Purdue Climate Change Research Center

ANNUAL REPORT 2008-2009

PURDUE UNIVERSITY
Discovery Park

The **Purdue Climate Change Research Center** (PCCRC) is a faculty-led, university-based research center on the campus of Purdue University. The PCCRC serves to increase scientific and public understanding of the causes and impacts of climate change through fundamental research and effective education and outreach.

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Cover photos from left to right: Leigh Raymond, PCCRC Associate Director, presents a paper on carbon emissions trading policy at the National Conference on Climate Governance; scientists associated with the Ocean-Atmosphere-Sea Ice-Snowpack (OASIS) project, led by Paul Shepson, prepare to collect samples on the frozen Chukchi Sea in April, 2009, near Barrow, Alaska; Yini Ma, 2008 PCCRC Graduate Fellow, collects samples from the research forests at the Smithsonian Environmental Research Center in Edgewater, Maryland to monitor the impact of earthworm activity on soil organic matter stabilization.

Otto Doering

Professor and Interim Director

Message from the Director

We owe a debt of gratitude to Noah Diffenbaugh for serving as Interim Director of the PCCRC for the past year. This is not an easy task, as I have discovered in taking over this responsibility for the coming year, until we find a permanent Director. The PCCRC is one of three centers; energy, environment, and climate, that the university has designated as the core of a sustainability focus at Purdue. The intent is to engage the centers jointly in cross center collaborations that encompass more than just the expertise and focus of the individual centers. This will require a commitment on the part of all three centers to make this successful. PCCRC is also fortunate that we have a continuing resource commitment from the Schools of Agriculture, Science, Engineering and Liberal Arts for the Center's work. This makes a tremendous difference in our ability to support our associated faculty in their research, teaching, and outreach efforts related to climate science and climate issues. It will also give us more flexibility for collaborations of all sorts.

Our attention this year has continued to focus primarily on expanding our research profile and we have achieved significant gains. Eight new research grants from various funding agencies have been awarded this year to projects that will explore weather extremes in a changing climate, improve our understanding of the role of clouds in climate dynamics, and study the impacts of climate change and land use change to the people in boreal Eurasia to mention a few. You will find more information in the report.

Our research projects have produced 39 journal articles this year, and the number of those papers featured in scientific and popular media outlets is on the rise. Three new books and 4 reports were (co)authored by PCCRC faculty. These include a new book on the economic analysis of land use in global climate change policy, and a comprehensive report on abrupt climate change sponsored by the U.S. Climate Change Science Program. I am pleased that faculty members associated with our Center are communicating to the broader community as well as to their peers in their specific areas of interest.

To minimize obstacles to collaboration and increase external proposal submissions to funding agencies, the Center launched a seed grant competition and funded 5 interdisciplinary, cross-college projects with high potential to secure external funding. We don't know how successful this effort will be, but will try to continue this for the coming year.

To enhance the success of our graduate students we offered travel scholarships, providing 7 students with the opportunity to present their research at professional conferences and workshops, and awarded PCCRC Graduate Fellowships to recruit two outstanding graduate students to Purdue. We have the opportunity to offer at least two fellowships for the coming year. I am convinced that the encouragement of student success is one of the most important things we can do.

We continue reaching out to new partners and actively forge new collaborations. For instance, working with Agricultural Communications and the Indiana State Climate Office, we created a climate change exhibit for the Indiana State Fair where thousands of visitors learned about the science and impacts of climate change as well as the technological innovations that will take us to a low carbon future.

I am looking forward to the coming year working with those associated with the Climate Center and the sustainability initiative at Purdue. Our Center faculty are the reason I was willing to take this job on. Not only are they good at what they do, but they are good to work with.

Otto Doering

Professor of agricultural economics and PCCRC Interim Director

A project led by Jeff Trapp, associate professor of earth and atmospheric sciences, is part of the second Verification of the Origins of Rotation in Tornadoes Experiment, or VORTEX 2, field study. Through this field study the team hopes to discover more about what causes a tornado, why one becomes stronger than another, and what characteristics of the tornado cause damage.

Funded by the National Science Foundation and the National Oceanic and Atmospheric Administration, VORTEX 2 involves scientists from 14 universities and institutions and is sampling supercell thunderstorms and tornadoes that form over the Great Plains of the United States through June 13, 2009. In the photo above, Andrew Arnold and Evan Bookbinder (National Weather Service) deploy a "tornado pod." This rugged instrument measures temperature, humidity, and winds near the ground below a storm or tornado.

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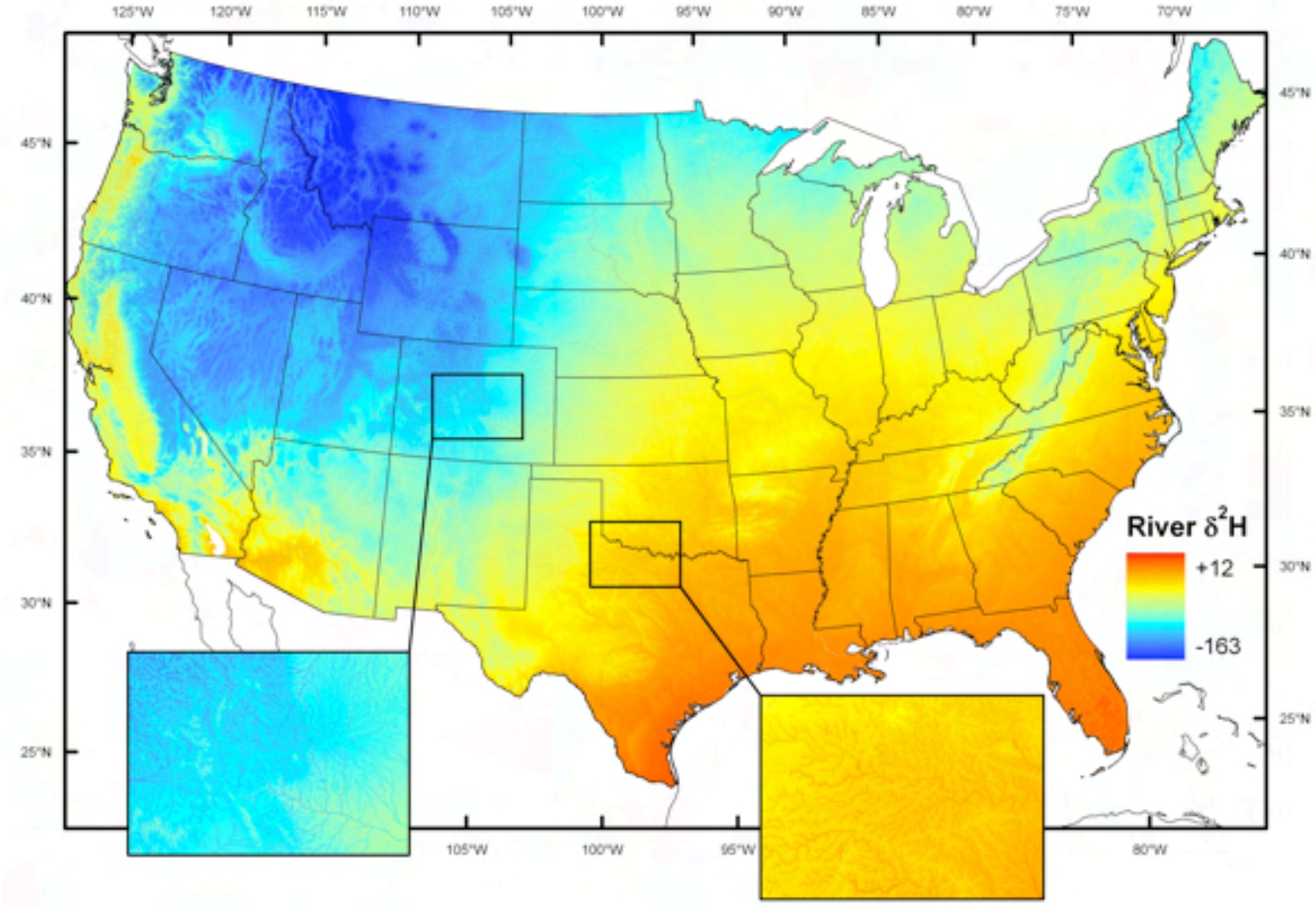


The "isoscape" (isotopic landscape) map above shows estimated hydrogen isotope ratios (δ2H) of river water overlain on that of precipitation. The map was produced by combining modeled estimates of precipitation hydrogen isotope ratios with a GIS runoff routing model and assimilation of isotopic monitoring data. Water isotopes can be used at a wide range of spatial scales to identify and quantify hydrological fluxes, such as the contribution of low-δ^2H mountain runoff to stream discharge (left inset) and evaporative water loss, which leave behind high-δ^2H stream water (right inset). Researchers in the Isotope Ratio Hydrology and Ecology group (led by assistant professor Gabriel Bowen, EAS) are applying water isoscapes to problems ranging from quantification of land-atmosphere water fluxes to the forensic identification of human remains. Learn more about their work at www.purdue.edu/eas/ireh/.

DISCOVERY

The PCCRC seeks to build and apply the scientific knowledge needed to address issues related to the Earth's changing climate system. Our projects and collaborations span the globe, from the Arctic Circle to the Atacama Desert, from Ojibwa Nation forests to the urban centers of developing countries; and cross a full range of scales from the molecular dynamics of carbon storage to global maps of socio-climatic exposure.

Sponsored Research

The Center facilitates and supports interdisciplinary collaborations, assisting our faculty as they initiate new projects and compete for funding. In this section, read about our newest research grants.

New Grants

PCCRC research projects sponsored by external funding totaled approximately $3 million in FY 2008-2009, with another $2.1 M recommended for funding. Support came from the National Science Foundation, the National Aeronautics and Space Administration, the Department of Energy, and The Nature Conservancy.

Changes of Land Cover and Land Use and Greenhouse Gas Emissions in Northern Eurasia: Impacts on Human Adaptation and Quality of Life at Regional and Global Scales

Qianlai Zhuang, *Departments of Earth & Atmospheric Sciences and Agronomy*, (Funded by the National Aeronautics and Space Administration).

Northern Eurasia accounts for about 20% of the Earth's land surface and 60% of the terrestrial land cover north of 40°N. It contains 70% of the Earth's boreal forests and more than two-thirds of the Earth's land that is underlain by permafrost. The region is covered by vast areas of peatland, complex tundra in the north and semi-deserts and deserts in the south, including the Mongolia plateau. The surface air temperature has increased in the last half century and this increase will continue during this century. To date, studies have generally focused on analyzing climate change effects on biogeochemical processes and mechanisms governing the carbon and water dynamics in the region or potential changes in the distribution of natural vegetation. While the team will also examine such issues, they will focus on how patterns of land use in Northern Eurasia may change in the future due to: 1) economic pressures for providing food, fiber and fuel to a growing global population; 2) opportunities for expanding managed ecosystems into areas that experience a more favorable climate in the future; and 3) abandonment of managed ecosystems in other areas that experience a less favorable climate.

The research team will examine how these future changes in land use and land cover could influence the exchange of CO_2 and CH_4 between terrestrial ecosystems and the atmosphere, terrestrial carbon storage and primary productivity, water supply, and radiative forcing of the atmosphere through changes in surface albedo. They will also assess how human adaptation and quality of life may be impacted by these changes. To conduct this analysis, a system of linked models that include the MIT Emissions Prediction and Policy Analysis (EPPA) model of the world economy, the SiBCliM bioclimatic vegetation model, and the Terrestrial Ecosystem Model (TEM) will be used.

The multi-disciplinary U.S. scientific team includes ecosystem scientists, biogeochemical modelers, and economists, which will be complemented by international collaborators from the Russian Academy of Sciences, the International Institute of Applied Systems Analysis (IIASA) in Austria, the National Institute for Environmental Studies in Japan, and the Chinese Academy of Sciences.

The Isotope Networks Portal: Data Integration for Biogeochemistry and Ecology Through Web-based Geospatial Modeling

Gabe Bowen, *Department of Earth & Atmospheric Sciences* and co-Is Lan Zhao, *Rosen Center for Advanced Computing*; Chris Miller, *Libraries*; Tonglin Zhang, *Statistics*; and Jason West, *Texas A&M University* (Funded by the National Science Foundation).

With funding from NSF, the team will develop and deploy the Isotope Networks Portal (INPort), an extensible, web-based platform for the analysis and modeling of stable isotope data with respect to space and time. INPort will provide a transparent interface between data consumers and data

Gabe Bowen and students collect samples from the Wasatch Plateau in Utah.

Bryan Pijanowski's group is developing a spatially-explicit projection of at-risk prairies.

Greg Michalski tests his irms system for measuring isotopes in nitrous oxide.

sources by providing integrated data querying, data acquisition, and geospatial modeling operations. It will consist of a web-based GIS interface linked to a data and application management system that will conduct data identification, acquisition, and processing and model execution behind the scenes.

The primary output of INPort will be spatially and temporally explicit maps of environmental isotope distributions. INPort software and products will serve a growing number of research programs that generate or use spatiotemporally-resolved environmental isotope data to address key problems in biogeochemistry, organismal ecology, and hydrology, including national-scale monitoring initiatives in these areas. These programs promise to generate large quantities of spatially resolved isotope data from a range of environmental systems, and successful and appropriate integration of this data with existing data sets and ancillary spatial data will be key to maximizing its scientific impact. INPort will facilitate the transformation of these diverse, heterogeneous data into derived products having a uniform, intelligible data type, encouraging learning and data access by a wide range of scientists and non-scientists.

Risk Assessment of Prairies to Agriculture Conversion

Bryan Pijanowski, *Department of Forestry & Natural Resources* (Funded by The Nature Conservancy).

The natural prairies in the northern Plains States are at risk of conversion to cropland due to an anticipated expansion from increased biofuel demand. The Nature Conservancy (TNC) is working collaboratively with Pijanowski's Human-Environment Modeling and Analysis Lab to develop a spatially-explicit projection of at-risk prairies located all across the Plains States. These projections will help TNC identify areas at-risk to conversion so that they might be protected in the future.

Pijanowski's GIS and neural network based Land Transformation Model (LTM) is being reconfigured to estimate the risk to agriculture expansion across the Plains States. An economic forecast model with biofuel demand is being coupled to the LTM to generate a map of high risk of prairie conversion in years 2010 through 2040. The project is also compiling massive amounts of GIS data, including SSURGO soils, MLRC and NASS land use, NWI wetlands, digital elevation models, hydrography and transportation layers for modeling and analysis.

Using Oxygen Isotopes to Constrain Ozone Sources and Sinks

Greg Michalski, *Department of Earth & Atmospheric Sciences* (Funded by the National Science Foundation).

Ozone plays a critical role in global and regional atmospheric chemistry and has a significant impact on global climate, making it vital to understand ozone source and sink processes. Although substantial progress has been made, there are many open questions regarding ozone dynamics, long-range transport, and the importance of stratospheric exchange. Variation in the oxygen isotope composition of ozone provides a window into these processes; however, data are very limited because existing methods for sampling ozone for isotopic analysis are complex, cumbersome, and impractical for routine application. Uncertainties in laboratory-determined pressure and temperature dependencies of ozone isotopic composition also hinder progress. This work will focus on the development and application of a new analytical and experimental framework for the analysis of ozone dynamics.

Collaborative Research: Understanding the Role of a High-Latitude Convective Cloud Feedback in Equable and Future Climate Dynamics

Matthew Huber, *Department of Earth & Atmospheric Sciences* with Eli Tziperman, *Harvard University* (Funded by the National Science Foundation).

This grant will support work to investigate equator-to-pole temperature differences and high-latitude seasonality during the equable climate of the Eocene Period, when both were much smaller than they are today. These circumstances are difficult to explain within the framework of the current understanding of climate dynamics. Huber and Tziperman seek to: 1) understand what factors control the critical carbon dioxide level at which the convective cloud feedback activates and the magnitude of the surface warming the feedback can produce; 2) determine the ability of convective cloud feedback to provide warming in continental interiors as well as over ocean, consistent with Eocene fossil and proxy observations; 3) constrain the convective cloud feedback using modern observations; and 4) investigate the possible implications of the convective cloud feedback for future climate.

Quantifying Predictability in Nonlinear Multiscale Systems with Applications to Tropical Cyclone Prediction

Wen-wen Tung, *Department of Earth & Atmospheric Sciences* with Jianbo Gao, *University of Florida* (Funded by the National Science Foundation)

This project will utilize a new, fundamental, and unified approach to quantify predictability in complex systems involving a vast-range of interacting spatial-temporal scales. Examples of these types of multiscale phenomena include power outages, earth quakes, tsunami, and tropical cyclones (TCs). TCs in particular, are responsible for billions of dollars of damage annually in the United States alone. The work outlined in this project will fundamentally advance our understanding of ensemble prediction, an important forecasting technique, especially for weather and climate (including TC forecasting). It will drastically improve forecast accuracy from weather to climate scales and tremendously reduce computational complexity and data storage. This work will enable, for the first time, objective and model-independent determination of predictability from observational data, and may ultimately help design better evacuation plans for areas prone to tropical cyclones.

The Response of Convective Precipitating Storms to Anthropogenically Enhanced Global Radiative Forcing

Robert (Jeff) Trapp, *Department of Earth & Atmospheric Sciences*, and co-Is Noah Diffenbaugh, *EAS*; Michael Baldwin, *EAS*; and Alexander Gluhovsky, *EAS and Statistics* (Funded by the National Science Foundation).

Convective precipitating storms (CPSs) and the associated hazards of hail, destructive surface winds, tornadoes, and flash floods pose serious risks to life and property. These hazardous phenomena are governed by the 3D distributions of atmospheric moisture, temperature, and wind. Simple physical arguments suggest that changes in these variables resulting from anthropogenic increases in greenhouse gas concentrations will in turn affect the frequency and intensity of CPSs. As the investigators have shown in their pilot project, valuable insight about the dynamics of this local response can be gained using climate models in which convective processes are parameterized at subgrid scales. However, the limitations of this "indirect" approach highlight the importance of applying numerical models that explicitly resolve convective storms over large continental areas. In their preliminary work, the team also established the basic viability of telescoping modeling strategies that consist of integrations of a convective-cloud-permitting model [the Weather Research and Forecasting model] nested within a global model (the G-C strategy) and within a regional model that is itself nested within a global model (the G-R-C strategy). Building on the success of the pilot work, the team will utilize these strategies to generate climatologies of CPSs and associated hazards over modern and future time periods.

Quantifying Climate Feedbacks from Abrupt Changes in High-Latitude Trace-Gas Emissions

Qianlai Zhuang, *Departments of Earth & Atmospheric Sciences and Agronomy*, with Adam Schlosser, *Massachusetts Institute of Technology*; Jerry Melillo, *Marine Biological Laboratory*; and Katey Walter, *University of Alaska, Fairbanks* (Funded by the Department of Energy)

The overall goal of this project is to quantify the potential for threshold changes in natural emission rates of trace gases, particularly methane and carbon dioxide, from pan-Arctic terrestrial systems under the spectrum of anthropogenically forced climate warming, and the extent to which these emissions provide a strong feedback mechanism to global climate warming. This goal is motivated by the premise that polar amplification of global climate warming will induce widespread thaw and degradation of permafrost, and would thus cause substantial changes in the extent of wetlands and lakes, especially thermokarst (thaw) lakes, over the Arctic.

Through a suite of global model experiments that encapsulate the fundamental processes governing methane emissions – as well as their coupling to the global climate system - the team will test the following hypothesis: A climate warming threshold exists beyond which permafrost degradation becomes widespread and instigates strong and/or sharp increases in methane emissions (via thermokarst lakes and wetland expansion). These emissions would outweigh any increased uptake of carbon (e.g., from peatlands) and would result in a strong, positive feedback to global climate warming.

Early Results: Impacts of Cloud-System Resolving Regional Modeling on the Prediction of Monsoon Depressions

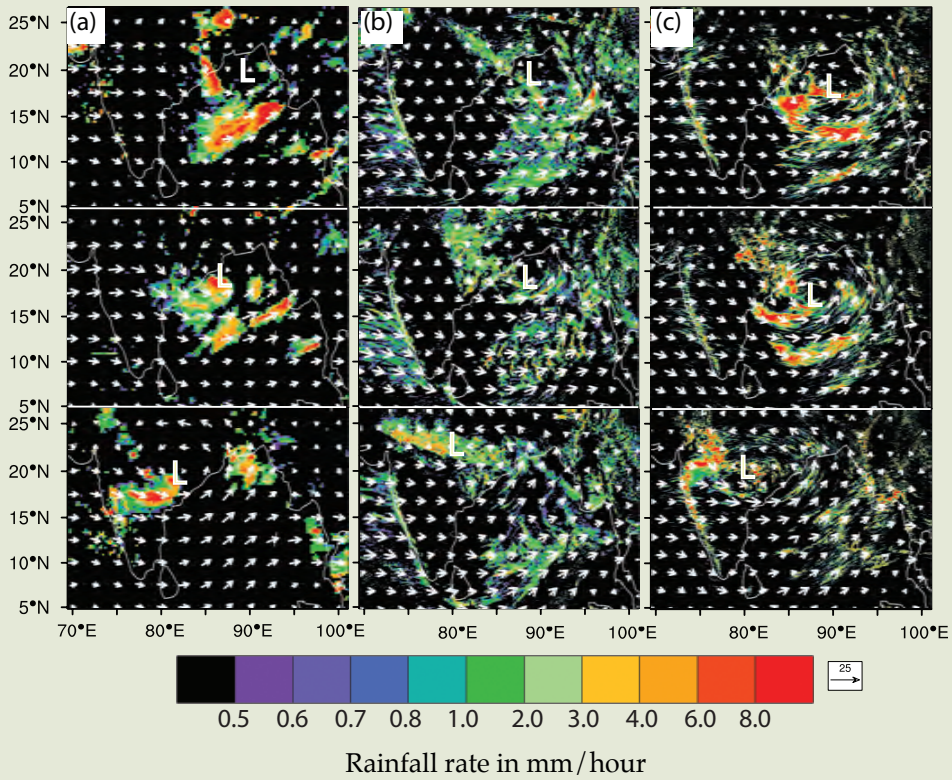
Professor Wen-wen Tung and graduate student Yi-Chi Wang, Department of Earth & Atmospheric Sciences

Monsoon depressions (MDs) are among the major precipitating systems during the south-Asian summer monsoon. Typically forming over the Bay of Bengal, these depressions could be highly destructive if they track over populated urban areas in India, Bangladesh or even Burma. In a devastating recent example, a monsoon depression in the Bay of Bengal formed into tropical cyclone Nargis, which killed over 140,000 people after making landfall on May 2, 2008 in Burma. Predicting the track and intensity of MDs in these highly populated regions of the world is vital, as is knowing the limits of predictability of these systems. With this information in hand, better response and adaptation strategies can be designed and implemented.

Previous studies have suggested that moist convection plays an important role in the growth and propagation of MDs. To address how a model's predictive utility for MDs is affected by the incorporation of better-resolved moist convection, we used the WRF-ARW model to examine the impacts of a regional cloud system-resolving model (CSRM).

Using global reanalysis (NCEP/NCAR) and satellite observations (TRMM 3B42) (panel a), it was found that the CSRM might not be required to capture MD genesis and its initial westward propagation as the coarser-resolution setup with cumulus parameterization performed just as well (panels b and c). However, the CSRM had a significantly improved predictive utility for the subsequent ~48-hour track and rainfall predictions (panel c). It corrected the northward track bias observed in the coarser-resolution hindcast. Such improvements might be attributed to a better simulation of energetics among the interacting multi-scale convective systems within the monsoon circulation.

The CSRM provided a means to examine the core structure of evolving and propagating monsoon depressions, which could help discriminate between the various genesis and maintaining mechanisms proposed for these systems.



This figure shows snapshots of 850-hPa wind vectors and rainfall rates at 0, 24, and 72 hours after 0900 UTC on Aug. 1, 2006, from top to bottom, (a) in NCEP/NCAR reanalysis and TRMM, (b) in two-domain hindcast, and (c) in CSRM hindcast. The 'L' indicates the center of the monsoon depression.

Acknowledgments:
This project has benefited from invaluable discussions with PCCRC members Profs. Noah Diffenbaugh, Harshvardhan, Dev Niyogi, and Jeff Trapp, as well as Ms. Hsin-I Chang. The research utilized computational facilities at the NCAR CISL and at the Purdue RCAC, and is supported by the U.S. NSF CMMI-0826119 and CMMI-0825311.

Project updates

Below is a listing of our previously funded (pre-2008) active projects, with select examples of recent results and work in progress.

1. Collaborative Research: Dynamics of Carbon Release and Sequestration: Case Studies of Two Early Eocene Hyperthermals - **Gabe Bowen**, *EAS*, with A. Winguth, *University of Wisconsin*; H. Stoll, *Williams College*; J. Zachos, *University of California, Santa Cruz*; K. Farley, *California Institute of Technology*; M. Pagani, *Yale University*; R. Zeebe, *University of Hawaii*; and T. Bralower, *The Penn State University* (NSF).

Work at Purdue has focused on coupled land-ocean carbon cycle feedbacks in response to global greenhouse warming at the Paleocene-Eocene boundary (55.5 million years ago). Records from continental and shallow marine sediments at sites in Wyoming, Utah, New Jersey, New Zealand, and the Arctic Ocean have been analyzed and show significant climate-induced shifts in rates and mechanisms of organic carbon burial that may have acted to stabilize and ultimately led to recovery of the climate system after ~3,000 billion tons of carbon were rapidly released to the atmosphere. Importantly, many of the mechanisms identified as controlling carbon burial changes in the coastal ocean at this time involve changes in the flux and mineralogy of sediment from the continents, a flux which humans have intensely perturbed in the modern. The award has supported work by EAS postdoc Aya Schneider-Mor and three Purdue undergraduate students.

2. Holocene Water Balance of the Northeastern Great Basin - **Gabe Bowen**, *EAS* (NSF)

Work on this project is providing new Holocene climate records from northeastern Utah that will improve understanding of the causes and history of drought in the western U.S. Results obtained thus far include the development of a new paleoclimate proxy based on the isotopic composition of the structural carbohydrate chitin preserved in the cysts of brine shrimp living in saline lakes, multi-substrate radiocarbon age models that reveal changes in Holocene sedimentation rates and storage of carbon within the Great Salt Lake Basin, and mineralogical records showing climate-driven fluctuations in sedimentary deposits within the Great Salt Lake. The project has supported work by EAS graduate students Kristine Nielson and Justin VanDeVelde as well as 2 Purdue undergraduate students.

3. Climate Variability and the Poor in Southern and Eastern Africa - **Thomas Hertel**, *Agricultural Economics* and **Noah Diffenbaugh**, *EAS* (World Bank TFESSD).

The world's poor are particularly sensitive to changes in the agricultural sector, both because the majority of the poor rely on agriculture for their livelihood, and because they spend a disproportionate share of their income on food. Work on this project is helping to quantify the impacts of climate variability and change on the world's poor on seasonal-to-decadal time-scales using a novel economic-climate analysis framework. This year, the team examined the potential economic influence of adverse climate events, such as heat waves, drought and heavy rains, on those in 16 developing countries. They find that extremes under present climate volatility increase poverty across the developing country sample - particularly workers in Bangladesh, Mexico and Zambia—with urban wage earners the most vulnerable group.

Ahmed, S. A., N. S. Diffenbaugh and T. W. Hertel, Climate Volatility Deepens Poverty Vulnerability in Developing Countries. *Environ. Res. Lett.*, 2009; 4: 3.

4. Natural Capital and Poverty Reduction **- Gerald Shively**, *Agricultural Economics* (USAID)

Throughout the developing world, common-pool resources such as forests, pastures, and water resources contribute in important ways to the well-being of rural populations. Field studies show that income from resource extraction accounts for up to half of total livelihood for many rural households. The importance of resource extraction is amplified in the presence of risk, and such risk is expected to intensify as future climate change precipitates more extreme weather events, especially in marginal agricultural areas. These observations motivate several questions that we are examining using a range of household and market survey data from Malawi, Uganda and elsewhere. These questions include: how important is the safety-net role of local natural resources for households experiencing idiosyncratic and covariate shocks? How does reliance on the commons for shock coping vary by household socioeconomic characteristics, market forces, and geographic factors? How does climate change influence these outcomes and how does resource use create feedbacks into the climate system? These are all questions with high policy relevance in the developing world and are closely related to national-government strategic policy objectives in our countries of focus.

During the past year the team has embarked on data collection to better document and understand the markets for charcoal and timber products and how household participation in these activities is influenced by weather risk and agricultural capacity. Three graduate students at Purdue are involved in the project: Christopher Chibwana, John Mazunda and Patrick Ward. Collaborators include researchers at Makerere University (Uganda), the University of Malawi, the International Food Policy Research Institute and the Norwegian University of Life Sciences.

Photo: Fuelwood being transported by bicycle outside Lilongwe, Malawi. Copyright (c) 2009 Gerald Shively.

5. Experimental Testbeds for New Applications of Environmental Trading Programs -**Timothy Cason**, *Economics*; John Stranlund and John Spraggon, *University of Massachusetts*; James Murphy, *University of Alaska*; David Porter, Stephen Rassenti and Vernon Smith, *Chapman University* (EPA).

6. Brown-rot Fungal Mechanisms as a Model for Biomass Saccharification - **Timothy Filley**, *EAS*; Jonathan Schilling and Robert Blanchette, *University of Minnesota* (DOE).

7. Soil Carbon Responses to Atmospheric CO_2 Enrichment - **Timothy Filley**, *EAS*; J. Jastrow, *Argonne National Laboratory*; T. Boutton, *Texas A&M*; M-G. Meler and R. Matamala, *University of Illinois, Chicago* (DOE).

8. Forest Structure and Biodiversity on a Steep Geophysical Gradient: the Cloud Forest Lee Margin - **Kerry Rabenold**, *Biological Sciences;* R. Lawton, R. Welch, U. Nair, *University of Alabama, Huntsville*, and W. Haber, *Missouri Botanical Gardens* (NASA).

The project supported the work of three biological sciences graduate students. All three students completed their studies this year: Keiller Kyle, Edge effects in tropical avian communities as harbingers of impacts of climate change (MSc 2008); Matthew Gasner, Stability of endemic bird populations in a tropical cloudforest and probable response to climate change (MSc 2008); and Meghan Lout, Interspecific competitive effects on ecological range boundaries in tropical thrushes (MSc 2009).

9. Exploration of the Mechanistic Relationship Between Improved Regional North American Inverse Carbon Fluxes and Climate Variability/Trends - K**evin Gurney**, *EAS and Agronomy* (DOE).

10. Collaborative Research: Impacts of Vegetation Change on Stabilization and Microbial Accessibility of Soil Organic Matter: A Microbiological, Isotopic and Molecular Study - **Timothy Filley**, *EAS*; Diane Stott, *National Soil Erosion Lab*; and Thomas Boutton, *Texas A&M* (NSF).

11. A Multiphase Study of the Nature, Sources, and Fate of Atmospheric Organic Nitrogen - **Paul Shepson**, *Chemistry* (NSF).

At the frontiers of science in the Arctic and Antarctica

12. Collaborative Research: Impact of Permafrost Degradation on Carbon and Water in Boreal Ecosystems," **Qianlai Zhuang**, *EAS and Agronomy*; J. Harden, *USGS Menlo Park*; R. Striegl, *USGS Denver*; Y. Shur, *University Alaska, Fairbanks*; D. Jorgenson, *Alaska Ecological Survey* (NSF).

This large-scale field and modeling study seeks to 1) assess interactive effects of climate change and fire on permafrost stability; 2) quantify how the varying modes of permafrost degradation initiate various thaw regimes on the landscape by affecting the microtopography, drainage, and soil thermal regimes of boreal systems; 3) determine how various thaw regimes such as drained or ponded systems affect carbon loss or accumulation in biomass and soils, and 4) characterize the export of dissolved organic carbon from watersheds in an effort to fingerprint the various thaw regimes induced by permafrost degradation.

Two field campaigns in years 2007 and 2008 have been completed at five study sites, with a third field season planned for summer, 2009. Temperature, moisture, and water table data will be collected to parameterize the physical conditions of each thaw regime and the team will test model results based on water melt chemistry and trace gas fluxes.

The process-based modeling system has been further developed to couple hydrology and heat conduction dynamics in soils and permafrost. The revised model has been applied to the Alaskan boreal forest and tundra ecosystems to examine changes in soil thermal and hydrological regimes and their impacts on plant phenology (Tang and Zhuang, 2009, in review, *Journal of Climatic Change*). The modeling system has explicitly considered the feedbacks between soil moisture and water table depth, and soil temperature profile and active layer depth, and PCCRC graduate student fellow Jinyun Tang served as lead author on the paper.

From January through mid-April, 2009, the OASIS (Ocean-Atmosphere-Sea Ice-Snowpack) program (www.oasishome.net) conducted an intensive field study in Barrow, Alaska. Paul Shepson, a co-organizer and executive committee member of OASIS, and members of his research group, including graduate students Chelsea Thompson and Travis Knepp, were in Barrow to study ozone depletion events.

Near-surface ozone depletion events at Arctic latitudes have been studied since their occurrence was first discovered in 1986. Following the onset of polar sunrise, background levels of ozone were observed to drop suddenly from a typical background of ~40 ppb to near zero within a matter of hours. These events could last for up to several days before ozone levels would recover. Soon after, it was discovered that low levels of ozone corresponded to high levels of bromine in the air. It is now generally understood that these ozone depletion events are caused by a chain reaction mechanism that involves molecular bromine and BrCl from surfaces photolyzing into reactive radical species which break down ozone while forming bromine oxide (BrO). Known colloquially as the "bromine explosion," the reaction sequence is catalytic and self-perpetuating, as the BrO radicals are able to self-react to reform molecular bromine.

Although this bromine chemistry has been tracked using spectroscopic methods, the radicals themselves have not been directly measured due to the inherent difficulty in measuring highly reactive species. Moreover, this chemistry is thought to also occur with chlorine radicals, though scant data exists on Cl or ClO levels during polar spring. In order to try to measure these species directly, the Shepson group utilized a unique flowing chemical reaction chamber coupled to a gas chromatograph to sample ambient air over the Arctic tundra near Barrow. Reacting the radicals instantaneously with reagent gases, turns them into stable compounds which can be chromatographically detected and quantified. This technique was first successfully used last year by Phil Tackett (PhD 2008) aboard the Amundsen research icebreaker. Data analysis for the Barrow campaign is in progress at this time. The photos to the right, from top to bottom, show Chelsea out on the snowpack, Paul and Travis with an instrumented buoy, and Arctic sunrise from the field site.

This work was supported by the following grants:

13. The Collaborative O-Buoy Project: Deployment of a Network of Arctic Ocean Chemical Sensors for the IPY and Beyond - **Paul Shepson**, *Chemistry*; P. Matrai, *Bigelow Laboratory*, J. Bottenheim, *Environment Canada*, U. Frieß, U. Heidelberg, D. Perovich, *CRREL*, and W. Simpson, *University of Alaska, Fairbanks* (NSF).

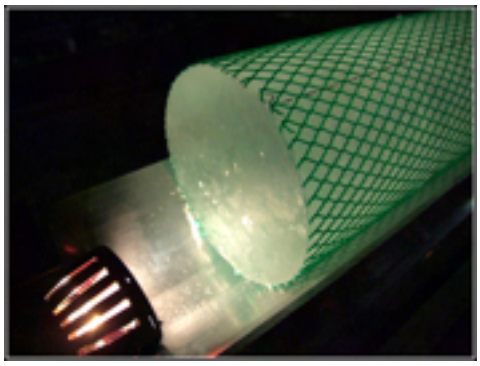
14. Computational and Laboratory Studies of Arctic Sea Ice Halogen Chemistry **Paul Shepson**, *Chemistry* (Camille and Henry Dreyfus Foundation).

15. Halogen Chemistry and Ocean-Atmosphere-Sea Ice-Snowpack (OASIS) Chemical Exchange During IPY **Paul B. Shepson**, *Chemistry* (NSF).

16. Collaborative Research: Synthesis of Arctic System Carbon Cycle Research through Model-Data Fusion Studies Using Atmospheric Inversion and Process-Based Approaches - **Qianlai Zhuang**, *EAS and Agronomy*, with D. McGuire, *University of Alaska, Fairbanks*; J. Melillo, *Marine Biological Laboratory*; and M. Follows, *MIT* (NSF).

To improve how we simulate and predict carbon dynamics in high latitudes, this project seeks to comprehensively analyze the carbon cycle of the Arctic system. An important factor to consider is wildfire frequency, and the team has made progress in this area, as reported in their paper, "Characterization of Wildfire Regimes in Canadian Boreal Terrestrial Ecosystems." The authors find that regional wildfires exhibit a robust power law relationship between the number of fires and burn area, which allowed for the estimation of fire return intervals for each spatial unit (ecozone).

Using a biogeochemistry model (the Terrestrial Ecosystem Model), the team also estimated net methane emissions from Arctic wetlands. Emissions from the entire Pan-Arctic region (45°N) during the period 1996-2006 were 51 Tg CH_4/year, with emissions of 11 Tg CH_4/year from Boreal North America and 29 Tg CH_4/year from Boreal Asia. The Arctic Basin releases

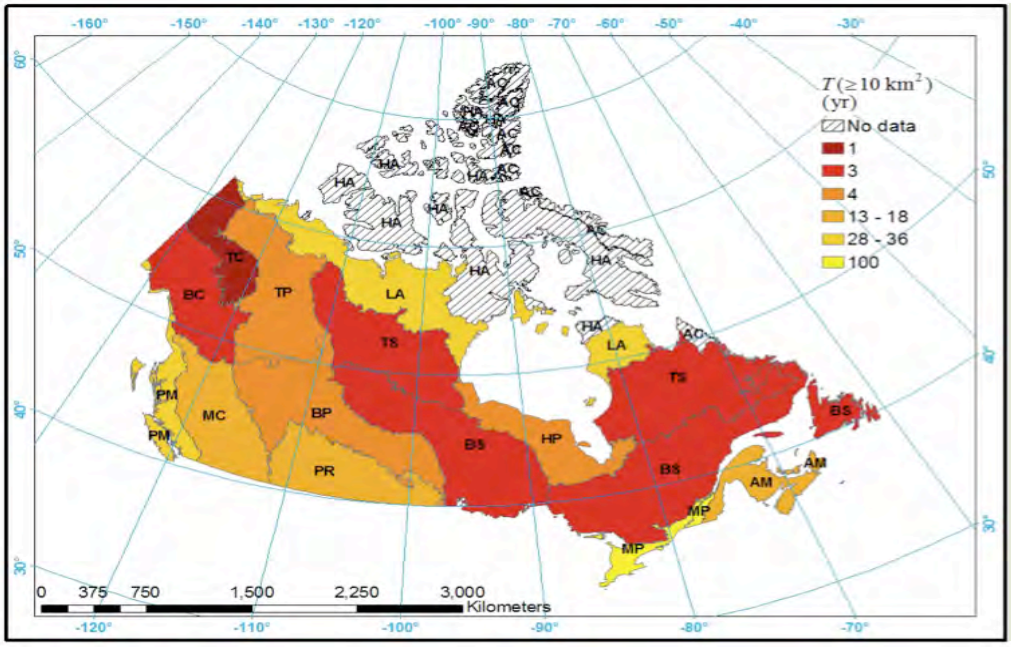


The ice core above was obtained during the WAIS 2008-2009 field season. The green netting is used to protect the ice. *Photo courtesy of NSF.*

approximately 38 Tg CH_4/year to the atmosphere, and the emissions grew on average by 0.5 Tg CH_4/year over the decade of analysis. Terrestrial methane emissions due to wildfires were 3.5 and 5 Tg CH_4/year for the Basin and the Pan-Arctic region, respectively. There is significant interannual variation in total emissions over the simulation period, with a peak in 1998 and the lowest emissions in 1997. In Boreal Asia, there is an increase trend while the emissions are stable in Boreal North America since 2001. Peak methane emissions consistently occur in July for the whole Pan-Arctic region. These process model simulations are in agreement with estimates obtained using a 3D inverse model methodology for the North American and Eurasian Arctic sectors.

17. Cosmogenic Nuclides on the West Antarctic Ice Sheet (WAIS)- **Marc Caffee,** *Physics and EAS* (NSF).

The West Antarctic Ice Sheet Divide Ice Core Project will reach down through 3,500 meters of ice and reveal 100,000 years of climate history. Essential to our understanding of past changes in atmospheric circulation and the Earth's magnetic field is the measurement of cosmogenic radionuclides. Long-lived radioisotopes such as beryllium 10 (^{10}Be) and chlorine 36 (^{36}Cl) are produced in the atmosphere by cosmic rays and deposited in accumulating snow. Current work on the project is focused on the measurement of 187 samples from the top 500 meters of core (in collaboration with Kuni Nishiizumi and Kees Welten at the Berkeley Space Sciences Laboratory). Beginning in June, 2009, ^{10}Be and ^{36}Cl will be measured using accelerator mass spectrometry at the Purdue Rare Isotope Measurement Laboratory.



Spatial distribution of fire recurrence intervals in Canada (1980-1999). The map to the left shows the recurrence intervals, T, in units of years for a fire that is equal to or larger than 10 km² in every 10,000 km² area. The two letter abbreviations are ecozone names in Canada. For more details, see Jiang et al., 2009.

Jiang, Y., Q. Zhuang, J. Little, and M. Flannigan, Characterization of Wildfire Regimes in Canadian Boreal Terrestrial Ecosystems, in press at *International Journal of Wildland Fire*.

18. Modeling Coherent Structures in Convective Boundary Layers - **Alexander Gluhovsky** *EAS and Statistics* and **Ernest Agee**, *EAS* (NSF).

Coherent structures (CSs) are organized motions that spontaneously arise, are long-lived, trap much energy, and they occur in dynamical systems of all kinds, including in the Earth's atmosphere and oceans. Turbulent convection in the atmosphere develops CSs called buoyant plumes, which under the effect of rotation, can turn into more dramatic events such as tornadoes and hurricanes. This project seeks to develop low-order models to capture the dynamics of CSs in convective boundary layers.

Describing turbulent flows with CSs is a formidable challenge. Turbulent flows with CSs are characterized by non-Gaussian statistics and are usually identified by values of skewness and kurtosis different from those for a Gaussian distribution (0 and 3, respectively). However, the accuracy of these measurements by conventional methods is low. The principal result of the team's latest work is the development of subsampling techniques for computing reliable confidence intervals (CIs) for the skewness and kurtosis as a viable alternative to current practices (see Gluhovsky and Agee, 2009). This led to proposing subsampling techniques to construct simultaneous confidence bands (SCBs) for trends in meteorological and climatological variables (a pilot version was presented at the European Geosciences Union conference). SCBs quantify the associated uncertainty, similar to CIs in classical statistics. The grant supported the work of 3 students, Han Wu (PhD), Erin Jones (MS), and Emily Cornett (undergraduate).

Agee, E., and E. Jones, 2009: Proposed Conceptual Taxonomy for Proper Identification and Classification of Tornado Events. *Wea. Forecasting*, 24, 609-617.

Gluhovsky, A., and E. M. Agee, 2009: Estimating higher-order moments of nonlinear time series. *J. Appl. Meteorol. Climatol.* (accepted for publication).

Gluhovsky, A., 2009: Subsampling confidence bands for trends in atmospheric time series. European Geosciences Union General Assembly 2009, Vienna, Austria. *Geophys. Res. Abstracts*, 11.

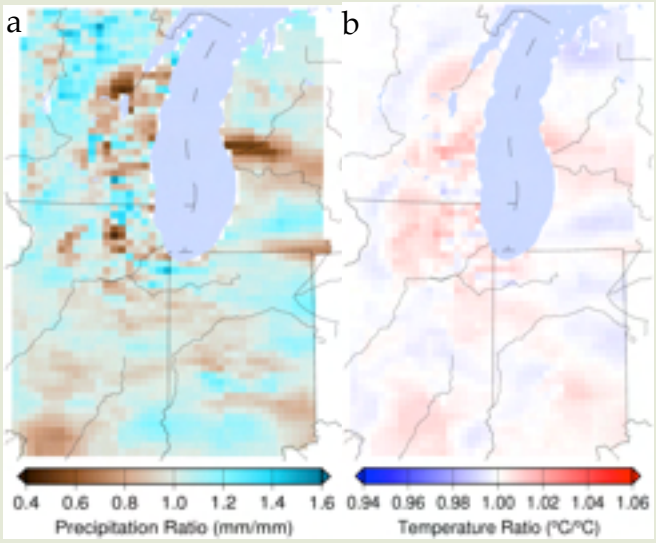
19. Urbanization Impacts on the Hydrometeorology of the Upper Great Lakes Region - **Laura Bowling**, *Agronomy*; **Keith Cherkauer**, *ABE*; **Bryan Pijanowski**, *FNR*; and **Dev Niyogi**, *Agronomy and EAS* (NASA).

This interdisciplinary project, beginning its third year of funding, addresses the impact of future urban growth on both meteorology and hydrology. Hydrologists have known for some time that through a reduction in infiltration and an increase in fast surface runoff, impervious area leads to a change in the character of river discharge. Similarly, recent research suggests that through increased heating and surface roughness, urban environments can increase convergence during convective events, impacting the magnitude and distribution of rainfall. For both of these, the role of the spatial arrangement, orientation and connectivity of urban development is unclear.

In the last year, land use projections have been completed for five year increments from 2010 to 2030 using the Land Transformation Model for the entire four state study area (Wisconsin, Michigan, Illinois and Indiana). Between 2010 and 2030, the largest rates of residential and commercial growth were forecast in Michigan. Agricultural and wetland areas decrease in all states, with some of the area replaced by forest re-growth in Wisconsin and Michigan.

The 2010 and 2030 land cover projections were used to specify the land surface characteristics for two applications of the Regional Atmospheric Modeling System (RAMS) model version 4.3 with the LEAF2 land surface scheme for a single convective storm event, on June 22, 2006. As shown in the figure below, the projected land cover change between 2030 and 2010 leads to heterogeneous changes in precipitation and temperature during this summer storm event. In general, areas of warming coincide with regions of precipitation decrease and cooling with precipitation increase. The spatial distribution in precipitation changes leads to differences in streamflow response, depending on the orientation of the contributing watershed relative to the urban area.

Streamflow has also been simulated for each scenario using the Variable Infiltration Capacity model with different land cover and weather inputs. For example, the Muskegon River in southern MI shows large changes in simulated peak streamflow due to projected precipitation increases, although the change in streamflow due to impervious area alone is small. In contrast, for the White River in Indianapolis, IN simulated changes in convective precipitation have negligible influence on the simulated hydrograph, but the impacts of increasing impervious area on infiltration are large.



For the storm event of June 22-24, 2006, the ratio of a) RAMS-simulated precipitation with 2030 land cover to simulated precipitation with 2010 land cover and b) RAMS-simulated temperature with 2030 land cover to simulated temperature with 2010 land cover.

20. Soil-Earthworm-Litter System Controls on the Stabilization of Organic Matter in Forests - **Timothy Filley**, *EAS*, and **Cliff Johnston**, *Agronomy*; Melissa McCormick, *Smithsonian Environmental Research Center*; Kathy Szlavecz, *The Johns Hopkins University;* Susan Crow, *University of Hawaii* (NSF).

Because soil acts as both a sink and a source for carbon, a detailed, mechanistic understanding of the controls on the conversion of litter organic matter and its subsequent stability in soil is critical to accurately account for the changing balance between the atmospheric, terrestrial plant, and soil carbon reservoirs. Surprisingly, earthworm (EW) activity, with its feedbacks to plant biopolymer alteration, enzymatic activity, and microbial community structure is generally not considered in studies of soil organic matter stabilization.

This project seeks to document and quantify how these protective mechanisms interact in natural and experimental systems impacted by different degrees of EW activity. This year, a preliminary study of EW activity and soil organic dynamics at the research forest at the Smithsonian Environmental Research Center (SERC) has been completed. The study focused on analyzing wood, root, and foliar biopolymer distributions among soil particle fractions to assess the competing controls that inherent plant chemistry, delivery rate, and earthworm activity might have in determining the chemical landscape measured at SERC. The results of the study (Crow et al., 2009) indicate that selective feeding on leaf body tissue by invasive earthworms contributes to a shift in the biopolymer composition of litter residue and that this chemical trajectory persists below ground in soil particulate organic matter (POM). Furthermore, the findings show that stand age, tree species and selective feeding by invasive earthworms all impacted POM composition in different manners, and should be considered together as aspects of forest succession that affect soil carbon chemistry and thus potentially influence carbon stabilization in soil.

Earthworm identification at the SERC field site.

Crow, S.E., T. R. Filley, M. McCormick, K. Szlavecz, D. E. Stott, D. Gamblin, G. Conyers, Earthworms, stand age, and species composition interact to influence particulate organic matter chemistry during forest succession. Biogeochemistry, (2009); 92:61-82.

21. Impacts of High Resolution Extreme Events on U.S. Energy Demand and CO_2 Emissions in the 21st Century - **Noah Diffenbaugh**, *EAS*, and **Kevin Gurney**, *EAS* and *Agronomy* (DOE).

The overall objective of this project is to build fundamental knowledge regarding the impact of weather extremes on particularly sensitive portions of the energy sector. This year, work focused on 1) developing present relationships between weather extremes and the heating/cooling demand of the U.S., 2) analyzing the statistics of daily-scale temperature and precipitation events, and 3) examining the intensification of heat stress.

Using the Vulcan fossil fuel CO_2 emissions inventory, the Gurney group constructed a framework to evaluate the relationship between the space heating CO_2 emissions of the Vulcan inventory and surface temperature, at an hourly resolution. The work focused on heating in the residential and commercial sectors, with cooling to be completed in the future.

Diffenbaugh and his group examined the ability of a high-resolution nested climate model RegCM3, to capture the statistics of daily-scale temperature and precipitation events over the conterminous U.S., using observational and reanalysis data for comparison. Their findings appear in a recent paper in *Climate Dynamics*. Briefly, the authors find that the analysis does capture the pattern of mean, interannual variability, and trend in tails of the daily temperature and precipitation distributions. Consistent biases were found, however, including wet biases in the western U.S. and hot biases in the southern and central U.S. These biases indicate that relatively subtle errors in the simulation of atmospheric circulation and surface energy and moisture fluxes can produce relatively large errors in the simulations of the statistics.

Using a suite of global and nested climate model experiments, the group quantified the the potential emergence of extreme heat in the U.S. Included in that suite is the first high-resolution, multi-decadal, ensemble climate model experiment for the United States ("the RCM ensemble"), as well as output from the CMIP3 climate model archive ("the GCM ensemble"). The hottest season of the 1951-1999 period was used as a metric for extreme heat. They find that the exceedence of this historical hottest-season threshold increases over the first four decades of the 21st century and that the pattern and magnitude of emerging heat stress in the coming decades is not dictated simply by the mean warm-season temperature change. In addition, they find that relative to the GCM ensemble, the RCM ensemble offers a more realistic representation of the magnitude and spatial heterogeneity of the warm-season temperature. This work was presented at the *International Scientific Congress on Climate Change* in Copenhagen, Denmark in March, 2009.

Walker, M.D. and N.S. Diffenbaugh, Evaluation of high-resolution simulations of daily-scale temperature and precipitation over the United States. *Climate Dynamics*, (2009) 10.1007/s00382-009-0603-y.

Seed Grant Program

The Center's seed grant program provides funding to encourage research and education activities involving cross-College collaborations and to catalyze interdisciplinary projects that have strong potential for subsequent extramural support.

Reciprocal Community Dynamics in Headwater Stream Ecosystems: Defining Ecological Roles and the Potential for Disruption via Climate Change

Reuben Goforth, *Forestry and Natural Resources*; Jeffrey Dukes, *Forestry and Natural Resources and Biological Sciences*; Timothy Filley, *Earth and Atmospheric Sciences;* Maria Sepúlveda, *Forestry and Natural Resources and Civil Engineering;* and Rod Williams, *Forestry and Natural Resources*

The central hypothesis of this work is that fishless headwater streams and their receiving watersheds will have diminished ecosystem functions and services as a result of climate change-mediated losses of stream-breeding salamanders. These salamanders are the chief predators in many fishless headwaters, and in general, predators have been shown to stabilize communities and increase species diversity in both empirical and theoretical studies. However, stream breeding salamanders are also potentially vulnerable to factors related to climate change, such as the rapid spread of an emerging infectious disease, chytridiomycosis. This disease can decimate amphibian populations and is particularly harmful to stream breeding amphibians. The loss of salamanders from headwater streams as a result of phenomena associated with climate change could have significant implications for headwater stream ecosystem biological community structure and stability, nutrient processing, and food web dynamics, both locally and in downstream areas.

This research team will address the potential for climate change to have widespread influence on headwater stream ecological function and ecosystem services by investigating: 1) the ecological roles of salamanders in stream community dynamics and nutrient processing, and 2) the potential susceptibility of stream-breeding salamanders to chytridiomycosis over a range of simulated climate change scenarios.

Explaining Participation in Environmental Meetings in Indiana

Linda Prokopy, *Forestry & Natural Resources*; Daniel Aldrich, *Political Science*; Shannon Amberg; *Forestry & Natural Resources;* and Janet Ayres, *Agricultural Economics*

Drs. Amberg, Aldrich, Ayres and Prokopy will undertake a study to understand what motivates people to participate in environmental meetings in Indiana. This will help us understand what can be done to get people to participate in solutions to climate change.

While many Federal procedures require input from affected citizens, average participation at local meetings concerning environmental issues is often quite low. Successful and sustainable solutions to global warming require greater levels of participation from our civil societies. Analyzing what facilitates or blocks local participation in meetings will help both scholars and decision makers think about the most effective procedures for maximizing citizen input. The PIs have also received a College of Agriculture mission oriented grant in support of this effort.

Prairie Carbon Offset Accounting

Helen Rowe, *Forestry & Natural Resources;* Joe Fargione, *The Nature Conservancy;* Cynthia Cambardella, *National Soil Tilth Laboratory;* Pauline Drobney, *USFWS*; and Jeff Dukes, *Forestry & Natural Resources and Biological Sciences*

Currently proposed legislation for a U.S. cap and trade system will likely require reduced uncertainty through scientifically-based, quantitative assessment of sequestration as justification for payments. Additional research is needed to develop credible and practical methods for measuring soil carbon sequestration in grasslands and to develop a model that can inform accurate and reliable carbon accounting in prairie soils.

Evaluating climate change mediated aquatic and terrestrial feedbacks in riparian ecosystems.

Investigating soil carbon dynamics during grassland to woodland transitions in the context of global change.

Increasing citizen input to create successful, sustainable climate change solutions.

The proposed work seeks to establish a robust soil carbon sampling design on an ongoing, multi-site, long-term, grassland restoration program via unique partnerships with The Nature Conservancy and their world's largest private network of grassland restorations, and the U.S. Fish and Wildlife Service and their long-term prairie restoration carbon sequestration project at Neal Smith National Wildlife Refuge, Iowa.

This work will allow for comparisons across the breadth of the tallgrass productivity gradient and across a large chronosequence of sites to build on existing soil carbon research in the areas of 1) the effects of grassland composition, productivity, and diversity, 2) saturation of carbon storage over time, 3) the effects of soil texture and soil type, and 4) the effects of climate.

Quantifying the Physical, Social and Economic Feedbacks Between Climate Change and Deforestation: A Framework for Comprehensive Decisionmaking

Kevin Gurney, *Earth & Atmospheric Sciences and Agronomy*; Matt Huber, *Earth & Atmospheric Sciences*; and Gerald Shively, *Agricultural Economics*

The proposed research will explore a more realistic evolution of deforestation scenarios and their coupling to the earth-atmosphere system through the integration of physical, biological, and human elements. Recent research has shown that large-scale deforestation can impact climate change through alterations in the carbon cycle, the water cycle and other aspects of the surface energy budget. However this work has yet to simulate realistic (patchy, human-driven patterns), time-dependent deforestation scenarios and has to drive these scenarios with socioeconomic drivers, which themselves are influenced by climate.

Towards this end, the team will embed a constrained optimization model of tropical land socioeconomic behavior into the CCSM4 model suite. The addition of a socioeconomic module will allow us to drive land-use by opportunity cost measurements associated with timber, agricultural products, product market prices, and other variables such as spatial constraints, fire, policies, social norms, etc. Most importantly, these socioeconomic variables will be directly and indirectly influenced by the climate.

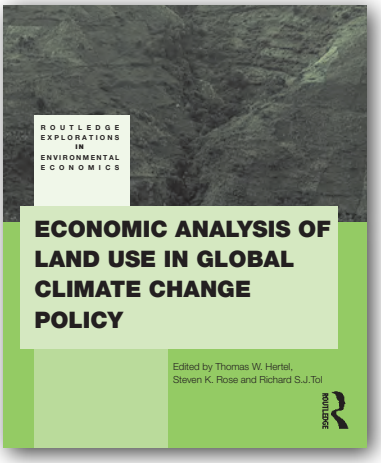
Microbial and Soil Faunal Linkages Controlling Soil Carbon Dynamics During Grassland to Woodland Transitions.

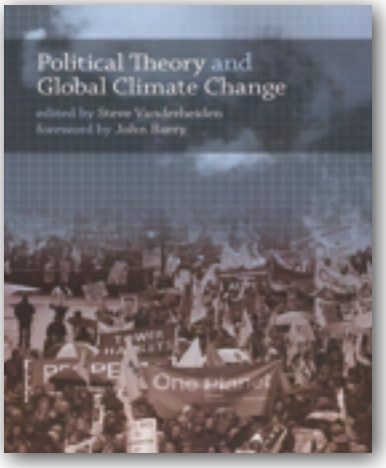
Timothy Filley, *Earth and Atmospheric Sciences*; Ron Turco, *Agronomy*; and Cliff Johnston, *Agronomy*.

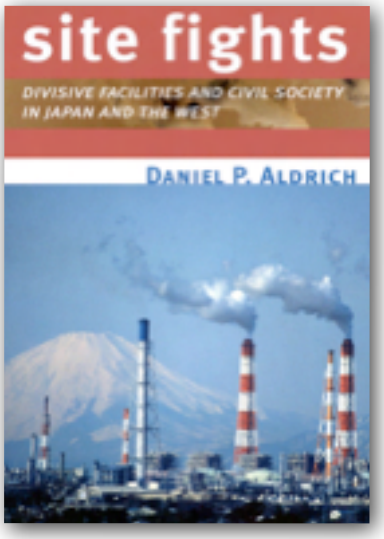
C3-woody plant encroachment (WPE) into C4-grasslands and savannas is a widespread phenomenon that alters soil organic carbon (SOC) dynamics through changes to the mode, chemistry, and rate of litter inputs. This land cover change has occurred in many grassland regions around the world over the last 100–150 years and is caused largely by livestock grazing and fire suppression, which favor the establishment and expansion of woody plants. At the global level, impacts to SOC resulting from this phenomenon are of great interest given that grasslands and savannas account for ~35% of the global terrestrial net primary productivity. Controls on the magnitude and direction of the impact of WPE on SOC stocks remain controversial; field observations demonstrate a variety of responses ranging from accrual to losses of SOC compared to pre-encroachment level. For a soil to accrue SOC over the long-term, organic matter inputs must exceed the rate of decomposition and the system must possess mechanisms to stabilize plant detritus in pools with relatively slow turnover times. The activity and structure of the soil microbial and faunal community is a fundamental control on the chemical trajectory and rate soil carbon stabilization/destabilization. These microbial controls are an active field of study but the direct relationship to the nature of carbon accrual is unknown.

The PIs will investigate the direct activity and microbial community structure through a chronosequence of woody plant encroachment at the LaCopita Research Station located in the Rio Grande Plains of southern Texas to determine the control of specific microbial groups on the documented accrual patterns. They will use a combination of phospholipids and stable carbon isotopes analyses on soils collected from the research site.

New Books







Economic Analysis of Land Use in Global Climate Change Policy

Land has long been overlooked in economics. That is now changing. A substantial part of the solution to the climate problem may lie in growing crops for fuel and using trees for storing carbon. This book investigates the potential of these options to reduce greenhouse gas emissions, estimates the costs to the economy, and analyzes the trade-offs with growing food. It presents new databases that are necessary to underpin policy-relevant research in the field of climate change while describing and critically assessing the underlying data, the methodologies used, and the first applications.

Together, the new data and the extended models allow for a thorough and comprehensive analysis of a land use and climate policy. This book outlines key empirical and analytical issues associated with modeling land use and land use change in the context of global climate change policy. It places special emphasis on the economy-wide competition for land and other resources, especially 1) the implications of changes in land use for the cost of climate change mitigation, 2) land use change as a result of mitigation, and 3) feedback from changes in the global climate to land use.

By offering synthesis and evaluation of a variety of different approaches to this challenging field of research, this book will serve as a key reference for future work in the economic analysis of land use and climate change policy.

Thomas Hertel is Executive Director and founder of the Global Trade Analysis Project at Purdue and Professor of Agricultural Economics. **Steven Rose** is a key researcher of the US Environmental Protection Agency. **Richard S. J. Tol** is Research Professor at the Economic and Social Research Institute, Ireland.

Political Theory and Global Climate Change

There is a growing area of scholarship concerned with the appropriate rights and duties of individuals and nations with respect to complex global problems like climate change, problems that threaten to become more common in the future. The book argues that the conceptual tools of political theory can help us understand the obstacles to fair and effective global climate change policies, and offers a selection of innovative and integrative scholarly efforts to do so. In his chapter, "Allocating the Global Commons," Leigh Raymond reflects on past experiences with distributing global common pool resources and what those experiences suggest for political theorists trying to find an ethical and politically viable method of distributing the atmosphere's ability to absorb greenhouse gases.

Leigh S. Raymond is Associate Director of the Purdue Climate Change Research Center and Associate Professor of Political Science.

Site Fights: Divisive Facilities and Civil Society in Japan and the West

One of the most vexing problems for governments is building controversial facilities that serve the needs of all citizens but have adverse consequences for host communities. Policymakers must decide not only where to locate often unwanted projects but also what methods to use when interacting with opposition groups. In Site Fights, Daniel Aldrich gathers quantitative evidence from five hundred municipalities across Japan to show that planners deliberately seek out acquiescent and unorganized communities for such facilities in order to minimize conflict.

When protests arise over nuclear power plants, dams, and airports, agencies rely on the coercive powers of the modern state, such as land expropriation and police repression. Only under pressure from civil society do policymakers move toward financial incentives and public relations campaigns. Through fieldwork and interviews with bureaucrats and activists, Aldrich illustrates these dynamics with case studies from Japan, France, and the United States. The incidents highlighted in Site Fights stress the importance of developing engaged civil society even in the absence of crisis, thereby making communities both less attractive to planners of controversial projects and more effective at resisting future threats.

Daniel Aldrich is Assistant Professor of Political Science.

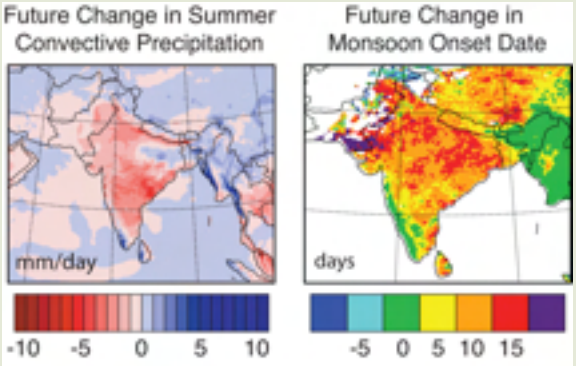
Journal Articles

This year's peer-reviewed publications and highlights from selected papers in which our graduate students served as lead authors are listed. Purdue students' names are underlined, and Purdue authors appear in bold.

- Abbot, D. S., **M. Huber**, G. Bousquet, and C. C. Walker, High-CO_2 cloud radiative forcing feedback over both land and ocean in a global climate model. *Geophysical Research Letters,* (2009); 36, L05702.
- **Agee, E**. and **E. Jones**, Proposed conceptual taxonomy for proper identification and classification of tornado events. *Weather and Forecasting,* (2009); 24:2, 609-617.
- **Andrysco, N**., **K.R. Gurney**, **B. Beneš**, K. Corbin, Visual exploration of the Vulcan CO_2 data. *Computer Graphics and Applications*, (2009); 29:1, 6-11.
- Boutton, T.W., J.D. Liao, **T.R. Filley**, S.R. Archer, Belowground carbon storage and dynamics accompanying woody plant encroachment in a subtropical savanna. Soil Carbon Sequestration and the Greenhouse Effect (R. Lal and R. Follett, eds.) Soil Science Society of America, Madison, WI. pp181-209 (2009).
- **Bowen, G.J**., J.B. West, B.H. Vaughn, T.E. Dawson, J.R. Ehleringer, M.L. Fogel, K.A. Hobson, J. Hoogewerff, C. Kendall, C.T. Lai, C.C. Miller, D. Noone, H.P. Schwarcz, and C.J. Still, Isoscapes to address large-scale Earth science challenges. *Eos,* (2009); 90, 109-116.
- Castañeda, I.S., J. P. Werne, T. C. Johnson, and **T. R. Filley**, Late Quaternary vegetation history of southeast Africa: The molecular isotopic record from Lake Malawi. *Palaeogeography, Palaeoclimatology, Palaeoecology,* (2009); 275, 100–112.
- **Crow, S.E**., **T. R. Filley**, M. McCormick, K. Szlavecz, **D. E. Stott**, **D. Gamblin, G. Conyers**, Earthworms, stand age, and species composition interact to influence particulate organic matter chemistry during forest succession. *Biogeochemistry,* (2009); 92:61-82.

Approximately half of the world's population depends on the Asian monsoon rains for agriculture, drinking water, and hydroelectric power generation. The rains provide 90% of India's water supply and 75% of the total rainfall in much of the region. Future monsoon activity is typically studied using general circulation models (GCMs). While these models capture large-scale climate features, they are not as capable of representing fine scale processes.

Applying a high resolution nested climate model, graduate student Moetasim Ashfaq (PhD, August 2009) and collaborators were able to improve the representation of fine-scale dynamics associated with physiographic complexity, land cover heterogeneity, and atmospheric convection to study the response of South Asian summer monsoon dynamics to climate change. Their model simulations project a delay in the start of monsoon season from 5-15 days along with an overall weakening of summer monsoon precipitation, and longer breaks between rainy periods. Their findings also indicate an eastern shift in monsoon circulation which would result in more rainfall over the Indian Ocean, Bangladesh, and Myanmar and less rain over India, Pakistan and Nepal. The paper highlights the importance of spatial complexity in the climate response and argues for improved understanding of climate processes.



These maps show projected future changes in South Asian summer precipitation and monsoon onset date. A Purdue-led team found that rising future temperatures could lead to less rain and a delay in the start of monsoon season by up to 15 days by the end of the 21st century.

- **Ashfaq, M**., Y. Shi, **W.-w. Tung**, **R. J. Trapp**, X. Gao, , J. S. Pal, **N. S. Diffenbaugh**, Suppression of South Asian summer monsoon precipitation in the 21st century. *Geophysical Research Letters*, 2009, 36(1): L01704.

- **Diffenbaugh, N. S.**, F. Giorgi, J. S. Pal, Climate change hotspots in the United States. *Geophysical Research Letters,* (2008); 35, L16709.

- **Diffenbaugh, N.S.**, **C. H. Krupke**, M. A. White, **C. E. Alexander**, Global warming presents new challenges for maize pest management. *Environmental Research Letters,* (2008); 3/4 044007.

- **Diffenbaugh, N.S.**, **R. J. Trapp**, H. E. Brooks, Does global warming influence tornado activity? *Eos,* (2008); 89(53), 553-554.

- **Diffenbaugh, N.S.**, Influence of modern land cover on the climate of the United States. *Climate Dynamics*, (2009); 10.1007.

- Eldrett, J. S., D. R. Greenwood, I. C. Harding, and **M. Huber**, Increased seasonality through the Eocene to Oligocene transition in northern high latitudes. *Nature,* (2009); 459, 969-973 (18 June 2009).

- Geib, S.M., **T. R. Filley**, P. G. Hatcher, K. Hoover, J. E. Carlson, M. del Mar Jimenez-Gasco, A. Nakagawa-Izumi, R. L. Sleighter, M.Tien, Lignin degradation in wood-feeding insects. *Proceedings of the National Academy of Sciences,* (2009); 105(35): 12932-12937.

- Giorgi, F., **N. S. Diffenbaugh**, X. J. Gao, E. Coppola, S. K. Dash, O. Frumento, I. Seidou Sanda, S. Rauscher, A. Remedio, A. Steiner, B. Sylla, A. Zakey, The regional climate change hyper-matrix framework. *Eos,* (2008); 89(45), 445-446.

- **Gurney, K. G.**, **D. L. Mendoza**, **Y. Zhou**, M. L. Fischer, **C. C. Miller**, S. Geethakumar, S. de la Rue du Can, High resolution fossil fuel combustion CO_2 emission fluxes for the United States. *Environmental Science & Technology,* (2009); 43(14), 5535-5541.

- **Gurney, K. R.**, D. Baker, P. Rayner, S. Denning, Interannual variations in continental-scale net carbon exchange and sensitivity to observing networks estimated from atmospheric CO_2 inversions for the period 1980 to 2005. *Global Biogeochemical Cycles,* (2008); 22, GB3025.

- Jackson, R. B., J. T. Randerson, P. Canadell, R. Anderson, R. Avissar, D. D. Baldocchi, G. B. Bonan, K. Caldeira, **N. S. Diffenbaugh**, C. B. Field, B. A. Hungate, L. M. Kueppers, D. E. Pataki, Protecting climate with forests. *Environmental Research Letters,* (2008); 3/4/044006.

- **Jankowski, J. E.**, **A. L. Ciecka**, **N. Y. Meyer** and **K. N. Rabenold**, Beta diversity along environmental gradients: implications of habitat specialization in tropical montane landscapes. *Journal of Animal Ecology*, (2009); 78, 315–327.

- Liu, Z., M. Pagani, D. Zinniker, R. DeConto, **M. Huber**, H. Brinkhuis, S. Shah, R.M. Leckie, A. Pearson, Global cooling during the Eocene-Oligocene Climate Transition. *Science,* (2009); 323(5918): 1187–1190.

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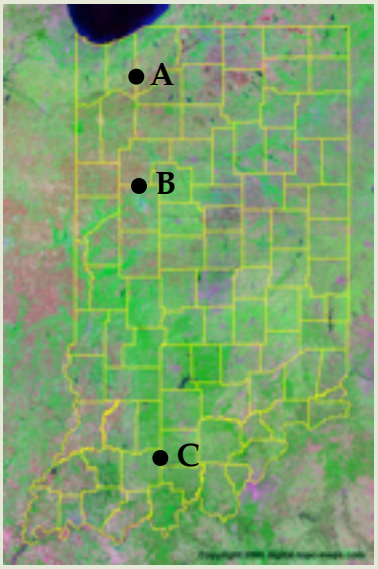
The seasonal freezing and thawing of soils impacts the exchange of energy and water between the land surface and overlying atmosphere. How seasonal freeze/thaw cycles respond to a changing climate system and how climate, in turn, will be affected by the freeze/thaw patterns of the soils are active areas of investigation. In this study, graduate student Tushar Sinha (PhD, 2008) and his advisor Keith Cherkauer, test for the presence of significant trends in soil freeze–thaw cycles and soil temperatures at several depths and compare these with other climatic variables including air temperature, snowfall, snow cover, and precipitation. Data for the study were obtained from three research stations located in northern, central, and southern Indiana that have collected soil temperature observations since 1966.

Observations from 1967 to 2006 indicate that air temperatures during the cold season are increasing at all three locations, but there is no significant change in seasonal and annual average precipitation. At the central and southern Indiana sites, soil temperatures are generally warming under a bare soil surface, with significant reductions in the number of days with soil frost and freeze–thaw cycles for some depths. Meanwhile, 5-cm soils at the northernmost site are experiencing significant decreases in cold season temperatures, as an observed decrease in annual snowfall at the site is counteracting the increase in air temperature. Seasonal mean maximum soil temperatures under grass cover are increasing at the southernmost site; however, at the central site, it appears that seasonal minimum soil temperatures are decreasing and the number of freeze–thaw cycles is increasing.



The map shows the location of the three Indiana research stations collecting soil temperatures and other meteorological data since 1966: (A) PPAC near Wanatah, (B) ACRE near West Lafayette, and (C) SIPAC near Dubois.

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Widespread coral bleaching in the tropics is predicted to increase in the future due to rising ocean temperatures. A recent study has proposed that reefs in the Western Pacific Warm Pool (WPWP) are protected by an ocean "thermostat" that limits the maximum sea surface temperature (SST) in this warm region of the Pacific. This was based in part on the observation of anomalously low levels of coral bleaching in the WPWP compared to other tropical regions.

In their paper, ***Equivocal evidence for a thermostat and unusually low levels of coral bleaching in the Western Pacific Warm Pool***, graduate student Ruben van Hooidonk (PhD, 2009) and his advisor Matt Huber analyze WPWP SST trends and coral bleaching using HadISST data and a coral bleaching database to explore the concept of a natural ocean thermostat. The authors do not find a physical basis or geologic evidence of a thermostat in the WPWP. Because there are very few observations of coral reefs in the WPWP (bleached or not), the low number of bleaching events are most likely due to underreporting from this remote region. Their work concludes that there is insufficient evidence to support the concept of a thermostat in the WPWP.

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People

As a faculty-led center, we know that our strength derives from the scholarship, creativity, and energy of our members. The PCCRC was founded by a group of 12 faculty members representing 8 academic units across campus and has since grown to include 54 active members from 16 departments.

Our newest members

Daniel Aldrich, Assistant Professor, Department of Political Science

Professor Aldrich's research focuses on the resilience of post-disaster communities especially the role played by local networks and social capital. In an era where the long term cumulative effects of global warming are becoming clear, and the impact upon coastal communities around the world will become only more severe, we need a better understanding of why certain cities and neighborhoods display resilience while others do not. Based on his fieldwork in India, Japan, and the United States, Daniel seeks to provide both a theoretical model for recovery and concrete policy recommendations.

Nancy Emery, Assistant Professor of Biological Sciences and Botany and Plant Pathology

Professor Emery joined the department of Botany and Plant Pathology in August, 2008. She is interested in the evolution of the ecological niche, and how ecological processes shape the evolutionary trajectories of populations and species. Nancy's research integrates community ecology, population biology, and phylogenetics; she uses field experiments, molecular methods, anatomical techniques, and comparative methods to address a variety of questions about the evolution of the ecological niche in plant populations and species.

Ben Gramig, Assistant Professor of Agricultural Economics

Professor Gramig's research activities are focused primarily on environmental and natural resource economics. He has a strong interest in the interface between agriculture and the environment; his work is motivated by public policy and the role of human activity in environmental change. Ben's research interests center on decision making under uncertainty, information economics, climate change, markets for environmental goods and services, invasive species management, and spatial dimensions of environmental and natural resource management.

Thomas Hertel, Professor, Department of Agricultural Economics and Executive Director, GTAP

Professor Hertel is Distinguished Professor of Agricultural Economics. He teaches and conducts research on the economy-wide impacts of trade and environmental policies. His most recent research has focused on the impacts of energy and climate policies on global land use. This has been the subject of a long term project with the US-Environmental Protection Agency, culminating in a book on climate policy and global land use. In addition, Tom has conducted extensive research on the linkages between global trade policies and poverty in developing countries. During the 2004/5 year he was on sabbatical leave with the Trade Research Group of the World Bank, where he completed a book on the poverty impacts of a WTO agreement.

Mark Tilton, Associate Professor, Department of Political Science

Professor Tilton's research is in the field of comparative political economy, with a specialization in Japan. He has worked on antitrust and regulatory policy and is currently researching climate change policy. Mark's teaching is also in the area of comparative and East Asian politics.

Hao Zhang, Professor, Department of Statistics and Forestry & Natural Resources

Professor Zhang's current research centers on the analysis of spatial and space-time data. These kinds of data are being observed in many fields such as climatology, geophysics, geology, natural resources, agriculture, health sciences, economics, and marketing. Technological advances have made it feasible to collect and archive space-time data at large scales that were not possible just a decade ago. These massive and correlated data create challenging and interesting statistical problems, and demand innovative computational and methodological research.

PCCRC Membership

Agronomy: Laura Bowling, Melba Crawford [1], Richard Grant, Cliff Johnston, Dev Niyogi [2], and Ronald Turco

Agricultural & Biological Engineering: Indrajeet Chaubey [2], Keith Cherkauer, and Rabi Mohtar

Agricultural Economics: Otto Doering, Ben Gramig, Thomas Hertel, Edna Tusak Loehman, Gerald (Jerry) Shively, and Wally Tyner

Biological Sciences: Kerry Rabenold

Botany & Plant Pathology: Nancy Emery [5]

Building & Construction Management: Kirk Alter

Chemistry: Paul Shepson

Civil Engineering: Larry Nies, Suresh Rao [4]

Earth & Atmospheric Sciences: Ernest Agee , Michael Baldwin, Gabriel Bowen, Noah Diffenbaugh, Timothy Filley, Alexander Gluhovsky[3], Kevin Gurney [4], Jennifer Haase, Harshvardhan, Matthew Huber, Sonia Lasher-Trapp, Greg Michalski, R. Jeffrey Trapp, Wen-wen Tung, Qianlai Zhuang[4]

Economics: Timothy Cason

Forestry and Natural Resources: Jeffrey Dukes [5], Reuben Goforth, Bryan Pijanowski, Linda Prokopy, Helen Rowe, Guofan Shao, and Robert Swihart

IT Discovery Resources: Gilbert Rochon[2]

Mechanical Engineering: Jay Gore, Greg Shaver

Political Science **:** Daniel Aldrich, Elizabeth McNie [2], Leigh Raymond, and Mark Tilton

Sociology: Martin Patchen

Statistics: Hao Zhang [6]

Executive Committee

Otto Doering, Interim Director (October 1, 2009-present).

Laura Bowling

Noah Diffenbaugh, Interim Director (Sept 1, 2008-September 30, 2009).

Timothy Filley

Richard Grant

Matthew Huber

Larry Nies

Kerry Rabenold

Leigh Raymond, Associate Director

Gerald Shively

Jeff Trapp

Ronald Turco

Administrative Staff

Glenda Bauer, Secretary

Rose Filley, Managing Director

[1] joint appointment in Civil Engineering; [2] joint appointment in Earth & Atmospheric Sciences; [3] joint appointment in Statistics; [4] joint appointment in Agronomy; [5] joint appointment in Biological Sciences; [6] joint appointment in Forestry & Natural Resources.

Jeff Trapp leads the Doppler on Wheels, or DOW, branch of the VORTEX 2 field project. The DOW are a fleet of mobile weather radars used to collect data from underneath and within supercell thunderstorms and tornadoes. Two of Trapp's students and three student volunteers from Purdue also are participating in the study. The DOW team plans to use the data they collect to improve the accuracy of the tornado record and to develop methods to better use available weather data for tornado prediction.

In the photo above, members of the Doppler on Wheels team stand in front of its research vehicle. From left are postdoctoral researcher Karen Kosiba; student Andrew Arnold; Jeff Trapp, associate professor of earth and atmospheric sciences; and students Jacob Carley and Kevin Burris (missing is Mallie Toth).

LAUNCHING TOMORROW'S LEADERS

As we work to ready our students for the challenges of the 21st century, the PCCRC strives to create a learning environment that introduces students to interdisciplinary thinking and fosters the development of cross-disciplinary interactions and collaborations.

Enriching Experiences

The success of our students is a top priority. The Center supports and enhances the activities of our faculty, and has created new resources to help develop our students into future junior colleagues.

Fall Poster Session and Mixer

A primary goal of the PCCRC is to establish and maintain good, direct communication between researchers from diverse backgrounds who share a common interest in climate change. To facilitate these cross campus interactions and collaborations, the Center hosted a poster session and fall mixer on Friday, November 21, 2008 in the Pfendler Hall Gallery. In a relaxed and informal atmosphere, over 75 faculty, students, post-docs, and staff gathered to learn about the great variety of climate change research taking place at Purdue. In all, 23 student posters were presented by graduate students from the Departments of Agricultural Economics, Chemistry, Earth & Atmospheric Sciences, Electrical and Computer Engineering, and Forestry & Natural Resources.

To honor the years of inspiration, leadership, and service that Paul Shepson (PCCRC founding director) has given to the campus climate community, the ***Paul B. Shepson Award*** was initiated to recognize outstanding graduate student research.

This year, the Shepson Award was given to the best graduate student presentation at the fall poster session. Courtney Creamer (EAS doctoral student) won the inaugural Shepson Award for her poster, "Microbial accessibility of soil organic matter following woody plant encroachment into grasslands."

"Attending the AGU fall meeting afforded me the opportunity to interact with the larger scientific community, meet with several individuals to discuss postdoctoral positions, and while presenting my current research, discuss new collaborations with scientists from the USDA...these opportunities would not have been possible without funding from the PCCRC."

Joe Alfieri (PhD, August 2009)

Travel Grant Program

To help support the professional development of our students, the PCCRC instituted a Student Travel Grant Program. Through this program, the Center provides funding to help graduate students defray the cost of presenting their scholarly work at professional conferences or workshops. Awards were given to seven students this academic year: Joseph Alfieri (Agronomy), Vidya Appukuttan-Suseela (Forestry & Natural Resources), Dolaporn Auyeung (Forestry & Natural Resources), Kendra Castillo (Earth & Atmospheric Sciences), Courtney Creamer (Earth & Atmospheric Sciences), Doug Martins (Earth & Atmospheric Sciences), and Philip Tackett (Chemistry).

Student Recruitment

This year, PCCRC and the Department of Earth & Atmospheric Sciences co-hosted a Purdue Reception at the fall meeting of the American Geophysical Union (AGU). Alumni, friends and students were invited to attend the open event, held at The Thirsty Bear restaurant in San Francisco, CA. Particular effort was made to invite prospective graduate students and post-doctoral researchers to introduce them to our faculty and current students in a casual and welcoming setting.

The evening was a huge success; providing a venue to renew old acquaintances, make new ones, and to celebrate the appointment of Suresh Rao as Purdue's newly elected AGU Fellow. Plans are underway to make this an annual event at the AGU fall meeting.

Purdue graduate students Kelly Ross, Mariya Petrenko, and Paytsar Muradyan chat with a prospective student at the Purdue AGU Reception.

Sara collects samples at the sweetgum FACE site in Oak Ridge, Tennessee.

Camille spends time with Mbeere farmers in Ndunduri, Kenya.

Chelsea out on the ice in Barrow, Alaska.

Field Work

Many PCCRC students participate in field research which can range from day trips to local sites to year-long stays in rural Kenya. In this section read about some recent examples of our students' field experiences.

Graduate student **Sara Top** (*Purdue University Life Sciences* and *EAS doctoral student*) is working on a comparative study of the role of invasive earthworms in processing above and below ground productivity in a high CO_2 environment. Sara's field sites include the Aspen and Sweetgum FACE (Free Air CO_2 Enrichment) plantations in Rhinelander, Wisconsin and Oak Ridge, Tennessee, respectively. Sara also plans to sample from the forests on the Red Lake Band of Chippewa Reservation in Minnesota.

Camille Ottombre-Washington (*FNR doctoral student*) spent a year in Embu, on the slopes of Mt. Kenya, Kenya. Using an integrated methodology, Camille is analyzing the effects of climate change on local agrosystems over time (1918-2050) and across space (from the household to the landscape level). Camille's four study sites are spread over the slopes of Mt. Kenya and represent a variety of climatic conditions, from humid to semi-arid. By combining life stories interviews, archival work, key informant interviews, focus groups, surveys on social networks and participation, role-playing games, a neural network model, and an agent-based model, this work will analyze the adaptive capacity of agrosystems to climate change and variability.

From January to April, 2009, **Chelsea Thompson** (*Chemistry doctoral student*) participated in the Ocean-Atmosphere-Sea Ice-Snowpack 2009 field campaign in Barrow, Alaska. Chelsea's research focuses on making atmospheric measurements of halogen radicals that are produced from photochemical reactions on the snowpack, sea ice, and sea salt aerosols. Initiated during polar sunrise, these halogen radicals are an important species in the Arctic troposphere because they greatly enhance the atmosphere's oxidative capacity. An example is the halogen-induced oxidation of gaseous elemental mercury to more reactive forms, which enhances its bioavailability. Chelsea's primary interest is in documenting how bromine contributes to the episodic ozone destruction events that have been observed in Polar regions.

New Courses

Topics in Paleoclimatology

Instructor: Gabriel Bowen

Course Description: Stable isotopes and radionuclides have been used in studies of the water cycle for more than 50 years, and form the foundation of methods now commonly used for tracing hydrological fluxes, dating groundwaters, and probing the biogeochemistry of hydrological systems. This mixed-format course (~2/3 lecture, 1/3 discussion) introduces isotopic methods used in water cycle research, with a focus on critical review of the theoretical basis for each method, and provides opportunities for group discussion of current literature employing these methods. Students develop an understanding of quantitative analysis of isotopic data through several problem sets involving recent data from the literature.

Trends, Extremes & Predictability

Instructor: Alexander Gluhovsky

Course Description: This interdisciplinary course combines topics of intense development in time series analysis, extreme value theory, and nonlinear dynamics to understand predictability and other weather and climate issues.

Literature Club

Literature Club doubled this year as **Topics in Climate Change,** a 2 credit course listed in 6 departments (ABE, AGEC, AGRY, BCM, BIOL, and EAS). Students enrolled in the class took an active role in choosing the papers and facilitating the discussions.

Fellow updates

Each year PCCRC awards up to two fellowships to recruit outstanding doctoral students to Purdue. In this section, meet our Fellows and read about their progress.

Yini Ma, 2008 Fellow

Yini Ma joined the department of Earth & Atmospheric Sciences (EAS) as a graduate student interested in ecosystem and global climate change. She is working on soil carbon stabilization with her advisor, Prof. Timothy Filley. Specifically, Yini will focus her attention on how invasive earthworms (both exotic and native) and past land use influence soil aggregation and carbon stabilization processes. Since arriving in fall, 2008, Yini has made excellent progress in both course work and her research. In November 2008, she participated in the PCCRC and ESE Symposium poster sessions and presented preliminary results from her first field season, as well as an outline of her future research: "Soil-Earthworm-Litter System Controls on the Stabilization of Soil Organic Carbon in Eastern Deciduous Forests."

Han Wu, 2008 Fellow

Han Wu joined the Department of Statistics in the fall, 2008. In his first year at Purdue, Han has completed coursework in computational statistics, probability, regression, stochastic process, and a cross-departmental course on the statistics of extremes. Han has begun working with his advisor, Prof. Alexander Gluhovsky on the estimation, via computer-intensive bootstrap methods, of the so-called "tail index" that plays a central role in predicting extreme events.

Yini collects samples from the research forests at the Smithsonian Environmental Research Center in Edgewater, MD to monitor the impact of earthworm activity on soil organic matter.

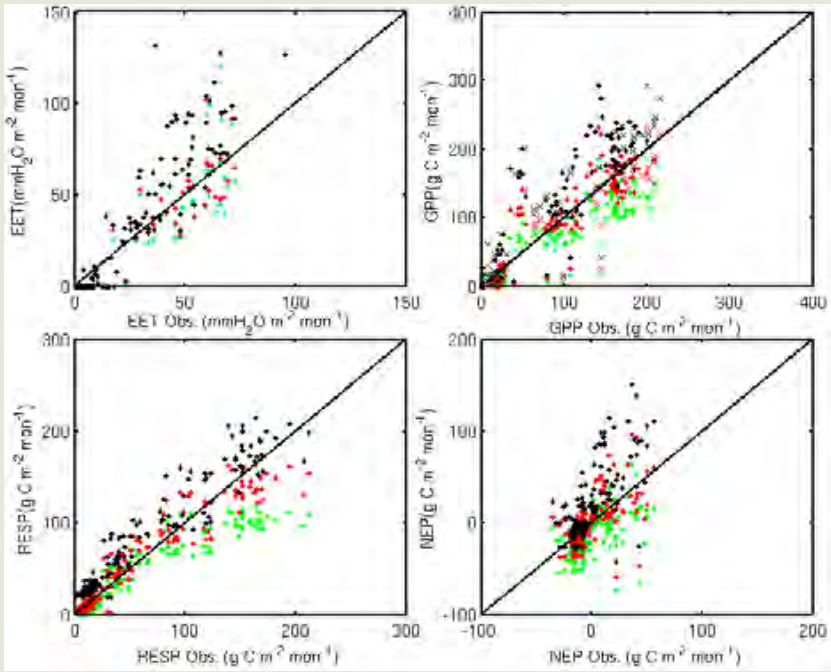
Charlotte Kendra G. Castillo, 2007 Fellow

During the 2008-2009 academic year, Kendra (EAS; Prof. Kevin Gurney, advisor) was renewed as a Fulbright scholar and an International Peace Scholar of the PEO Sisterhood. She was also awarded a Faculty for the Future Fellowship by the Schlumberger Foundation for the 2010 academic year. Kendra has passed her qualifying exams and continues with her research on tropical deforestation and climate change. She is currently modifying the offline version of the Community Land Model of the National Center for Atmospheric Research, and running test simulations of the biospheric response. At the fall poster session Kendra presented an outline of her proposed research: "Quantifying the Physical and Socio-economic Feedbacks between Climate Change and Deforestation: A Framework for Comprehensive Decision-making," with co-authors Kevin R. Gurney, Matt Huber, and Jerry Shively.

This year Kendra also co-authored, "The Co-Benefits Approach: An Integrated Policy Response to Climate Change and Development in Asia," which is included as a chapter in the book, "Climate Change Negotiations: Can Asia Change the Game?" [Edited by Christine Loh, Andrew Stevenson and Simon Tay. Hong Kong Civic Exchange and Singapore Institute of International Affairs, 59-73, 2008].

Jinyun Tang, 2006 Fellow

This year Jinyun (doctoral student, EAS; Qianlai Zhuang, advisor) submitted two papers for publication. The first, (Tang and Zhuang, *JGR-Atmosphere*) explored how to improve the parameterizations of a biogeochemistry model by making use of various observational data, e.g. tower eddy flux data and MODIS GPP. In this paper, he showed how the predictability from a monthly time step biogeochemistry model, the Terrestrial Ecosystem Model (TEM), could be improved by fusing the observations using a Bayesian inference technique. He also showed, through a global sensitivity analysis, that the impact of different observational data on the model parameterizations could be clearly disentangled.



Scatter plots of the posterior TEM outputs against observations after Bayesian inference. The data points from 01/2003 to 12/2004 were used in Bayesian conditioning, the rest of data, including the derived GPP from 04/1994 to 12/2006 were used for verification.

The figure is taken from Tang and Zhuang, *JGR-Atmosphere.*

Jinyun also spent time upgrading the soil thermal and hydrology module of the TEM by developing a coupled framework that considers the daily time step interactions between the thermal and moisture dynamics of soils. A paper describing this work is in review at the journal, *Climatic Change*. The framework was applied to analyze changes in growing season length in Alaska for the historical and projected period covering the years 1923-2099. The results show that in response to historical climate change, the growing season length in the Alaskan boreal forest and tundra ecosystems have both shortened and lengthened over different time periods. This historical analysis tracked the results from studies that used satellite products, e.g. NDVI. The model simulation showed the tundra ecosystem is more vulnerable to climate change, which also supports the findings of other studies. Finally, the model projections of a warmer climate indicate a longer growing season in this region in the future.

Tang, J., and Q. Zhuang, A Global Sensitivity and Bayesian Inference Framework to Improve the Parameter Estimation and Prediction of Process-Based Terrestrial Ecosystem Models. *J. Geophys. Res. - Atmosphere;* 114, D15303 (2009).

Vimal Mishra, 2006 Fellow

Vimal Mishra (doctoral student, Agricultural and Biological Engineering; Prof. Keith Cherkauer, advisor) continues to make progress on his doctoral research project, "understanding the role of historic climate variability and future climate change on lakes in the Great Lakes Region." In addition to his dissertation topic, Vimal has been working on analyzing land-atmospheric interactions in the Midwestern United States and on the occurrence and severity of droughts under historic and projected future climate. Over the last year Vimal's progress includes the submission of three articles for publication, and 5 conference presentations.

Joseph G. Alfieri, 2005 Fellow

Working both in West Lafayette and at the National Center for Atmospheric Research, Joseph Alfieri, (doctoral student, Agronomy; Dev Niyogi, advisor) has continued his research into the impacts of surface heterogeneity on land-atmosphere exchange processes. That work has focused on three areas. The first is the development of new methods to identify and quantify the variability in land surface properties such as land use and vegetation density. The second, closely related focus area is the development and extension of both statistical and physically-based methods to better characterize the spatial patterns observed in the exchange of water and heat between the land surface and the atmosphere. The final focus area seeks to incorporate spatial information into the validation process for land surface and numerical weather models. The research of the last year has contributed to four publications with an equal number currently in review. Joseph also presented aspects of this work at the "Workshop on Envirometrics" sponsored by the American Statistical Association and the Fall Meeting of the American Geophysical Union. He was also invited to speak about this research at Michigan State, Texas A&M, the Pacific Northwest National Laboratory, and the USDA Hydrology and Remote Sensing Laboratory. In addition to his dissertation research, Joseph continues to collaborate with scientists at the University of Colorado, NCAR, and the USDA on a number of projects.

*Visitors of all ages were able to learn about climate change at the 2008 Indiana State Fair exhibit, "**Climate Change: Footsteps for the Future**." This new exhibit was a collaborative effort between the PCCRC, Agricultural Communications, and the State Climate Office designed to promote an understanding of climate change and what we can do to deal with it.*

The exhibit provided fairgoers with the scientific context of climate change, featured interactive elements, and gave visitors steps they can take to reduce their own carbon footprint. State-of-the-art model simulations showing U.S. fossil carbon emissions and the latest energy innovations were also on display to show the creative and transformative ways Purdue is helping us move towards a low carbon future.

DISCOVERY with DELIVERY

In this section, we provide a snapshot of our collaborative partnerships that put our knowledge and expertise regarding the complex, multidimensional issue of climate change to work.

Informing Policy

The PCCRC works to bring objective, science-based information to the policy making process.

National Conference on Climate Governance

Over December 11–12, 2008, the Miller Center of Public Affairs at the University of Virginia convened the National Conference on Climate Governance (video and audio of the event are available at the website: http://millercenter.org/scripps/archive). Led by Miller Center Visiting Scholar Dr. Barry Rabe, Professor of Public Policy at the Gerald Ford School of Public Policy at the University of Michigan, this conference brought together some of the most preeminent scholars and practitioners of environmental policy in the country to consider a wider array of policy options regarding climate change.

Leigh Raymond, PCCRC associate director and associate professor of political science, presented *The Emerging Revolution in Carbon Emissions Trading Policy* in session three of the conference: Market Approaches to Climate Governance. The session examined the governance challenges of two policy alternatives that take a market approach, cap-and-trade and taxation schemes for carbon emissions meant to deter the use of fossil fuels.

The conference report, the "Climate Policy Blueprint," focuses on key findings and recommendations to establish a viable strategy for governing climate change both at home and abroad. Updated versions of the conference papers will be published in a forthcoming book by Brookings Press.

Leigh Raymond speaking at the National Conference on Climate Governance.

Federal Briefings

On April 27, 2009, Wally Tyner and Noah Diffenbaugh were invited to brief the Indiana congressional delegation on how projected changes to the climate system could impact the State, and how various climate change policy options could impact Indiana. Diffenbaugh's presentation focused on quantifying the costs of a no-action approach to climate change. The presentation included a broader discussion of potential impacts to the U.S. and the rest of the world.

Tyner discussed the Waxman-Markey Clean Energy Bill and he presented an overview of two policy options aimed at decreasing carbon dioxide emissions -a cap and trade system and a carbon tax. In considering two important criticisms of either option, namely that increasing energy costs would stymie economic growth and disproportionately affect the poor, Tyner reported that most studies indicate the impact to economic growth is likely to be very small, especially if other taxes are reduced, and that a reduction in income taxes targeted towards lower income families would offset higher energy costs.

Climate Change Policy in Asia

In March, 2009, the Center was pleased to welcome two distinguished experts on climate change policy, from Japan and China, respectively.

Professor Jusen Asuka from the Center for Northeast Asian Studies, Tohoku University, Japan, presented a talk entitled: ***The Emission Trading Scheme in Japan: Effectiveness, Efficiency and Concern about Carbon Leakage.*** Professor Asuka, is chairman of the Competent Authority for Japan's Voluntary Emission Trading Scheme, Ministry of the Environment, (2006-present). He also serves on the Special Committee for International Strategy on Climate Change Negotiations Beyond the Kyoto Protocol, Ministry of the Environment, Japan (2004-present), and consults for the United Nations Development Program on Clean Development Mechanism buildings.

Professor Edward Wang from Sun Yat-sen University, China presented a talk entitled: ***How Concerns about International Reputation May Change Chinese Climate Policy post-2012***. Professor Wang is the author of, "State Reputation and Foreign Strategy: China's Participation in International Institutions after the Cold War" (Tianjin People's Publishing House, 2007) and is currently a Freeman Fellow at the University of Illinois, Champaign, working on China's climate change policy.

Professors Asuka and Wang were joined by Purdue's Mark Tilton (*Political Science*) for an open discussion with a multidisciplinary group of students and faculty from across campus.

Media Coverage

The Center's key strength is reflected in the strong record of scholarship of our members. This is evident in many ways, including book publications, journal articles, working papers, course development, software, databases, and many other products typically targeted to a specific audience. Increasingly, PCCRC research has been featured in a variety of broadly accessible scientific media outlets as well as the popular press. In this section, read about several projects that have been recently highlighted in various press outlets around the world.

- A paper by Ashfaq, Diffenbaugh and colleagues exploring the response of the South Asian Summer Monsoon dynamics to elevated greenhouse gas concentrations has been published in *Geophysical Research Letters*: *USA Today, YahooNews, UPI, Radio Australia News, The Times of India, The Economic Times, The Tehran Times, Channel News Asia, Daily Times Pakistan, The Dawn Pakistan,The Daily Star Bangladesh, Wall Street Journal Market Watch, L'Expresse France, Tribune De Geneve, Australia News Network.*

- Otto Doering and a team of 22 other scientists wrote in the journal *Science* that there is an urgent need for more comprehensive and collaborative research needed to help the next generation of biofuels avoid unintended consequences: *Cattle Network, Ft Wayne Journal Gazette, Laf Journal and Courier.*

- In a *Nature* News & Views article Matt Huber explores what inferences about past tropical climate are to be drawn from the finding of a new giant species of fossil snake: *New York Times, Newsweek, NPR, BBC online, Christian Science Monitor, Discover Magazine, Globe and Mail (Canada), EchoroukOnline, Evolution Diary, Sydney Morning Herald, Waikato Times, Bloomberg News.*

- Developed by Kevin Gurney and collaborators at Google, a new high-resolution, interactive map of U.S. carbon dioxide emissions from fossil fuels is now available on Google Earth. With a few clicks on Google Earth, anyone can view pollution from factories, power plants, roadways, and residential and commercial areas for their state, county or per capita. Individuals also can easily see how their county compares to others across the nation: *Economic Times (India), newKerala.com, Thaindian News, webindia, WSBT Radio (South Bend), Salon, Science Daily, businessinsider.com, Earthobserver (NASA), Edmonton Journal (Canada), Industry Week Magazine, PhysOrg, USA Today, Youtube, Boston Globe, BNET, Huffington Post,Laf Journal and Courier, New York Times, RedOrbit.com, Agence France-Presse, First Science, Los Angeles Times, MSN, Wall Street Journal.*

- A paper by Filley, Johnston and colleagues published in the *Journal of Geophysical Research* found that earthworms can change the chemical nature of the carbon in North American forest litter and soils, potentially affecting the amount of carbon stored in forests: *Nature, The Gazette (Langston Univ), Earthobserver (NASA), Africaleader, Brightsurf, PhysOrg, First Science, Science Daily, Laf Journal and Courier, Greenedia, Bio-medicine, Innovations Report, Thaindian News, Forest Policy Research, Ecofriendly mag.*

- A paper by Diffenbaugh and colleagues testing the response of agricultural pests to future climate change has been published in *Environmental Research Letters*: *Chicago Tribune, Reuters, The Guardian, Indianapolis Star, UPI, Scientific American online, Yahoo News!, ClimateWire, San Francisco Examiner, The National Post, The Times of India, The Hindu, Discovery Channel News.*

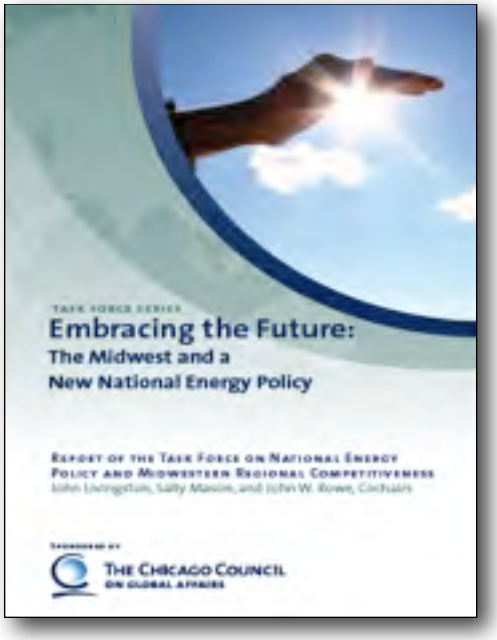
Reports

Our faculty engages in multidisciplinary analysis to provide science-based information tools for researchers, students, elected officials, and the public.

Embracing the Future: The Midwest and a New National Energy Policy

The Task Force on National Energy Policy and Regional Competitiveness was convened by the Chicago Council on Global Affairs to bring a midwestern perspective to the national energy policy debate, help build consensus among the various stakeholders within the Midwest around actions that address climate change and energy challenges, and work to advance the region's interests in that context. The 32-member Task Force included Purdue's **Wally Tyner,** Professor of Agriculture Economics, and other midwestern leaders from the fields of government service, business, civic and advocacy organizations, and academia.

After a year long series of meetings and working groups, the Task Force released a report documenting their efforts entitled, "Embracing the Future: The Midwest and a New National Energy Policy." The report is based on the presumption that human-induced climate change is occurring, and argues that a national policy to mitigate emissions contributing to climate change is appropriate to put in place. The report provides an overview of the Midwest's current energy economy, identifies areas of opportunity and

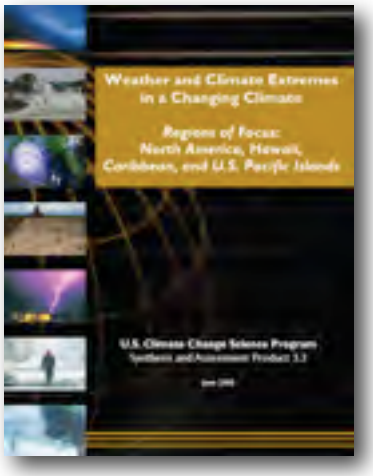


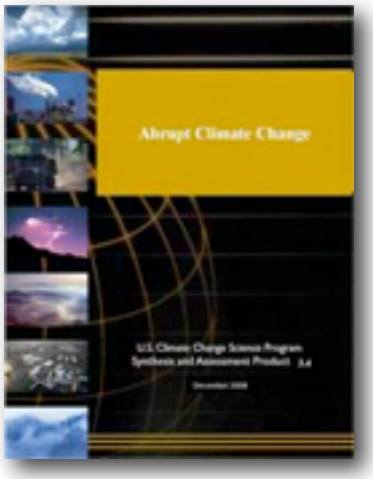
vulnerability, and establishes an analytical framework for organizing various technologies and policy options (with emphasis on energy efficiency and emissions offsets). It includes a discussion of long-term, low-carbon energy supply options, and explores the critical barriers that need to be overcome to ensure that the Midwest has adequate, secure, reliable, economically viable, and environmentally acceptable energy resources.

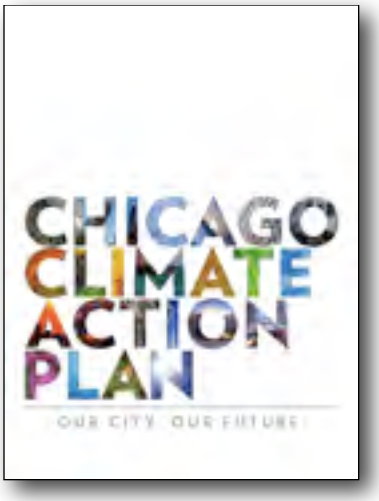
Key Task Force findings include:

- *The Midwest can and must turn the challenges of changing energy and climate policy to its economic advantage*
- *Prompt enactment of national climate change legislation is essential to the Midwest's future prosperity and competitiveness*
- *Regional and local action is likewise essential.*
- *Addressing carbon emissions will not be cheap.*

The group also focused on developing a series of recommendations on issues that are likely to be a part of future legislation such as cap-and-trade programs, low-carbon supply technologies, and increasing energy efficiency. The report outlines additional areas in which states and the broader region can move forward including maximizing the energy efficiency of buildings, industries and transportation systems; modernizing outdated infrastructure; developing new energy technologies; engaging the region's universities in leading-edge energy research and innovation; addressing critical workforce issues; and improving regional coordination and cross-jurisdictional decision-making.







Weather and Climate Extremes in a Changing Climate

The U.S. Climate Change Science Program (CCSP) integrates federal research on climate and global change, with a key goal being the development of decision support resources such as scientific synthesis and assessment reports. In Synthesis and Assessment Product 3.3, "Weather and Climate Extremes in a Changing Climate," the authors detail the observed and projected changes in extreme events in North America and U.S. territories. **Jeff Trapp** (associate professor of earth and atmospheric sciences) served as contributing author to chapter 3, "Causes of Observed Changes in Extremes and Projections of Future Changes."

Major findings reported in this assessment are that droughts, heavy rain, excessive heat, and intense hurricanes are likely to become more common as humans continue to increase the atmospheric concentrations of greenhouse gases. Cold days and cold nights are very likely to become much less frequent. Sea ice extent is expected to continue to decrease and may disappear entirely in the Arctic Ocean in summer in the coming decades. This will cause extreme coastal erosion in Arctic Alaska and Canada due to the increased exposure of the coastline to strong wave action. The report also outlines the highest priority areas improving understanding of weather and climate extremes.

Abrupt Climate Change

The United States faces the potential for abrupt climate change in this century that could pose clear risks to society in terms of our ability to respond and adapt to future changes. This topic is examined in CCSP Synthesis and Assessment Product 3.4, "Abrupt Climate Change." In the report, "abrupt" changes are defined as those that can occur over decades or less, persist for decades or more, and cause substantial disruption to human and natural systems. The report considered 4 types of abrupt changes, including widespread and sustained changes to the hydrologic cycle.

Noah Diffenbaugh (associate professor of earth and atmospheric sciences) served as contributing author to the chapter on hydrologic variability and change, which reports that drought is among the greatest recurring natural hazard facing both the the U.S. and the world today, and in the foreseeable future. Floods, though generally more localized in time and space than droughts, are also a major natural hazard, and share with droughts many of same large-scale controls and the potential for experiencing major changes in these controls in the future. The report provides recommendations for enhancing abrupt climate change research.

The Chicago Climate Action Plan

Commissioned by the City of Chicago, the Climate Change Action Plan (CCAP) describes the major effects climate change could have on the City and outlines a detailed strategy to help lower greenhouse gas emissions and address climate change. The City's overall plan is focused on reducing greenhouse gas emissions to 25 percent below 1990 levels (1990 levels are the recommended baseline according to the Kyoto Protocol). While other cities have set similar goals, Chicago's plan is the first to both identify emission sources and anticipated impacts, and propose ideas that specifically respond to those findings.

Contributing author of the CCAP, **Keith Cherkauer** (assistant professor of agricultural and biological engineering) was a member of the climate science team reporting on climate change impacts to water resources. The group examined how expected changes in temperature and precipitation will affect the region's hydrologic balance, including changes to river flow, lake levels, ice cover, water quality, and finally, the impact to aquatic ecosystems in the Chicago area.

Part of the community

Science is a shared knowledge. PCCRC researchers participate in a variety of local activities aimed at advancing scholarship, contributing to public education, and facilitating technology transfer.

PCCRC at the Indiana State Fair

Working with Purdue's Department of Agricultural Communications and the Indiana State Climate Office, the PCCRC helped create an exciting educational program to bring the issue of climate change to the 2008 Indiana State Fair. The 12-day fair welcomed over 850,000 visitors to the Indiana State Fairgrounds in Indianapolis through August 6-17, and presented an outstanding opportunity to engage a large audience in addressing climate change.

The climate change program was focused on helping visitors of all ages explore the science of climate change and how it affects their lives. It included a 300 ft^2 exhibit and an "Ask the Experts" panel discussion with PCCRC faculty.

The exhibit, **Climate Change: Footsteps for the Future**, provided fairgoers with an overview of the science of climate change, including a look back at the Earth's CO_2 and temperature trends over hundreds of thousands of years. It featured interactive elements and gave visitors steps they could take to reduce their own carbon footprint. State-of-the-art model simulations showing U.S. fossil carbon emissions (from the Vulcan project) and the latest energy innovations (e.g., fast growing hybrid poplar trees that can be used to produce ethanol, and model wind turbines) were also on display to show the creative and transformative ways Purdue is helping us move towards a low carbon future.

Paul Shepson visits the climate change exhibit on Purdue Day at the Indiana State Fair.

On Purdue Day, PCCRC members Laura Bowling, Tim Filley, Dev Niyogi, and Paul Shepson offered a short presentation on how climate change may impact Indiana residents in the future and then answered questions from the audience.

2008 PCCRC Distinguished Lectures

The Center welcomed four speakers to campus this year to present talks in the PCCRC Distinguished Lecture series:

Professor Dennis P. Lettenmeier, University of Washington, Seattle: *125 Years of Hydrologic Change in the Puget Sound Basin: The Relative Signatures of Climate and Land Cover.*

Professor Murugesu Sivapalan, University of Illinois: *Response of Floods to Climate and/or Land Use Changes: Is There a Role for Similarity Concepts and Catchment Typology?"*

Professor James Famiglietti, University of California, Irvine: *Terrestrial and Global Hydrology from GRACE with Implications for Land Contributions to Global Mean Sea Level Rise.*

Professor Bruce Hungate, Northern Arizona University: *From the Globe to the Cell and Back: Biogeochemistry in a Changing Climate.*

Celebrating Green Week

As part of Purdue's first "Green Week," the PCCRC, in collaboration with the Center for the Environment and the Energy Center, co-sponsored a two-day program to focus discussion on the intersection of climate change, the environment, and energy technology. The program encouraged participants to consider the science, environmental impacts, and socioeconomic challenges we face as we work to bring sustainable energy sources into everyday use.

In addition to talks by Jim Hurrell, Eugene Brower, David Hawkins, and John Wall, the Green Week program included a poster session, a town-hall meeting, and ended with a lecture by Pulitzer Prize-winning journalist and author, Thomas Friedman, who discussed his new book, "Hot, Flat, and Crowded."

What did our Green Week speakers have to say about...

The state of the science?

Dr. James Hurrell, Senior Scientist from the National Center for Atmospheric Research, underscored the conclusions presented in the IPCC's 4th Assessment Report: the warming of the climate system is "unequivocal" and the observed increase in anthropogenic greenhouse gas concentrations is "very likely" the cause. He went on to say:

"The latest numbers indicate that our increases in dumping CO_2 into the atmosphere are exceeding even the increases that were modeled in the most pessimistic scenarios."

Impacted communities?

Mr. Eugene Brower, former mayor of the North Slope Borough, Barrow, Alaska and a third generation whaling captain, discussed how both climate change and the energy industry have impacted the indigenous people of Arctic Alaska:

"We're working with scientists to try to come up with ways to protect our marine resources and our way of life...I'd like to continue teaching my grandson how to read the ocean, the currents, and what we do."

What could we do?

Mr. David Hawkins, director of the Climate Center at the Natural Resources Defense Council (NRDC), is convinced that the United States can set the path towards meeting our energy needs and that we can do it without wrecking the climate. He described the NRDC's strategy to cut US emissions by 80% from today's levels between now and 2050 while simultaneously working on policies that will set the planet on a path towards sustainable energy use:

"We need to stop thinking about global warming as a drag on the economy and thinking about it simply as a way of investing money differently and a way that we can accomplish several things together."

Technology solutions?

Dr. John Wall, vice president and CTO of Cummins, Inc., offered the perspective of an industry leader. He discussed the multiple ways Cummins is reducing the CO_2 footprint of their heavy duty diesel engines with gains in waste energy reduction, high efficiency combustion and idle reduction. Dr. Wall commented:

"For us, CO_2 reduction and energy efficiency are two sides of the same coin."

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