10–13 July 2006

Steamboat Springs, Colorado

Seventh Summer Institute

NOAA Climate and Global Change Postdoctoral Fellowship Program

Proceedings from the

Seventh NOAA Summer Institute

on

Climate and Global Change

July 10-13, 2006
Steamboat Springs, Colorado

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Goals of the Institute

Develop a sense of community among climate and global change postdoctorates and senior researchers.

Explore the breadth of climate and global change research problem areas.

Discuss the future directions of climate science research.

Discuss the bridge between climate and global change scientific goals and public policy.

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NOAA Postdoctoral Program in Climate and Global Change
7th Summer Institute
July 10-13, 2006

Scientific Program Leader:
Kerry Emanuel, *Massachusetts Institute of Technology*

Workshop Coordinators:
Meg Austin, *UCAR/VSP*
Susan Baltuch, *UCAR/VSP*

It was my pleasure this year to help organize the 7th Summer Institute in Steamboat Springs, Colorado. Twelve of the current postdoctoral fellows were joined by a number of alumni of the program, some hosts of current and past fellows, and some additional scientists in an intense four-day program of scientific talks and discussions covering the wide range of disciplines represented by the expertise of the participants.

In listening to the talks by the postdoctoral fellows, alumni, and other scientists, one is struck by the degree to which the *NOAA Climate and Global Change Postdoctoral Fellowship Program* has succeeded in its goals of stimulating climate research. In this its 16th year, the program has acquired a justified reputation for attracting the best and brightest of recent graduates to tackle what may very well be the most important scientific problem of our generation. The Summer Institute is a key component of the program, allowing the postdoctoral fellows, who are working on a highly diverse set of climate-related problems, to interact with each other, with program alumni, and with more senior scientists. I view it also as a valuable barometer of where the field is headed, and of all the various workshops I have attended in recent years, this one is both the most instructive and the most enjoyable.

It is also fascinating to observe how the topics selected by the fellows have evolved since the first workshop I attended. In the early history of the program, ENSO and the Arctic Oscillation seemed to dominate the discussions, whereas not a single talk focused on either of these issues at this workshop; instead, the present generation of young scientists are taking on the grand issues of paleoclimate, the physics of long-term climate change including the critical roles of oceans and ice, and tough problems in geochemistry. On the atmospheric side, one is struck by the renewed interest in the role of water and its phase changes in atmospheric dynamics and climate. This evolution is a sure sign of the health of the program, whose contributions to climate science continue to impress.

7th Summer Institute
NOAA Postdoctoral Program in Climate and Global Change
10-13 July 2006
Steamboat Springs, Colorado

<u>LOCATION:</u>
Sheraton Steamboat Resorts
2200 Village Inn Court
Steamboat Springs, CO 80477
Telephone: 970-879-2220
Fax: 970-879-7686
Meeting Location: Aspen Board Room

Sunday, 09 July

6:00-7:00 pm Registration/Icebreaker – Aspen Board Room

Monday, 10 July

7:45 am Registration/Breakfast – Aspen Board Room

Introductory Talks

8:15 Welcome and Introductions (Kerry Emanuel, Institute Chair)

8:30 *Climate in Washington* (Chester Koblinsky)

Science Talks

Ice & Paleoclimate

9:00 am *On the transient atmospheric response to Arctic sea ice and North Atlantic sea surface temperature trends* (Clara Deser)

9:30 *Trends in sea ice retreat and subsequent advance in response to ENSO and SAM variability at high southern latitudes* (Sharon Stammerjohn)

10:00 Break

10:15 *Pleistocene glacial variability and integrated insolation forcing* (Peter Huybers)

10:45 *Multiple modes of orbital-scale change in thermohaline circulation* (Lorranie Lisiecki)

11:15 *Gulf Stream hydrography and transport during the last millennium* (Bill Curry)

11:45 Lunch break (on your own)

1:15 pm *Stability analysis of the sea ice edge* (Eric DeWeaver)

1:45 General Discussion

Atmospheric Dynamics and Physical Oceanography

2:15 *The role of tropical storms in climate and climate change* (Kevin Trenberth)

2:45 *Hurricanes and climate change* (Kerry Emanuel)

3:15 Break

3:45 General discussion

4:15 Adjourn until evening session

Evening Session

6:30 pm Informal buffet dinner served in Aspen Board Room

7:00 *Simple models of moist static energy fluxes in the atmosphere* (Dargan Frierson)

7:30 *Extratropical influences on the ITCZ* (Ray Pierrehumbert)

8:00 *Regime transitions of the global circulation of the atmosphere: Implications for climate and monsoon dynamics* (Tapio Schneider)

8:30 *The tropopause height and the zonal-mean zonal wind response to global warming in the IPCC scenario integrations* (David Lorenz)

9:00 General Discussion

9:30 Adjourn

Tuesday, 11 July

8:00 am Breakfast – Aspen Board Room

8:30 *Dynamics of intertropical convergence zones* (Adam Sobel)

9:00 *Global warming and the hydrological cycle* (Isaac Held)

9:30 *Eddies, waves and hurricanes: Monitoring ocean dynamics with a new generation of profiling floats* (James Girton)

10:00 Break

10:30 *Moist convection and mesoscale predictability* (Rich Rotunno)

11:00 *How and why to improve global models with better cloud physics* (Richard Somerville)

11:30 Buffet lunch served

12:00 General discussion during lunch

12:30 Adjourn for day

Wednesday, 12 July

8:00 am Breakfast – Aspen Board Room

Atmospheric Chemistry

8:30 *Top-down constraints on emissions of biogenic trace gases from North America* (Dylan Millet)

9:00 *New perspectives on atmospheric mercury* (Daniel Jacob)

Aerosols

9:30 *Exploring the impact of geo-engineering by stratospheric sulfate aerosol in countering global change, by Philip Rasch and Paul Crutzen* (Phil Rasch)

10:00 *Effects of biomass burning-derived aerosols on precipitation and clouds in the Amazon basin: a satellite-based empirical study* (John Lin)

10:30 *Regional air quality and climate impact of Central American biomass burning aerosols* (Jun Wang)

11:00 *Organic carbon aerosol in the free troposhere* (Colette Heald)

Carbon Dioxide

11:30 *Communities, climate change, and carbon: Understanding responses and contributions to climate change among forest-dependant communities in Mexico* (Robert Bailis)

12:00 Open discussion

12:15 Adjourn until evening dinner reception

Evening Session

7:00 – 9:00 Reception and buffet dinner at Sheraton Hotel – Seven's Restaurant

Thursday, 13 July

8:00 am Continental breakfast – Aspen Board Room

Carbon talks continued

8:30 *Nitrogen alters fungal communities in boreal forest ecosystems: implications for carbon cycling* (Steve Allison)

9:00 *The role of ocean circulation in determining the biological carbon pump efficiency and atmospheric pCO2* (Irina Marinov)

9:30 Break

10:00 *Tips for scientists on talking to the media* (Susan J. Hassol)

10:30 Institute wrap-up (Michael Hall)

11:00 Adjournment

Postdoctoral Fellows Abstracts

Nitrogen Alters Fungal Communities in Boreal Forest Ecosystems: Implications for Carbon Cycling

Steven D. Allison, China Hanson, Claudia Czimczik, Kathleen K. Treseder
University of California, Irvine

Nitrogen deposition and warming-induced increases in nutrient mineralization have the potential to increase N availability in many ecosystems. In boreal forest ecosystems, understanding the microbial and biogeochemical consequences of increasing N availability is critical because these systems are expected to warm disproportionately due to climate change, and they contain large stocks of soil C. Also, C mineralization depends heavily on fungal decomposers that may respond negatively to N deposition. We used nucleotide analog addition, cloning, and DNA sequencing to test whether fungal community structure changes in response to added N in Alaskan boreal forest. Soil enzyme activities and respiration rates were also measured to determine if N suppresses the biogeochemical functioning of soil fungi. We obtained 517 ITS sequences from the litter layer of a recently-burned site using Basidiomycete-specific primers and 572 18S-rDNA sequences from the O-horizon soil of an unburned site using general fungal primers. The soil was dominated by Basidiomycetes, including many mycorrhizal groups, while sequences from litter were dominated by saprotrophic fungi of the order Ceratobasidiales. Principal coordinates analysis showed that fungal community composition in the soil shifted only slightly in response to N addition, whereas more dramatic changes occurred in the litter community. N addition increased the activity of a cellulose-degrading enzyme in the soil, but suppressed lignin-degrading enzyme activity late in the growing season. Rates and sources of soil respiration did not respond to N fertilization or warming treatments. Although N does alter fungal communities, soil processes in this boreal forest ecosystem are largely resistant to increased N deposition.

Climate Changes

Robert Bailis
Yale School of Forestry & Environmental Sciences

Vulnerability to climate change is not evenly distributed among the global community. Poor communities are more vulnerable than non-poor communities and forest-dependent communities in the tropics are particularly precarious positions. However, forest communities are unique among vulnerable groups. In spite of their vulnerability, they represent an important anthropogenic feedback because they are in a position to affect large stocks of carbon. This unique position has generated talk of recruiting such communities into the fight to slow climate change by paying them for carbon sequestration – one of many "no-regrets" scenarios posited by the international community that would, in theory, contribute both to mitigation and poverty reduction. However, in order to understand if, and how, such schemes would affect these communities and, indeed, if they are even interested in participating, the response of forest-dependent communities to climate perturbations and related environmental change needs to be better understood. This project explores responses to climate change among forest communities in Mexico, where one fourth of the country is covered by closed-canopy forests that largely fall under community control. These communities are vulnerable not simply to increased temperatures, but to greater variability and uncertainty in the climate regime. However, climate change is a slow process that will play out over generations. Though some changes are already evident, the bulk of the impacts have yet to be realized. Moreover, adaptation at the community level is only likely if communities perceive a risk. Therefore, this study explores three aspects of the problem: 1) community perceptions of climate change and the associated risks; 2) community responses to past climate anomalies such as El Niño events; and 3) formal and informal coping mechanisms for future climate-related stresses. The project is in its early stages and preliminary data will be discussed.

Atmospheric Moisture Content

Dargan Frierson
Department of the Geophysical Sciences
University of Chicago

With increasing global mean temperatures, atmospheric moisture content will certainly increase. We investigate some of the dynamical implications of this, in particular relating to poleward fluxes of energy and moisture, using a hierarchy of atmospheric models. We start with an intermediate complexity moist general circulation model, that ignores the radiative impacts of moisture in order to isolate the effect of latent heat release. The model has an aquaplanet mixed layer ocean, which ensures that the atmosphere performs all the energy transport in the time mean. In this model, the energy transports change very little as a function of atmospheric moisture content: as the moisture fluxes increase, there is a nearly perfect compensating decrease of dry static energy fluxes. We use one-dimensional diffuse energy balance models to interpret this behavior, and compare with full GCM's to evaluate the effects of the various simplifications in the physical parameterizations.

Organic Carbon Aerosol

Colette Heald
Center for Atmospheric Sciences
University of California, Berkeley

Organic carbon (OC) is a major component of the atmospheric aerosol with both important anthropogenic and biogenic sources. There are large uncertainties on both the primary sources of OC aerosol from fossil fuels and biomass burning and the secondary production of OC from the oxidation of volatile organic compounds (VOCs) in the atmosphere. Early aircraft measurements identified a high-altitude source. Two recent aircraft campaigns have provided extensive measurements of organic carbon (OC) aerosol mass concentrations in the free troposphere, and reveal values considerably larger than presently simulated by global chemical transport models (CTMs). The ACE-Asia campaign in spring of 2001 off the coast of Japan found concentrations that are 10-100 times higher than computed with the GEOS-Chem CTM which includes a standard simulation of secondary organic aerosol (SOA) formation from biogenic sources. More recent measurements of water-soluble OC aerosol made during the ICARTT campaign over the eastern U.S. in summer 2004, also show high concentrations in the free troposphere. We present GEOS-Chem simulations of the ACE-Asia and ICARTT periods examining different possible mechanisms to account for the high observed OC aerosol concentrations in the free troposphere. Biospheric emissions of the precursor gases leading to secondary organic aerosols (SOA) formation are an important perturbation to the radiative balance and composition of the atmosphere. These recent field observations of organic carbon aerosols highlight the uncertainties in current laboratory and modeling studies of SOA formation.

Summer Insolation

Peter Huybers
Geology & Geophysics
Woods Hole Oceanographic Institution

Long-term variations in Northern Hemisphere summer insolation are generally thought to control glaciation. But the intensity of summer insolation is primarily controlled by 20,000-year cycles in the precession of the equinoxes, whereas early Pleistocene glacial cycles occur at 40,000-year intervals, matching the period of changes in Earth's obliquity. The resolution of this 40,000-year problem is that glaciers are sensitive to insolation integrated over the duration of the summer. The integrated summer insolation is primarily controlled by obliquity and not precession because, by Kepler s second law, the duration of the summer is inversely proportional to Earth s distance from the Sun.

Effects of Biomass Burning-derived Aerosols on Precipitation and Clouds in the Amazon Basin: A Satellite-based Empirical Study

J.C. Lin, T. Matsui, R.A. Pielke, Sr., C. Kummerow
Department of Atmospheric Science
Colorado State University

Biomass burning in the Amazon provides strong input of aerosols into the atmosphere, with potential effects on precipitation, cloud properties, and radiative balance. However, few studies to-date have systematically examined these effects at the scale of the Amazon Basin, over an entire burning season, using available datasets. We empirically study the relationships of aerosol optical depth (τ_a) versus rainfall and cloud properties measured from satellites over the entire Brazilian Amazon during the dry, biomass burning seasons (Aug~Oct) of 2000 and 2003.

Elevated τ_a was associated with increased rainfall in both 2000 and 2003. With enhanced τ_a cloud cover increased significantly, and cloud top temperature/ pressure decreased, suggesting higher cloud tops. The cloud droplet effective radius (R_e) exhibited minimal growth with cloud height under background levels of τ_a, while distinct increases in R_e at cloud top temperatures below –10^{o}C, indicative of ice formation, were observed with aerosol loading.

Although empirical correlations do not unequivocally establish the causal link from aerosols, these results are consistent with previous observational and modeling studies that pointed to dynamical effects from aerosols that invigorate convection, leading to higher clouds, enhanced cloud cover, and stronger rainfall.

We speculate that changes in precipitation and cloud properties associated with aerosol loading observed in this study could have important radiative and hydrological effects on the Amazonian climate system. The accelerated forest burning for agricultural land clearing and the resulting enhancements in aerosols and rainfall may even partially account for the observed positive trend in Amazonian precipitation over the past several decades.

Multiple Modes of Orbital-Scale Change in Thermohaline Circulation

Lorraine Lisiecki
Boston University

Principal component analysis of Late Pleistocene benthic $\delta^{13}C$ records from 29 globally distributed marine sites reveals two independent modes of change associated with different orbital frequencies. Most paleoclimate studies of deep ocean circulation have either reconstructed only a few points in time (e.g., comparing the Last Glacial Maximum and the Holocene) or have examined the temporal evolution of relatively few paleoceanographic records. These techniques have produced a simple model of circulation change in which North Atlantic Deep Water (NADW) shoals during glacial conditions and is replaced at depth by Circumpolar Deep Water (CPDW) formed in the Southern Ocean. Our analysis is consistent with NADW shoaling proportional to ice volume change over the last four glacial cycles. However, we also observe a second, independent mode of change in $\delta^{13}C$ with more precession power. Some sites near the NADW-AABW boundary in the Atlantic have strong precession responses, with lighter $\delta^{13}C$ values in phase with summer insolation maxima. This precession response appears to be caused by movement of the NADW-CPDW boundary in the opposite direction of that which would be expected due to ice volume change.

Climate Models

David Lorenz
Atmospheric and Oceanic Sciences Department
University of Wisconsin-Madison

The change in the extratropical circulation under global warming is studied using the climate models participating in the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report. The IPCC models predict a strengthening and a poleward shift of the tropospheric zonal jets in response to global warming. The change in zonal jets is also accompanied by a strengthening and a poleward and upward shift of transient kinetic energy and momentum flux. Similar changes in circulation are simulated by a simple dry general circulation model (GCM) when the height of the tropopause is raised. The similarity between the simple GCM and the IPCC models suggests that the changes in mid-latitude circulation are predominantly driven by a rise in the height of the tropopause, and that other factors such as increased moisture content and the change in the low-level pole-to-equator temperature gradient, play a secondary role. In addition, the variability of about the ensemble-mean of the zonal wind response is significantly correlated with the variability of the tropopause height response over the polar cap, especially in the Southern Hemisphere.

The role of Ocean Physics in Determining the Biological Carbon Pump Efficiency and Atmospheric "pCO2"

Irina Marinov
Department of Earth, Atmospheric & Planetary Sciences
Massachusetts Institute of Technology

Atmospheric pCO2 depends in a crucial way on the efficiency of oceanic carbon pumps, which depends in turn on ocean physics. A more efficient biological pump results in more carbon sequestered in the deep ocean and smaller atmospheric pCO2.

Here we show that diapycnal mixing and Southern Ocean winds strongly impact biological pump efficiency and atmospheric pCO2 by changing the amount of deep water ventilation through the Antarctic Bottom Water pathway.

We introduce the concepts of preformed PO4 and remineralized PO4. By analyzing the impact of winds and mixing on the globally averaged preformed PO4, we show that this is an excellent metric for biological pump efficiency and atmospheric pCO2. By contrast, we show that biological export production, often associated in the literature with the strength of the biological carbon pump, is NOT a good predictor for atmospheric pCO2.

Emissions of Reactive Trace Gases From the North American Terrestrial Biosphere

Dylan Millet
Department of Earth and Planetary Sciences
Harvard University

New measurements from recent field experiments (ICARTT, INTEX-B, and MILAGRO) and from space (OMI, aboard Aura) provide constraints on emissions of reactive trace gases from the North American terrestrial biosphere. We use a 3D chemical transport model (GEOS-Chem) to interpret these datasets and the constraints they imply for the budgets of isoprene and methanol, two of the most important biogenic volatile organic compounds. Aircraft observations of methanol over North America during ICARTT are inconsistent with current understanding of its sources; preliminary results indicate that current bottom-up biogenic emission estimates are too high. In the case of isoprene, new formaldehyde column measurements from OMI afford unprecedented top-down constraints on the spatial distribution of isoprene emissions. We will apply GEOS-Chem to explore these issues, and test our understanding of the isoprene and methanol budgets against their observed distributions and correlations with other species.

Trends in Sea Ice Retreat and Subsequent Advance in Response to ENSO and SAM Variability at High Southern Latitudes

S.E. Stammerjohn, D.G. Martinson, R.C. Smith, and X. Yuan
NASA Goddard Institute for Space Studies

The Antarctic Peninsula (AP) region is rapidly warming, ice shelves and marine glaciers are retreating, and winter sea-ice duration is decreasing. Elsewhere in Antarctica and the Southern Ocean, climate trends are weak or indicate cooling. In an attempt to understand the mechanisms of climate change in the AP region, we first identify when and where the most profound sea ice changes in the Southern Ocean are occurring, then we explore how the physical system is sensitive to these changes. Towards this objective, newly analyzed data reveal strongly opposing trends in the *timing* of annual sea ice retreat (Nov-Feb) and the subsequent advance (Feb-May) in two regions of the Southern Ocean. Sea ice is retreating earlier and advancing later in the southern Bellingshausen Sea, resulting in a decrease of 80 ± 13 annual sea ice days over 1979-2002. In the western Ross Sea, opposite trends have resulted in an increase of 55 ± 12 annual sea ice days. An intensification of the high latitude response to La Niña (more so than to El Niño) during the spring-to-autumn period in conjunction with increased polarity of the Southern Annular Mode (SAM) help to explain both the intensification and localized nature of these opposing sea ice trends. Additionally, inter-seasonal feedbacks help to explain the amplified winter warming in the Antarctic Peninsula region: changes occurring in the atmospheric circulation during austral spring, summer and autumn are negatively affecting the advance and retreat such that winter sea ice duration, concentration and thickness are decreasing, and ocean winter heat flux is increasing; these changes in turn amplify the increase of air temperature in autumn and winter.

Regional Air Quality and Climate Impact of Central American Biomass Burning Aerosols

Dr. Jun Wang
Division of Engineering & Applied Sciences
Harvard University

Under favorable meteorological conditions, smoke aerosols produced by the Central American Biomass Burning (CABB) can be transported northward across the Gulf of Mexico and intrude into the southeastern United States, thousands of kilometers from the source region. These widely dispersed smoke aerosols not only degrade the air quality and visibility, but also impact the meteorological and photochemical processes through their radiative effects.

In this talk, I will focus on the CABB smoke events in April – May 2003 that were the largest since 1998. A coupled aerosol-radiation-meteorology mesoscale model, RAMS-AROMA, together with satellite observations from GOES and MODIS, is used to investigate the smoke impact on the regional air quality, surface energy budget, boundary layer processes, and cloud formation. RAMS-AROMA originates from RAMS model, but has newly-developed capabilities of Assimilation and Radiation Online Modeling of Aerosols (AROMA). In the seminar, an introduction of RAMS-AROMA and a comprehensive evaluation of the model performance will be presented. The model limitations attributed to the differences between model simulation and satellite observation will be quantitatively analyzed, and the improvement by nesting RAMS-AROMA with Harvard's GEOS-CHEM model will be described. In the end, a preliminary analysis of CABB aerosols on the cloud formation and precipitation process will also be discussed.

Guest Speakers Abstracts

Gulf Stream Hydrography and Transport During the Last Millennium

W. B. Curry, *WHOI;* D. C. Lund, *Cal Tech.*, J. Lynch-Stieglitz, *Georgia Tech.*

Variations in ocean temperature and salinity affect both the density of sea water and the oxygen isotopic composition of carbonate-secreting organisms living in the water. Thus by measuring the $\delta^{18}O$ values of carbonate fossil shells in deep sea sediments, it is possible to estimate past density gradients in the water column and across prominent ocean currents. The horizontal density gradient is proportional to the vertical shear in mass transport, so estimates of net mass transport can be calculated using the geostrophic method. In order to calculate absolute transports, a velocity measurement must be known. Often a "level of no motion" is assumed. We have applied this technique using cores from the Florida and Bahamas margins of the Florida Straits spanning the full depth of the straits. We have measured the $\delta^{18}O$ values of a bottom-living taxonomic group (the *Cibicidoides* and *Planulina* spp. of foraminifera) which are known to accurate reflect the water column temperature and salinity properties in which they calcify. The Florida Current flows through this location with a total transport of ~ 31 Sv and includes flows from recirculated North Atlantic subtropical gyre waters (~19 Sv) and the returning, upper limb of the Atlantic Meridional Overturning Circulation (MOC, ~12 Sv). Direct observations of the flow of the Florida Current are limited to the last few decades, so geological reconstructions are required to evaluate how the current changed on longer time scales. Two reconstructions have been made. Using a series of cores that penetrate to the last glacial maximum (21,000 years ago), we observed that the density gradient was significantly reduced at about 700 m water depth and, based on an assumed level of no motion at the bottom of the straits, we estimated that the total mass transport was reduced to about 2/3 of the modern value (Lynch-Stieglitz *et al*., 1999). The other reconstruction evaluated the flow during the last millennium and found that during the Little Ice Age mass transports were reduced by no more than about 10%. For both the glacial period and for the last millennium, when density gradient was reduced (and presumably mass transport as well) higher salinities were associated with the waters flowing through the Florida Straits (Schmidt *et al*., 2004; Lund *et al*., 2006). This is the expected result if a feedback exists between variations in Atlantic Ocean circulation and the climate of the tropics in which the latitudinal position of the ITCZ is affected by changes in North Atlantic SST (Vellinga and Wu, 2004).

The Transient Atmospheric Circulation Response to Arctic Sea Ice Trends

Clara Deser
NCAR CGD

Arctic sea ice cover has undergone pronounced trends in recent decades, with large reductions in summer and offsetting regional changes in winter (decreases east of Greenland and increases in the Labrador Sea). Although driven in large part by changes in atmospheric flow (the positive polarity of the North Atlantic Oscillation), the winter sea ice trends exert a significant negative feedback upon the atmospheric circulation (Deser et al., J. Climate, 2004). To better understand the response of the atmospheric circulation to the winter sea ice trends, we have conducted a series of transient atmospheric general circulation model experiments forced with observed daily sea ice trends from December 1 – April 30. We find that the adjustment of the atmospheric circulation to the imposed boundary forcing consists of two stages: an initial stage characterized by a strong out-of-phase relationship between geopotential height anomalies in the lower and upper troposphere localized to the vicinity of the forcing that sets up within a day and lasts for approximately 2-3 weeks; and an equilibrium stage characterized by an equivalent barotropic response that is hemispheric in scale and resembles the model's leading mode of intrinsic variability (e.g., the Northern Annular Mode) and reaches its maximum amplitude in approximately 2 – 2.5 months. The equilibrium response is approximately twice as large as the initial response. The initial baroclinic response is maintained primarily by diabatic heating anomalies associated with the imposed thermal forcing, while the equilibrium response is maintained primarily by transient eddy fluxes of heat and vorticity, with the latter dominating the former particularly in the upper troposphere. The results of this study will be described in a forthcoming publication available from the author's web site:
http://www.cgd.ucar.edu/cas/cdeser/press.html

Stability Analysis of the Sea Ice Edge

Eric DeWeaver
Atmospheric and Oceanic Sciences Department
University of Wisconsin-Madison

A simple "toy" model is devised to study the stability and climate sensitivity of oceanic regions which are sea-ice covered in winter but ice free in summer. The premise of the model is that the rates of ice freezing and melting and ice-free mixed layer warming and cooling are determined by external climate forcing, independently of the lengths of the seasons. The system adjusts to changes in external climate forcing through changes in the lengths of the freezing, melting, cooling, and warming seasons. We first examine the stability of the seasonal ice states with respect to perturbations in the start dates of the seasons. Stability can be assessed by considering the ratio of the freezing rate to the melting rate or the ratio of the mixed layer warming and cooling rates. More simply, stability can be assessed by comparing the durations of the freezing and melting seasons or the durations of the warming and cooling seasons. Roughly speaking, the seasonal ice climate is stable if the ice "wants" to melt but the mixed layer "wants" to freeze.

To examine the sensitivity of the seasonal ice climate to changes in external climate forcing we construct a 4-by-4 matrix which can be solved for the lengths of the four seasons. The matrix then is reduced to two equations for the lengths of the ice freezing and mixed layer cooling seasons. The lengths of the freezing and cooling seasons can be represented by the intersection of the lines representing the two equations. When the system is stable with respect to initial conditions, a shift to warmer climate forcing causes the intersection of the two lines to move upward and to the left, signifying a transition to a longer ice-free cooling season and a shorter ice-covered freezing season.

Finally, we compare the climate sensitivity of two versions of the toy model, one in which the rates are determined entirely by external climate forcing and one in which the lengths of the seasons can influence the rates (a nonlinear calculation). The linear stability criterion is satisfied by the nonlinear calculation, and there is qualitative similarity between the linear and nonlinear calculations. However, the nonlinear calculation is less sensitive near the ice-covered limit. The reduced sensitivity can be understood in terms of the ice thickness-ice growth feedback. As climate warms, the growth rate of ice is reduced. However, the length of the freezing season also shortens, which reduced the thickness of the ice, thereby increasing the freezing rate, since thin ice grows faster than thick ice. The increase in freezing rate due to the shortened season thus partially offsets the decrease in freezing rate due to the change in climate forcing.

Climatic Effects on Hurricane Activity

Kerry A Emanuel
Department of Earth, Atmospheric & Planetary Sciences
Massachusetts Institute of Technology

It has been known for some time that hurricane activity is sensitive to regional climate phenomena such as ENSO, and it has become apparent that hurricane activity is also responding to global climate change. In this talk, I will review what is known about climatic effects on hurricane activity from analysis of hurricane observations, as well as from theory and models. I will also argue that hurricanes are not merely responding passively to climate change, but are an active component of the climate system, providing the mixing of the upper ocean needed to drive the thermohaline circulation. Changing hurricane activity therefore has an important feedback on the climate system, moderating tropical climate change but amplifying changes at higher latitudes.

Eddies, Waves and Hurricanes: Monitoring Ocean Dynamics with a New Generation of Profiling Floats

James B. Girton
Applied Physics Laboratory
University of Washington

The "Electromagnetic Autonomous Profiling EXplorer" (EM-APEX), a recently-developed enhancement of the Argo-type profiling float that measures a profile of horizontal water velocity using the principal of geomagnetic motional induction, has now been deployed in two experiments to give a detailed look at the evolution and mixing of the upper-ocean under varied atmospheric forcing. In the first, the ONR-sponsored Coupled Boundary Layer Air-Sea Transfer (CBLAST) experiment, 3 floats were air-dropped in the path of Hurricane Frances as it approached the Bahamas from the southeast. The increase in surface waves in advance of the storm, mixed layer acceleration and deepening as the eye passed overhead, and surface cooling and internal wave radiation in the storm's wake were all observed in unprecedented detail. These measurements are yielding new insight into the processes of upper-ocean mixing, surface wave evolution, and air-sea momentum transfer under extreme wind conditions. Each of these processes have implications for the forecasting of future hurricanes.

In the second deployment, four EM-APEX were launched near Bermuda along with a patch of the chemical tracer sulfur hexafluoride (SF6) as part of the NSF-sponsored EDDIES experiment aimed at understanding the influence of mesoscale oceanic variability on nutrient budgets of the upper ocean. The floats stayed within a single anticyclonic eddy for 6 weeks, sampling the evolution of the internal wave field and mixed layer as 3 tropical cyclones passed over head. While the tracer patch was below the mixed layer during the entire duration of the experiment, enhanced shear due to the storms was seen at the tracer depth and clearly played a role in the moderately elevated levels of mixing seen there. Biological productivity in many regions of the world's oceans is limited by the rate of nutrient transport into the upper ocean (euphotic zone) and the influence of tropical cyclones and mesoscale eddies on these budgets has only just begun to be evaluated.

Future potential uses for the EM-APEX include additional hurricane air-sea interaction studies, investigation of winter mode-water formation in the subtropical North Atlantic, measurements of internal tide radiation from sea straits, and studies of mesoscale velocity structure and internal wave climate of the Antarctic Circumpolar Current.

Talking to the Media: Tips for Scientists on Communicating With the Press, Public, and Policymakers

Susan Hassol
Aspen Global Change Institute

Scientists have a responsibility to communicate their findings to the wider world. Unfortunately, they too often lack the tools to do that effectively.

Communicating global change science well presents several problem areas:
1. Scientific literacy (or the lack of it) on the part of the public and journalists.
2. Communication skills and interests (or their lack of) on the part of scientists.
3. Differences in how scientists, journalists and the public think and talk.
4. Differing agendas among policymakers, industry actors, and environmentalists.

Scientists can improve communication in several ways:
1. Avoid jargon.
2. Avoid terms that mean different things to scientists and non-scientists (e.g., enhance, positive/negative feedback, ozone, aerosol, radiation, sensitivity, theory, regime, sign, significant, exotic, organic, forcing, SST).
3. Carefully craft press releases to properly shape the key message(s).
4. Place new findings in context.
5. Use metaphors that speak powerfully to non-scientists.
6. Pay careful attention to how uncertainty and caveats are expressed.
7. Anticipate and address potential questions and misunderstandings.

When scientists are unaware of these concerns and simply do what comes naturally to them, the public often receives the wrong message. Many recent examples illustrate missed opportunities to educate the public on important issues.

Global Model Projections

Isaac Held
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The ensemble of global model projections for 21st century changes in the hydrologic cycle gathered for the 4th IPCC Assessment are used to illustrate some aspects of this response that are robust across the models, and some aspects that are not robust. One example of a robust response is in the zonal mean precipitation, which scales with the control distribution of precipitation minus evaporation. Another robust result is that the global mean precipitation grows more slowly than the water content in the atmosphere, which, in turn, results in a robust reduction in the strength of tropical convection. Climate change over Africa, especially in the Sahel, is used as an example of hydrological responses that are not robust across the ensemble of models. The problem of how to evaluate models to judge which of the disparate responses is more plausible is briefly discussed.

New Perspectives on Atmospheric Mercury

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Mercury is a global pollutant accumulating in ecosystems and harmful to humans through fish consumption. Anthropogenic emissions of mercury have led to large increases in mercury abundances in surface reservoirs. Because elemental mercury has a large vapor pressure, the transfer of mercury between reservoirs mainly takes place through the atmosphere and involves atmospheric oxidation of elemental mercury to Hg(II) followed by deposition. Better understanding of the redox chemistry of atmospheric mercury has important implications for defining source-receptor relationships and enabling effective regulation. We use a global 3-D model of atmospheric mercury (GEOS-Chem) to interpret worldwide observations of total gaseous mercury (TGM) and reactive gaseous mercury (RGM) in terms of the constraints they provide on the chemical cycling and deposition of mercury. Our simulation including a global mercury source of 7000 Mg y^{-1} and a TGM lifetime of 0.8 y reproduces the magnitude and large-scale variability of TGM observations at land sites. However, it cannot capture observations of high TGM from ship cruises. Observed TGM seasonal variation is consistent with a photochemical oxidation for Hg(0) partly balanced by photochemical reduction of Hg(II). Observations of increasing RGM with altitude imply a long lifetime of Hg(II) in the free troposphere. We find in the model that Hg(II) dominates over Hg(0) in the upper troposphere and stratosphere, and that subsidence is the principal source of Hg(II) at remote surface sites. RGM observations at Okinawa Island (Japan) show large diurnal variability implying fast deposition, which we propose is driven by fast RGM uptake onto sea-salt aerosols. Observed mercury wet deposition fluxes in the United States show a maximum in the southeast, which we attribute to photochemical oxidation of the global Hg(0) pool. They also show a secondary maximum in the industrial Midwest, due to regional emissions of RGM and particulate mercury (Hg(P)), which is underestimated in the model because Hg(II) is mostly removed by dry deposition rather than wet. We estimate that North American anthropogenic emissions contribute on average 20% to U.S. mercury deposition.

Geo-Engineering Climate Change with Sulfate Aerosols

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We explore the impact of injecting a precursor (SO2) of sulfate aerosols into the middle atmosphere where they would act to increase the planetary albedo and thus counter some of the effects of greenhouse gase forcing. We use an atmospheric general circulation model (CAM, the Community Atmosphere Model) coupled to a slab ocean model for this study. Only physical effects are examined, that is we ignore the biogeochemical and chemical implications of changes to greenhouse gases and aerosols, and do not explore the important ethical, legal, and moral issues that are associated with deliberate geo-engineering efforts.

Four simulations are made to examine the implications of injecting approximately 1Tg of Sulfur as Sulfur Dioxide (SO2) at 25km in altitude in the tropical stratosphere. The model simulations use a 2x2.5 degree grid resolution in the horizontal, with vertical resolution of 52 layers and a model top at approximately 80km. The four simulations are:

1) a control simulation using aerosol and greenhouse gas distributions fixed at present day concentrations.
2) a simulation in which CO2 has been doubled, and the aerosol distribution remains fixed at present day values.
3) a simulation in which CO2 is fixed at present day concentrations and the geo-engineering source of SO2 is added to present day aerosols.
4) a simulation in which CO2 is doubled and the geo-engineering source of SO2 is present.

The simulations suggest that the sulfate aerosol produced from the SO2 source in the stratosphere is sufficient to counterbalance most of the warming associated with the greenhouse gas forcing. Surface temperatures return to within a few tenths of a degree (K) of present day levels. Sea ice and precipitation distributions are also much closer to their present day values. The polar region surface temperatures remain 1-3 degrees warm in the winter hemisphere than present day values.

This study is very preliminary. Only a subset of the relevant effects have been explored. The effect of such an injection of aerosols on middle atmospheric chemistry, and the effect on cirrus clouds are obvious missing components that merit scrutiny. There are probably others that should be considered. The injection of such aerosols cannot help in ameliorating the effects of CO2 changes on ocean PH, or other effects on the biogeochemistry of the earth system.

Moist Convection and Mesoscale Predictability

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Soon after the beginning of numerical weather prediction, the following question presented itself: "What degree of improvement in the prediction can be expected from a given improvement of the initial condition?" If only small improvements were to be obtained for a much more accurate initial condition, then there would be an effective limit on the ability to predict the weather (i.e. a limit on predictability). A consensus has formed behind the idea of Lorenz that predictability is limited for flows with many scales of motion in which errors in small scales grow faster than and spread to errors in larger scales. This idea is supported by numerical experiments using turbulence models under varying degrees of idealization and approximation. However, as complicated as the latter models are, they are considerably simpler than numerical weather prediction models as they do not take into account moist convection, cloud microphysics, complex orography and physiography, etc. In this talk, results will be presented from recent studies examining error growth in relatively high-resolution numerical weather prediction models initialized with idealized (but meteorologically relevant) initial conditions. These studies indicate the critical importance of moist convection in the initial rapid error growth at small scales which, consistent with the Lorenz idea, eventually transition to more slowly growing larger-scale errors in the forecast. Although the latter supports the idea of a predictability limit, there remains the very practical question of whether error transfers slowly enough from convective scales to the mesoscale for the latter to retain useable information in short-term (~1 day) forecasts. Results will be presented from real-time high-resolution numerical weather forecasts in convective-weather situations showing that skill in predicting the mesoscale can translate into skill of forecasting aspects of convective weather such as its structure (e.g. squall lines, supercells, etc.) , and areal coverage (if not the exact placement and timing of convective cells).

Regimes of the General Circulation: Hadley Cell and Monsoon Dynamics

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Simulations with an idealized general circulation model reveal regime transitions of the global circulation of the atmosphere. The Hadley circulation exhibits a regime in which it is tightly coupled to eddy momentum fluxes in the subtropics and so is directly influenced by extratropical and subtropical eddy dynamics. Scaling laws of eddy fluxes and thus of the Hadley circulation exhibit a regime transition from a sensitive dependence on the meridional surface temperature gradient when convection controls the thermal stratification to a less sensitive dependence when large-scale eddies modify the subtropical and extratropical thermal stratification. If the maximum radiative heating is displaced sufficiently far away from the equator, the Hadley circulation undergoes a transition to a regime in which the influence of large-scale eddy fluxes on the circulation becomes weak. This latter regime may be that of monsoon circulation, and the regime transition may account, for example, for the sudden onset of monsoons.

Dynamics of Intertropical Convergence Zones

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Intertropical convergence zones (ITCZs) are narrow, zonally oriented regions of climatologically high precipitation over the tropical oceans. ITCZs are of interest for a number of reasons, not the least of which is that numerical climate models have persistent biases in their representation of them. To guide efforts to correct these biases, as well as for its own sake, a general theory for what controls the strength and position of ITCZs would be desirable. Many ideas have been put forward, most of which fall into two classes. In one, the local sea surface temperature (SST) and vertical profiles of free tropospheric temperature and humidity control the precipitation at a point, by controlling the stability of the atmosphere to deep convection. In the other, sea surface gradients control precipitation, by determining the atmospheric pressure gradient, and thus the horizontal flow and its associated moisture convergence, in the atmospheric boundary layer. We introduce a simple model which can incorporate both these mechanisms, in order to study their interaction. This model consists of an ABL with fully prognostic and nonlinear equations for momentum, temperature, and humidity, below a free troposphere very similar to that in the quasi-equilibrium tropical circulation model, including a barotropic and first baroclinic mode and a quasi-equilibrium convective scheme with a finite adjustment time. When forced by SST gradients comparable to those on earth, this model generates unrealistically intense ITCZs, unless considerable horizontal diffusion of moisture is used. Convergence in the boundary layer, driven directly by SST gradients, drives a "bottom-heavy" component of the large-scale vertical velocity, which imports moist static energy, and the intense precipitation and need for diffusion result from that. Although the final result may be unrealistic, comparison with recent studies of Reanalyses and climate simulations suggest that this thermodynamic forcing of the free troposphere by SST-induced boundary layer flow may occur in nature.

How and Why to Improve Global Models with Better Cloud Physics

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Why do GCMs need comprehensive cloud microphysics? The old reason is still valid: cloud-radiation feedbacks are critical for modeling climate sensitivity, and microphysics has a major effect on cloud radiative properties. Meanwhile, several newer reasons have come up: Regional climate change can depend on cloud feedbacks, precipitation is an important facet of climate change, cloud-aerosol interactions are inherently microphysical, and numerical weather prediction can provide synergies.

There are several key elements in this research. We first build parameterizations incorporating recent research on cloud microphysics and evaluate them against observations using a single-column model. We then put the parameterizations in CAM3 and investigate their influence on the model climate. In both cases, the parameterizations improve the model realism. We have begun to examine the parameterizations for their effect in numerical weather prediction models. Finally, we intend to develop and test stochastic parameterizations as a generalization of this approach.

References:

Iacobellis, S. F., G. M. McFarquhar, D. L. Mitchell, and R. C. J. Somerville, 2003: The sensitivity of radiative fluxes to parameterized cloud microphysics. Journal of Climate, 16, pp. 2979-2996.

Lane-Veron, D. E., and R. C. J. Somerville, 2004: Stochastic theory of radiative transfer through generalized cloud fields. Journal of Geophysical Research, 109, D18113, doi:10.1029/2004JD004524, pp. 1-14, 2004.

The role of Tropical Storms in Climate and Climate Change

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Are the bonanza Atlantic hurricane seasons of 2004 and 2005 becoming the norm? Is the record breaking number of typhoon hits in Japan in 2004 a wave of the future? Does the first known hurricane, Catarina, in the South Atlantic in March 2004 signal more? The climate is changing, and humans are partly responsible. Global mean temperatures continue to increase and are running 1° F or more above pre-1970s values. While 1998 remains the warmest year on record, 2002, 2003 and 2004 follow closely behind. These changes have been definitively linked to increases in greenhouse gases in the atmosphere, most notably carbon dioxide, which has increased 30% in the past century and half of that increase has occurred since 1970. This increase is from human activities and especially the burning of fossil fuels. As part of this global warming, sea surface temperatures (SSTs) in the tropics have increased 0.9° F since the early 1970s, and this increase is unprecedented over at least the last 150 years and perhaps the last several thousand years. It is almost certainly a result of the additional greenhouse gases mankind has put into the atmosphere. Associated with this is a physically related observed increase in atmospheric moisture (water vapor) on the order of 3.8%. This increases the energy available for clouds and storms in the tropics and middle latitudes and enhances the chances of heavy rains.

To explore the role of hurricanes in the climate system, a detailed analysis is made of the bulk atmospheric moisture budget of several simulated storms, with detailed results given for Ivan in September 2004 and Katrina in August 2005. The simulations are with the Weather and Research Forecasting (WRF) model at 4 km resolution without parameterized convection. As the initial state is from global analyses, the vortex spins up over about 12 hours, and the intensity does not match observed but the track forecast is excellent. It is demonstrated that the heavy precipitation in the core of the storms, with rainfall rates exceeding 20 mm/h, greatly exceed – by an order of magnitude – the surface flux of moisture through evaporation within 100 km of the center of storm, even though surface latent heat fluxes exceed 1000 W m^{-2} (note 1 mm/h is equivalent to 700 W m^{-2}). Hence vertically-integrated convergence of moisture into the tropical storms, which occurs mainly in the lowest 1 km of the atmosphere, is by far the dominant term in the moisture budget, and transports of moisture from distances up to 1600 km from the storm center are required to balance the moisture budget. Although the moisture convergence is driven by the storm dynamics and local surface fluxes, this highlights the importance of the larger-scale environment in which the storms are embedded. Simulations are also run for the Katrina case with sea surface temperatures (SSTs) increased by +1° C and decreased by –1° C, and we will focus on statistics for hours 48 to 54 after the start of the simulation, and discuss the role of hurricanes in the climate system.

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Scrap Book 2006

7th Summer Institute
Steamboat Springs, Colorado
July 10 – 13, 2006

Front Row (L to R) Phil Rasch, Irina Marinov, Lorraine Lisiecki, Colette Heald, Susan Hassol, Dylan Millet, Meg Austin, Clara Deser, Sharon Stammerjohn, Susan Baltuch **Standing (L to R)** Eric DeWeaver, Adam Sobel, Raymond Pierrehumbert, Tapio Schnider, Jon Lin, Peter Huybers, Rob Bailis, Richard Sommerville, Jun Wang, Michael Hall, Kevin Trenberth, Steve Allison, Jim Todd, David Lorenz, Rich Rotunno, Issac Held, Kerry Emanuel, Bill Curry, Dargon Frierson **Not Pictured**: Randy Borys, James Girton, Daniel Jacob, John Kermond, Chester Koblinski, Gene Martin, Sabine Mecking, Melanie Wetzel

Sheraton Hotel in beautiful Steamboat Springs, Colorado

Slope side, Steamboat Springs ski area

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(left to right) Jon Lin, Gene Martin and John Kermond

(left to right) Rich Rotunno, Adam Sobel and Kerry Emanuel

Jim Todd, Bill Curry

(left to right) Mike Hall, Rob Bailis, Irina Marinov and Jun Wang

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Dylan Millet, Lorraine Lisiecki

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(left to right) John Kermond, Adam Sobel, Gannet Hallar and family

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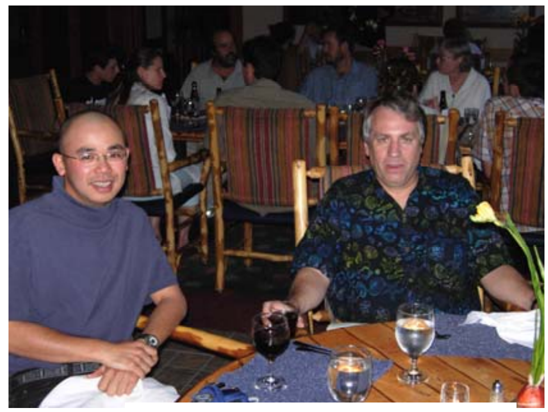

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