Large-Scale Climate Change Research at Rutgers: Modeling and Observations

Alan Robock

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Current Rutgers faculty and their climate modeling and observational projects	
Civil Engineering	
Monica Mazurek	Atmospheric aerosols
Ecology, Evolution, and Natural Resources	
Ed Green	Forest biomass and carbon storage
Richard Lathrop	Regional wildfire/ecosystem modeling, forest biomass and carbon storage, sea level and storm surge impacts
Ming Xu	Regional wildfire and ecosystem modeling, historical climate change
Environmental Sciences	
Anthony Broccoli	Paleoclimate, global modeling, regional modeling, patterns of climate change
Ying Fan Reinfelder*	Hydrological modeling and impacts
Alan Robock	Volcanic eruptions, soil moisture, nuclear winter, hydrological impacts, global and regional modeling, data analysis
Georgiy Stenchikov	Volcanic eruptions, nuclear winter, global and regional modeling
Barbara Turpin	Atmospheric aerosols
Christopher Weaver	Regional climate modeling, land-atmosphere interactions
Geography	
David Robinson	Snow cover, climate data
Will give Research Highlight * also Geology	

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Geology	
Gail Ashley	Human evolution and climate
Miriam Katz	Paleoclimate change indicators
Kenneth Miller	Paleoclimate sea level changes, North Atlantic ocean circulation
Gregory S. Mountain	North Atlantic ocean circulation
Roy Schlische	Climate records from lake basins
James D. Wright	North Atlantic ocean circulation, paleoclimate change indicators
Human Ecology	
Tom Rudel	Forests and greenhouse gas emissions
Marine and Coastal Sciences	
John Dighton	Rainfall effects on soil gas exchange
Paul Falkowski*	Carbon cycle
Jennifer Francis	Arctic climate, cloud-radiation interactions, remote sensing
Dale Haidvogel	Ocean circulation, biogeochemistry, and ecology modeling
James Miller	Arctic climate, global hydrologic cycle
Peter Rona*	Greenhouse gas emissions from the ocean bottom
Yair Rosenthal*	Western Pacific ocean circulation and past climate change, paleoclimate temperature and ice volumes
Sybil Seitzinger	Watershed modeling of transport to oceans
Liz Sikes	Paleoceanography and the carbon cycle
John Wilkin	Ocean circulation, biogeochemistry, and ecology modeling
Will give Research Highlight * also Geology	

Climate Change Fundamental Questions

1. How will the climate change in the future?
2. How will this climate change affect us?
3. What should we do about it?

Climate Change Fundamental Questions

1. How will climate change in the future?

Requires understanding of:

- past climate change (observations)
- the causes of climate change (the forcings)
- physics, chemistry, and biology of the climate system (climate processes)
- numerical modeling of climate system behavior

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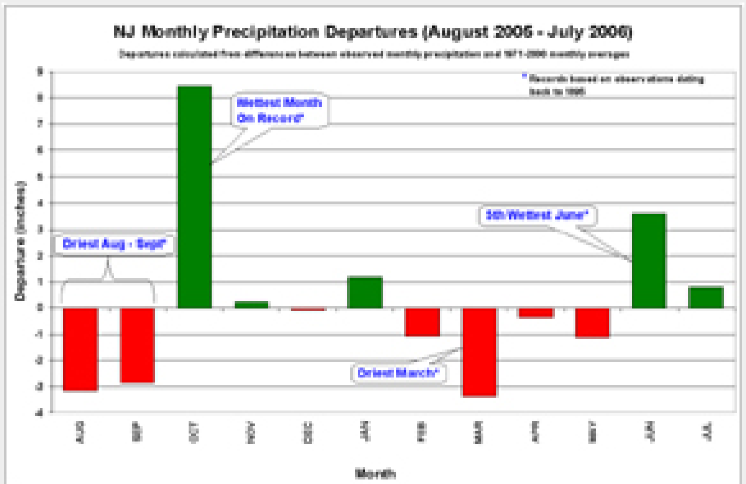
Areas of climate research at Rutgers

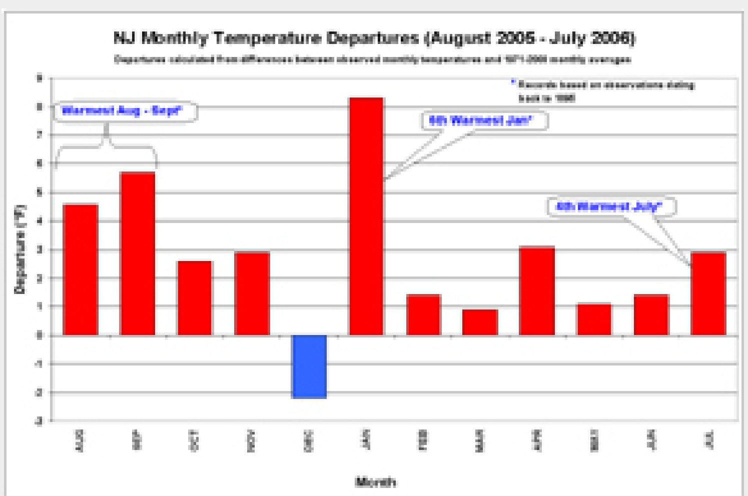
Climate observations

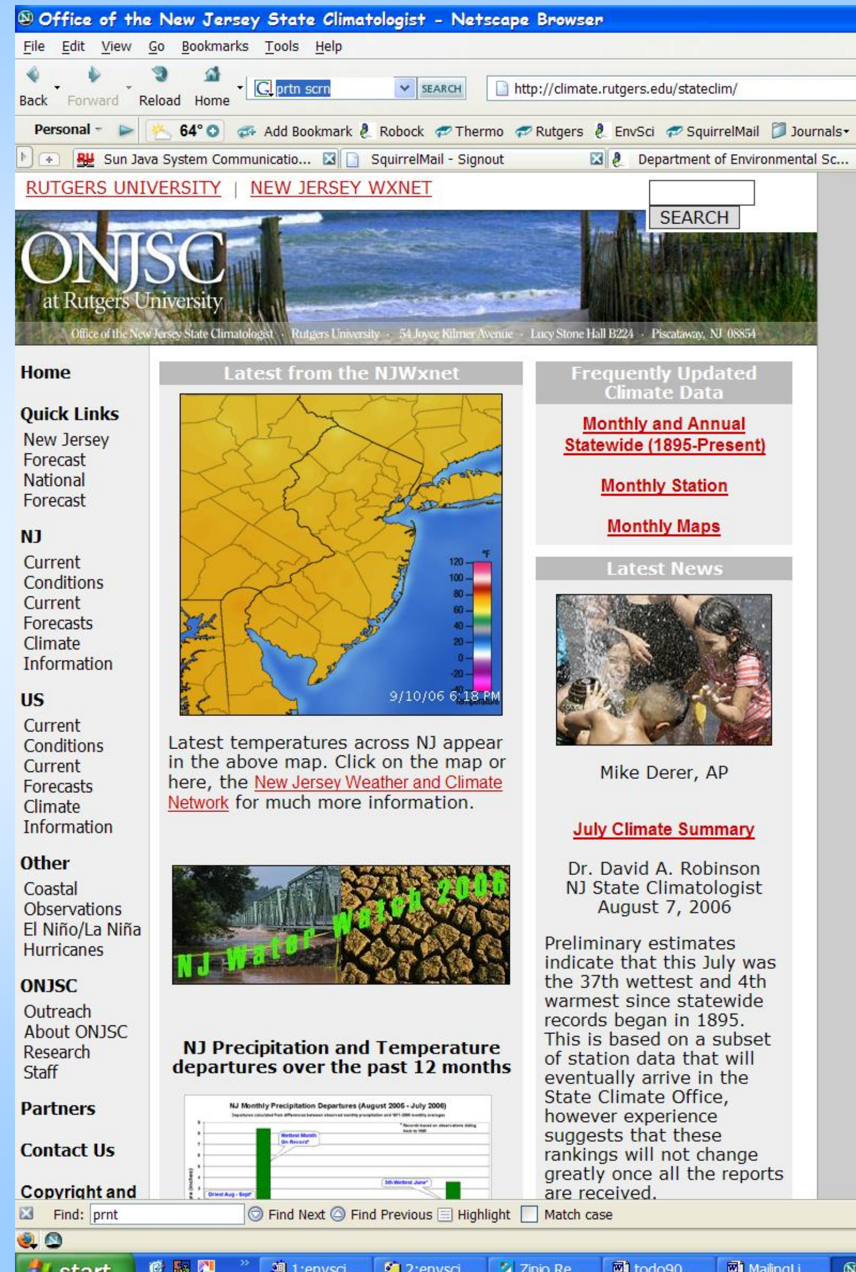
Temperature, precipitation	Robinson, Xu, Robock
Snow	Robinson
Soil moisture	Robock
Paleoclimate	Broccoli, Katz, K. Miller, Wright, Rosenthal, Sikes
Monsoon	Xu
Lakes	Schlische
Remote sensing	Francis, J. Miller, Robock, Stenchikov

Office of the New Jersey State Climatologist – Robinson

NJ Precipitation and Temperature departures over the past 12 months







Alan R
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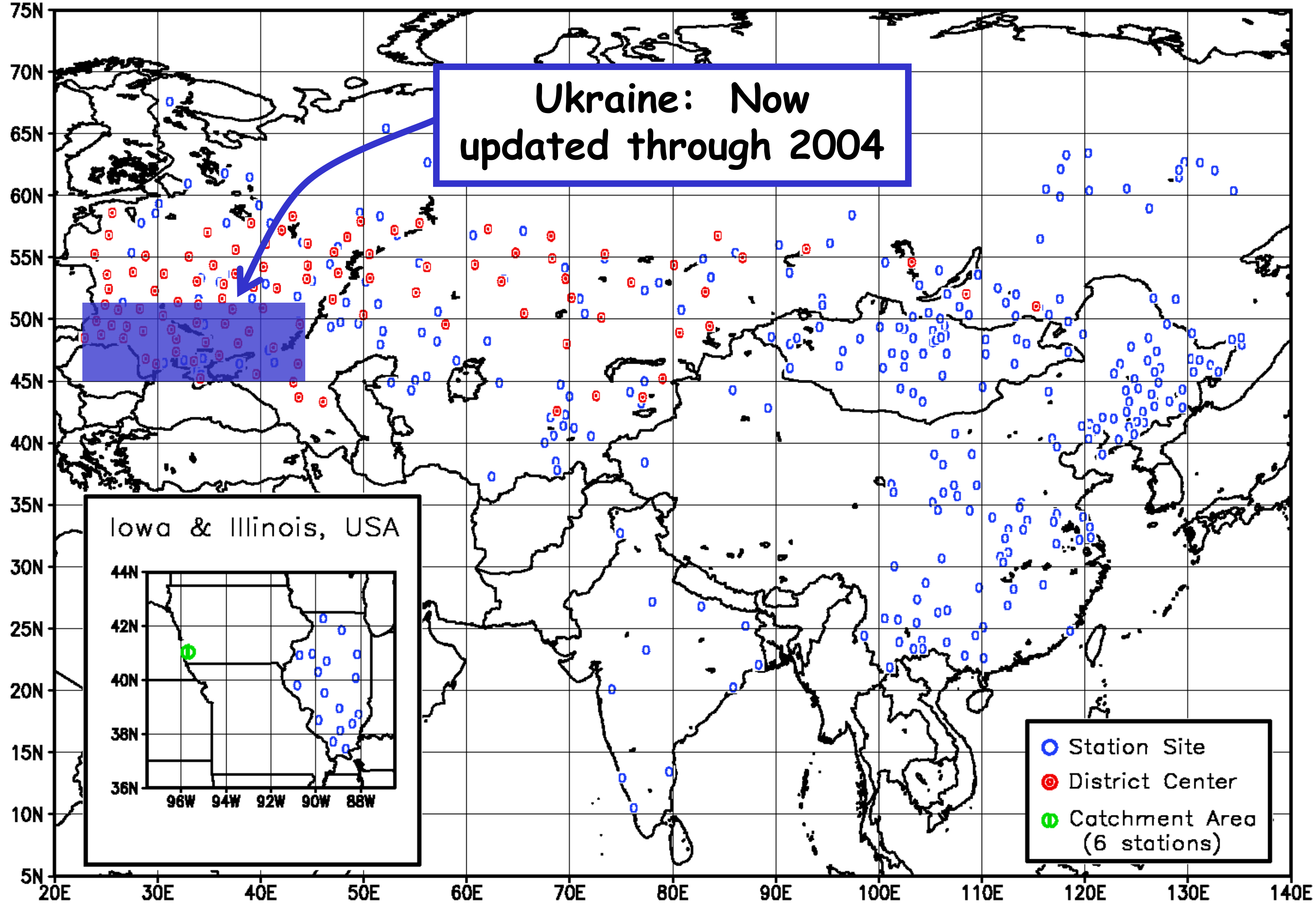
Global Soil Moisture Data Bank Stations
http://climate.envsci.rutgers.edu/soil_moisture



Global Soil Moisture Data Bank

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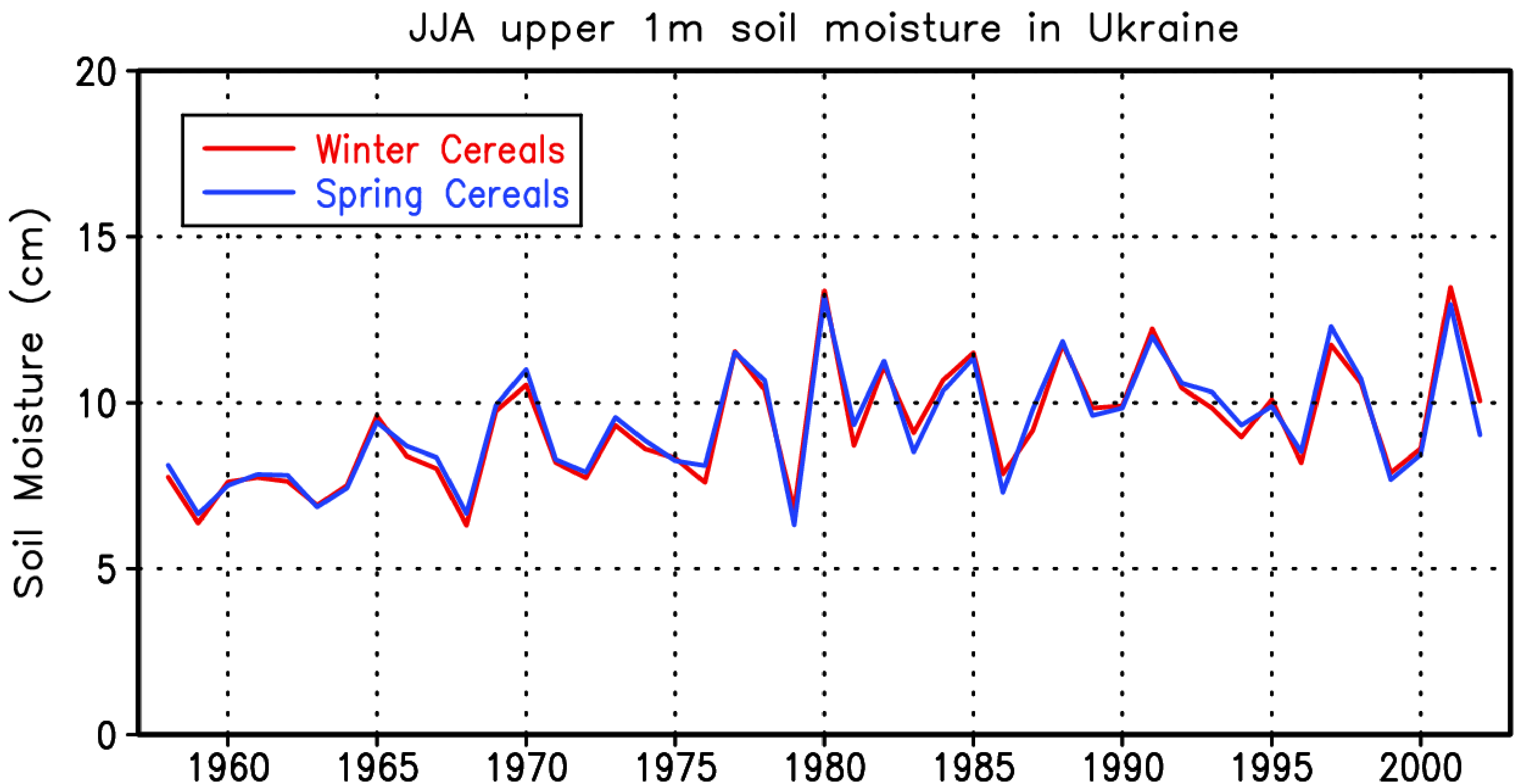
Data Collection and Distribution
Land Surface Modeling
Remote Sensing
Data Analysis

Alan Robock
Haibin Li
Konstantin Vinnikov

Ukraine soil moisture observations, averaged over 22-40°E, 46-52°N



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Data Collection and Distribution
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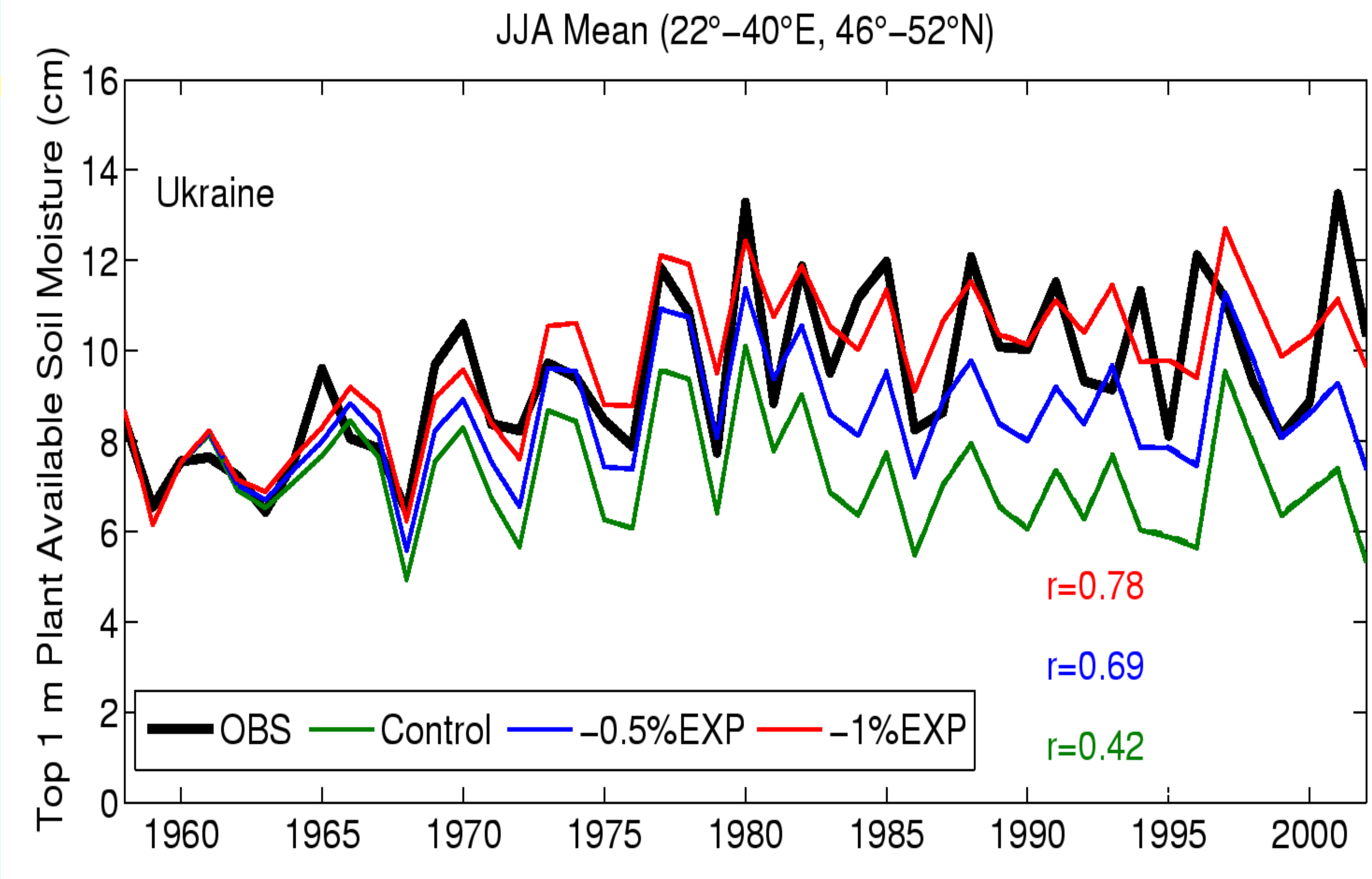
Upward trend caused by solar dimming (increased tropospheric aerosol pollution)



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Data Collection and Distribution
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Data Analysis

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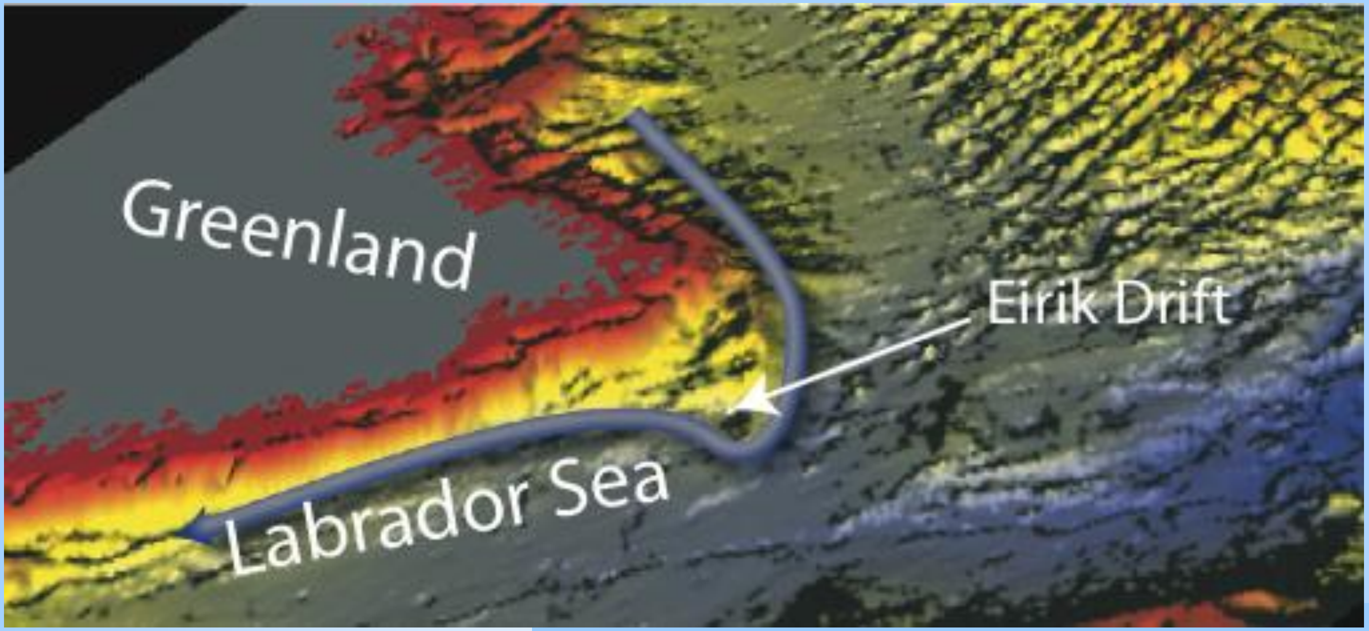
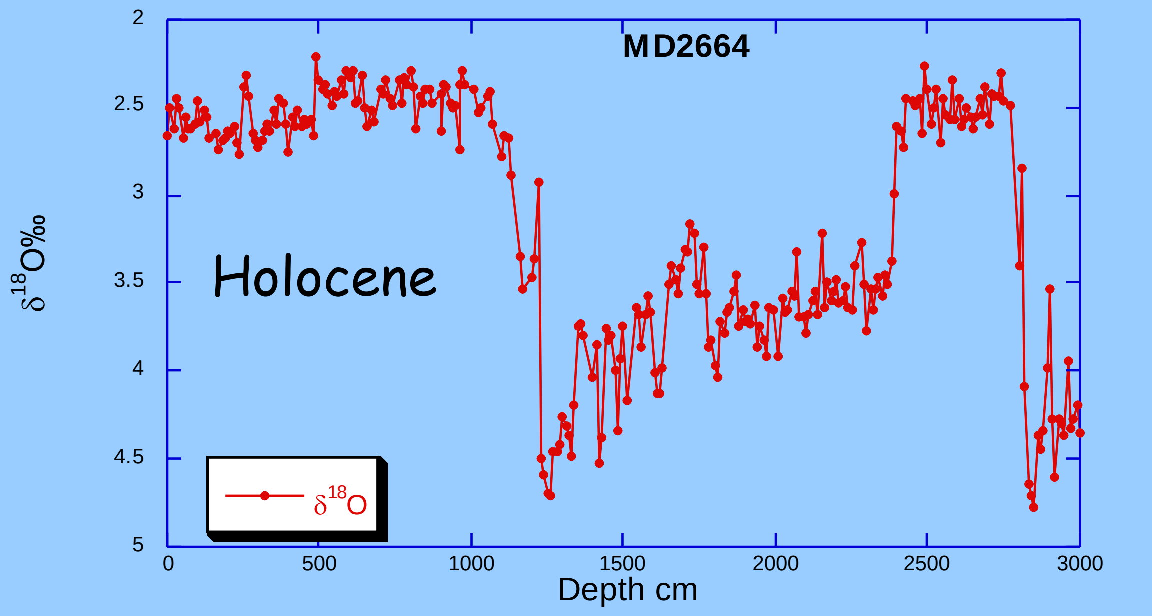
Deep ocean circulation wrapping around Greenland - Wright



Sediments are deposited at the toe of Eirik Drift at rates approaching 100 cm/kyr. The stable isotope record to the right shows 10 m of Holocene (last 10,000 yrs). High-resolution sampling affords decadal resolution in deep-ocean circulation changes.



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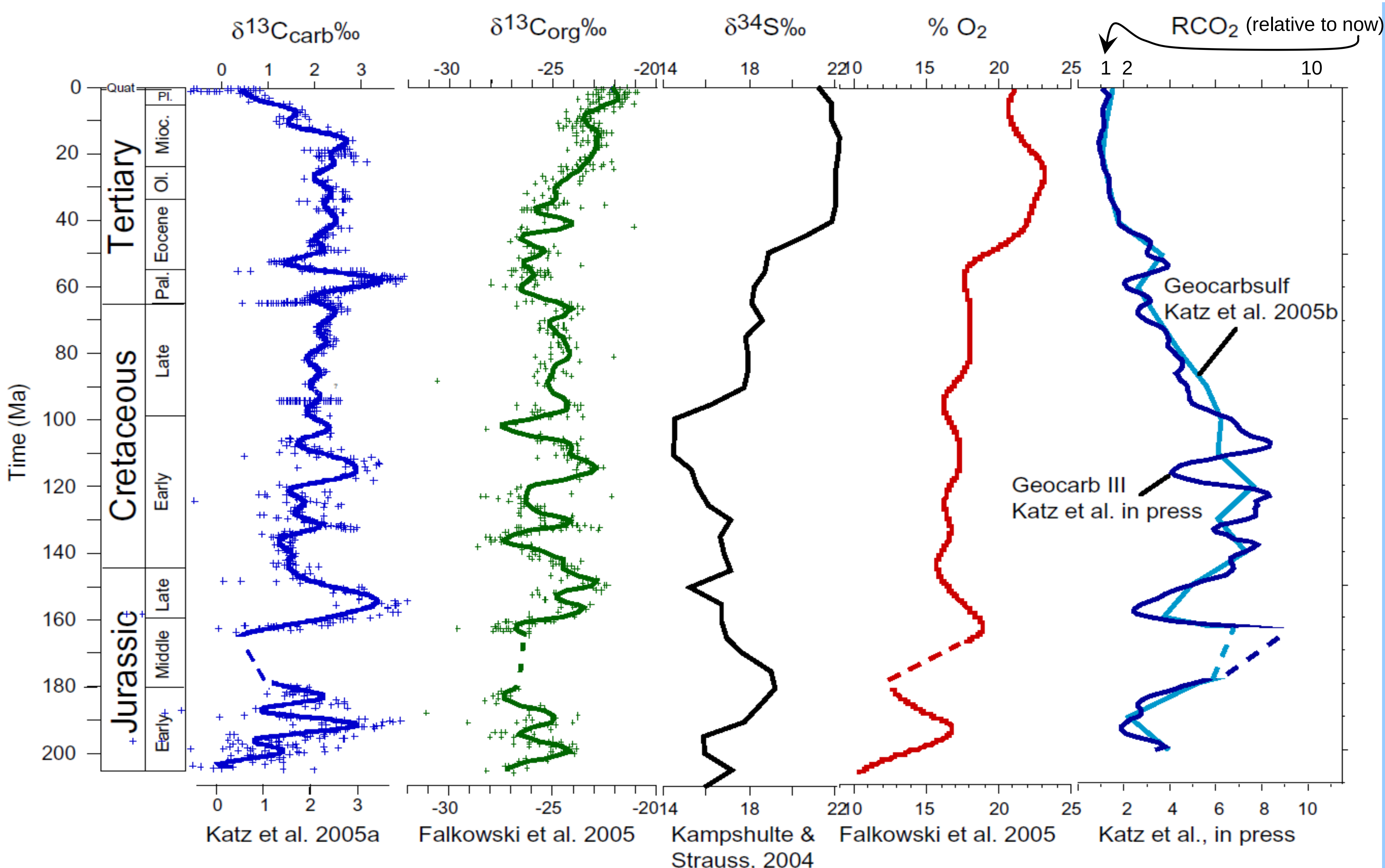
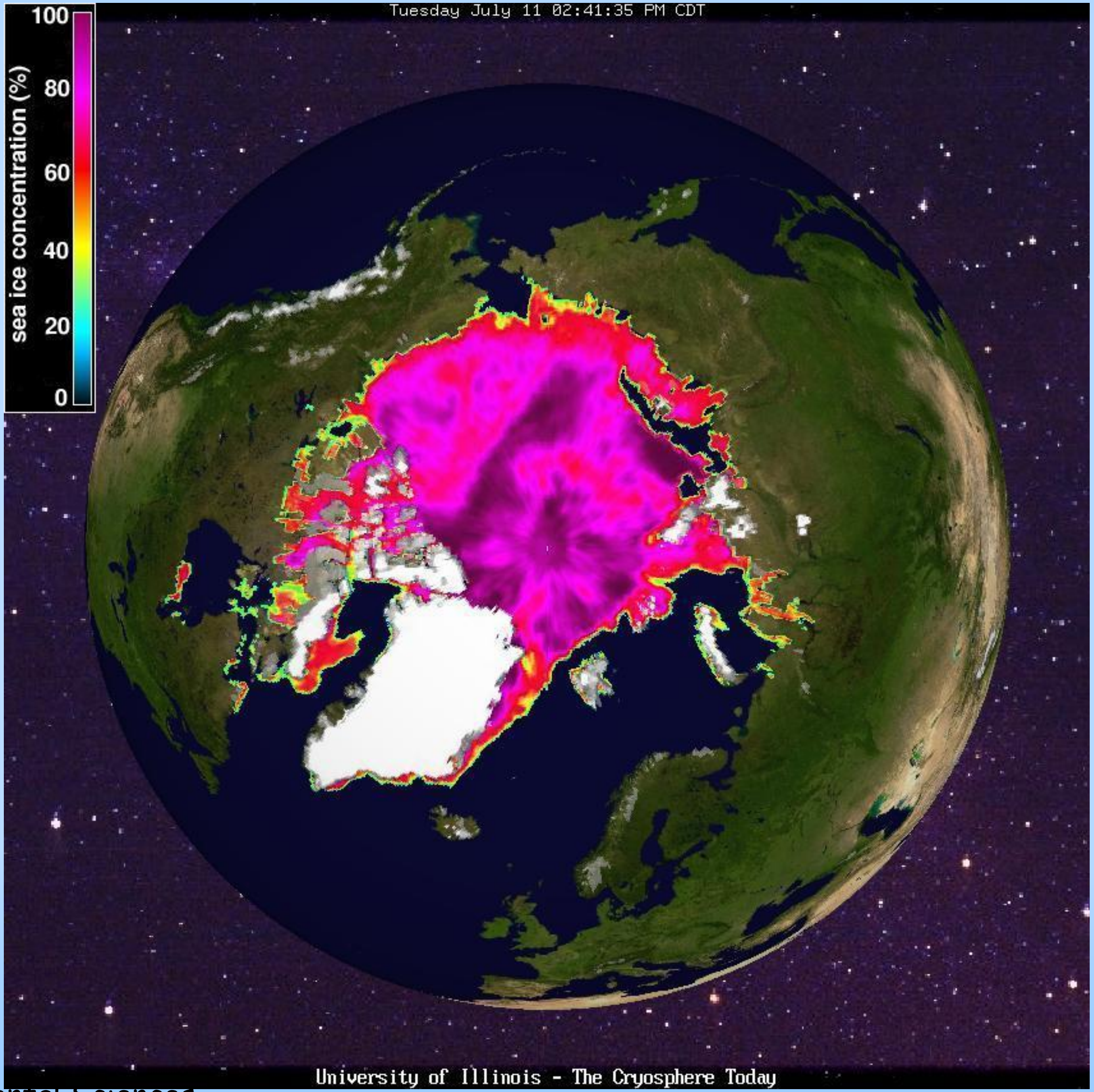
Using high-resolution carbon isotopic datasets of marine carbon to reconstruct atmospheric O_2 and CO_2 over the past 205 Myr, by Katz, Falkowski, K. Miller, and others



Investigating the causes and implications of the recent rapid ice melt using satellite information - Francis



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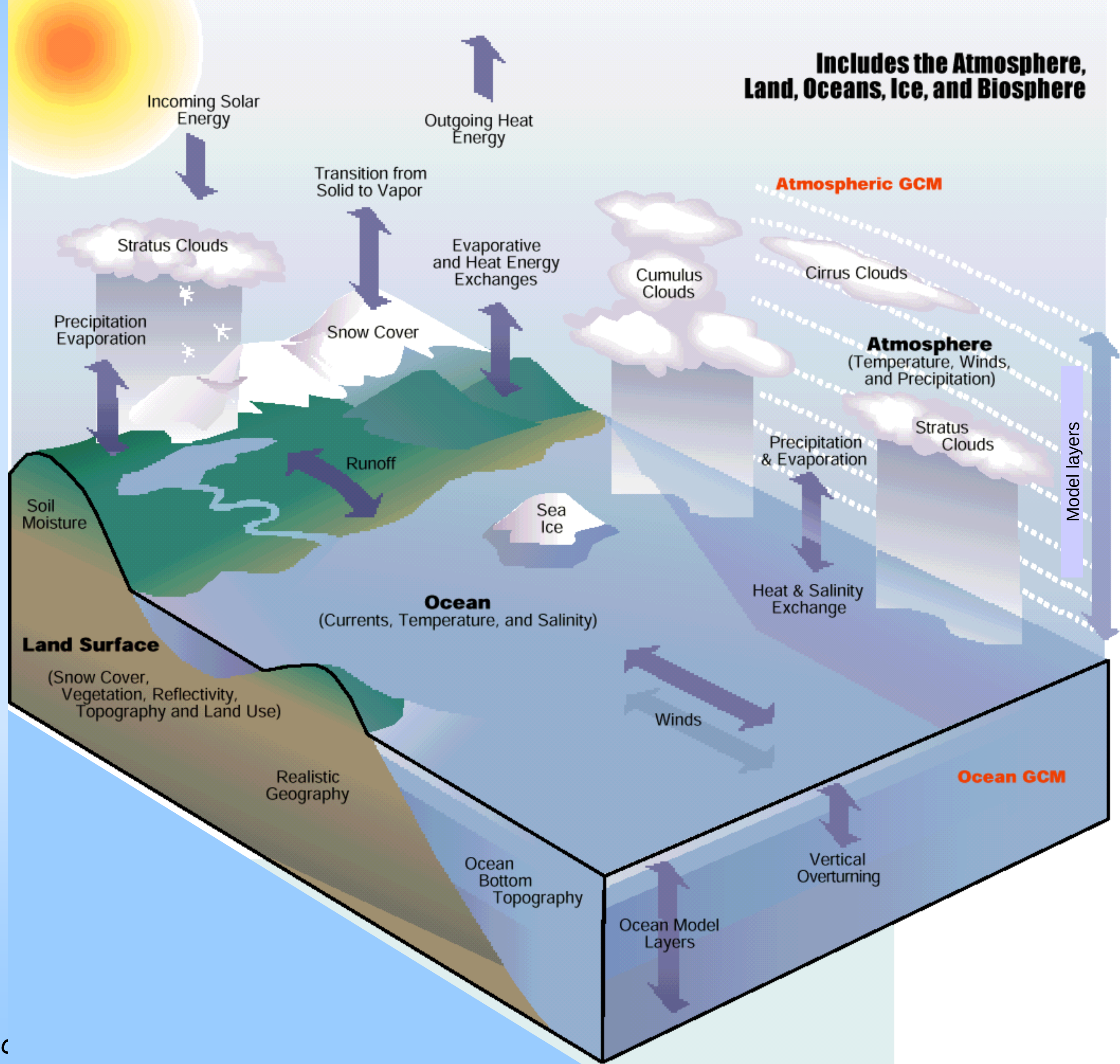
Climate System

1. Atmosphere
2. Hydrosphere (oceans, soil moisture, rivers, water table)
3. Cryosphere (snow, ice, glaciers)
4. Biosphere (including people)
5. Lithosphere (soil, land down to bedrock, volcanoes)

The Climate System



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Causes of Climate Change (Forcings)

Natural: Solar variations

Volcanic eruptions

Anthropogenic: Greenhouse gases CO_2, CH_4, CFCs, N_2O, O_3

Ozone depletion (indirect effect of CFCs)

Tropospheric aerosols

Sulfates, black carbon, organics, dust

Land surface modification

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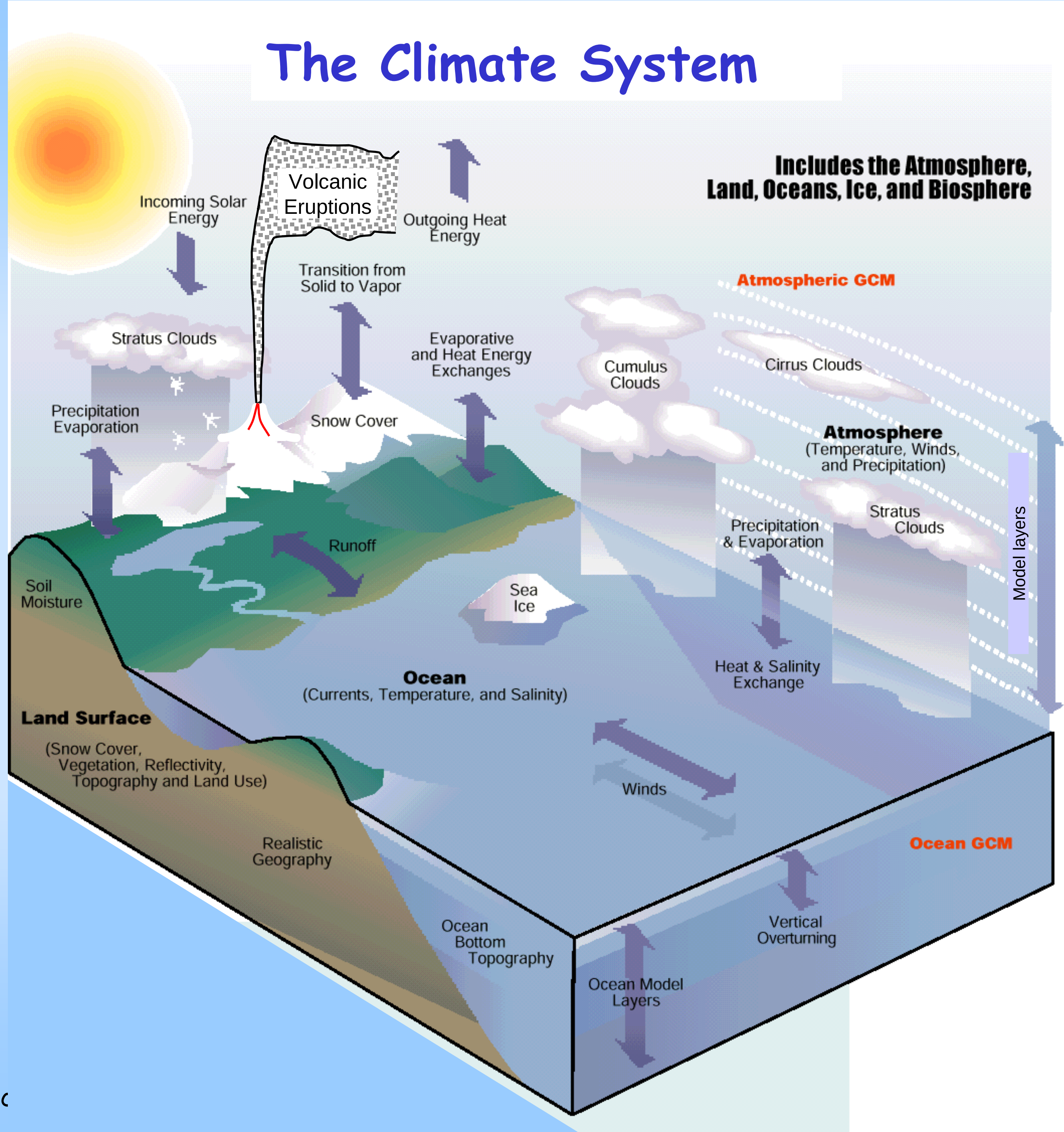
Areas of climate research at Rutgers

Forcings

Volcanic eruptions	Robock, Stenchikov
Land surface changes	Weaver
Tropospheric aerosols	Turpin, Mazurek
Smoke from nuclear fires	Robock, Stenchikov

Climate forcings

Volcanic eruptions
Robock, Stenchikov



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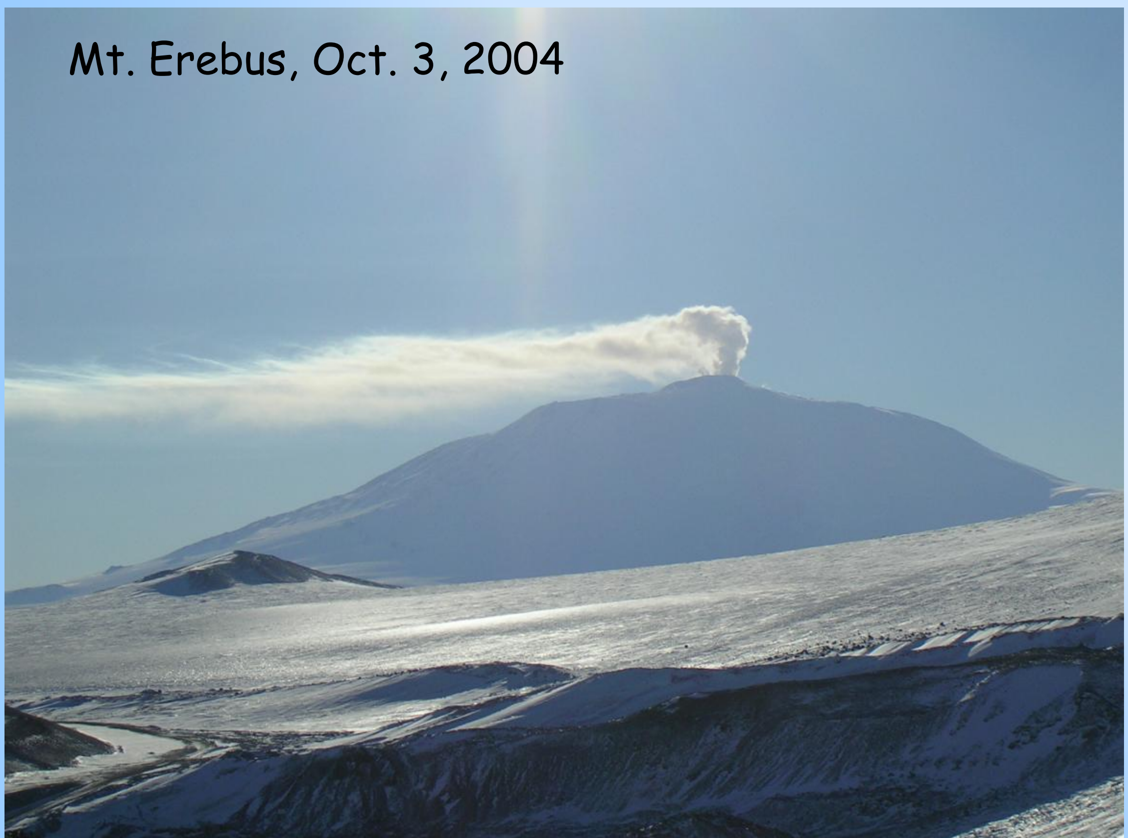
Modeling the climate response to large volcanic eruptions – Robock, Stenchikov, with postdoc Oman



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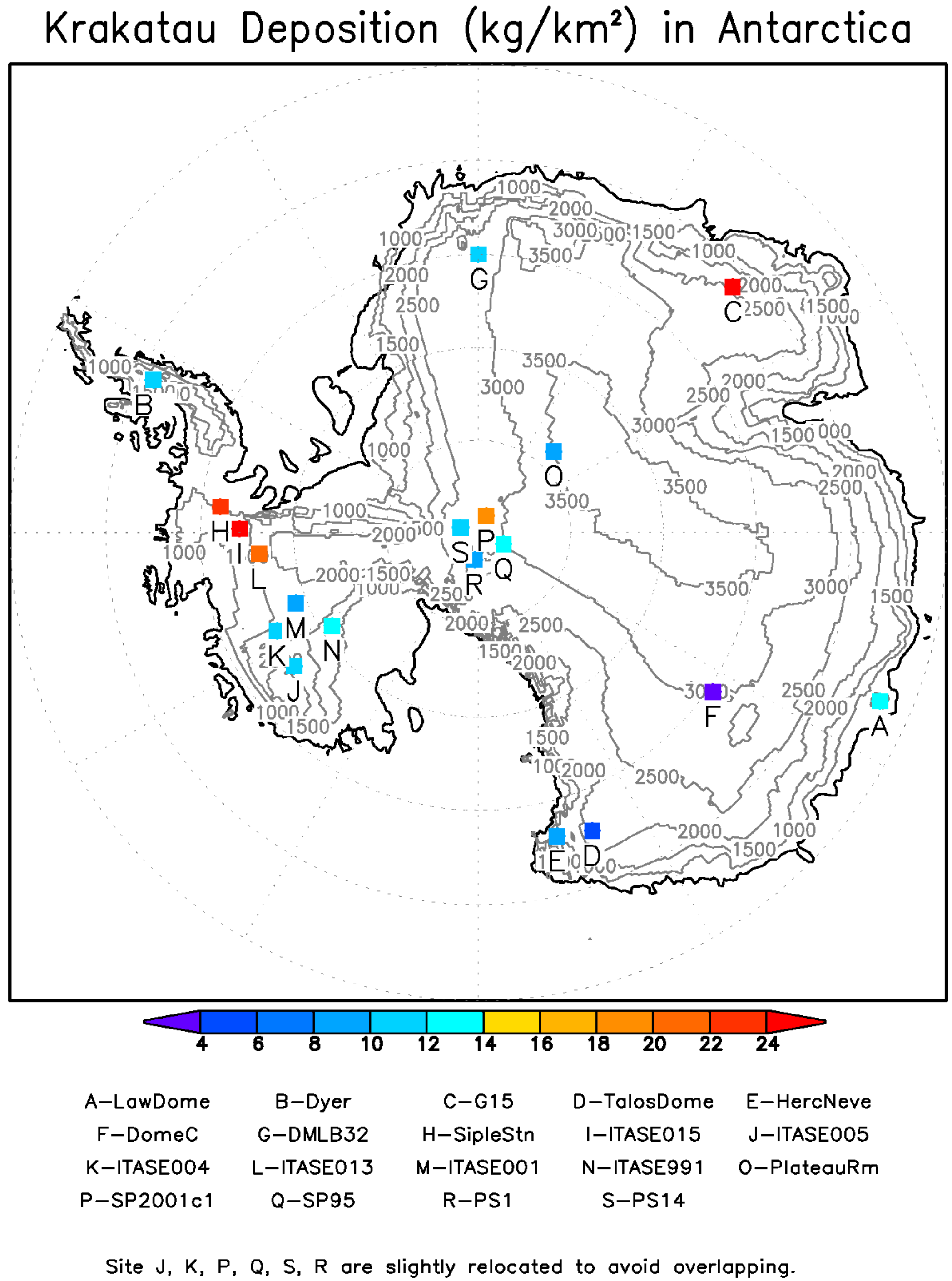
Volcanic sulfate in ice cores gives record of past climate forcing from volcanic eruptions – Robock, with student Gao



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Press Release

Professor Alan Robock
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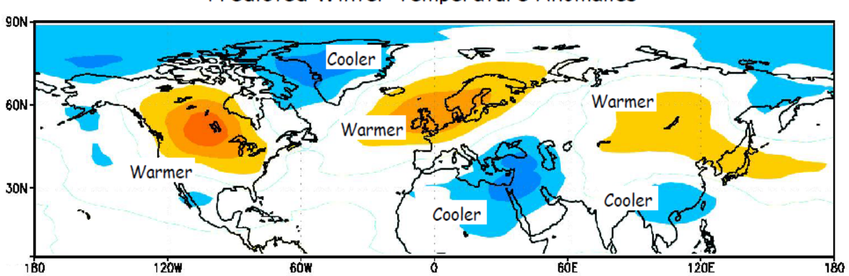
Fax: 1-732-932-8644
E-mail: robock@envsci.rutgers.edu

__ Volcano Erupts: Winter Warming and Summer Cooling Predicted

On ___, 20__ the ___ volcano in ___ erupted, putting ___ million tons of SO_2 into the stratosphere. This sulfur gas will produce a cloud of sulfuric acid particles that is the largest since the 1991 Mount Pinatubo eruption, and which will last for several years. Based on the Pinatubo experience, the observed climatic response to all large tropical volcanic eruptions in the past, and extensive computer modeling studies conducted since the Pinatubo eruption, it is possible to make a prediction of the climatic response over the next year.

Prediction: The coming winter of 20__-20__ will be warmer than normal by several degrees Fahrenheit over the central United States and Canada, western Europe and Siberia, and it will be cooler by several degrees Fahrenheit over northeastern Canada and Greenland, the eastern Mediterranean, and China. The volcanic particles will heat the lower stratosphere, producing a change in the atmospheric wind pattern. The winds will blow warm air into some regions and colder air into other regions more often than normal, producing particular patterns. The following map, based on what happened in the winter of 1991-92, shows areas where the climate will be significantly abnormal. The summer will be several degrees Fahrenheit cooler over most of North America, Eurasia, and Africa.

Predicted Winter Temperature Anomalies



Press Release

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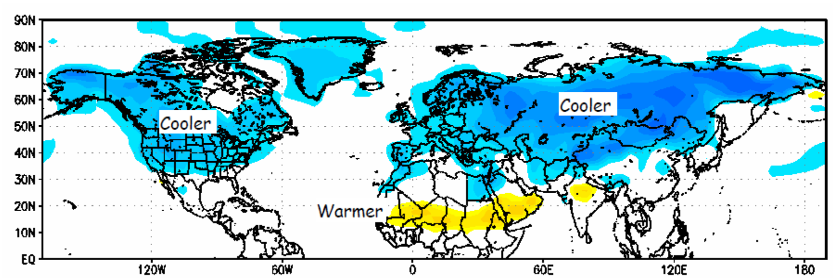
E-mail: robock@envsci.rutgers.edu

__ Volcano Erupts:
Strong Summer Cooling and Monsoon Failure over Africa and India Predicted

On ___, 20__ the ___ volcano in ___ erupted, putting ___ million tons of SO_2 into the stratosphere. This sulfur gas will produce a cloud of sulfuric acid particles that is the largest since the 1991 Mount Pinatubo eruption, and which will last for several years. This eruption, unlike Pinatubo, was at a high latitude, and the climate response will rather resemble that after the 1783 Laki eruption in Iceland and the 1912 Katmai eruption in Alaska. Based on the observed climatic response to these large high-latitude volcanic eruptions in the past, and extensive computer modeling studies conducted in the past several years, it is possible to make a prediction of the climatic response over the next year.

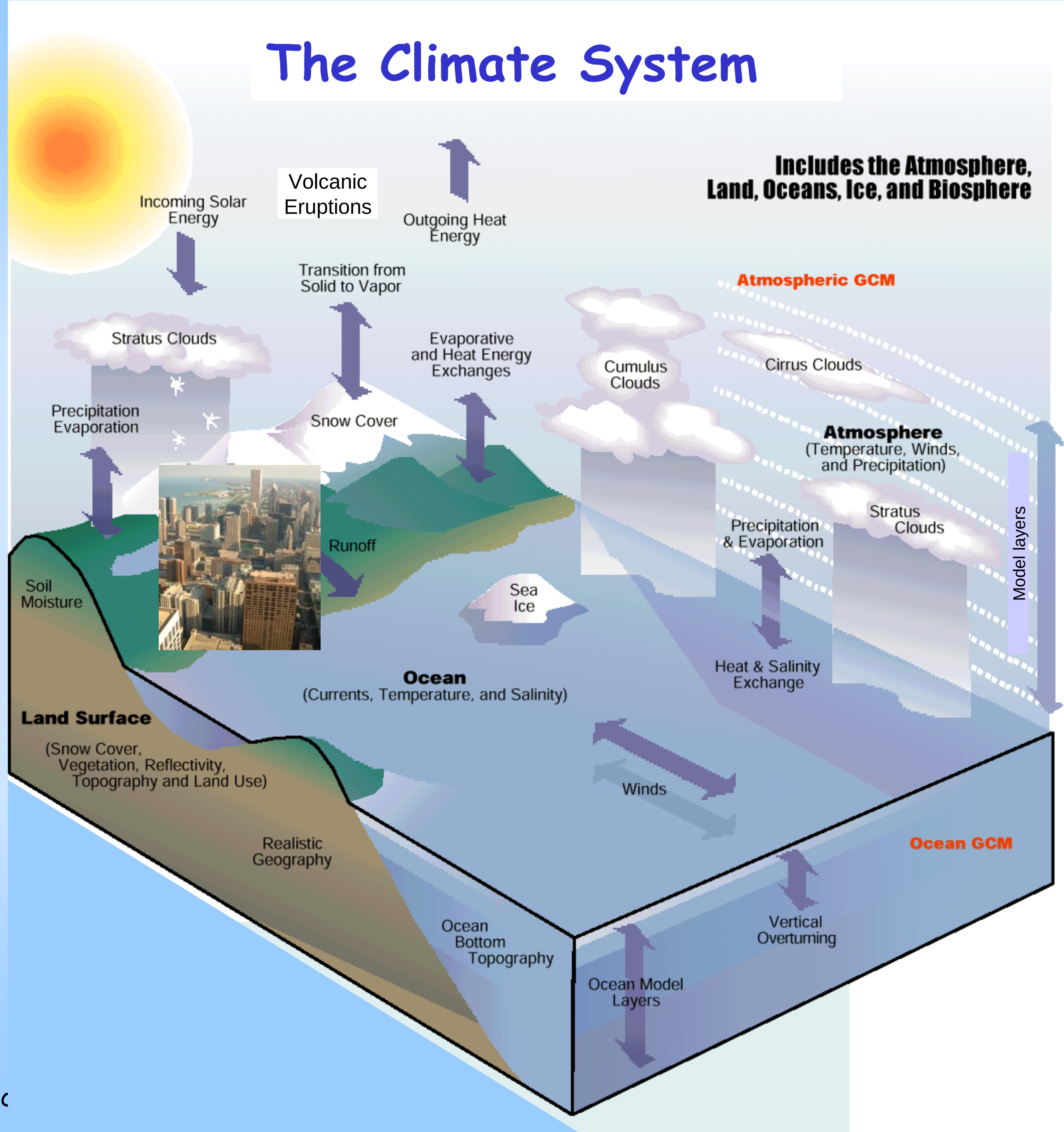
Prediction: The coming summer of 20__ will be colder than normal by several degrees Fahrenheit over most of North America and Eurasia, but warmer over the Sahel region of Africa. The Africa and Asian summer monsoon precipitation will be less than normal, and subsequent river flow in the Nile and Niger Rivers will be reduced for a couple years. This cooling will reduce the temperature difference between the continents and the oceans, and this is what normally drives the monsoon. The reduced precipitation and cloudiness over Africa and India will actually increase the temperature there. The winter over the continents will also be cooler, but the summer effect will be larger. The following map, based on simulations of the summer response to the Laki eruption, shows areas where the climate will be significantly abnormal.

Predicted Summer Temperature Anomalies



Climate forcings

Land Surface Changes
Weaver



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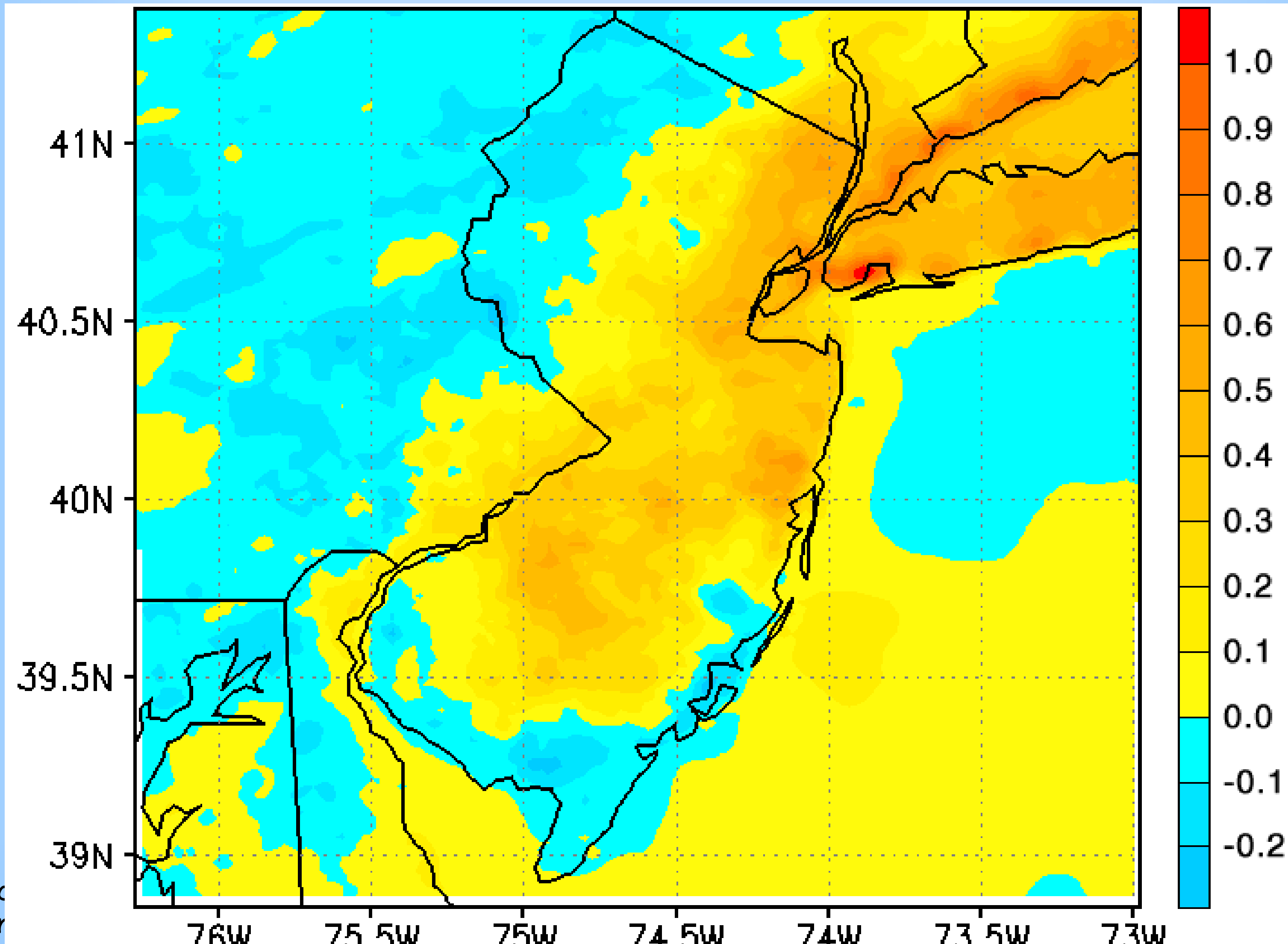
Modeled change in July surface air temperature (°C) due to urbanization of the past century (using the original land cover maps of George H. Cook) - Weaver



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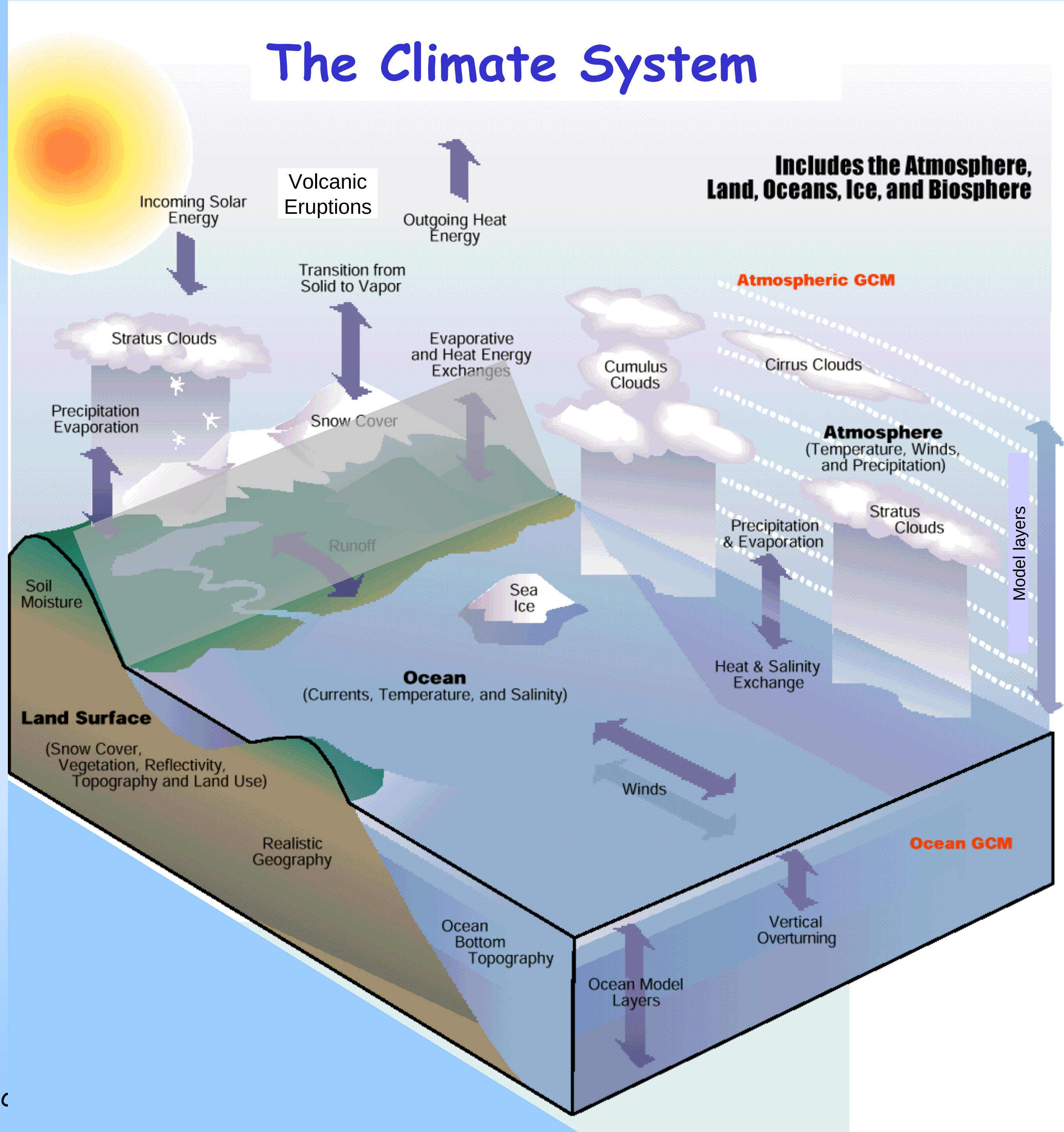
Climate forcings

Tropospheric aerosols
Turpin, Mazurek



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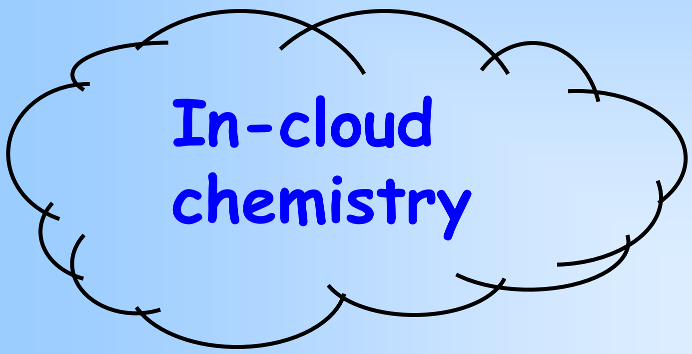
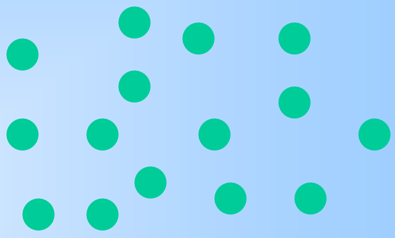
Organic particulate matter formed in clouds impacts radiative forcing in the free troposphere – Turpin

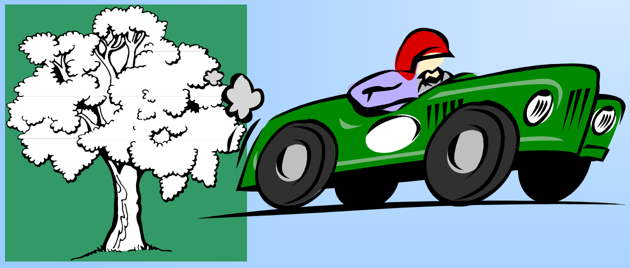


Cloud evaporation



SOA (secondary organic aerosol)

Reactive organic emissions



- Gas phase organic emissions are oxidized (e.g., in the interstitial spaces of clouds) forming water-soluble organic gases.
- Water-soluble gases partition into cloud droplets where they oxidize further, forming low volatility products.
- These products remain in the particle phase upon cloud evaporation, contributing secondary organic aerosol (SOA).

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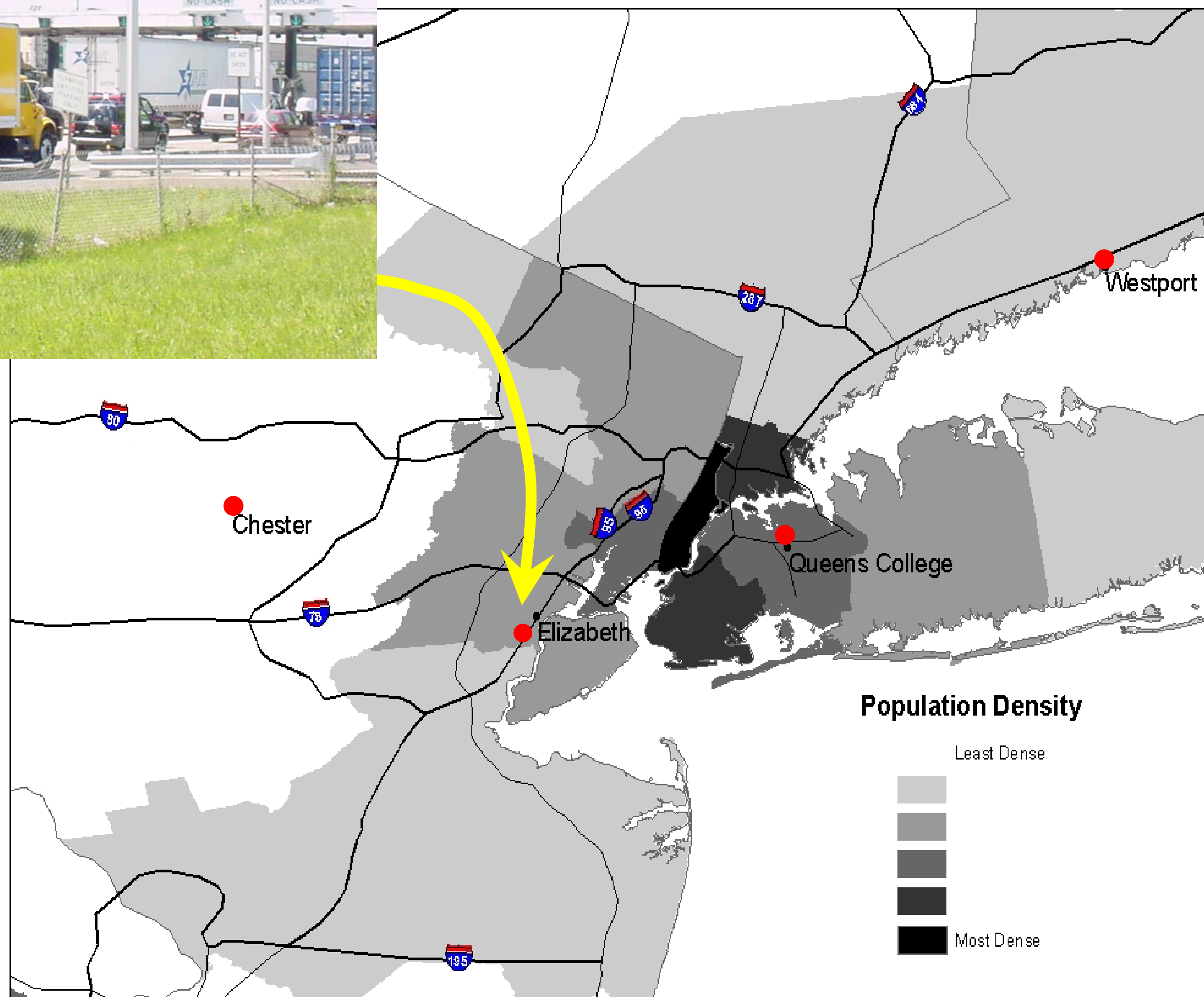
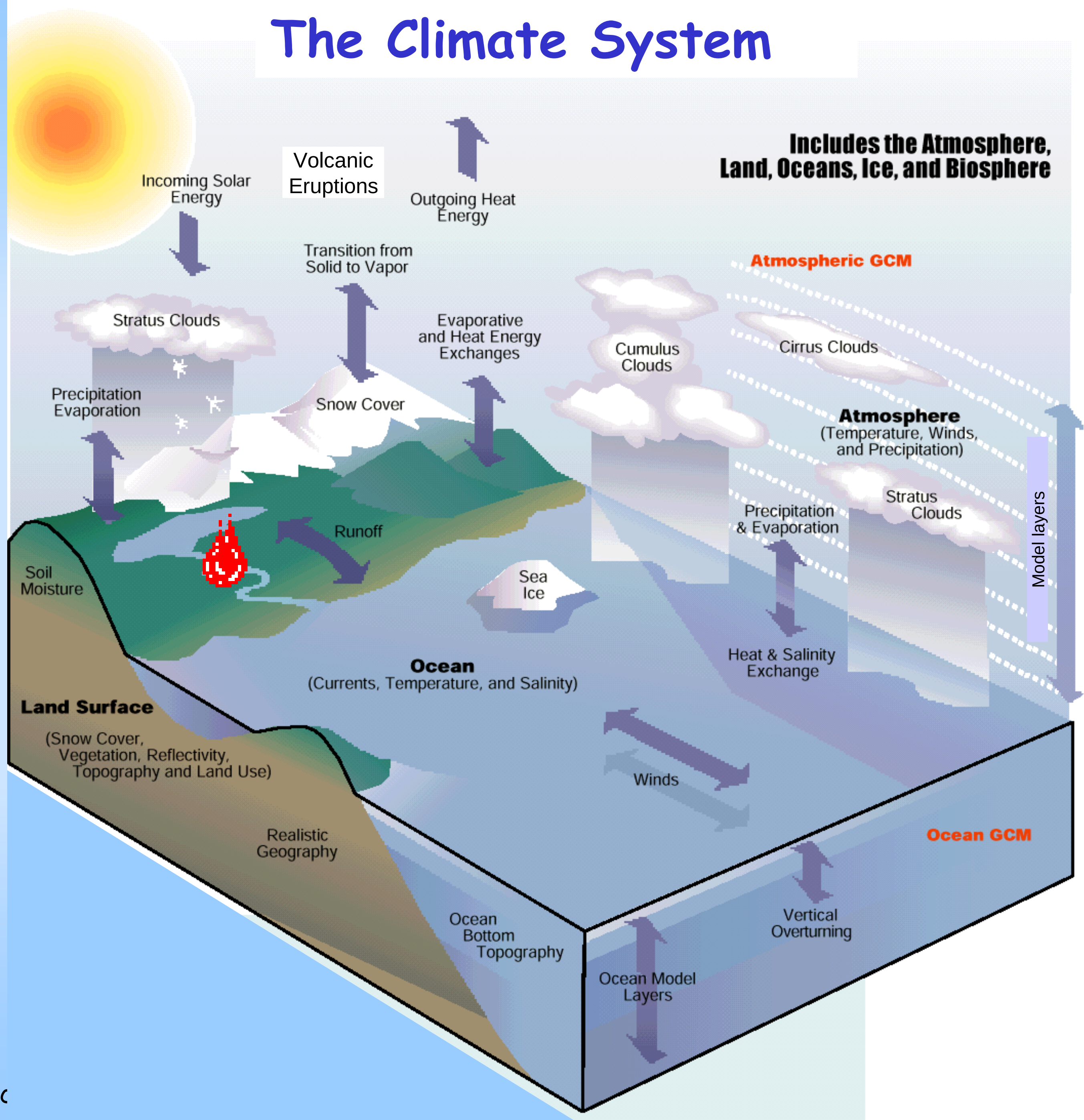
Aerosol sampling network
Mazurek



Climate forcings

Smoke from nuclear fires
Robock, Stenchikov



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Letter to Editor, *THE NEW YORK TIMES*, Sept. 19, 2006, p. F4.

Bigger Threat to Earth

To the Editor:

In "Updating Prescriptions for Avoiding Worldwide Catastrophe" (Conversation, Sept. 12), the scientist James Lovelock makes the absurd claim that "even the results of an all-out nuclear war pale into insignificance as unimportant compared to what's going to happen" with global warming. Rather, the nuclear winter after such a war would lead to mass starvation, killing most of the world's population.

Gradual global warming is a serious threat, but the climatic effects of nuclear war would be much worse, and are the greatest potential environmental danger to our civilization.

ALAN ROBOCK
New Brunswick, N.J.

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Department of Environmental Sciences

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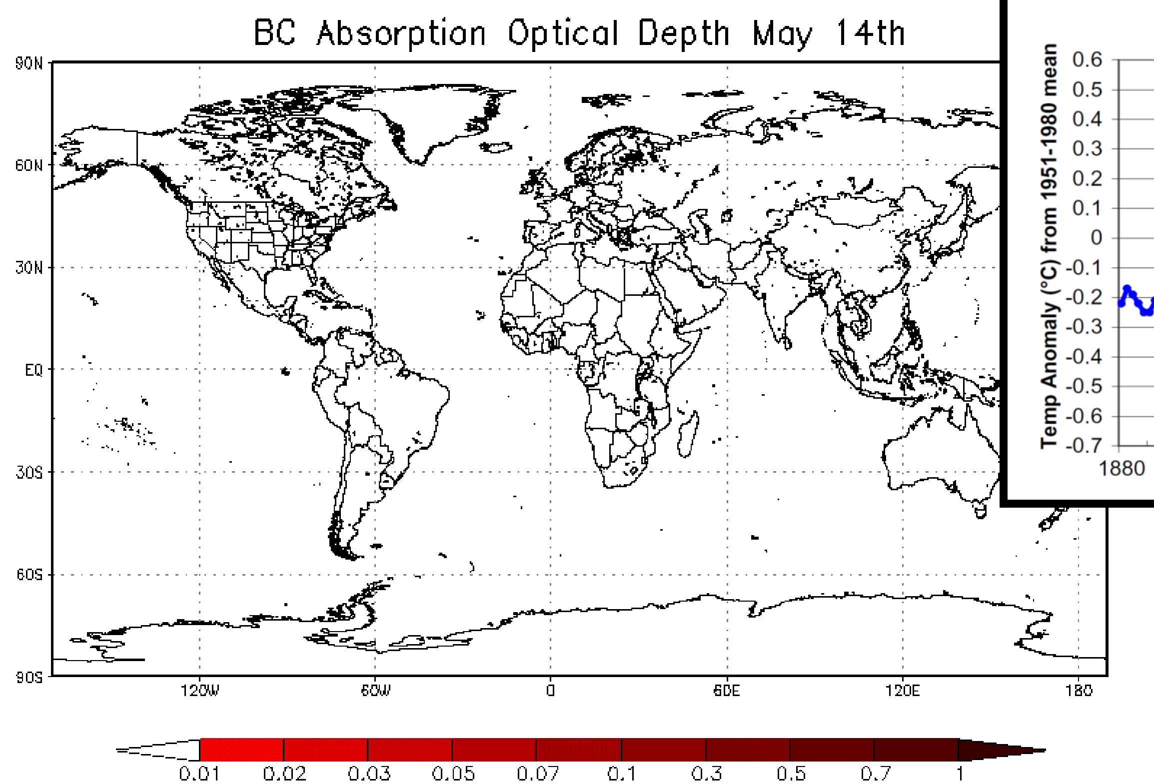
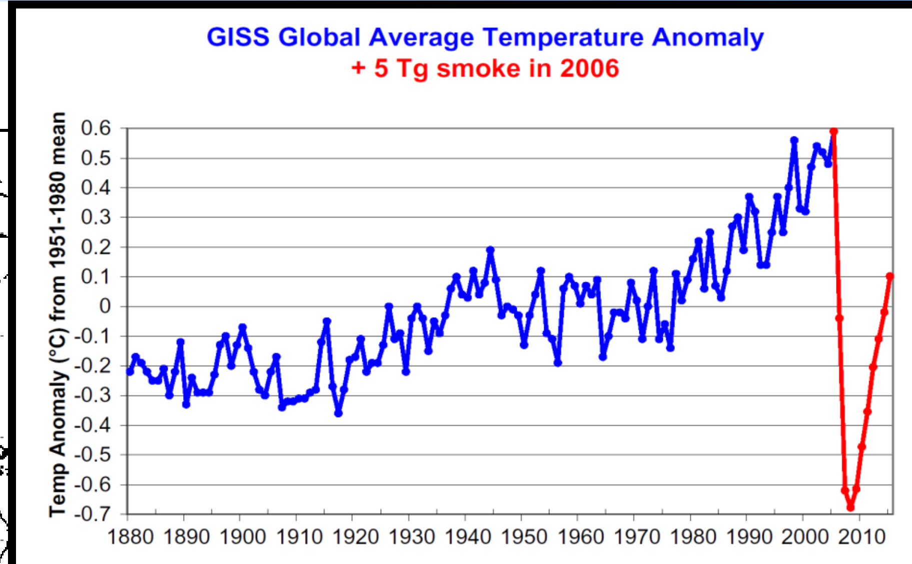
What would be the consequences of a regional nuclear war using 100 15-kt (Hiroshima-size) weapons?

(only 0.03% of the current world arsenal)

Robock, Stenchikov, with postdoc Oman





Global climate change unprecedented in recorded human history

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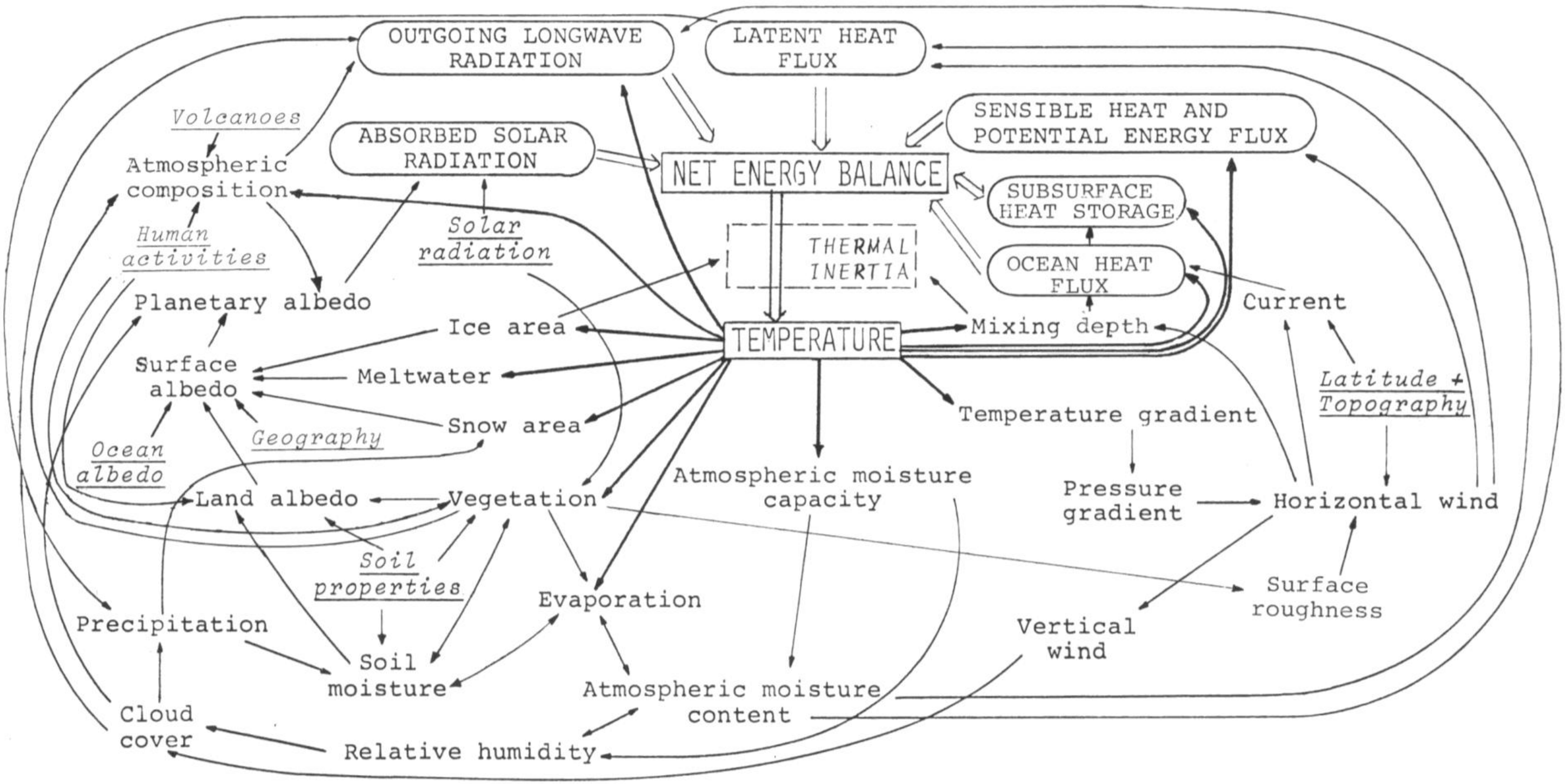
Climate Processes and Feedbacks



External forcing

Robock, Alan, 1985: An updated climate feedback diagram. *Bull. Amer. Met. Soc.*, **66**, 786-787.

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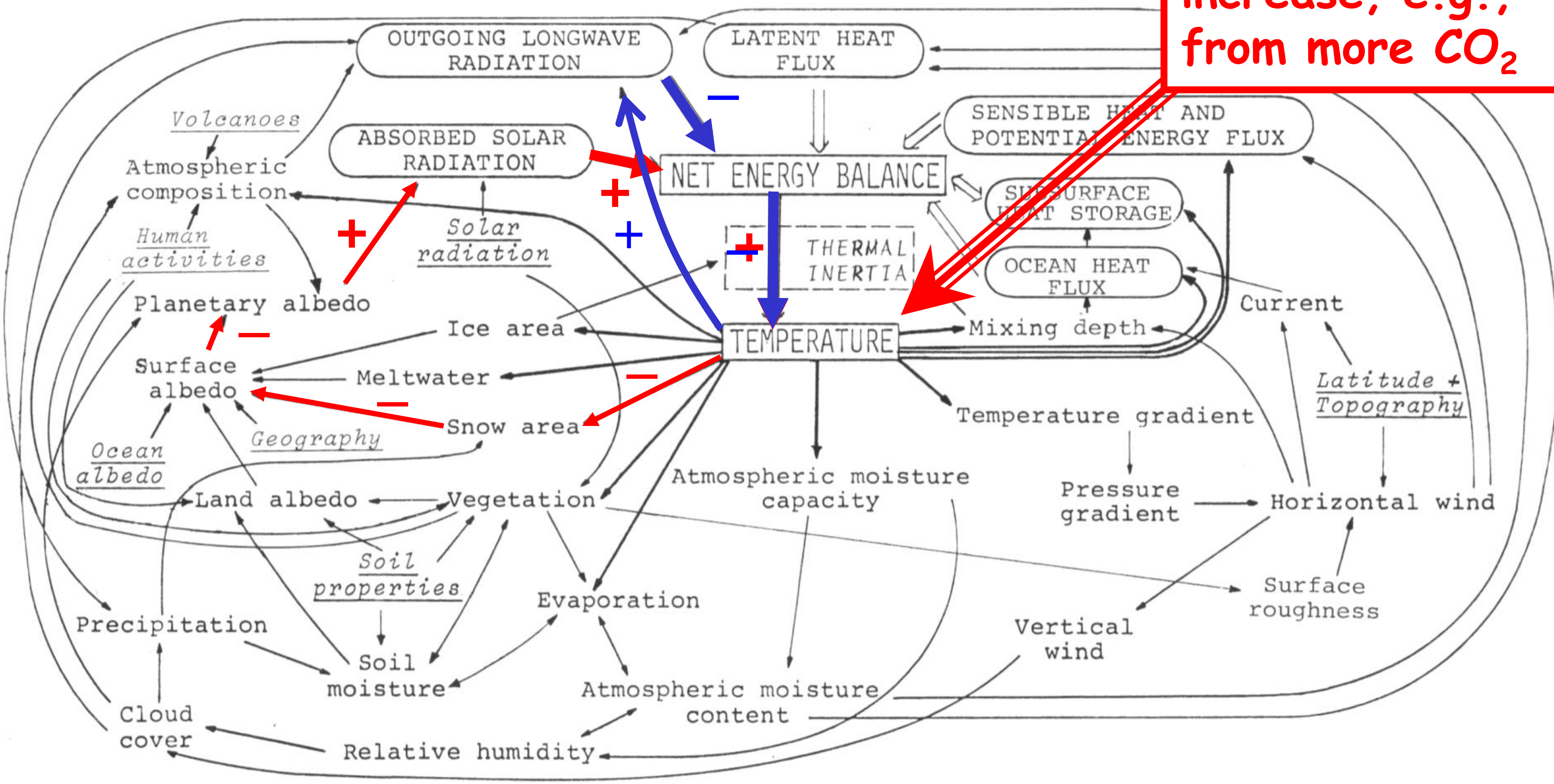
Temperature Feedbacks

Start with temperature increase, e.g., from more CO_2



External forcing

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Areas of climate research at Rutgers

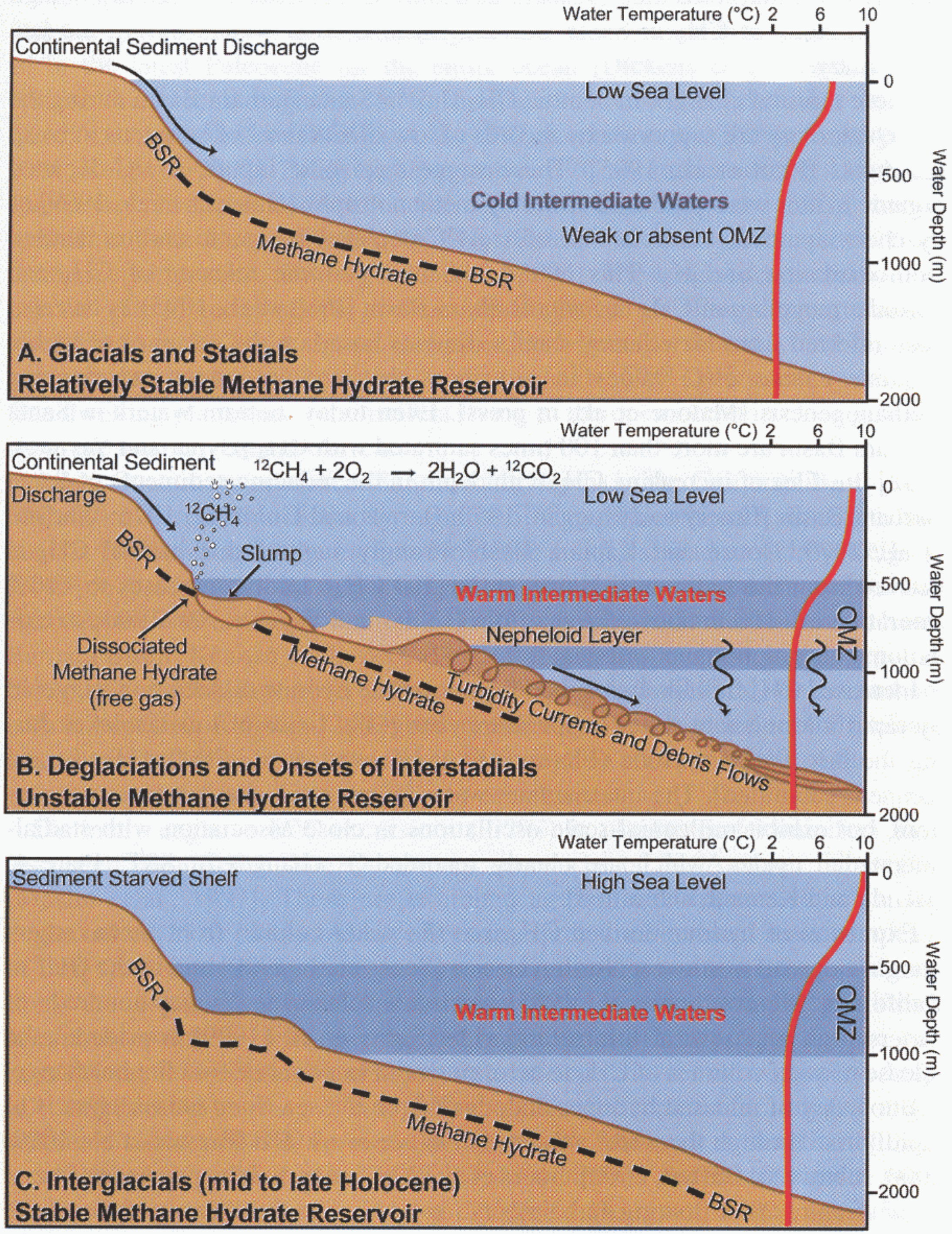
Climate processes

Carbon cycle	Falkowski, Green, Lathrop, Rudel, Sikes
Sea level	K. Miller, Lathrop
North Atlantic Oscillation	Robock, Stenchikov, Broccoli
Ocean circulation	Haidvogel, Rosenthal, K. Miller, Mountain, Wright
Aerosol transport	Stenchikov
Land hydrology	Fan, Robock, J. Miller
Forests, fires	Xu, Green, Lathrop
Arctic	Francis, J. Miller, Robock
Surface gas exchanges	Dighton, Rona, Xu
Clouds	Stenchikov, Francis
Land-atmosphere interactions	Weaver, Stenchikov, Fan, Robock
Global warming	Broccoli, Robock, Stenchikov, J. Miller
Evolution	Ashley
Biogeochemistry	Haidvogel, Wilkin

Forest CO_2 flux observations - Xu

Methane Hydrates – Rona

Climate change produces methane emissions from ocean bottom



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Vertical Mixing and Stratosphere-Troposphere Exchange of CO and O_3 Caused by a Severe Thunderstorm in North Dakota, 1989

Cloud Model Simulations

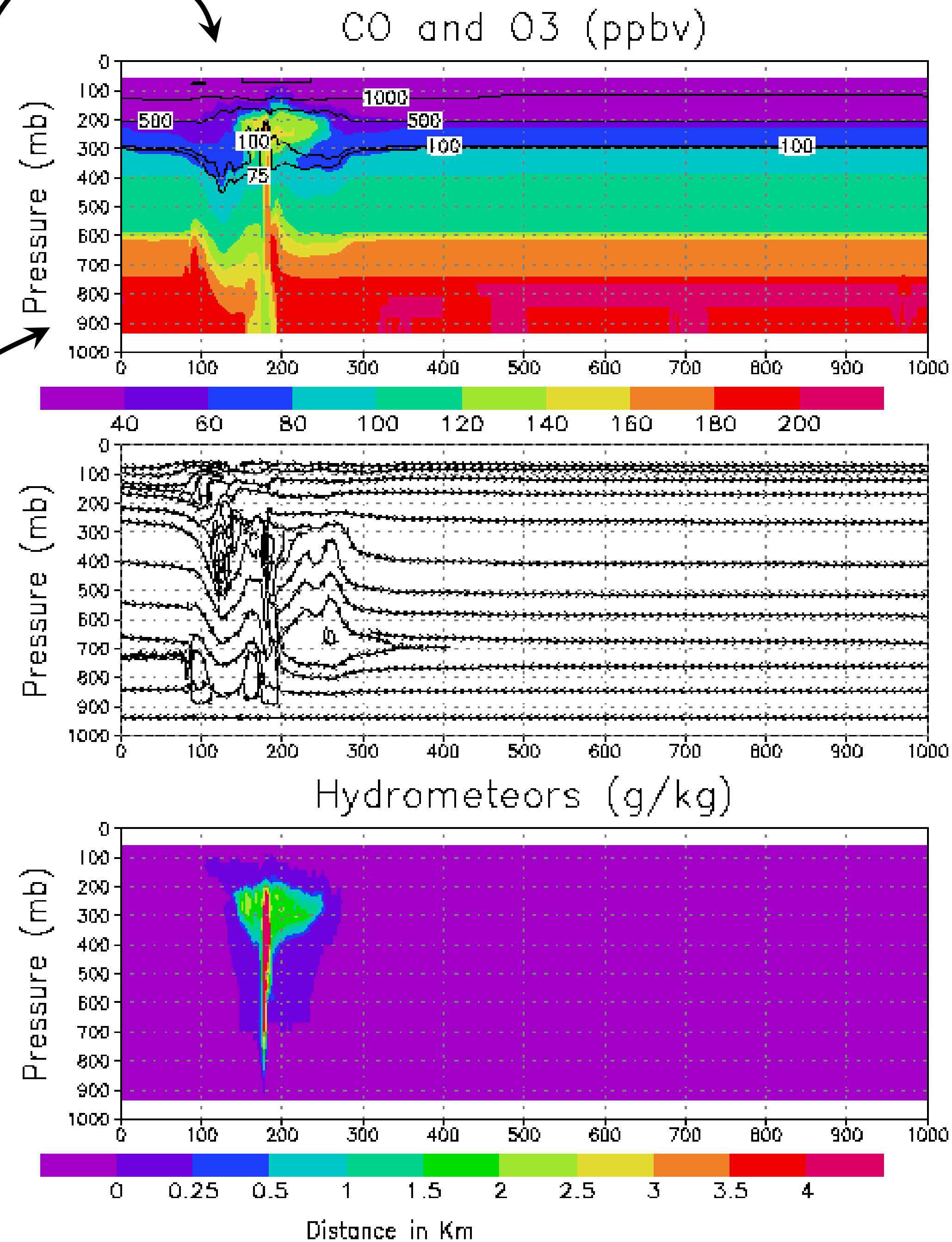
Stenchikov

Contours are O_3 concentration

Shading is CO concentration

Vertical motion in cloud

Cloud location, shown as cloud particle concentrations



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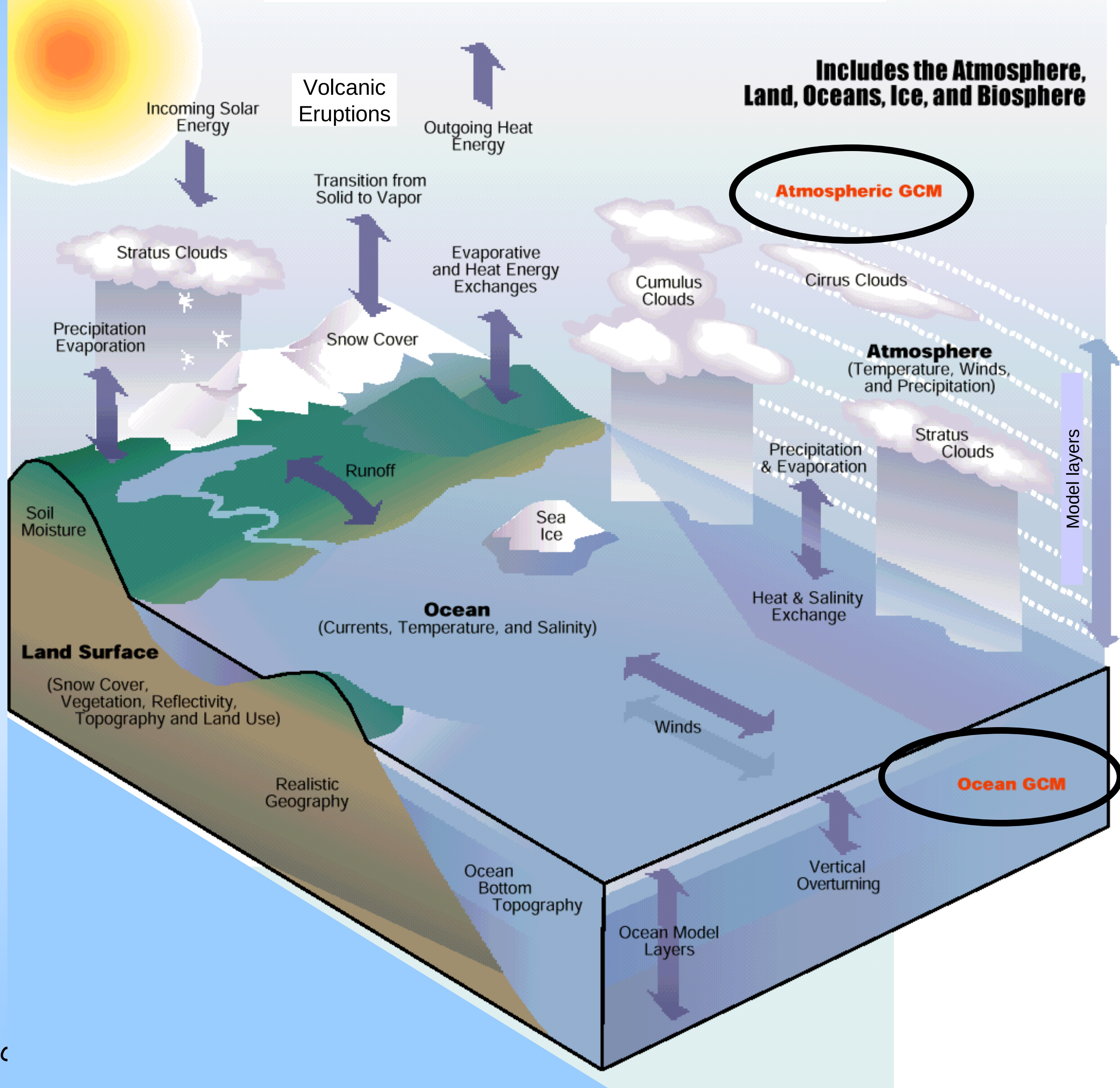
Climate modeling
Global atmospheric Broccoli, Robock, Stenchikov
Regional atmospheric Stenchikov, Weaver, Robock, Broccoli
Ocean Haidvogel, Wilkin
Land hydrology Fan, Robock, Seitzinger
Ecology Haidvogel, Wilkin, Xu, Lathrop

The Climate System



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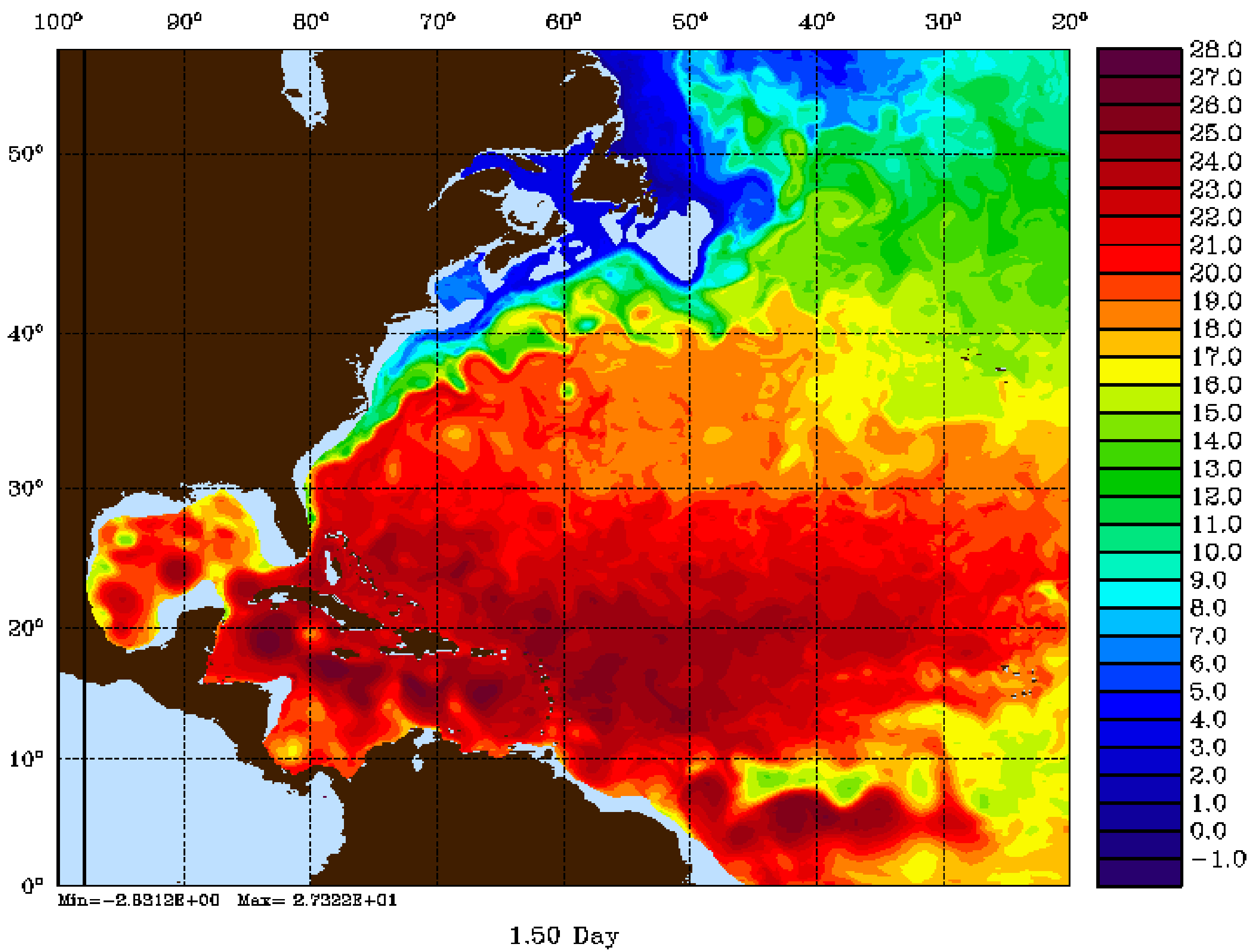
Regional Ocean Modeling System

Haidvogel, Wilkin, Arango, Hedstrom, Levin

ROMS beta 7.3
North Atlantic

Temperature of surface water (°C)



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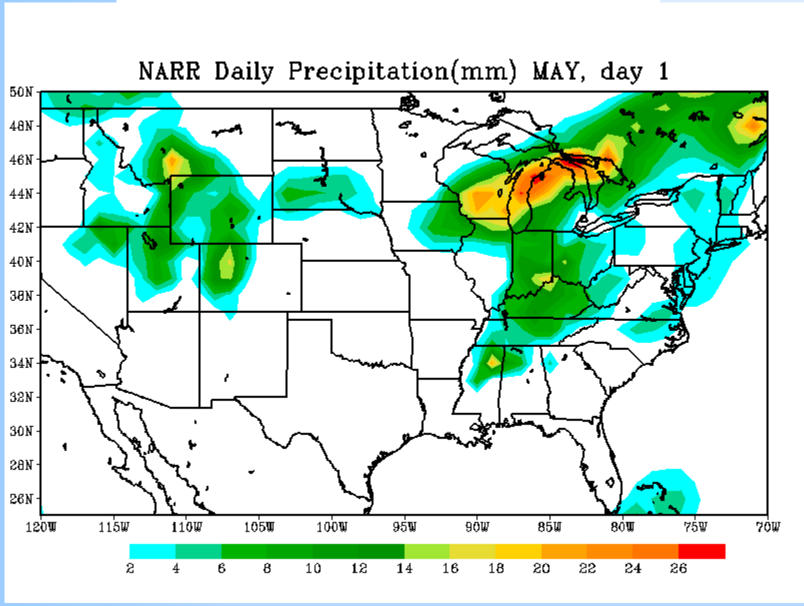
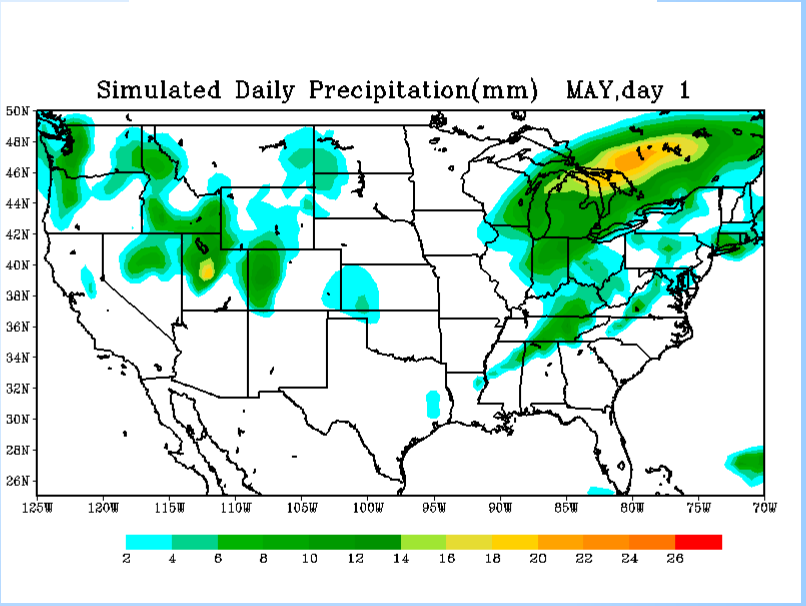
Modeling the detailed changes of temperature, precipitation, soil moisture, streamflow, and water table in New Jersey and the Northeast – Fan, Robock, Weaver, with postdoc Anyah

Observations



RAMS model



See talk by Ying Fan later today for details.

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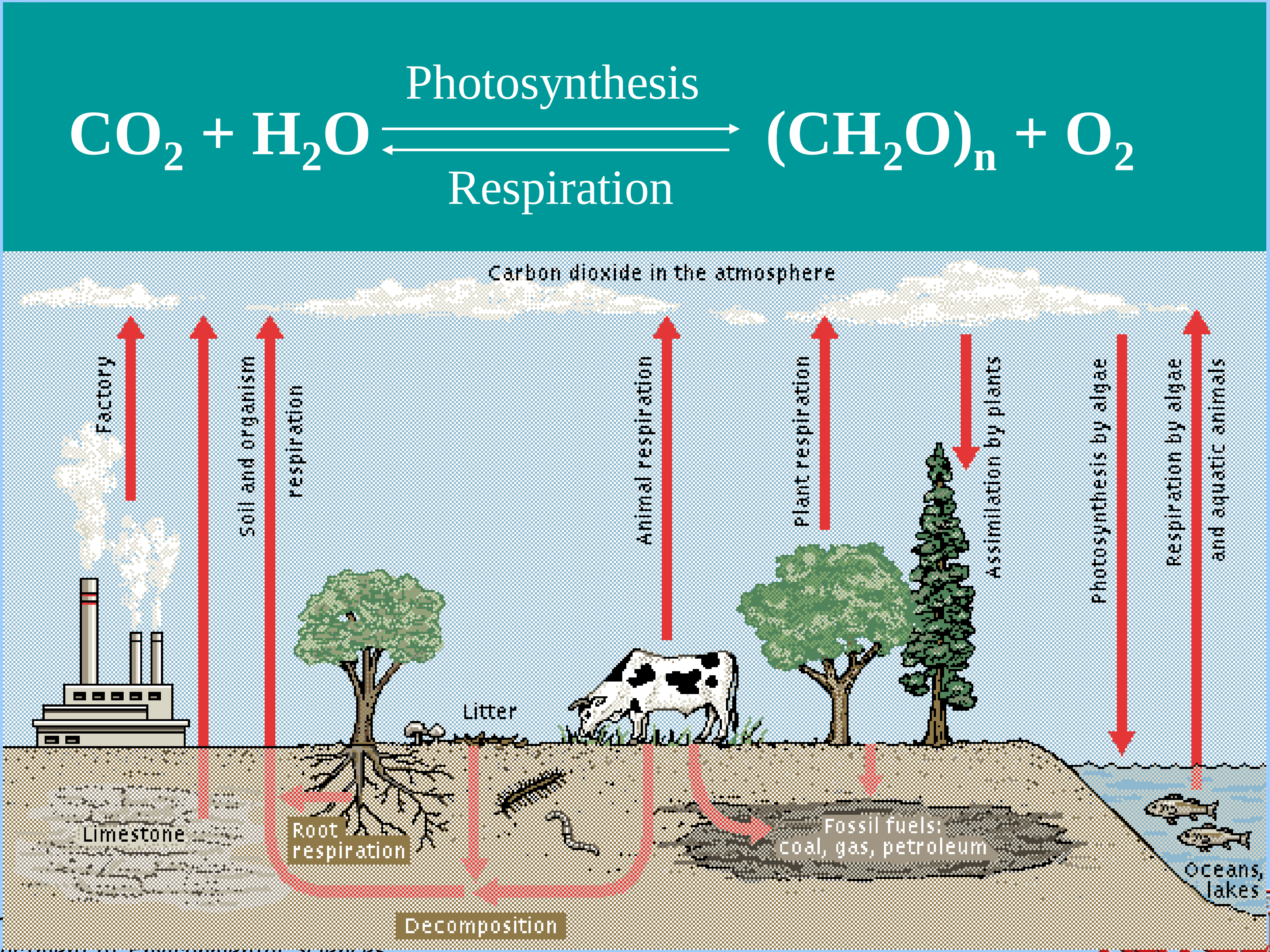
Land ecosystem carbon cycle - Xu



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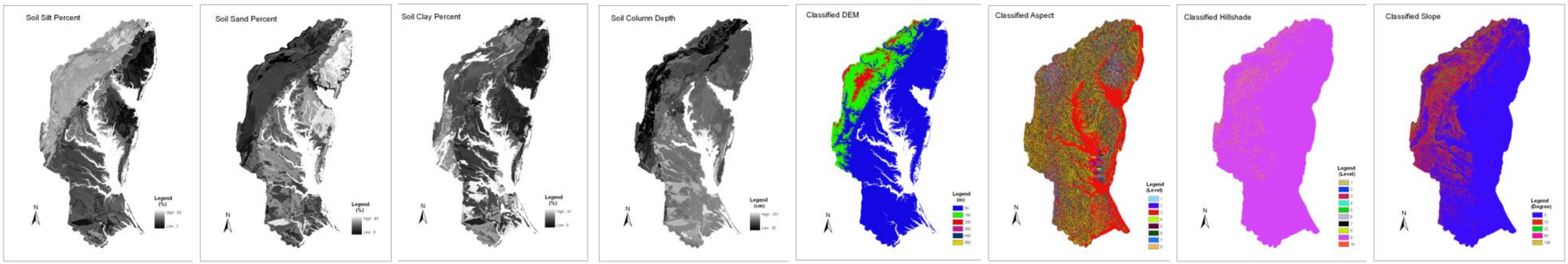
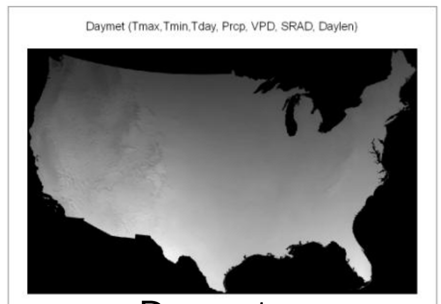
Input

Regional ecosystem and forest modeling – Lathrop, Xu, Miao

Soil silt | Soil sand | Soil clay | Soil depth | DEM | Aspect | Hillshade | Slope



Models



Daymet

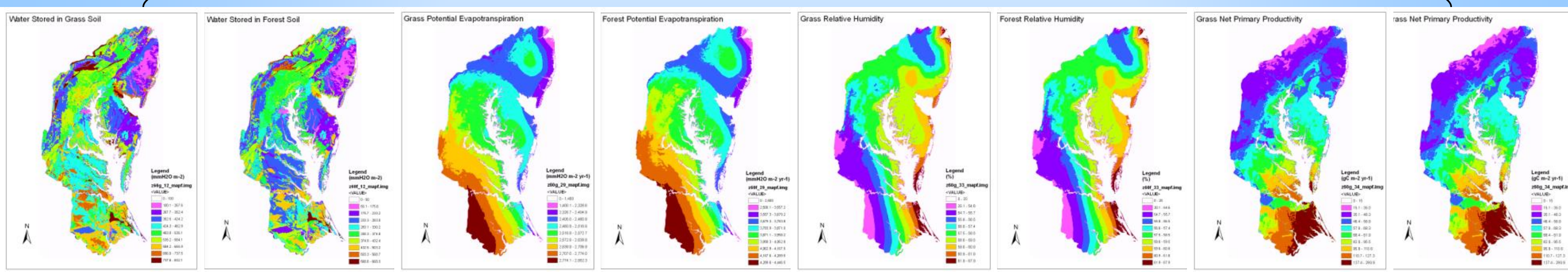
MakeSimu--Simuunits

WxBGC

Ecophysiol. var.
- Evergreen
- C3 Grass

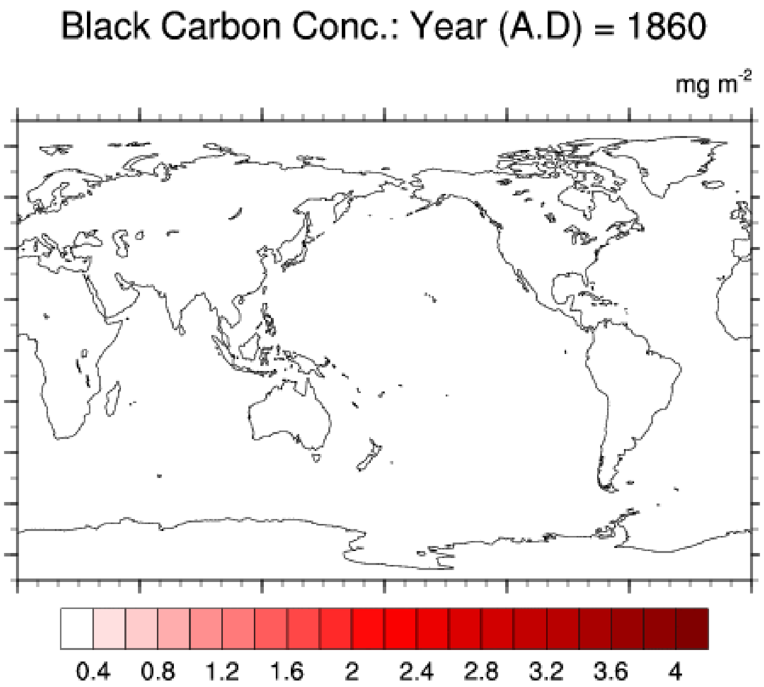
Other environ. var.

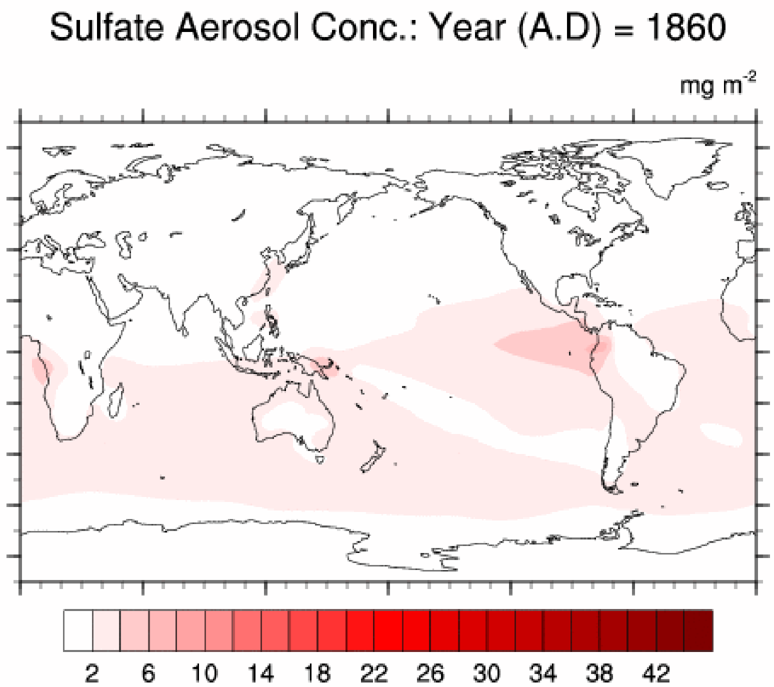
Output



Grass SoilW | Forest SoilW | Grass PET | Forest PET | Grass RelHum | Forest RelHum | Grass NPP | Forest NPP

Effects of black carbon and sulfate aerosols – Broccoli (with postdoc Yoshimori)

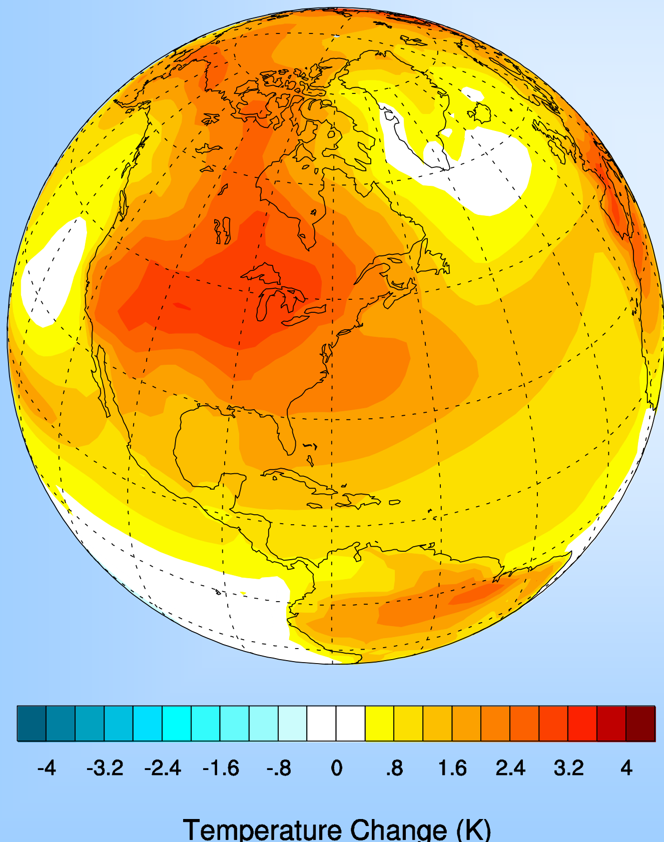




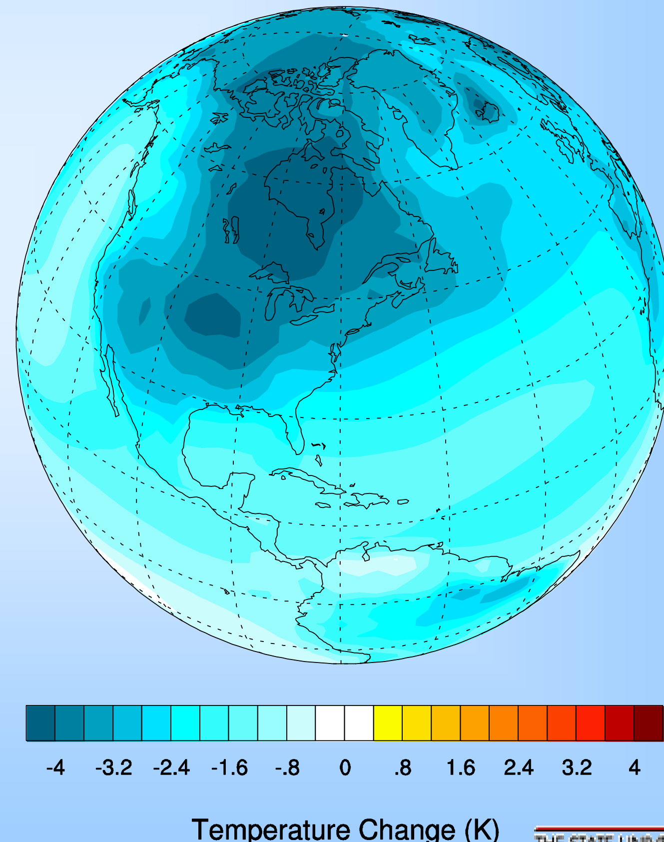
Data from NOAA/GFDL

Effects of black carbon and sulfate aerosols – Broccoli (with postdoc Yoshimori)

Simulated temperature change due to 3.3x black carbon (2000-1860)



Simulated temperature change due to 2.2x sulfate aerosol (2000-1860)



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Department of Environmental Sciences

We have developed close collaborations with major climate modeling centers in the U.S.

National Center for Atmospheric Research (NCAR)
Boulder, Colorado

NASA Goddard Institute for Space Studies (GISS)
New York City

NASA Goddard Space Flight Center (GSFC)
Greenbelt, Maryland

NOAA Geophysical Fluid Dynamics Laboratory (GFDL)
Princeton, New Jersey

Climate Change Fundamental Questions

2. How will climate change affect us?

Requires understanding of:

- All our activities affected by climate
- Adaptation and technical responses

Needs <u>scenarios of future climate</u>, with specific variables that are of concern, at the appropriate temporal and spatial scales

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Areas of Human Endeavor That Could Be Affected by Global Warming

Agriculture
Water Resources
Fisheries
Air Pollution
Human Health
Recreation
Insurance
Wetlands
Forestry

Electricity Demand
Wind Energy Generation
Solar Energy Generation
Hydroelectricity Generation
Ocean Transportation
Air Transportation
Land Transportation
Political Systems

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Climate Change Fundamental Questions

3. What should we do about it?

This is a political decision to be made by society and individuals, and is based on values.

Cannot be answered directly by science, but <u>mitigation</u> and <u>adaptation</u> need to be informed by scientific results, for example:

- the response to different mitigation choices

- scenarios for implementation of mitigation and adaptation, such as wind climate for wind generators, or future climate for agriculture

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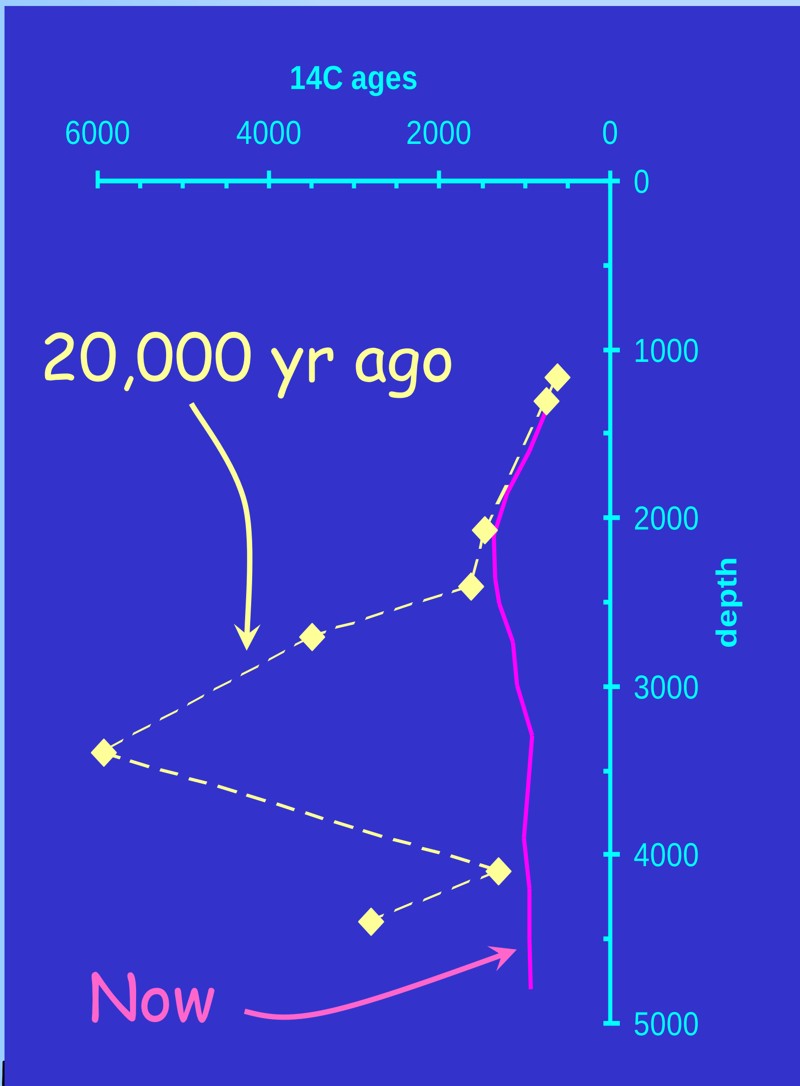
CO_2 Storage in the Ocean - Sykes



Modern profile (in pink) shows oldest water at mid-depths, this represents storage of CO_2 in the ocean interior.

Glacial profile (in yellow) shows oldest water was ~1500 m deeper and that this water was as much as 4000 years older than deep waters today.

The implication is that in the past, larger amounts of CO_2 were held longer in the deep ocean, significantly impacting exchange with the atmosphere.

Al
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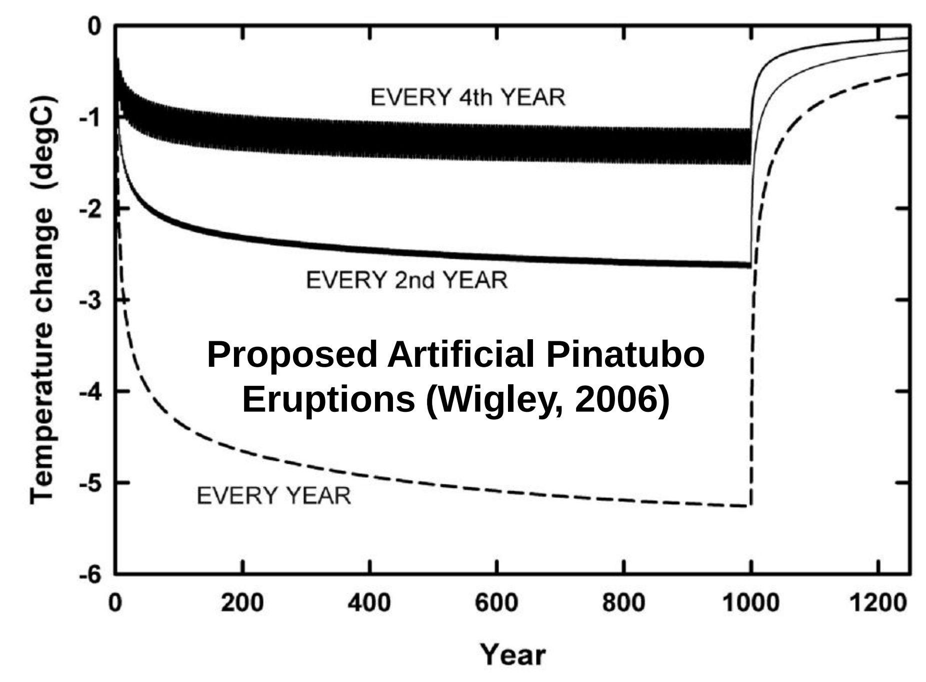
Evaluating Geoengineering – Robock, Stenchikov, postdoc Oman

In the past two months, Paul Crutzen (1995 Nobel Prize winner) and Tom Wigley (NCAR) have proposed a geoengineering solution to global warming by polluting the stratosphere with aerosols.

We are using the GISS climate model to do the first GCM simulations of the effects of these proposals on patterns of climate change.



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Department of Environmental Sciences

How can we serve as a resource to help New Jersey deal with climate change?

Mitigation

Adaptation

Education

Technology

Policy implementation

Once we identify the scope of our Climate Initiative, we will be able to determine where the gaps are in our current research programs.

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