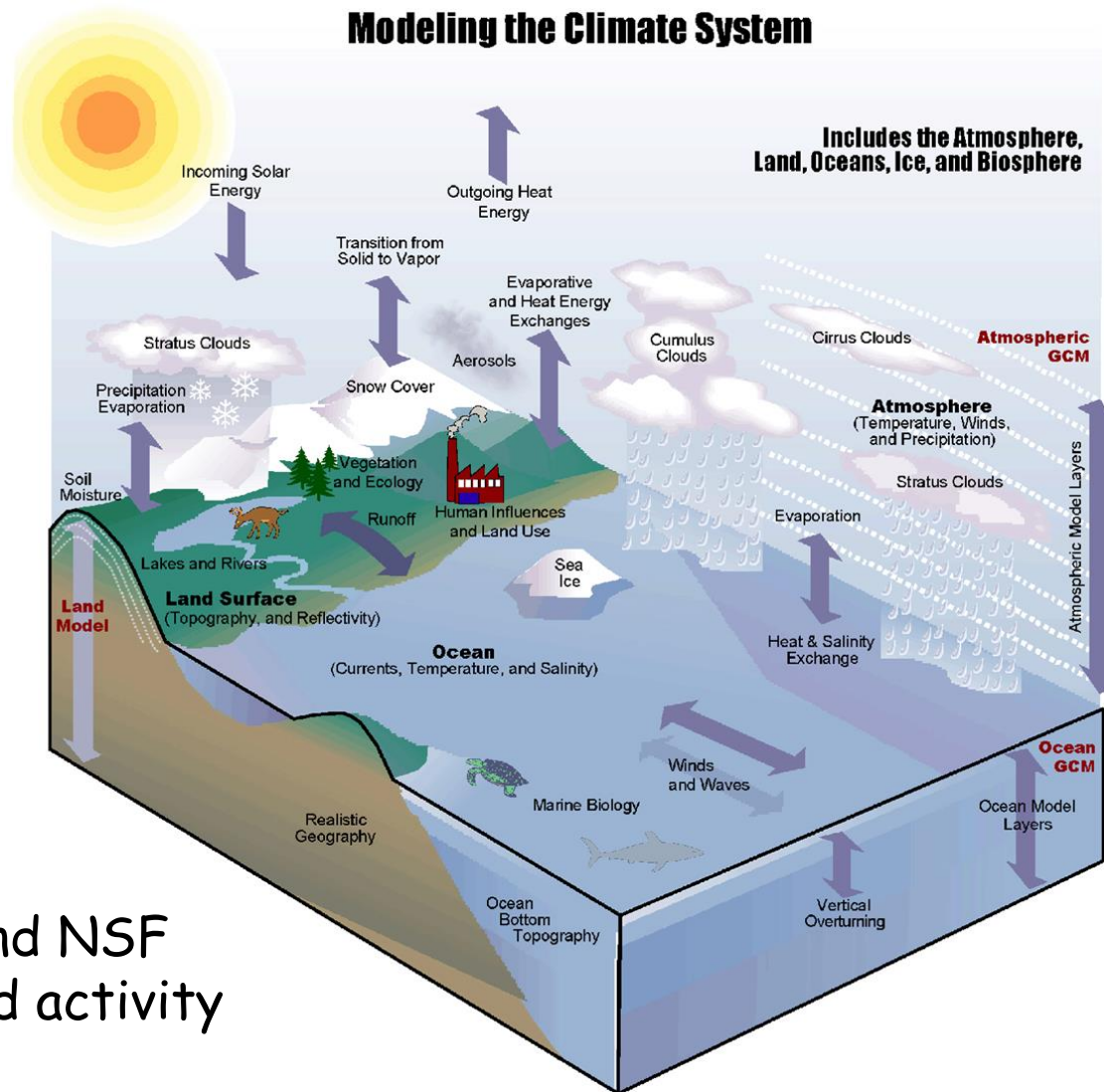


Gas law

$$p = \rho RT$$

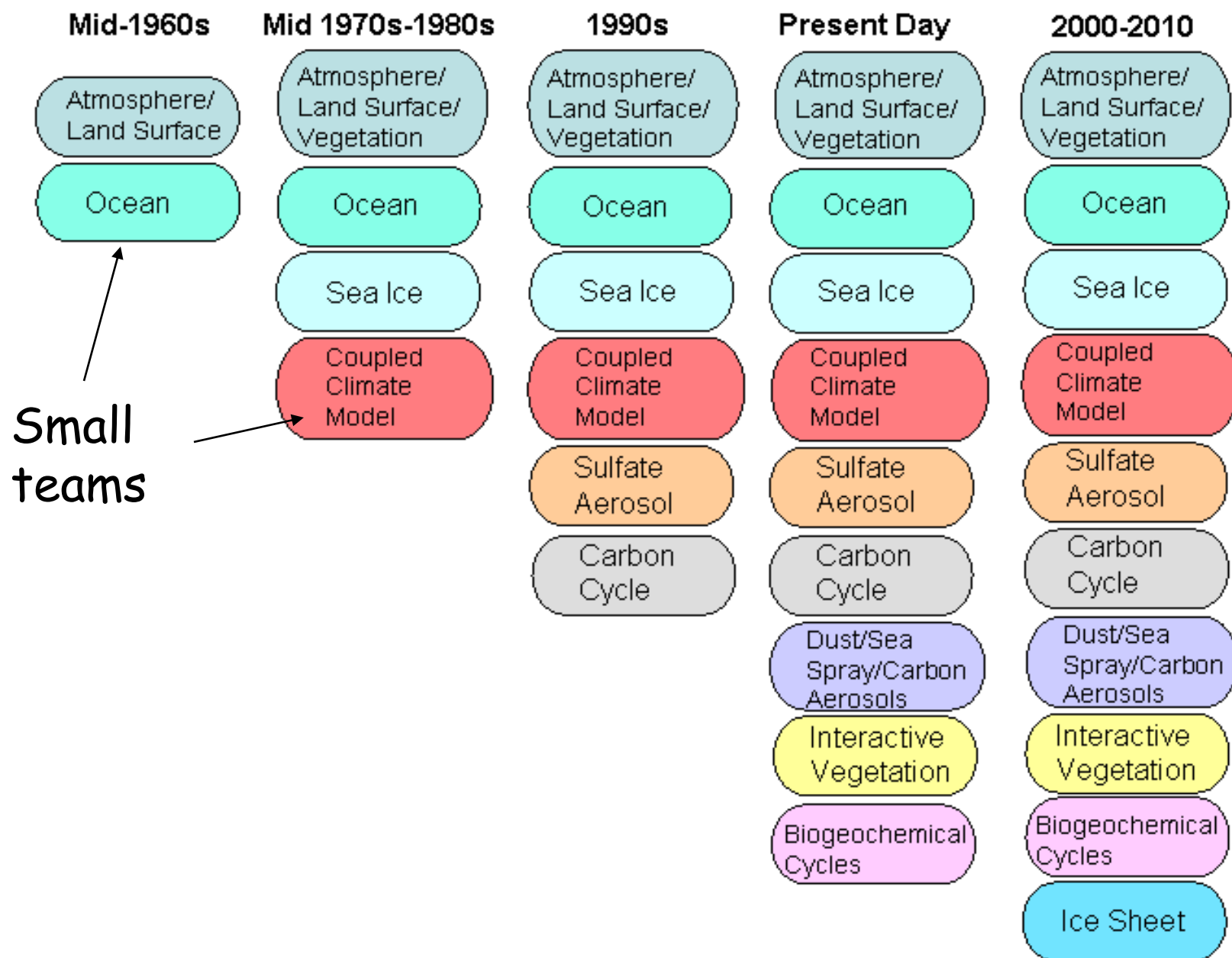
(u, v, w, ρ, p , and T),

The Community Earth System Model (CESM) is becoming more complete



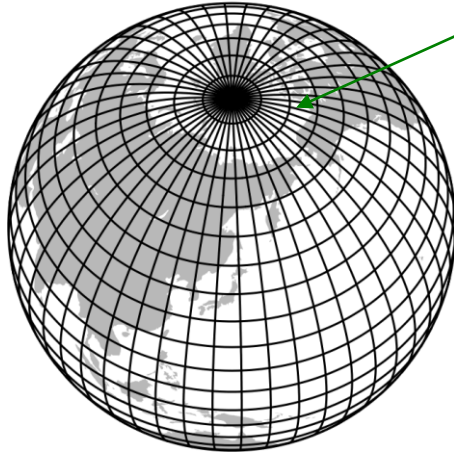
A DOE and NSF
supported activity

Timeline of Climate Model Development



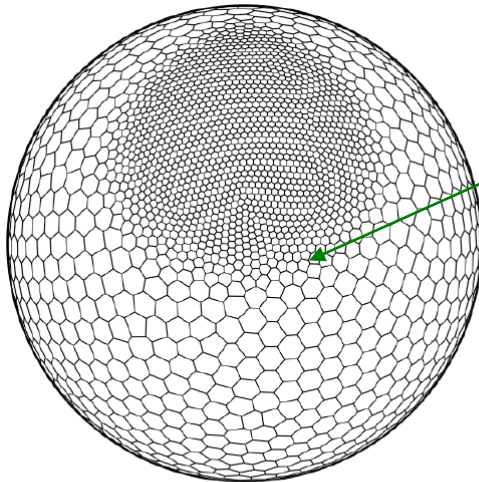
Atmospheric Grids

LATITUDE-LONGITUDE GRID

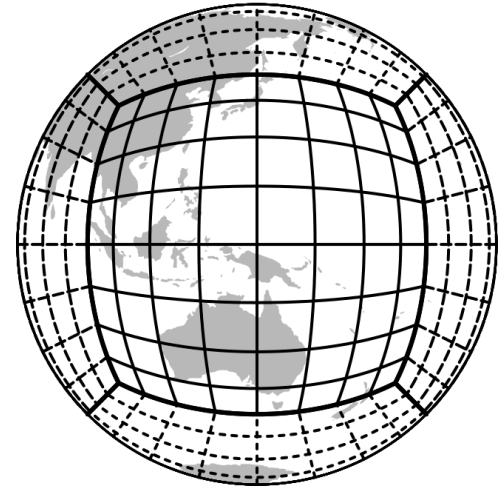


Problem near the poles
where longitudes converge

Regional focus



CUBED SPHERE GRID



SPHERICAL GEODESIC
OR ICOSAHEDRAL GRID

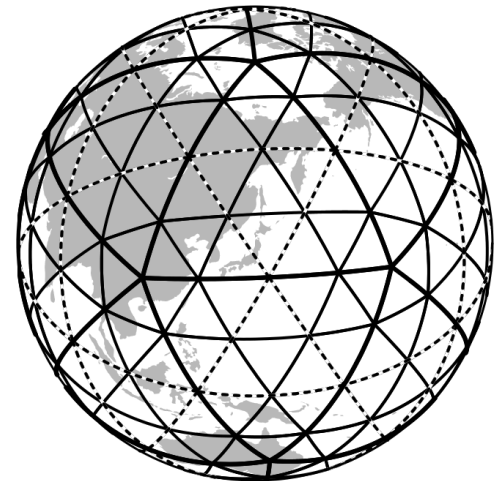
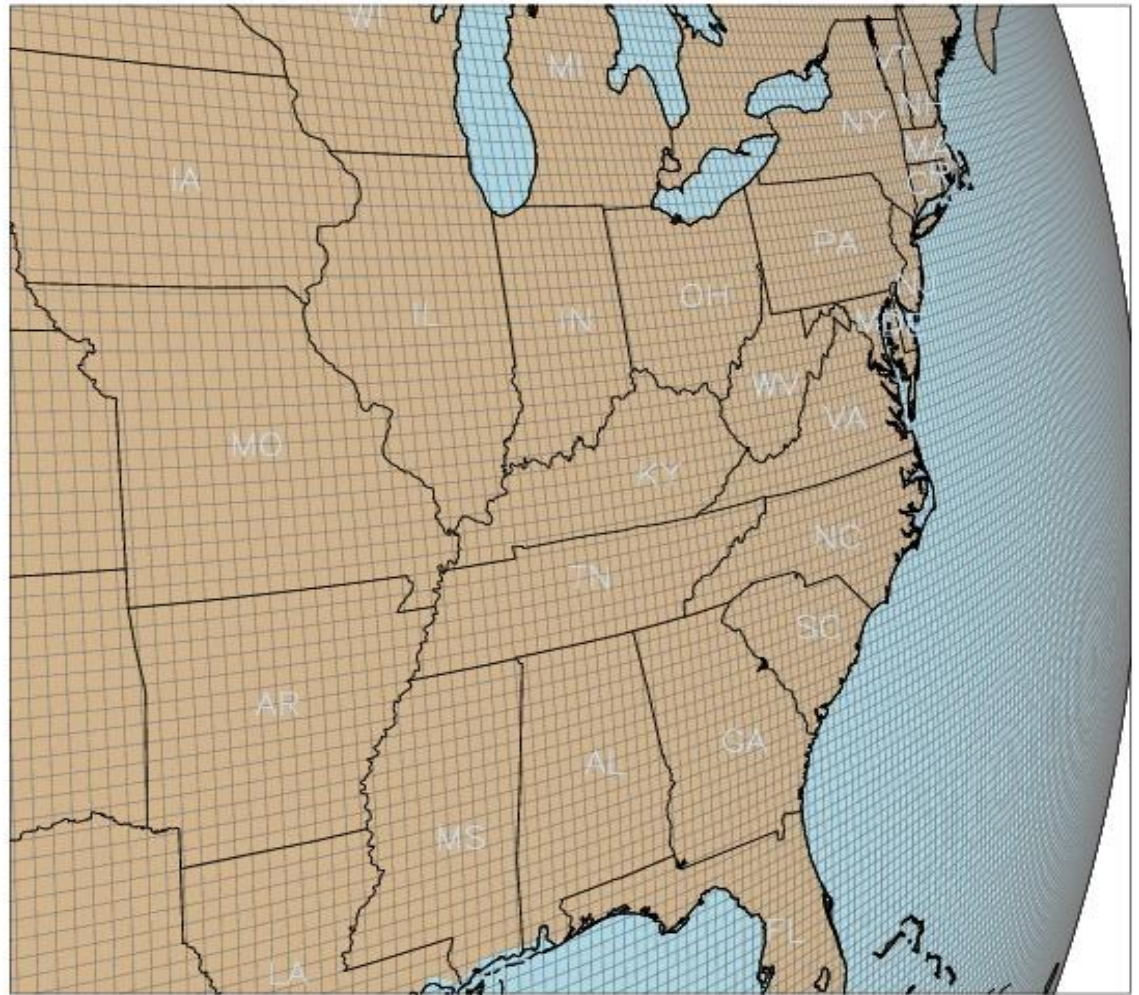


Figure V.1. A variable resolution grid
based on a Spherical Centroidal Voronoi
Tessellation.

From C. Hannay, NCAR

Part of the
global grid
(25 km) for
the next
IPCC
simulations

1/4 degree grid



Vertical Grid

- Vertical resolution is also important for quality of simulations
- Levels are not equally spaced (levels are closer near surface and near tropopause where rapid changes occurs)
- In CAM: "hybrid" coordinate
 - bottom: sigma coordinate (follows topography)
 - top: pressure coordinate
 - middle: hybrid sigma-pressure

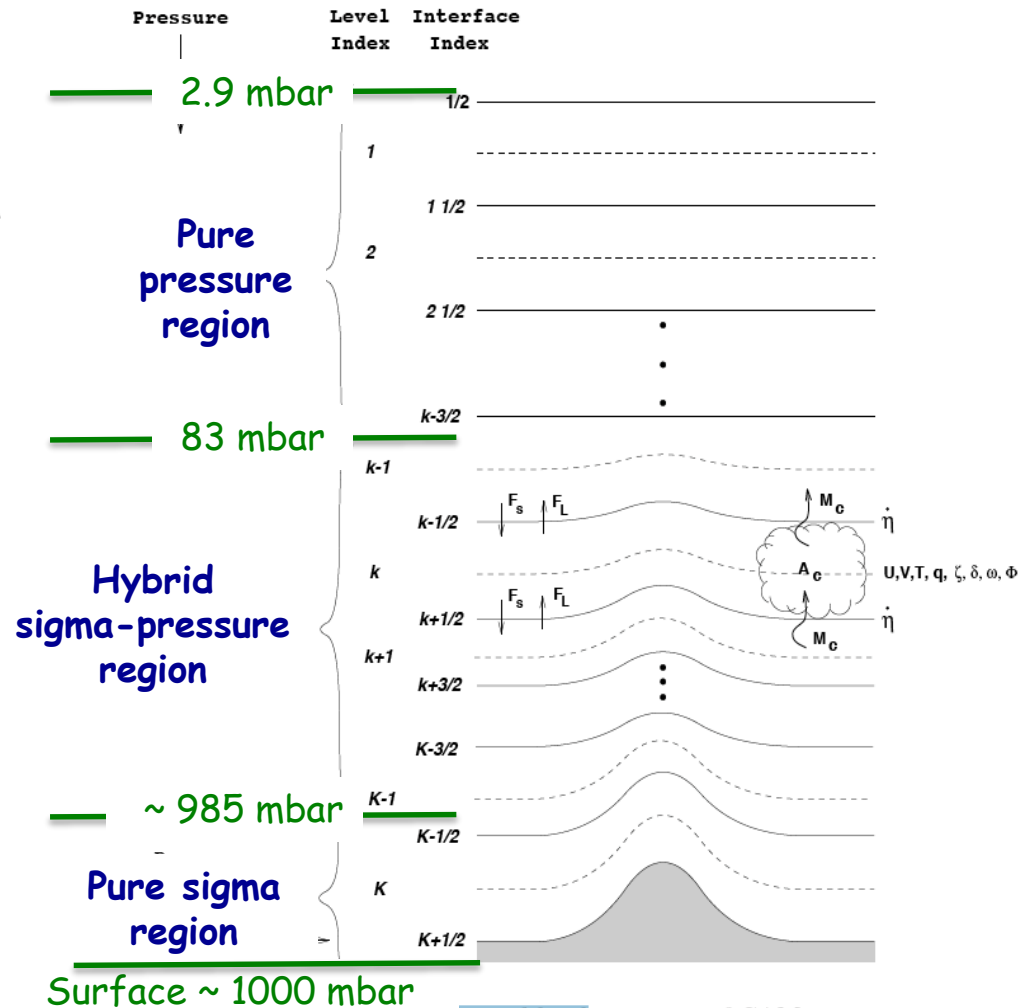
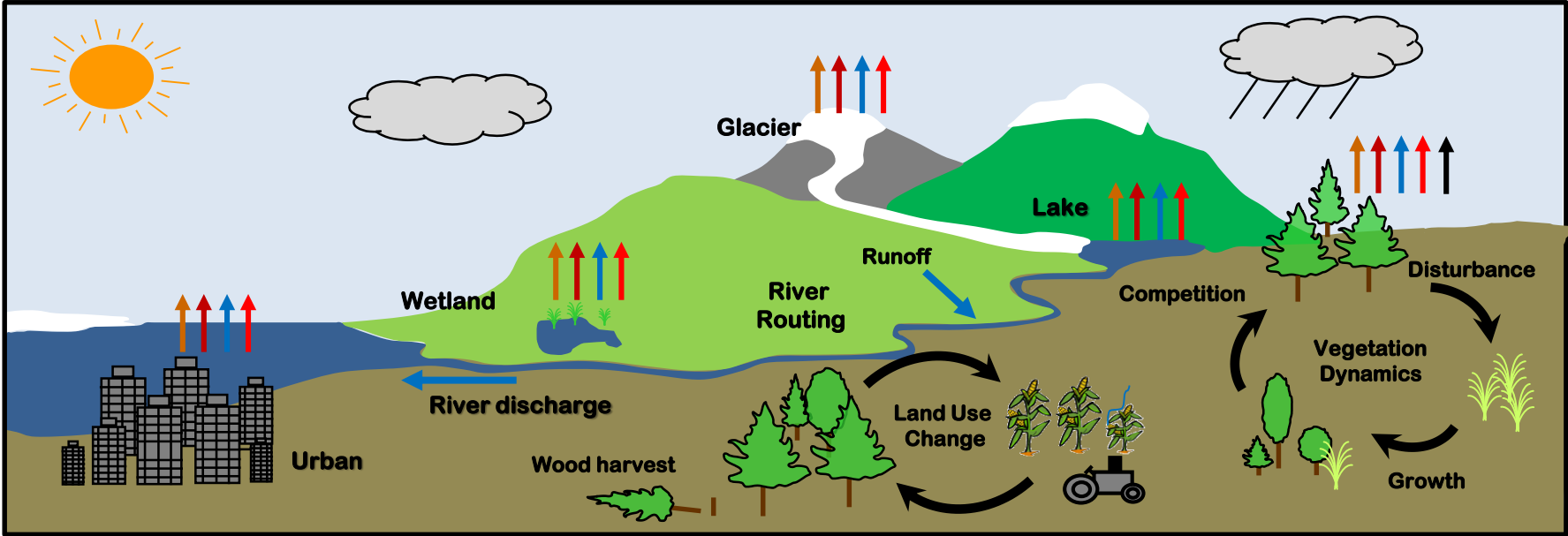
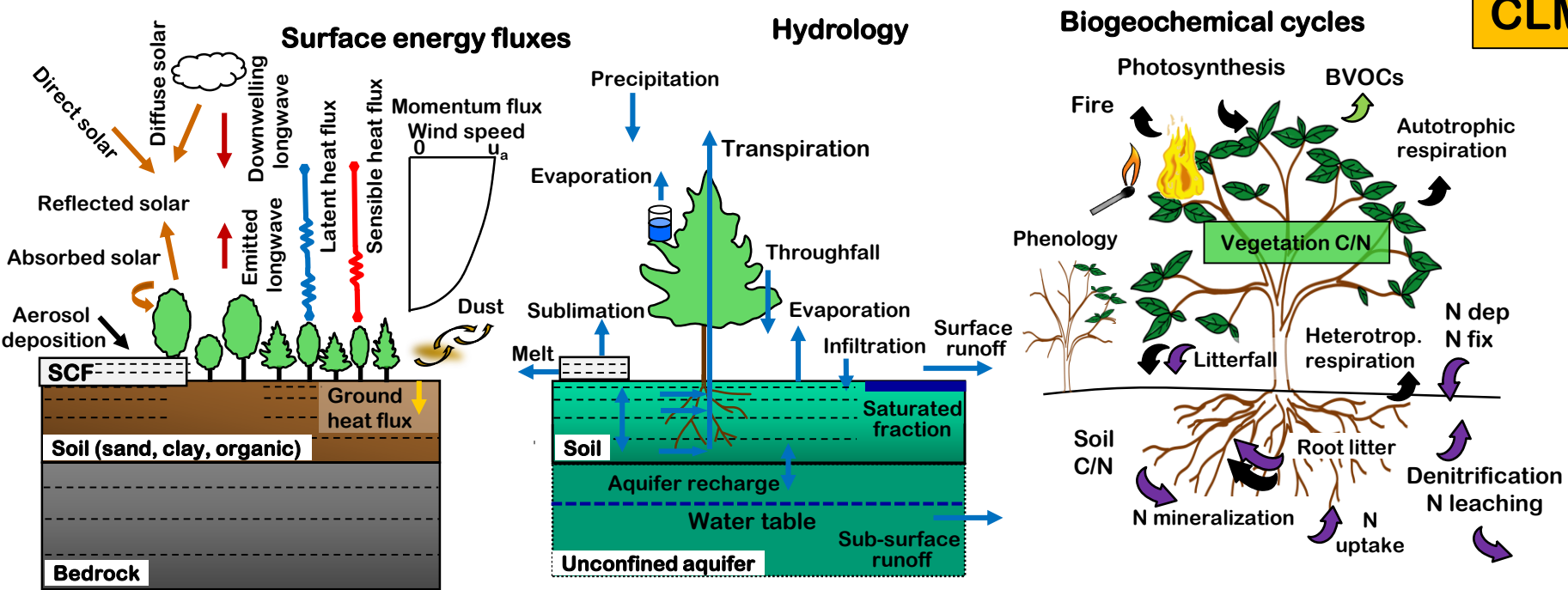
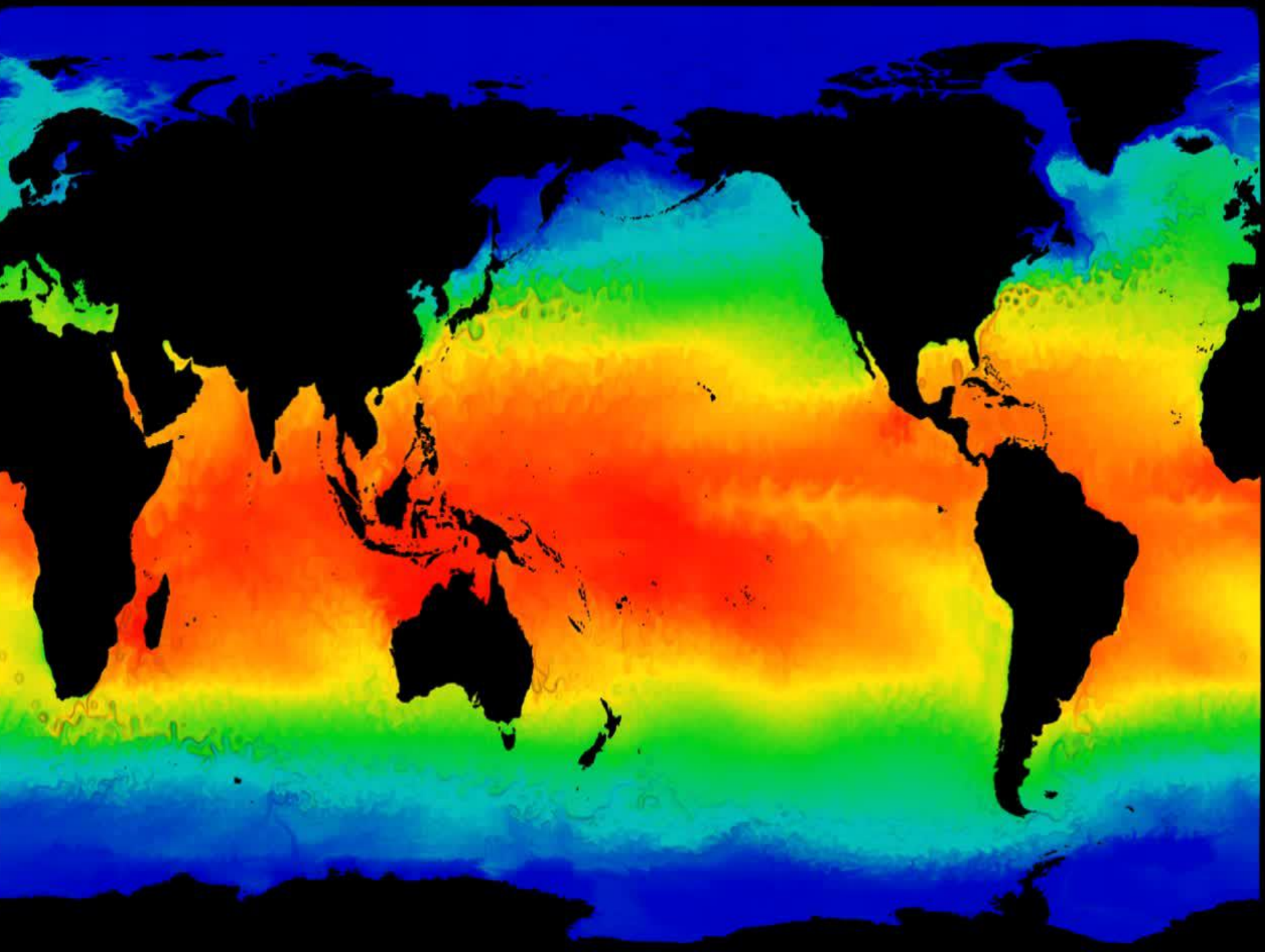


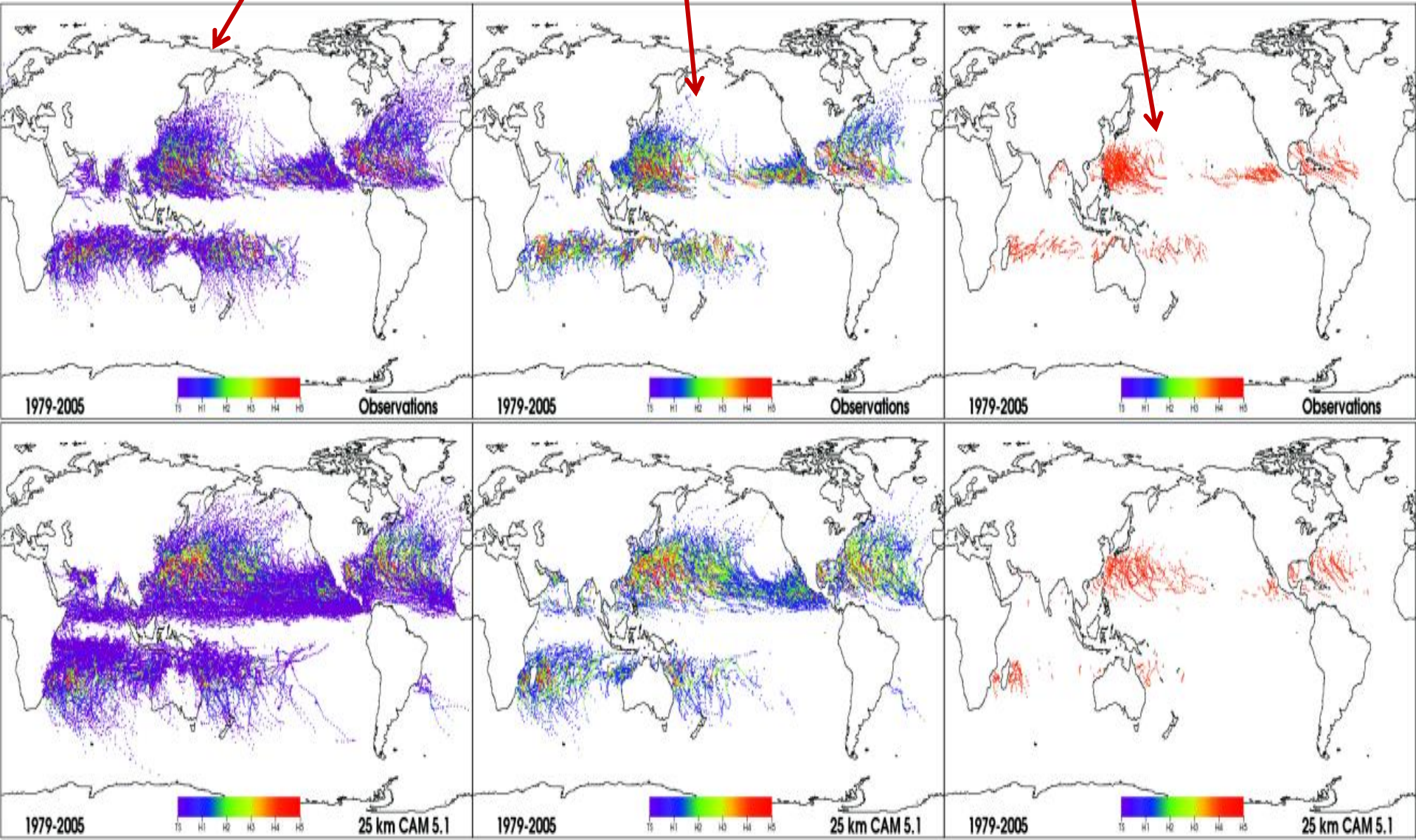
Figure 3.1. Vertical level structure of CAM 4.0







Tropical storms, hurricanes, and intense hurricanes for high resolution (25 km) atmospheric model(CAM5) M. Wehner, DOE LBL

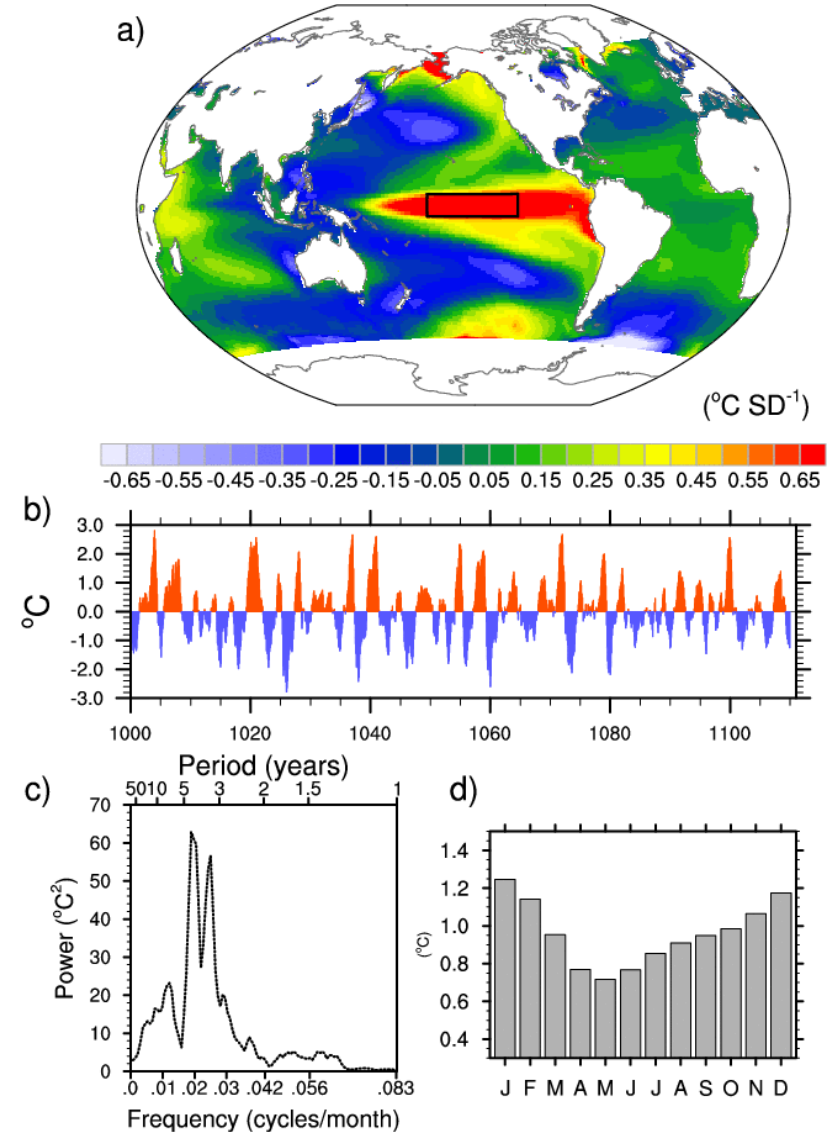
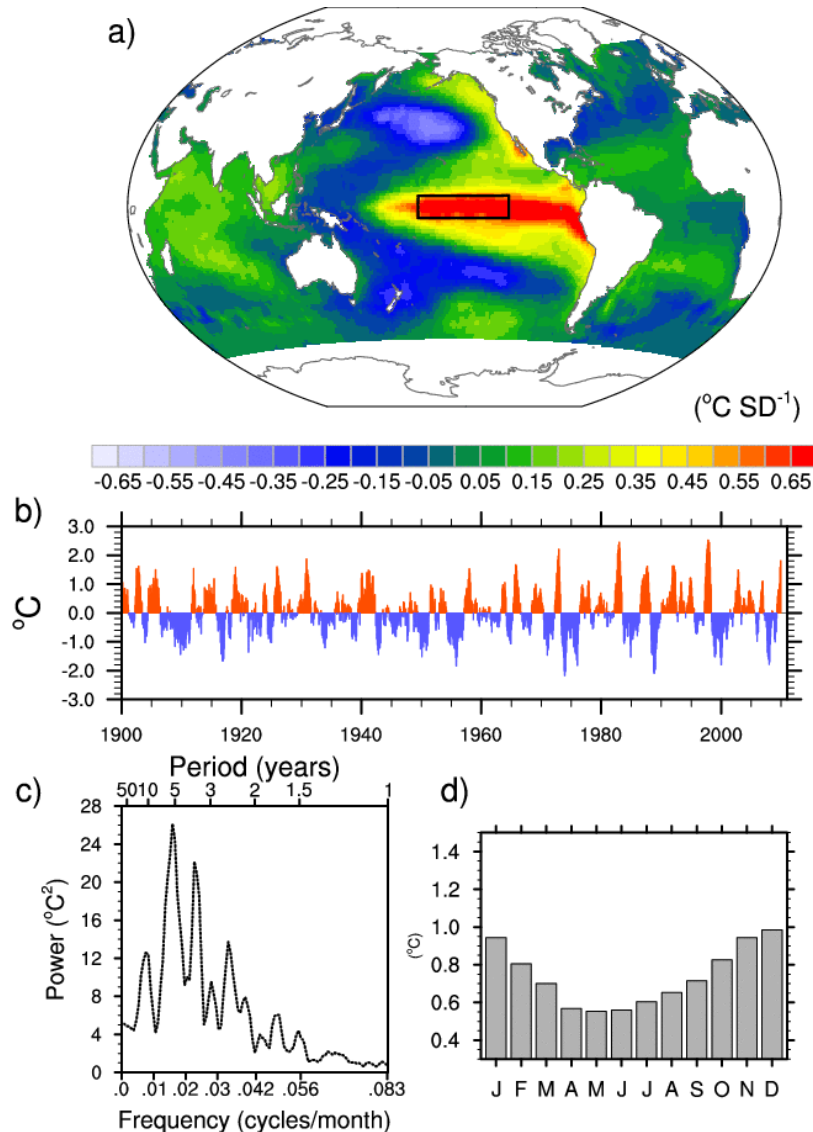


Leading Mode of Global SST Variability

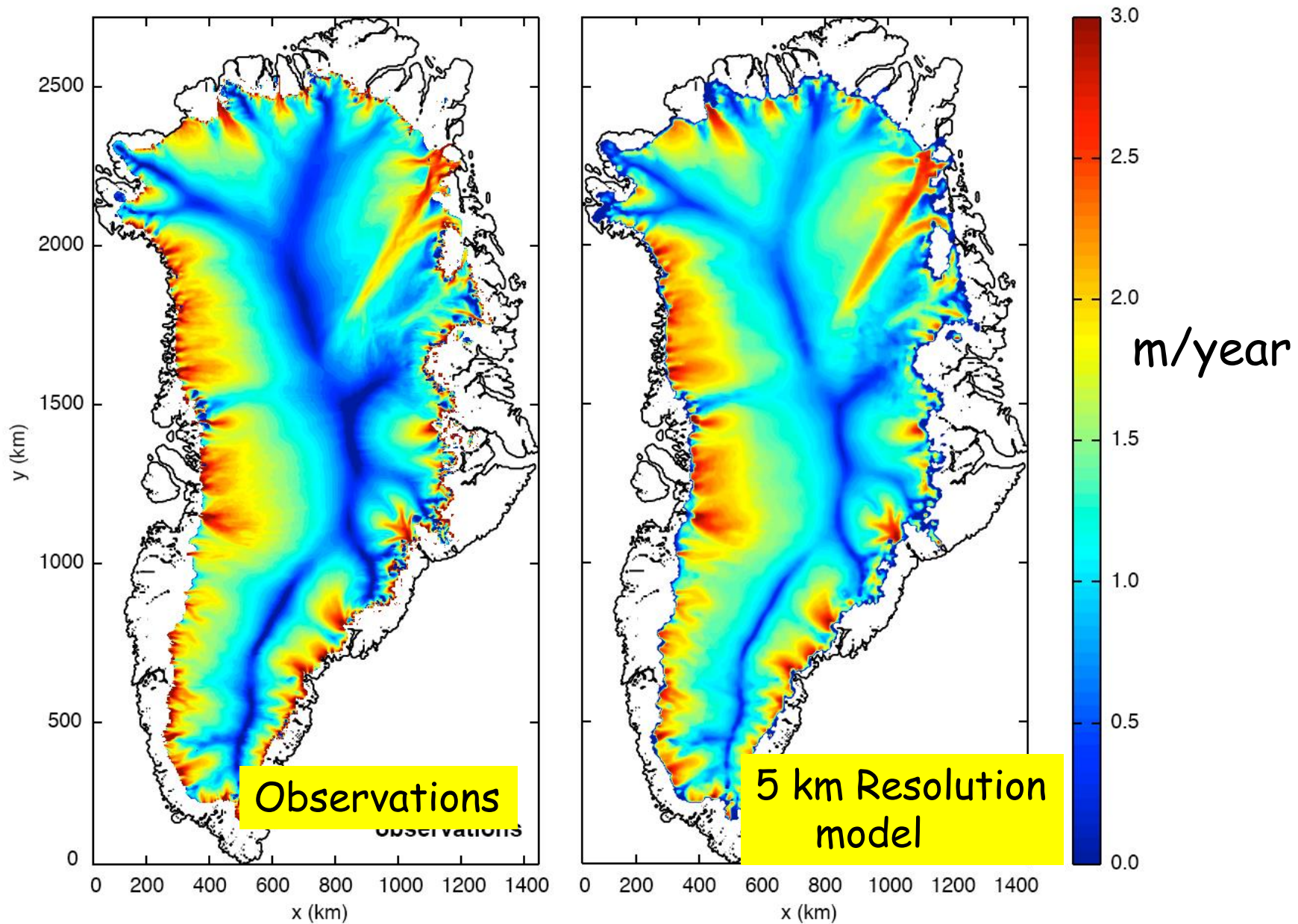
Seasonal Capability (Neale, NCAR)

Observations

CCSM4



Velocities

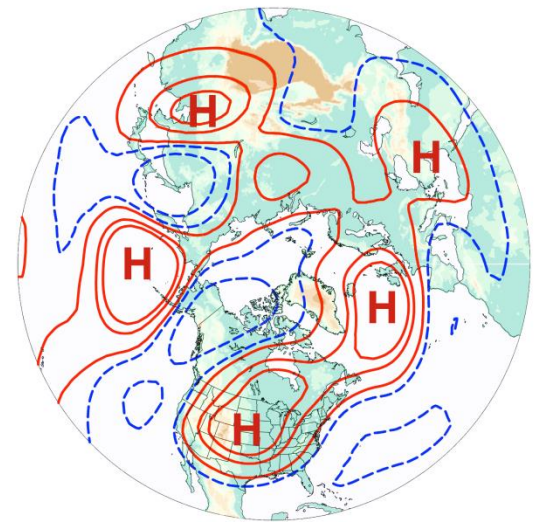


Price, Lipscomb et al, DOE/LANL, 2010

Examples of Climate Change

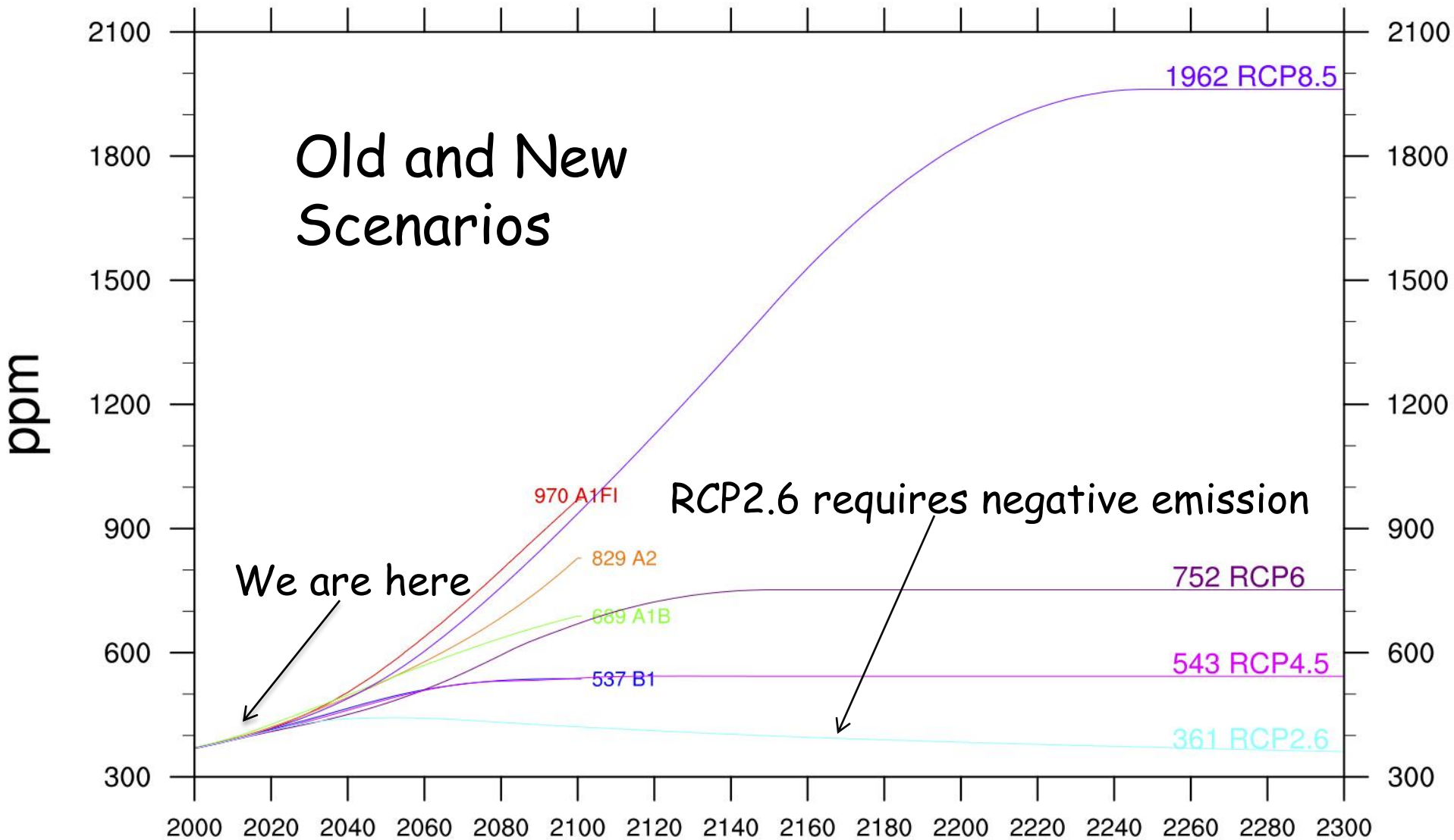
- 20th and 21st century simulations for IPCC
- Single forcing simulations
- Hurricane changes
- Closing Bering strait
- Heat waves, etc.
- Model development

Probability of US heat Waves Affected by a Subseasonal Planetary Wave Pattern: Prediction 15-20 days in Advance



Haiyan Teng, Grant Branstator, Hailan Wang, Jerry Meehl, and
Warren Washington, (2013) *Nature Geoscience*


CO₂ concentrations



SRES: **A1FI** **A2** **A1B** **B1**

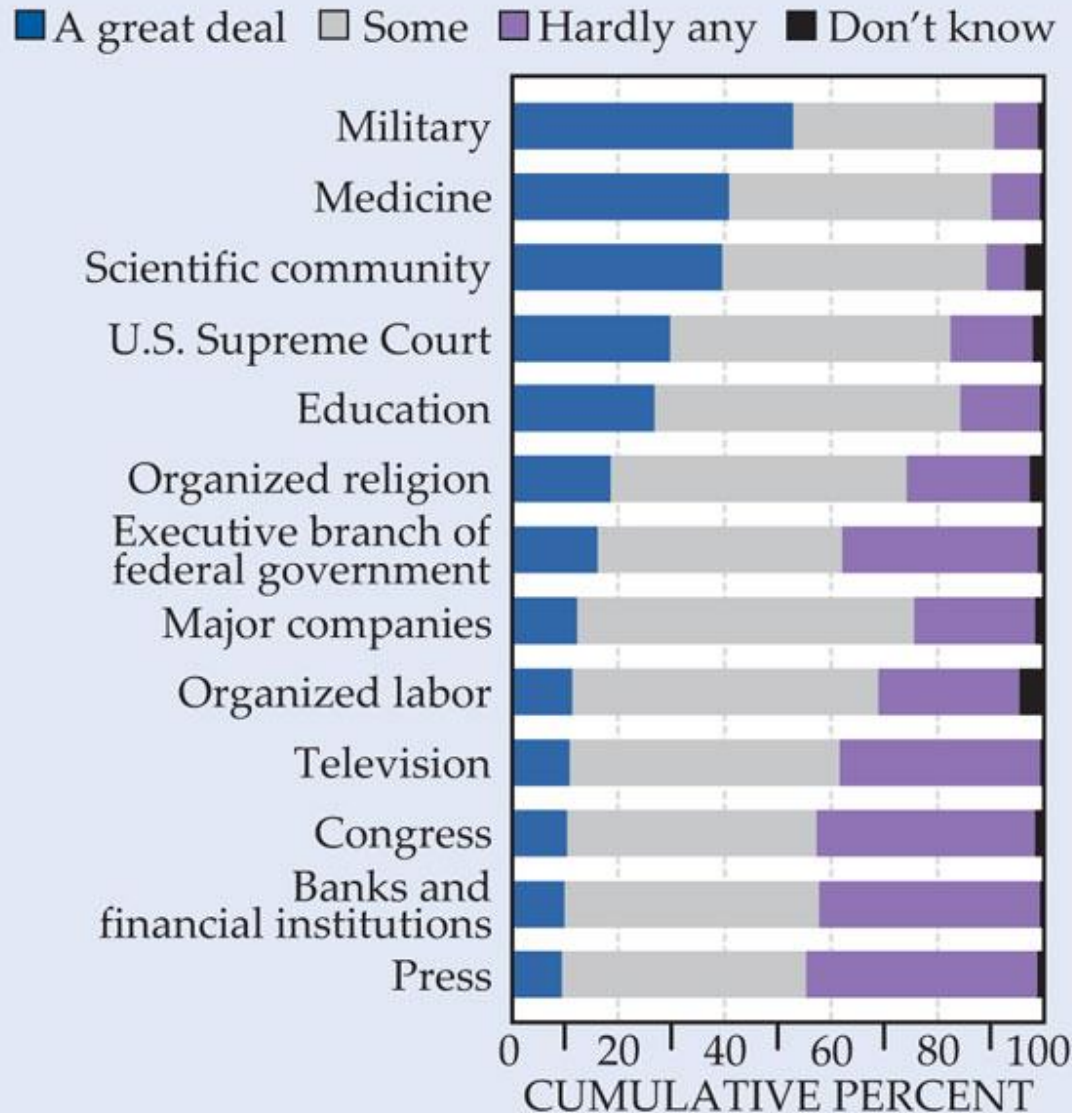
RCP: **RCP8.5** **RCP6** **RCP4.5** **RCP2.6**

G. Strand, NCAR



Climate and Earth System models have and continue to contribute to understanding and predicting the climate system. They allow the science community to determine objectively the possible impacts of climate change on food production, flooding, drought, sea level rise, and health as well as decision support. Higher resolution and more complete models will help.

Professions: Public Trust



Debate in Congress
about the President's
Climate Action Plan

From National Science
Board S & E Indicators (2012)

Genesis of U.S. Global Change Program

White House Cabinet meeting on climate change in 1990

President George H. W. Bush



John Sununu, Chief of Staff

We installed a climate model in The White House!



Allan Bromley, President's
Science Advisor

Convinced the cabinet about climate change.

We have loss the bipartisan approach.



U.S. Global Change Research Program

\$2.7 Billion over 12 agencies

Thomas R. Armstrong, PhD

Executive Director, USGCRP

Office of Science and Technology Policy

Executive Office of the President

Washington, DC



www.globalchange.gov

I chaired the Review Committee for the National Academies

Slides provided by Thomas Armstrong

Global Change Research Act

Global Change Research Act of 1190 (P.L. 101-606)

Act at <http://www.globalchange.gov/about/program-structure/global-change-research-act>

Called for a "comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change"

**OMB/OSTP FY 14 S&T Memo:
Guidance to the Agencies**

Memo at <http://www.whitehouse.gov/sites/default/files/omb/memoranda/2012/m-12-15.pdf>

"Emphasize research that advances understanding of vulnerabilities in human and natural systems and their relationships to climate extremes, thresholds, and tipping points"

Passed by bipartisan Congress

**National Climate Assessment
released on May 6, 2014
at the White House**

USGCRP Research Enterprise

Create new knowledge

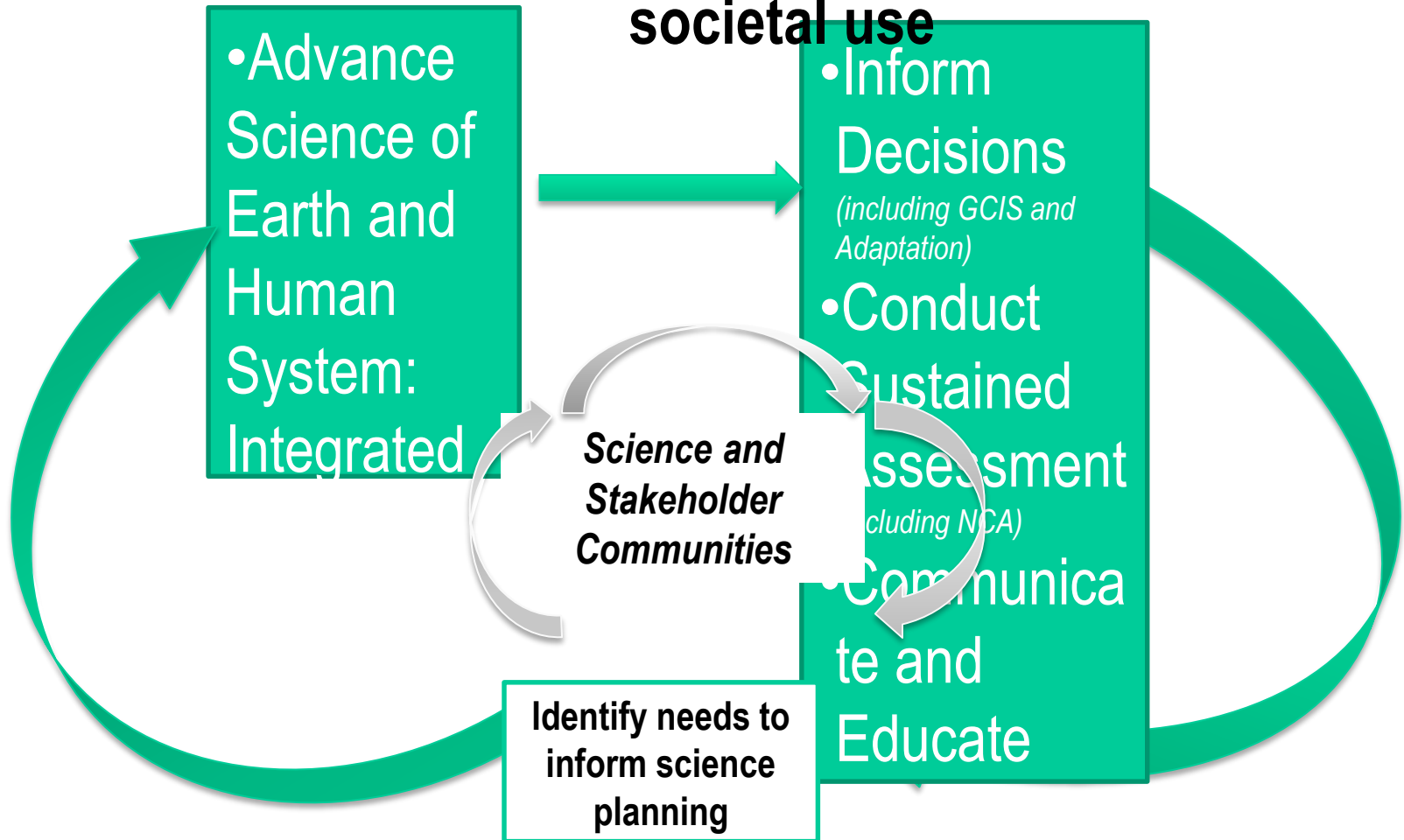
• Advance Science of Earth and Human System: Integrated

Translate, provide and assess knowledge for societal use

• Inform Decisions
(including GCIS and Adaptation)
• Conduct Sustained Assessment
(including NCA)
• Communicate and Educate

Science and Stakeholder Communities

Identify needs to inform science planning



USGCRP in the Federal Context

Principals: <http://globalchange.gov/about/program-structure/officials>



CENRS Sub-Committees, WGs, & Task Forces

Air Quality Research (AQRS)

Critical and Strategic Mineral Supply Chains (CSMSC)

Interagency Arctic Research Policy Committee Interagency Working Group (IARPC)

Integration of Science and Technology for Sustainability Task Force

National Earth Observations Task Force (NEO)

Disaster Reduction (SDR)

Ecological Services (SES)

Global Change Research (SGCR)

Ocean Science & Technology (SOST)

Water Availability & Quality (SWAQ)

Toxics & Risks (T&R)

US Group on Earth Observations (USGEO)

Research Goals

U.S. Global Change Research Program

- Goal 1. Advance science: Earth system understanding, science of adaptation and mitigation, observations, modeling, sharing information
- Goal 2. Inform decisions: Scientific basis to inform, adaptation and mitigation decisions
- Goal 3. Conduct sustained assessments: build capacity that improves Nation's ability to understand, anticipate, and respond
- Goal 4. Communicate and educate: Advance communication and educate the public, improve the understanding of global change, develop future scientific workforce

The USGCRP Strategic Plan

Outcomes and Priorities Activities

Outcomes

- Providing Knowledge on Scales Appropriate for Decision Making
- Incorporating Social and Biological Sciences
- Enabling Responses to Global Change via Iterative Risk Management

Priorities Activities

- Enhance Information Management and Sharing
- Enable new capabilities for Integrated Observations and Modeling
- Increase Proactive Engagement and Partnerships
- Leverage International Investments & Leadership
- Develop the Scientific Workforce for the Future



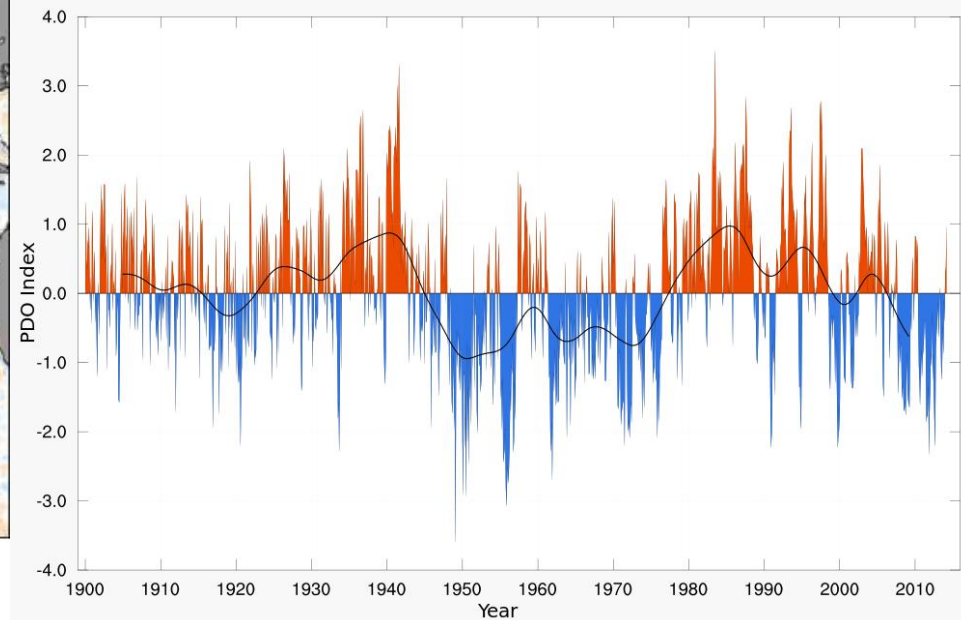
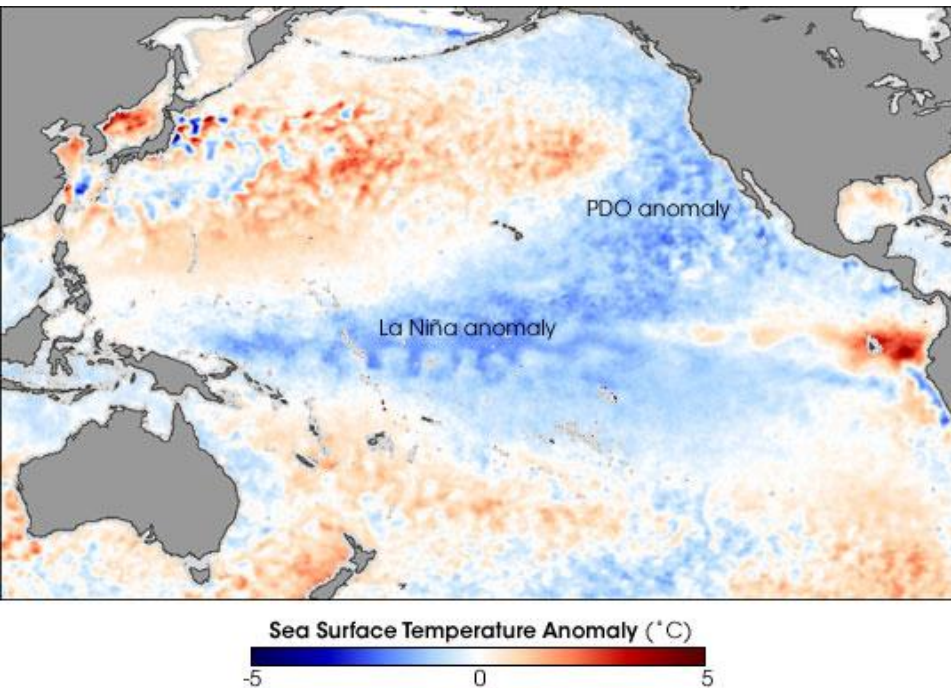
Future Earth

Future Earth is the global research platform providing the knowledge and support to accelerate our transformations to a sustainable world.

Bringing together existing programs on global environmental change*, Future Earth will be an international hub to coordinate new, interdisciplinary approaches to research on three [themes](#): Dynamic Planet, Global Development and Transformations towards Sustainability. It will also be a platform for international engagement to ensure that knowledge is generated in partnership with society and users of science. It is open to scientists of all disciplines, natural and social, as well as engineering, the humanities and law.

It is sponsored by the Science and Technology Alliance for Global Sustainability comprising the [International Council for Science](#) (ICSU), the [International Social Science Council](#) (ISSC), the [Belmont Forum](#) of funding agencies, the [United Nations Educational, Scientific, and Cultural Organization](#) (UNESCO), the [United Nations Environment Programme](#) (UNEP), the [United Nations University](#) (UNU), and the [World Meteorological Organization](#) as an observer.

Pacific Decadal Oscillation (PDO)



The End

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Special thanks to the
Department of Energy, Office of Science (BER),
the National Science Foundation (NSF), and OSTP

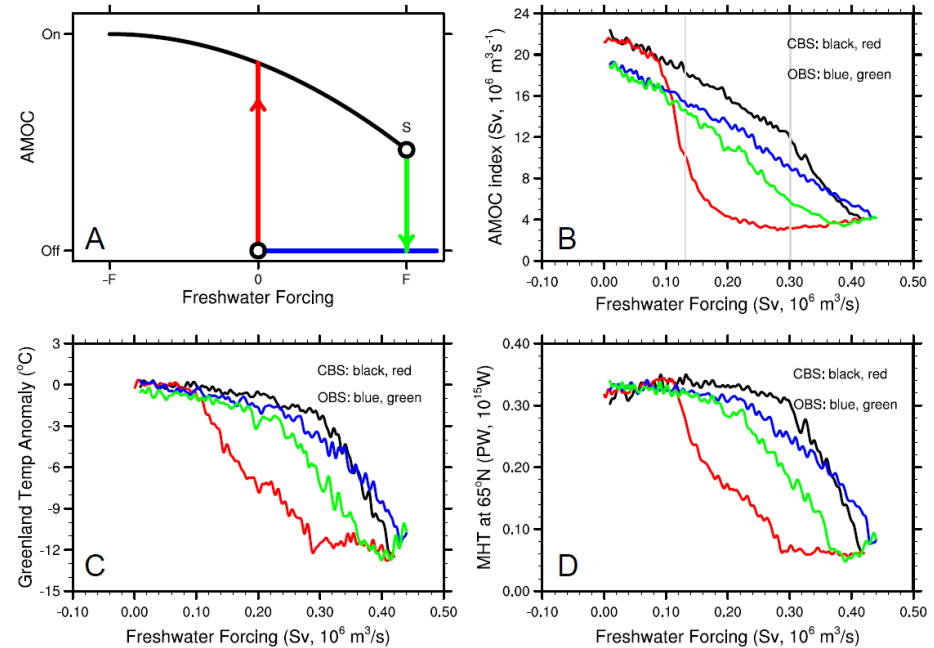
Role of the Bering Strait on the hysteresis of the ocean conveyor belt circulation and glacial climate stability

Objective

Study the influence of the Bering Strait opening/closure on the hysteresis of the Atlantic meridional overturning circulation (AMOC) and abrupt climate change

Approach

- CCSM3 is used as the primary tool.
- Two simulations have been done under present-day climate boundary conditions with everything identical except one with an open Bering Strait and the other has a closed one.
- Freshwater is slowly added into the North Atlantic until the AMOC collapses, then freshwater is slowly reduced until the AMOC restarts again. The simulations run 4400 years each at NERSC.



Impact

- Our results suggest that AMOC hysteresis only exists when Bering Strait is closed. Thus abrupt climate changes occur only in glacial time.
- This could have broad impact on both past and future climate studies.

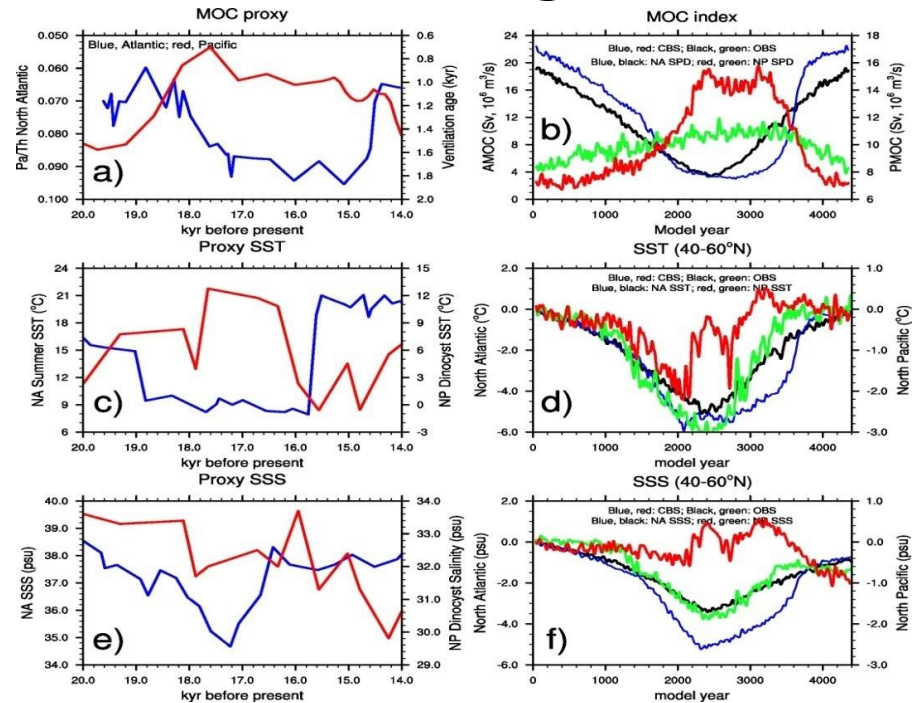
The Pacific-Atlantic Seesaw and the Bering Strait

Objective

Study the influence of the Bering Strait opening/closure on the Pacific-Atlantic climate response to a collapse of the Atlantic meridional overturning circulation (AMOC)

Approach

- CCSM3 is used as the primary tool.
- Two simulations have been done under present-day climate boundary conditions with everything identical except one with an open Bering Strait and the other has a closed one.
- Freshwater is slowly added into the North Atlantic until the AMOC collapses, then freshwater input is slowly reduced until the AMOC restarts again.



Impact

- Our results suggest that a seesaw-like climate change due to an AMOC collapse can only occur with a closed Bering Strait.
- This could have broad impact on both past and future climate studies.