Purdue Climate Change Research Center

2010-2011 ANNUAL REPORT




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: Sarah Rutkowski collecting water samples from ditches receiving agricultural tile drainage to assess how nitrate loads will change within the next century under future climate models; Wensheng Ge, Greg Michalski, Zhibing Liao and Fan Wang at their research site in the Kumtag Desert, China; Fluvial landscapes of the Saryjaz River valley looking south toward the glaciated peaks of the Kokshaal Range in the Kyrgyz Tian Shan Mountains; Yini Ma travels to her field sites at the Smithsonian Environmental Research Center in Edgewater, MD where she is studying the legacy effects of past land use and invasive species on present greenhouse gas emissions from soils.

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Message from the Director

I am finding that as the Center grows I increasingly have to describe to others what the Purdue Climate Change Research Center does. I also find it increasingly difficult to make the explanation simple. A little like Mark Twain's Connecticut Yankee's having difficulty in explaining the world he left in Connecticut to the world he joined in King Arthur's Court. There is no simple explanation. The PCCRC does a wide range of activities, undertakes numerous tasks, and is a dynamic confluence of individuals and partners that change as problems change. We now have 62 faculty associated with the Center across Purdue's various colleges and programs. Last year we were able to increase the research dollars coming to Purdue that involve the Center and its faculty. Today there are close to thirty climate research projects underway that Center faculty are involved in.

We are well aware that what we do occupies a publicly debated space between science, perception, and reality. Our objective is to pursue the best science we can and convey it to our students and the public, while understanding that what we communicate can be controversial and contrary to the perceptions that some have. One of our responses to this fact of life for climate science was the "Beyond Climategate" forum held in early November 2010. The panel and audience discussion flowed back and forth on the many roles for science and the media in the making of climate policy. We recognize skepticism of climate science by some policy makers. In contrast, looking across the multiple disciplines and fields of engagement of Purdue's colleges and departments, we see acceptance of climate change as a fact of life by much of the food security community, the biological and engineering communities, and those involved in dealing with resilience to extreme events. In essence, there are many different consumer publics for climate information and science at different levels and to different purposes. Some are accepting, some not, but an increasing number are engaged in activities to adapt to potential climate change or to undertake actions to mitigate it. As Senator Lugar has pointed out, doing what needs to be done to reduce our dependence upon petroleum and its strategic costs would achieve a substantial portion of the international commitment that the US might have made to reduce greenhouse gasses. We are seeing where the right things to save energy or increase plant nutrient efficiency can lead to reductions in greenhouse gases.

One of the things that the Center does is provide seed grants to individuals or groups to get something underway that relates to their interests and climate change. Sometimes this involves a small amount for travel for a student to attend a conference or special event. We have provided travel support to undergraduate observers to attend international climate change meetings and to graduate students to present their papers at conferences. This kind of support helps teaching, research, and outreach. There is great competition for top graduate students around the world. Some colleges at Purdue have allocated first year graduate fellowships to climate change related work and the Center works with faculty and departments to attract these outstanding students to Purdue. The Center also provides some additional resources to allow a department to enhance the attractiveness of these scholarships. We like to believe that our continued encouragement of these students helps them achieve outstanding contributions – some of which are highlighted in the report. The Center maintains a roster of courses across the university that have connections with climate science, policy, and the critical forces that shape both. Some of our faculty tailor courses to include critical climate and global change science and related issues. We also have a seminar that has a related focus of interest for faculty and students with attendance, discussion, and debate by both.

We also provide seed grants to incubate or jump-start research. We have had particular success in helping ideas get into the investigation stage and in carrying these to successful grant applications for full development. We supported five of these efforts in FY 2010-11. One of them had results highlighted in the London Financial Times and the National Geographic. This effort also represents collaboration between earth and health sciences. Another effort we have supported is competing for funding from the British Government, having already been funded partially from other sources. This effort, GEOSHARE, would link across the world with experts and data sources in other countries who would standardize and share basic information on climate, land, water and key environmental and social indicators. This would allow across the globe comparisons and contrasts and assessments of the directions being taken by earth systems and human well-being.

Quite rapidly, we have experienced a growing involvement by Center faculty and their students across a number of efforts to extend climate change information well beyond the scientific community. One example is the U2U (Useful to Usable) project which Purdue is leading as part of a US Department of Agriculture effort under its National Institute of Food and Agriculture. This effort aims to transform climate change information into useful information for cereal crop producers – starting with corn in the Corn Belt. The focus here is adaptation but some of the adaptation strategies also have a role in mitigation. The agricultural community has not had to participate very long in the climate debate to understand that it is on the front line of vulnerability to increased variability and extreme events. Another example is the Center's involvement in several efforts aimed at improving resources for science teachers in the public schools. This includes earth science tool kits and training opportunities for teachers. This is also being linked with materials and training for educators in Purdue's Cooperative Extension Service and other community groups that play informational roles in communities. Our multiplicity of roles and responsibilities is growing.

What trajectory might we expect for the Center in the coming years? Here are a few observations:

- Resources for research and discovery are going to be more difficult to obtain and we will have to become more competitive to obtain these resources. We are also going to have to combine resources and interests from different entities. We will have to seek out those with similar concerns and objectives and convince them of the advantages we can offer.
- We are seeing increasing work across disciplines. This is being forced by funding agencies, but also by the nature of the real world problems that are no longer amenable to strictly technical single discipline solutions.
- We are likely to see some of our most important work in the intersections between our fields of interest and others – not just disciplines, but subjects. The real world interconnections between climate, energy, water, food security and sustainability have to become the work arena for all involved in those areas. The nexus is becoming the operational field.
- We will increasingly have to engage our students and find ways to mentor, teach, and lead by example so that they develop skills and the desire to excel. This is a highly competitive world, and unless we can convey that desire to learn and excel, we will not be able to develop ways to address the problems that climate change will bring.

The strength of Purdue's Climate Center rests to some extent on the diversity of fields of study at Purdue. Those institutions that do not have this diversity cannot effectively take on the wide range of investigations that are necessary for real world climate issues.

We survive and prosper because we have a core faculty that is committed in terms of interest and in terms of the institution of the Climate Center. That is what gives the Center life and allows us as a group to come together to get things done. We have had critical financial support annually from many of Purdue's colleges. This gives us the ability to seed projects, enable students and researchers, and perform critical service functions to faculty in everything from grant writing to running a workshop or giving lunch to a seminar audience. Discovery Park also provides the Climate Center with an outstanding Managing Director who helps make all good things happen.

In a world that is seemingly inundated with problems of all sorts, our future success will depend on our ability to pick the most important ones to work on. We then will have to deliver on this by advancing science, informing the public, and training the next generation to be able to cope with the future.

Otto C. Doering, III

Professor and Director

The agricultural community recognizes that it will feel the impacts of climate change before other sectors. Either increased variability or more extreme events change the parameters for agricultural systems that have evolved over decades with more stable weather conditions. The growing season in the Upper Midwest is now six days longer than it was a couple decades ago. More highly variable precipitation puts a premium on soil moisture holding capacity. More extreme rain events can determine what we have to do anew to prevent soil erosion and nutrient loss.

DISCOVERY

The PCCRC seeks to encourage, in the broadest possible way, the application of evidence-based knowledge to address fundamental questions related to the Earth's changing climate system. Our faculty, students, postdoctoral researchers, and visiting scientists are expanding the boundaries of our knowledge through interdisciplinary, integrative projects. In this section, we invite you to explore our most recent research projects, latest scientific papers, and have a look at what's on the horizon.

SPONSORED RESEARCH

Innovation, creativity, problem solving. Our scientists are leading research projects aimed at understanding Earth's changing climate system and related global, regional, and local impacts. This year the USDA, NSF, and the UN provided over $9M to advance the research and creative scholarship activities of our faculty, staff, and students. Read a summary of these latest additions to our research portfolio below.

Useful to Usable (U2U): Transforming Climate Variability and Change Information for Cereal Crop Producers

Linda Prokopy (PI), *Forestry & Natural Resources;* Dev Niyogi, *Earth & Atmospheric Sciences* and *Agronomy;* Ben Gramig, *Agricultural Economics;* Carol Song, *Rosen Center for Advanced Computing*; and Otto Doering, *Agricultural Economics;* with collaborators from 9 different states (Funded by the U.S. Department of Agriculture-NIFA).

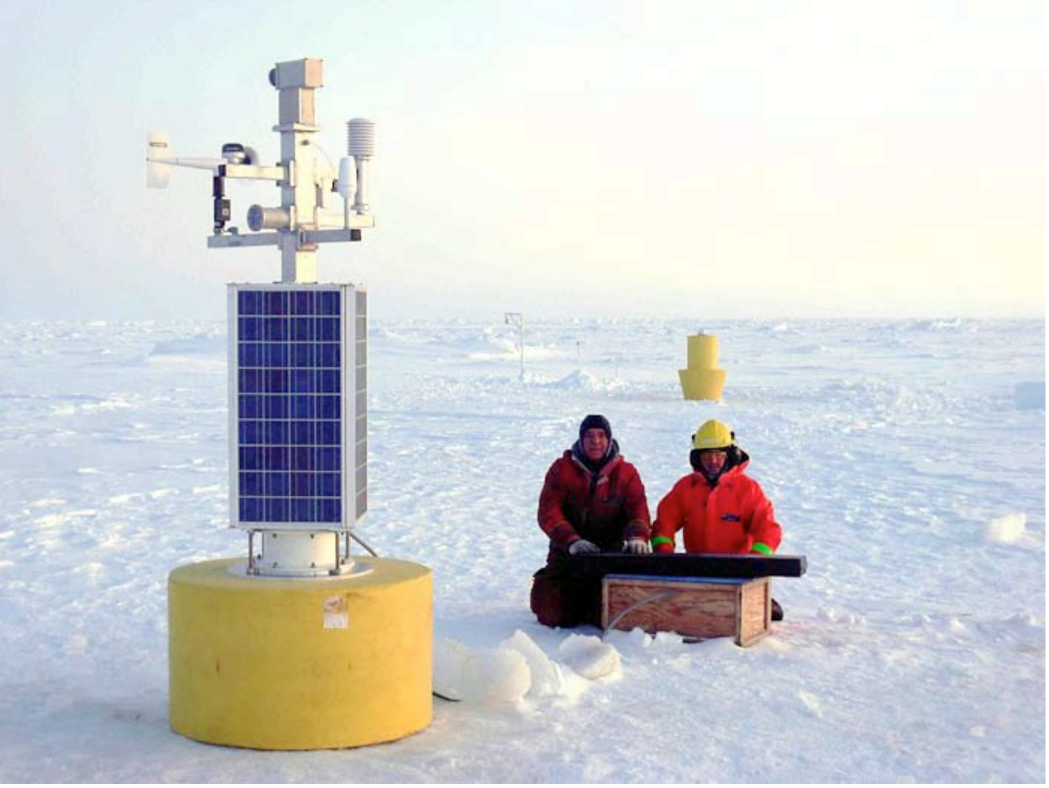
Corn and soybean production contributes over 100 billion annually to the U.S. economy, most of which comes from intensively cultivated corn-belt region of the Midwest. Successful crop production is highly dependent on favorable temperatures and appropriate precipitation patterns, making this industry vulnerable to increasingly variable climate patterns. Though predictive models are constantly improving, there are gaps in our understanding of how different management practices can be used to help farms adapt to climate change while maintaining economic viability. Furthermore, currently available tools and models are not meeting producers' needs, and little is known about the types of information they would like to access. This project seeks to improve the resilience and profitability of farms amid variable climate changes by providing stakeholders with enhanced decision support tools.

A Paradigm Shift in Ecosystem and Environmental Modeling: An Integrated Stochastic, Deterministic, and Machine Learning Approach

Qianlai Zhuang (PI), *Earth & Atmospheric Sciences* and *Agronomy;* Melba Crawford, *Civil Engineering* and *Agronomy*; Hao Zhang, *Statistics*; Dongbin Xiu, *Mathematics*; and Jian Zhang, *Statistics*; with collaborators Jerry Melillo at *Marine Biological Laboratory*, *Woods Hole*; and John Reilly, *MIT* (Funded by the National Science Foundation).

The project seeks to advance the ecological and environmental sciences through novel computational applications, primarily through the development of stochastic models coupled with geostatistical and machine learning techniques. The proposed approach will transform the current system modeling approach by developing a stochastic version of the deterministic differential equation models currently used to represent ecosystems and other environmental systems. This new, stochastic modeling approach will use both in situ and satellite remotely sensed data to improve model parameters and model structure. Once these advancements are made, the improved modeling system will be used to examine the societal and biogeochemical impacts of climate and land-use change. For example, an expected outcome includes the development of a cyber-enabled carbon-weather system that can quantify net carbon exchanges and associated probabilistic information at high spatial and temporal resolution for the continental U.S.

ABOVE: The U2U team includes a uniquely qualified group of climatologists, crop modelers, agronomists, economists, and social scientists from 10 partner universities across the Midwest. From Purdue University: Linda Prokopy (Project Lead), Otto Doering, Ben Gramig, Dev Niyogi, Carol Song, Bruce Erickson, Paul Preckel, and Melissa Widhalm; Iowa State University: Chad Hart, Lois Wright Morton, Gene Takle, and Roger Elmore; Michigan State University: Jeff Andresen; South Dakota State University: Dennis Todey; University of Illinois: Steve Hilberg, Jim Angel, and Atul Jain; University of Michigan: Maria Lemos; University of Minnesota: Tom Bartholomay; University of Missouri: Ray Massey and Pat Guinan; University of Nebraska-Lincoln: Cody Knutson, Martha Shulski, and Tonya Haigh; and from the University of Wisconsin: Tom Blewett and Rebecca Powe.



conservation tillage (including a control treatment with only basic information) and whether the treatment mentions offset payment opportunities, creating a 2 x 4 treatment matrix. Tests for statistically significant differences in positive response rates between treatments will allow for evaluation of the role of framing effects and economic incentives on interest in and adoption of offset-eligible practices.

Collaborative Research: The O-Buoy Network of Chemical Sensors in the Arctic Ocean

Paul Shepson (PI), *Chemistry* with Jan Bottenheim, *Environment Canada*; Francisco Chavez, *Monterey Bay Aquarium Research Institute*; Patricia Matrai, *Bigelow Laboratory for Ocean Sciences*; William Simpson; *University of Alaska Fairbanks*; and Donald Perovich, *U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory* (Funded by the National Science Foundation).

Collaborators from five institutions will work to build and deploy an Arctic Ocean network of rugged and autonomous buoys (named "O-Buoys") capable of observing atmospheric O_3, BrO, and CO_2 and oceanic pCO_2 for up to 5 years (with each O-Buoy being operational for up to 2 years). The original O-Buoy project funded by NSF included design and testing of the O-Buoys system. In the current project, 11 new O-Buoys will be constructed and deployed along with the four already built. As a pilot project, two of the new O-Buoys will include seawater sensors for CO_2, oxygen, temperature and salinity along with the atmospheric O_3, BrO, and CO_2 sensors. Throughout the project, data from each O-Buoy will be subject to QA/QC protocols by automated processing initially, with preliminary data available on a regular basis on the Cooperative Arctic Data and Information Service (CADIS) site. All final data and metadata will be ultimately archived on CADIS after final analysis at the end of each deployment. This network of O-Buoys, coordinated and clustered with other buoys in automated drifting stations, will enable the scientific community to first observe, and then, better understand the impact of Arctic surface change on atmospheric composition and chemistry.

Why do Farmers Adopt Offset-Eligible Practices? An Experimental Investigation of Framing Effects

Leigh Raymond (PI), *Political Science*; Ben Gramig, *Agricultural Economics;* and Rosalee Clawson, *Political Science* (Funded by the U.S. Department of Agriculture-ERS).

This project asks: To what degree do non-financial factors such as "framing" shape farmers' decisions to adopt offset-eligible agricultural practices? Because of agriculture's significant role in anthropogenic climate change, it is critical to understand why farmers adopt practices eligible for carbon offset credits. Based on recent work in economic, political, and agricultural decision-making, the primary hypothesis of this project is that frames will significantly affect farmers' interest in and adoption of offset-eligible practices. In many cases, this framing effect will be as strong as or stronger than the effect of a modest offset payment**.** The research team will test this hypothesis using a large-scale field experiment exposing a national sample of 6,000 farmers to mail and e-mail treatments promoting conservation tillage. Treatments will vary on two dimensions: the framing used to describe

Taming Complexity of Mesoscale Dynamics with Low-Order Models

Alex Gluhovsky (PI) and Ernie Agee, *Earth & Atmospheric Sciences* (Funded by the National Science Foundation).

Important new developments in modern nonlinear dynamics and time series analysis have become highly relevant to many areas of climate studies, where on the one hand, solutions of the governing nonlinear equations of geophysical fluid dynamics are elusive, while on the other hand, "we are buried in observational and modeled data we have yet to find appropriate ways to analyze". The research under this grant will focus on developing low-order models for mesoscale processes that inherit fundamental conservation properties of the fluid dynamical equations, thereby exhibiting sound physical behavior. It will also involve obtaining reliable inference from observed and modeled data regarding i) parameters of statistical distributions and trends, and ii) comparisons between models and observations. Traditional time series analysis with preponderance of linear models proves inadequate for the task, which motivates the work on subsampling methodologies that do not rely on strong assumptions (required in classical statistical methods), which are rarely met in atmospheric data.

ABOVE: The research team deploys an o-Buoy ~200km east of Churchill Manitoba, in Hudson Bay. This location is of interest because satellite images indicate this is an area of relatively intense halogen atom chemistry and thus ozone and mercury depletion, for reasons we do not understand. The buoy deployment will provide critical new information to help us understand the satellite data, and this environment.

Developing an Earth System Science Teacher Professional Development Tool Kit

Dan Shepardson (PI), *Curriculum & Instruction* and *Earth & Atmospheric Sciences* and Dev Niyogi, *Earth & Atmospheric Sciences and Agronomy* (Funded by the National Science Foundation).

This project uses existing climate change datasets, activities, and resources to develop a model teacher professional development tool kit and program for climate science. The target audiences for the tool kit are formal (teachers) and informal (naturalists, museum) educators who conduct teacher professional development. The secondary audience is secondary Earth science teachers. The tool kit is being developed in collaboration with educators from Benton Central Jr.-Sr. High School (Indiana) and St John's Lutheran School (Michigan), a naturalist with Tippecanoe County, IN, and representatives of the Environmental Education Association of Indiana. The project is divided into three phases. The first phase focuses on the development of the teacher professional development tool kit and program. The second phase involves using the tool kit to conduct teacher professional development, field testing, evaluating, and revising the tool kit. The third phase involves a summer institute to prepare formal and informal educators to use the tool kit, disseminating the tool kit to organizations and institutions, and establishing a Project Climate Science network. Collaborators include the National Weather Service, Indianapolis and Purdue Extension.

Collaborative Research: A New Reconstruction of the Last West Antarctic Ice Sheet Deglaciation in the Ross Sea

Nathaniel Lifton (Purdue PI), *Earth & Atmospheric Sciences and Physics* with Peter Clark (Project PI), *Oregon State University*; David Pollard, *Pennsylvania State University*; and Mark Kurz, *Woods Hole Oceanographic Institution* (Funded by the National Science Foundation).

Recent observations of startling changes at the margins of the Greenland and Antarctic ice sheets indicate that dynamic responses to warming may play a much greater role in the future mass balance of ice sheets than considered in current numerical projections of sea level rise. This project will focus on improving our understanding of the response of the West Antarctic Ice Sheet (WAIS) to current and possible future climate change, including the sea-level response to glacier and ice sheet melting, by studying the timing of the last deglaciation of the western Ross Sea. The work will address two questions: 1) what was the history of grounding-line retreat following the last glacial maximum ~15 ka? 2) what was the vertical-profile history of grounded ice, especially in relation to possible rapid drawdown around meltwater pulse 1A (an extraordinarily rapid (~500-year duration) episode of ~20 meter sea-level rise that occurred approximately 14,500 years ago. The timing of the last deglaciation of the western Ross Sea will be improved using in situ terrestrial cosmogenic nuclides (3He, 10Be, 14C, 26Al, 36Cl) to date glacial erratics at key areas and elevations along the western Ross Sea coast. A state-of-the art ice sheet-shelf model will be used to identify mechanisms of deglaciation of the Ross Sea sector of WAIS. The model results and forcing will be compared with observations with the aim of better determining and understanding the history and causes of WAIS deglaciation in the Ross Sea.

Assessment of Climate Change Impact on Economic Development Opportunities in North Africa: Case of Morocco and Tunisia

Wally Tyner (PI), *Agricultural Economics* with Channing Arndt and Imed Drine, *UNU-WIDER (*Funded by the United Nations University World Institute for Development Economics Research).

Sustaining development in developing countries has never been as complicated a task as it is today in the face of a world characterized by tremendous competition over resources that are becoming scarcer. Climate change and its impact on water resources and agriculture, is one of the major problems facing developing countries in Africa. The research effort in this project aims to measure the impact of climate change directly on agriculture, and indirectly through its linkages with other sectors. It will also examine the impacts of alternative mitigation policies. To achieve these objectives, an integrated methodological approach is being used. Research will be done at the country level to determine to what extent any policy set can be robust in the face of the huge uncertainty in climate forecasts. In addition, a global analysis will integrate two modeling frameworks that have been applied successfully on a wide range of problems: the GTAP model and the IMPACT-WATER model. The aim is to provide not only a country-based analysis, but to create analytical tools that can be applied in other countries and regions.

BELOW: Countries in arid regions, like Tunisia, are particularly affected by water scarcity and periodic drought. Climate change has and will likely introduce greater challenges that will come with increased temperatures, shifting patterns of precipitation, and extreme weather events. Developing adaptation strategies to increase resilience to climate change is a key priority for policymakers in the region.

ONGOING RESEARCH

Cutting-edge analysis leading to transformative discoveries. Our research portfolio includes projects that focus on a broad-range of scientific, technological, social and humanitarian issues related to climate change. In the following section, we list our ongoing research projects and highlight examples of our impact.

- Collaborative Research: Impacts of Climate Seasonality on Carbon Accumulation and Methane Emissions of Alaskan Ecosystems during the Holocene Thermal Maximum - Qianlai Zhuang, *Earth & Atmospheric Sciences and Agronomy*, with collaborator Zicheng Yu, *Lehigh University* (NSF)

- RCN: MSM: ETBC: Integrated Network for Terrestrial Ecosystem Research on Feedbacks to the Atmosphere and Climate: Linking experimentalists, ecosystem and Earth system modelers - Jeffrey Dukes, *Forestry & Natural Resources and Biological Sciences* with Aimee Classen, *University of Tennessee*, and Peter Thornton, *Oak Ridge National Laboratory* (NSF)

- Quantifying Climate Feedbacks from Abrupt Changes in High-Latitude Trace-Gas Emissions - Qianlai Zhuang, *Earth & Atmospheric Sciences and Agronomy*, with Adam Schlosser, *Massachusetts Institute of Technology*; Jerry Melillo, *Marine Biological Laboratory*; and Katey Walter, *University of Alaska*, *Fairbanks* (DOE)

- 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, *Earth & Atmospheric Sciences and Agronomy* (NASA)

- Quantifying Predictability in Nonlinear Multiscale Systems with Applications to Tropical Cyclone Prediction - Wen-wen Tung, *Earth & Atmospheric Sciences* with Jianbo Gao, *University of Florida* (NSF)

- Collaborative Research: The Role of Deep-Ocean Circulation in Greenhouse Climates: Integrating Numerical Simulations with Proxy Data of Water Mass Composition - Matthew Huber and *Earth & Atmospheric Sciences*, with Deborah Thomas and Robert Korty, *Texas A&M University* (NSF)

- Natural Capital and Poverty Reduction - Gerald Shively, *Agricultural Economics* with Charles Jumbe, *University of Malawi*, Disk Sserunkuuma, *Makerere University*, Pam Jagger, *Indiana University*, Monica Fisher, *Oregon State University*, and Arild Angelsen, *CIFOR* (USAID)

- Development, Improvement, and Assessment of the Accuracy of Aircraft-Based Mass Balance Measurements of the Integrated Urban Fluxes of Greenhouse Gases - Paul Shepson, *Chemistry*, with collaborators Kevin Gurney, *Arizona State University*; Scott Richardson and Natasha Miles from *The Pennsylvania State University;* and Colm Sweeny and Jocelyn Turnbul, *NOAA/ESRL* (NIST)

- Holocene Water Balance of the Northeastern Great Basin - Gabe Bowen, *Earth & Atmospheric Sciences* (NSF)

- A new regional paleo-precipitation proxy: oxygen isotopes in desert nitrate - Greg Michalski, *Earth & Atmospheric Sciences and Chemistry* (NSF)

- Collaborative Research: Impacts of urbanization on nitrogen biogeochemistry in xeric ecosystems - Greg Michalski, *Earth & Atmospheric Sciences and Chemistry* with Stevan Earl, Nancy Grimm, Kathleen Lohse, *Arizona State University* and Paul Brooks, *University of Arizona* (NSF)

- Collaborative Research: Integrating proxies and Earth System Models to elucidate water cycle dynamics: Did global warming cause an enhanced hydrological cycle in the Eocene? - Matthew Huber and Gabriel Bowen, *Earth & Atmospheric Sciences*, with Mark Pagani, *Yale University* (NSF)

- Collaborative Research: P2C2--Understanding the Role of a High-Latitude Convective Cloud Feedback in Equable and Future Climate Dynamics - Matthew Huber, *Earth & Atmospheric Sciences* and Eli Tziperman, *Harvard University* (NSF)

- Soil-Earthworm-Litter System Controls on the Stabilization of Organic Matter in Forests - Timothy Filley, *Earth & Atmospheric Sciences* and Cliff Johnston, *Agronomy,* with Melissa McCormick, *Smithsonian Environmental Research Center* and Kathy Szlavecz, *The Johns Hopkins University* (NSF)

- Using Oxygen Isotopes to Constrain Ozone Sources and Sinks - Greg Michalski, *Earth & Atmospheric Sciences and Chemistry* (NSF)

ABOVE: In many parts of the world, water is a limiting resource for plants, animals, and humans. For arid regions such as the southwestern United States, understanding variability in the availability of water is critical to forecasting and planning for the risks associated with population growth and urban development. This understanding must include an understanding of natural levels of variability in water balance (precipitation/ evaporation). With funding from the NSF, Gabe Bowen's group is working to generate records documenting the last ~8,000 years of water cycle history as recorded in the sediments of the Great Salt Lake.

Indianapolis Flux Experiment [INFLUX]

The Indianapolis Flux Experiment (INFLUX), led by Professor Paul Shepson, *Chemistry*, is a multi-institution, collaborative project that aims to develop and assess top-down and bottom-up approaches for quantifying urban-scale greenhouse gas emissions. Indianapolis was chosen as a test case because it is a compact, isolated urban center with relatively simple meteorology and a strong fossil fuel CO_2 emission (~3.4 MtC yr^{-1}) that is readily detectable in the atmosphere. The research team is measuring greenhouse (CO_2, CH_4) and trace gases using an aircraft (ALAR) and a network of towers around Indianapolis to provide high spatial coverage and temporal resolution. Both platforms make use of cavity ring-down spectroscopy for in situ measurement of carbon dioxide and methane as well as flask packages for taking intermittent air samples that are analyzed for ~55 trace gases and isotopes including CO_2, CH_4, CO, and $^{14}CO_2$, which is used as a proxy for fossil fuel CO_2.

Since fall of 2010, a total of 14 flight experiments were conducted using the Purdue Airborne Laboratory for Atmospheric Research (ALAR). By flying perpendicular to the prevailing wind direction, the mobility of the aircraft allows for multiple horizontal transect measurements (Figure 1) at various altitudes up to the top of the convective boundary layer to rigorously intercept and quantify the methane and carbon dioxide plumes. Figure 1 shows the flight path on June 1, 2011 as a function of the height above the ground. Also shown are the contour shapes of Indianapolis and the locations of various CO_2 and CH_4 sources. From the horizontal transect measurements, the greenhouse gas (CO_2 and CH_4) distributions directly downwind of the city are obtained and shown (Figure 2) as functions of the heights above the ground and the horizontal distances. Also shown in Figure 2 are the CO_2 and CH_4 hotspots corresponding to specific sources in the city, with enhancements in concentrations of about 10 ppm and 60 ppb above the background, respectively.

Preliminary results from particle back trajectory analysis (Lagrangian particle dispersion model) show that the observed methane hotspots correspond to a footprint that overlaps with the municipal solid waste facility (landfill) in the southern part of the city. Urban city centers have been previously reported to be large sources of anthropogenic methane with emissions much larger than currently reported in emission inventories. The challenge with methane is that the sources are very well known but the magnitudes of individual sources are not very well quantified. This is particularly true for landfills. Landfills are one of the most important anthropogenic sources of methane with global emission estimates ranging from 9 to 70 Tg/yr. Because of the spatial inhomogeneity and large areal extent of landfill sites, previous estimates of methane emissions from direct, small-scale surface enclosure techniques varied over seven orders of magnitude. Having observed the significant contribution of the landfill in Indianapolis to the total city-wide emission flux, we have since then measured the methane emission rates directly downwind from several Indiana landfill sites using the same aircraft-based mass balance approach, which is a whole landfill measurement technique. Figure 3 shows our horizontal flight track and the methane plume directly downwind from the Newton County Landfill, the largest municipal solid waste facility in Indiana. We would like to use the measured emission rates from several Indiana landfill sites to validate current emission models and improve our understanding of methane production from municipal solid waste facilities. This work is supported by a grant from the National Institute of Standards and Technology.

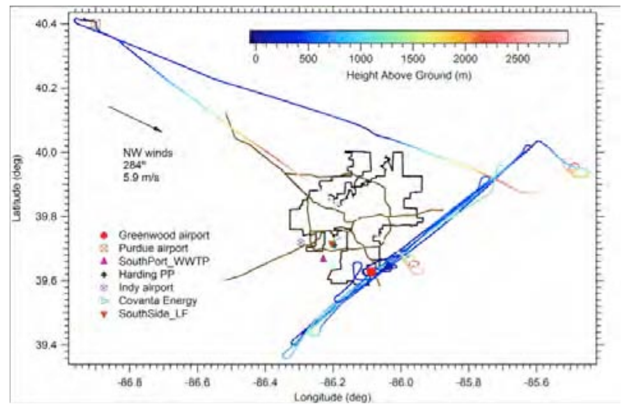


Figure 1. Flight path on June 1, 2011 showing the horizontal flight segments perpendicular to the wind direction; also shown are the locations of CO_2 and CH_4 sources in the city of Indianapolis.

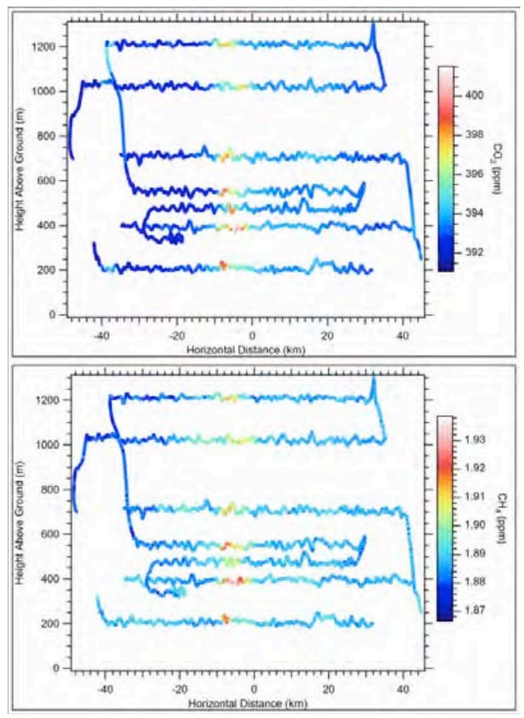


Figure 2. Carbon dioxide and methane distribution as a function of the height above the ground and horizontal distance along the curtain flight segments. CO_2 and CH_4 hotspots are observed at specific coordinates along the curtain flight segments.

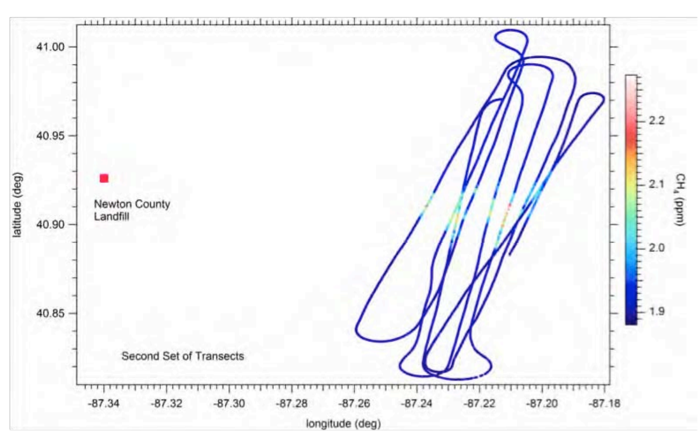


Figure 3. Horizontal flight segment and methane plume directly downwind from the Newton County Landfill.

- Brown-rot Fungal Mechanisms as a Model for Biomass Saccharification - Timothy Filley, *Earth & Atmospheric Sciences*, with Jonathan Schilling and Robert Blanchette, *University of Minnesota* (DOE)
- Collaborative Research: Synthesis of Arctic System Carbon Cycle Research through Model-Data Fusion Studies Using Atmospheric Inversion and Process-Based Approaches - Qianlai Zhuang, *Earth & Atmospheric Sciences and Agronomy,* with A. David McGuire, *University of Alaska, Fairbanks*; Jerry Melillo, *Marine Biological Laboratory*; and Michael Follows, *MIT* (NSF)
- The Boston-Area Climate Experiment: A gradient-based approach for characterizing ecosystem responses to warming and precipitation change - Jeffrey S. Dukes, *Forestry & Natural Resources and Biological Sciences* (Northeastern Regional Center of the Department of Energy's National Institute for Climatic Change Research, based at Pennsylvania State University)
- Experimental Testbeds for New Applications of Environmental Trading Programs - Timothy Cason, *Economics*, with John Stranlund and John Spraggon, *University of Massachusetts*; James Murphy, *University of Alaska*; David Porter, Stephen Rassenti and Vernon Smith, *Chapman University* (EPA)
- Halogen Chemistry and Ocean-Atmosphere-Sea Ice-Snowpack (OASIS) Chemical Exchange During IPY - Paul B. Shepson, *Chemistry* (NSF)
- The Isotope Networks Portal: Data Integration for Biogeochemistry and Ecology Through Web-based Geospatial Modeling - Gabe Bowen, *Earth & Atmospheric Sciences*; Lan Zhao, *Rosen Center for Advanced Computing*; Chris Miller, *Libraries*; Tonglin Zhang, *Statistics*; and Jason West, *Texas A&M University* (NSF)

29 *The number of active research projects led by our faculty. These projects are supported by grants from a wide range of funding agencies including the National Science Foundation (NSF), the Department of Energy (DOE), the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), U.S. Agency for International Development (USAID), the National Institute for Standards and Technology (NIST), and the National Aeronautics and Space Administration (NASA).*

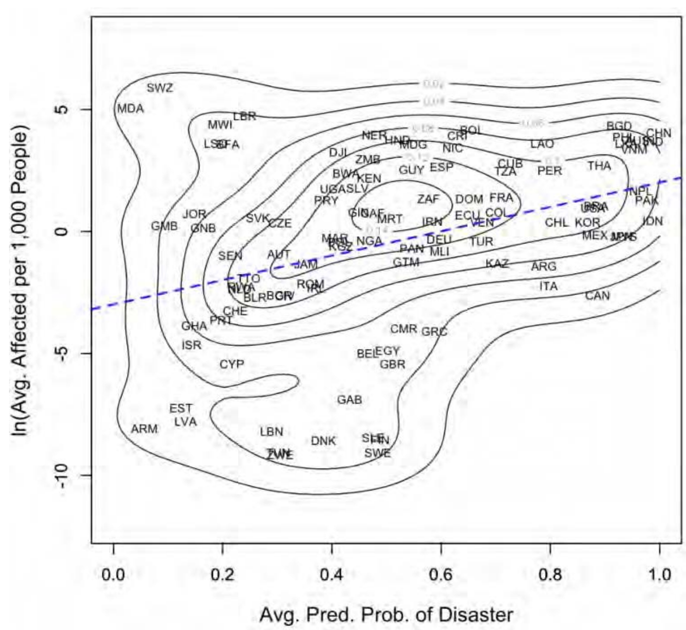
Disaster Risk, Social Vulnerability, and Economic Development

Gerald Shively

Patrick Ward

Professor Gerald Shively, *Agricultural Economics*, and recent graduate student Dr. Patrick Ward (*PhD, Agricultural Economics, 2011*) are examining the extent to which economic development reduces both a country's disaster risk and its social vulnerability to climate-related disasters. They use data from the EM-DAT database collected and maintained by the Center for the Research on the Epidemiology of Disasters (CRED). These data represent country-level observations over the period 1980-2007.

Analysis indicates that the ability of economic development to reduce disaster risk depends on a country's income level; additional income becomes less effective in reducing disaster risk as countries become wealthier. Conditional on a disaster occurring, higher incomes generally reduce a country's social vulnerability to such disasters. They additionally find that underlying social and political structures exert a strong influence over the human costs of disasters. The figure to the right comes from their paper and illustrates the joint probability density between disaster occurrence and deaths. Countries identified as above the dashed line in the figure have disaster impacts that are higher than average for their underlying level of disaster risk, and therefore can be categorized as being more vulnerable to those risks than countries below the line.



ABOVE: The figure shows predicted probability of disaster and average deaths per 1,000 people. (Source: Ward, P. and Shively, G., 2011. Disaster Risk, Social Vulnerability and Economic Development)

Controls on soil carbon accumulation during woody plant encroachment

Woody plant encroachment is a global phenomenon that alters the biogeochemical cycling of soil carbon and nutrients. Graduate student Courtney Creamer and her advisor, Professor Timothy Filley, *Earth & Atmospheric Sciences*, used soil physical fractionation, soil chemistry and respiration kinetics, and the isotopic composition of respired CO_2 to investigate microbial degradation of accrued soil organic carbon (SOC) along a chronosequence of woody plant encroachment into grassland in southern Texas.

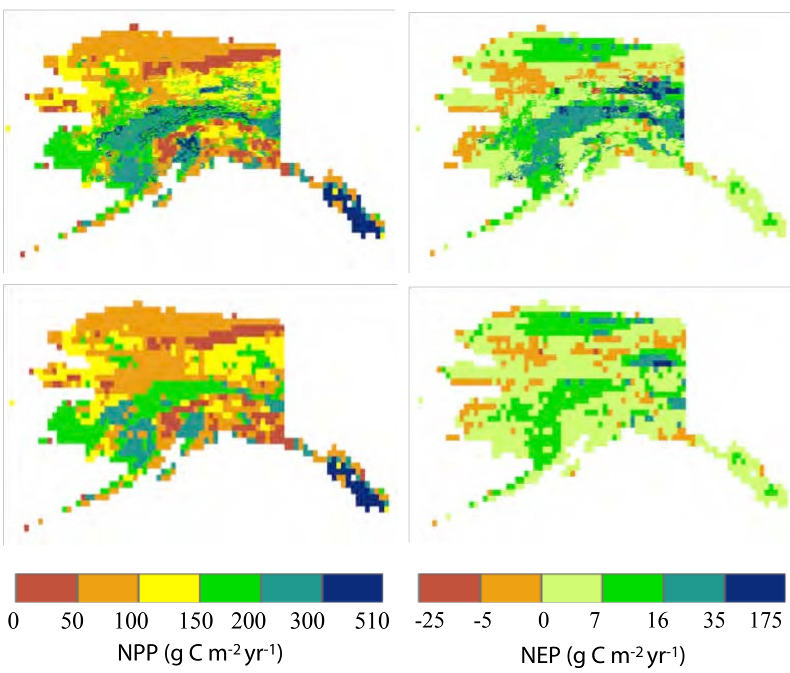
Despite previously observed changes in the chemistry and abundance of lignin and aliphatic biopolymers, during a long-term soil laboratory incubation they found no evidence for greater biochemical recalcitrance as a controlling mechanism for SOC accrual. δ13C values of respired CO_2 indicated that the mineralized CO_2 was predominately of woody-plant tissue origin and derived from physically accessible soil fractions. C accrual in these soils should therefore not be considered stable over the long-term, and this should be taken into account when considering the impact of land cover or climate change on C accrual in this region. This work has been expanded to similar global change phenomena taking place in Inner Mongolia, China, where overgrazing and climate change have caused severe degradation of the grasslands and promoted expansion of leguminous woody tissue. This work was funded by a grant from the National Science Foundation.

Modeling the Carbon Dynamics of Alaskan Boreal Forest Ecosystems

Boreal forests store a large amount of carbon whose fate under changing climate is uncertain. To date, most studies of the region are based on plant functional type (PFT) classifications. Since, according to field studies, species respond to climate differently with respect to carbon and nitrogen cycling, it is desirable to examine the regional carbon dynamics at a species level. Professor Qianlai Zhuang *Earth & Atmospheric Sciences*, and graduate students Yujie He and Min Chen conducted such a study for the Alaskan boreal forest ecosystems from 1922 to 2099 using a biogeochemistry model. The model was parameterized for five major boreal forest species, including white spruce, black spruce, aspen, birch and poplar. Species-level and PFT-based simulations were compared (see figure below).

The species-level simulations had a larger interannual variation and showed a 1 Tg C yr^{-1} larger sink than their PFT-based counterparts by the end of the 21st century. As a result, species-level simulations accumulated 0.5 Pg more carbon than PFT-based estimates during the period 1922-2099. Net primary production, vegetation and soil carbon levels were generally higher in the species-level simulations, and exhibited larger interannual variations. Aspen and poplar did not change their nitrogen stocks, while spruce ecosystems experienced a shift of nitrogen from soils to vegetation. This suggests that the nitrogen limitation may be more dramatic in conifer forest ecosystems than in deciduous forest ecosystems.

The research team also found that white spruce and aspen experienced a much higher growth rate under altered climate conditions, implying that they have a vulnerability and sensitivity to climate change (e.g., drought). This study is among the first to quantify boreal forest carbon cycling at a species-level and suggests that incorporating species-specific traits into ecosystem models should be a priority to more adequately quantify carbon dynamics at a regional scale. This work was funded by a grants from the National Science Foundation and the Department of Energy.



ABOVE: Average NPP and NEP in Alaska estimated based on species-level and plant-function-type based TEM simulations in the 1990s. Upper two panels are species-level simulations; lower two panels are plant-function-type based simulations.

The Early Eocene "Equable Climate Problem" and What it Means for Future Climate Change

Summary of Main Findings:

In a much warmer world, atmospheric circulation fundamentally transitions to a state of 'superrotation,' essentially a reversal of normal tropical wind directions to tropical Westerlies. This change to westerly winds decreases the formation of low clouds which has a warming effect on the planet and makes the atmosphere much more sensitive to greenhouse gas forcing. Super rotation also causes wind anomalies that drive a more El Niño-like ocean state. Through sensitivity studies, Professor Matthew Huber and his collaborators find that if a large warming anomaly (on the order of 5°C) is placed in the central equatorial Pacific, our modern climate could spontaneously transition into a super-rotating state.

Recent paleoclimate proxy reconstructions indicate that global-mean surface temperatures in past warm climates may have been 10-15°C higher than today. These new developments fundamentally change the perspective for warm paleoclimate modeling. If standard general circulation models (GCMs) are capable of a reasonable fit to proxy temperatures, then looking for equatorial 'thermostats' and other missing physics no longer seems a high priority. Instead, a new field opens up; that of high-temperature climate dynamics.

Until recently, little attention has been paid to the functioning of very warm tropical climates. We do not know if such climates differ qualitatively from the modern climate, and there have been no systematic studies of model responses to such high temperatures. In particular, at sufficiently warm enough temperatures, is it possible that the general circulation may transition to a qualitatively different state?

A research team led by Professor Matthew Huber, *Earth & Atmospheric Sciences*, studied this question in a set of simulations using the National Center for Atmospheric Research NCAR's Community Atmosphere Model coupled to a slab ocean with a range of CO_2 concentrations extending from preindustrial values (280 ppm) up to 8960 ppm (5 doublings), in modern, early Eocene, and 'aquaplanet' modes. Analysis revealed a surprising new result.

At high enough temperature, a standard GCM of the type used for projecting future climate change, spontaneously transitions to a super-rotating state. Superrotation is a common feature of planetary atmospheres, including those of Venus and Titan, and has previously been obtained in Earth-like atmospheric models but only by imposing ad hoc equatorial heating anomalies. Much of the interest in a transition to superrotation lies in its possibly profound impacts on Earth's tropical and global climate, which could explain some unsolved paleoclimatological puzzles.

One of these puzzles involves the ENSO, a mode of variability whereby surface ocean temperatures over vast areas in the eastern equatorial Pacific fluctuate by about 5°C from year to year, causing major disruption in the global atmospheric circulation. There is much climate proxy evidence suggesting that ENSO variability shut down during past warm climates with the eastern Pacific ocean settling into permanently warm conditions (the so-called 'permanent El Niño' state). However, there is currently no clear understanding of what may have caused a permanent El Niño.

Some researchers have speculated that a transition to superrotation could bring about a permanent El Niño because the convergence of eastward momentum onto the equator associated with super-rotation would add a permanent eastward component to tropical surface winds, causing the western Pacific warm pool to permanently extend eastward. Huber and his team have preliminary results confirming this hypothesis for the first time. Preliminary results from a study with near-modern boundary conditions shows that this may indeed be an important feedback. These results were documented in a recent paper to *Climate of the Past*, entitled, "Implications of the permanent El Niño teleconnection 'blueprint' for past global and North American hydroclimatology" in which the team elucidates the importance of ocean-atmosphere interaction patterns in determining large-scale hydrological/convection/cloud feedbacks, with an emphasis on super-rotation.

The novelty in this recent work is that super-rotation emerges spontaneously, as part of the model's intrinsic response to increasing temperature. This may be an issue of fundamental important in climate change, past present and future. This project is funded by a grant from the National Science Foundation.

- *Huber, M. and R. Caballero (2011) The Eocene Equable Climate Problem Revisited. Climate of the Past, 7, 603-633.*
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WESTERLY WINDS: Warm air around the equator rises and flows toward the poles. When the warm air moves to about thirty degrees north and south of the equator, it cools and sinks. Some of the sinking air moves back to the equator, with the rest flowing toward the poles. Between thirty and sixty degrees latitude, the winds that move toward the poles appear to curve to the east. Because these winds travel from the west to the east, they are called prevailing westerlies. Prevailing westerlies in the Northern Hemisphere are responsible for many of the weather patterns across the United States.

SEED GRANT PROGRAM

Promising research. The PCCRC provides funding to kick-start the outstanding ideas from our community of researchers. This year we supported work to incorporate human physiology into GCMs; to unravel the chemistry of aerosol formation; to study invasive species; to improve measurement of nitrogen fluxes from agricultural fields, and to establish a paleoclimate history of Central Asia.

What Will Increasing Intensity of Heat Waves Mean for Humanity?

Matthew Huber, *Department of Earth and Atmospheric Sciences*

While it is widely agreed that global warming of over 10°F would have disastrous consequences for humankind, it is very difficult to rigorously specify what the consequences of this warming would be, let alone to quantify the costs. Despite this uncertainty in future climate change impacts, most believe that humans could ultimately adapt to any possible warming, reasoning that people already tolerate a wide range of climates today. When measured in terms of peak heat stress, this is untrue. Recent work by Sherwood and Huber (2010) show that even modest warming could expose large fractions of the population to unprecedented heat stress; with more severe warming, the temperatures would become intolerable.

More detailed heat stress studies incorporating physiological response characteristics and adaptations are necessary to investigate the direct impact of climate change to humans. This project takes on this challenge and aims to include the representation of heat stress into an earth system model to better address the question, what will increasing intensity of heat waves mean for humanity?

The Effect of Climate Change on Plant Invasion in a Mixed-Grass Prairie

Jeffrey Dukes, *Departments of Forestry & Natural Resources and Biological Sciences*

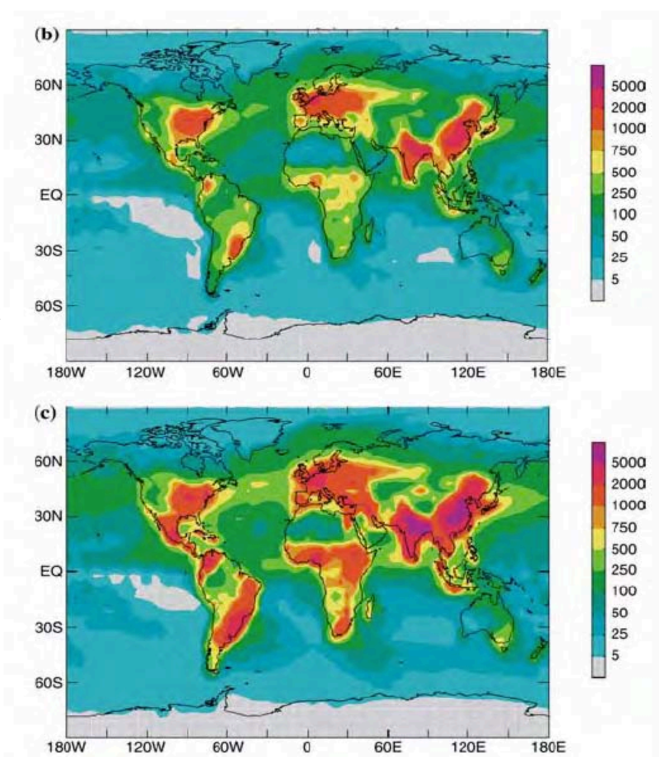
Exotic, invasive plant species cause significant ecological and economic damage to previously intact native systems. Many invasive plants share physiological and life history traits that help them outcompete native communities. These traits may give invasive plants an even greater advantage in responding to predicted climate change. While these conclusions are supported by a well-developed conceptual framework, few studies have empirically examined the success of invasive species in response to altered climate conditions. To better understand the impacts of climate change on invasive species, this project will investigate the effects of warming and altered precipitation on invasion in a northwestern Indiana prairie.

A New Approach to Understanding Aerosol Formation and the Impact on Climate: Coupling 3-D Modeling and Isotope Analysis

Greg Michalski, *Departments of Earth and Atmospheric Sciences and Chemistry*

A crucial uncertainty in understanding the human impact on climate is how aerosols, including nitrates, sulfates, and organic aerosols, can effect radiative forcing. Some aerosols, such as nitrates, can increase the planetary albedo (reflectivity) cooling the climate, while others, such as soot, can absorb solar radiation and heat the planet. Nitrate aerosols are derived from nitrogen oxides (NO_x) which are predicted to increase with global industrialization and expected population growth (figure, below) thereby making nitrate aerosols increasingly important in the climate system. Surprisingly, the chemical mechanisms that convert NO_x into aerosol nitrate are not well understood. This conversion process is important because it has a major influence on OH and O_3 concentrations. Increases in these two oxidants amplify the rate of SO_2 oxidation into sulfate, the most important secondary aerosol formation mechanism in the atmosphere. In addition, oxidation of soot and organic aerosols by O_3 and OH can convert them from a "warming aerosol" to "cooling aerosol" by altering their reflectivity and transforming them from hydrophobic to hydrophilic, which converts them from ineffective into effective cloud condensation nuclei.

Thus, from a climate perspective, increases in aerosol nitrate production has a "direct effect" by increasing planetary albedo, and an "indirect effect" by altering the chemistry of the atmosphere that impacts secondary aerosol formation and cloud production. Resolving the uncertainties associated with the conversion of NO_x into aerosol nitrate is critical if climate models are to account for such chemical dynamics and integrate such understanding into next-generation climate modeling studies. This project takes a new approach to understanding the oxidation chemistry that produces nitrate aerosols by combining stable isotope measurements with regional chemical transport models.



LEFT: The figure is taken from Galloway et al. (*Biogeochemistry,* 2004) and shows estimates of current (b) and projected, 2050 (c) global anthropogenic nitrogen deposition in units of mg/m²/yr, predominately as $NO_3^-{}_{atm.}$

Improving the Accuracy of N2O Flux Determinations from Fertilized Fields using Open-Path Micrometeorological Methods

Richard Grant and Cliff Johnston, *Department of Agronomy*

Of the primary greenhouse gases, nitrous oxide (N_2O) has over 300 times the global warming potential of CO_2. About 70% of all N_2O emissions originate from agriculture, and most of the latter comes from N fertilizers. Although N_2O emissions from agricultural soils associated with agricultural fertilization practices have been reported and used in national Greenhouse Gas Emission Inventories, most estimates rely upon chamber measurements which show high within-field variability and very little experimental data at the field scale is available to support or evaluate options available to Midwestern corn producers to minimize N_2O emissions.

This project will evaluate how well chamber measurements represent the temporal and spatial emissions of N_2O and NH_3 from adjacent plots following side-dressed urea ammonium nitrate application after planting in 2011. These evaluations will ultimately provide farmers with the information they need to help reduce N_2O emissions from their fields.

Glacial and Climate History of Central Asia and Tibet

Nathaniel Lifton, *Departments of Earth & Atmospheric Sciences and Physics,* and Jon Harbor, *Department of Earth & Atmospheric Sciences*

Testing global climate models requires well-constrained information on past climates for key regions around the world. Particularly important are paleoclimatic data for regions at the confluence of major climate systems, because these transitional regions are particularly responsive to changes in patterns of large-scale climate. Central Asia is one of the most extreme continental locations on Earth, and is particularly important because its glaciers and rivers respond to variations over time in the dominance of major regional weather systems. Quantifying past variations in the climate of Central Asia provides an exceptional opportunity to develop data with which to test the global circulation models that are used to predict future climate changes.

Despite its potential importance, the paleoclimate of Central Asia has received little attention compared to other critical areas, in part because of the challenges of working in this remote area. This grant will fund a field project in Kyrgyzstan as part of a long-term international effort to systematically map and date the glacial history of three major mountain ranges in Central Asia using consistent and reproducible methods. The team will use remote sensing to map out the glacial deposits of northern Kyrgyzstan, and collect rock samples for cosmogenic nuclide 10Be dating of moraines that constrain the former maximum extent of the glaciers. The outcome of the project will be detailed maps and glacial chronologies for the Krygyz Tian Shan range that will be integrated into related studies of the Chinese Tian Shan.

BELOW: Remote and stretching for 1,500 miles, the Tian Shan mountain range extends from the Xinjiang province of western China, across Kyrgyzstan, to the border of Uzbekistan. This stark and rugged landscape in Central Asia comprises one of the most extreme continental locations on Earth. It is a particularly important region to paleoclimatologists because the glaciers and rivers respond to temporal variations in the dominance of several major climatic systems. Quantifying past variations in the climate of this region provides an exceptional opportunity to develop data with which to test the global circulation models that are used to predict future climate change.

JOURNAL ARTICLES

Science is a shared knowledge. Our discoveries are shared with the scientific community through papers in academic journals; increasingly, our work appears in a broad range of print and broadcasting media outlets, reaching not only scientists, but policymakers and the public. This year's publications are listed below, along with headlines from the popular press that featured our work.

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'Cities affect storms, but downwind areas can get the worst of it'

'Heat Waves: The New Normal'

‘Climate change allows invasive weed to outcompete local species’

‘Drought-exposed leaves adversely affect soil nutrients, study shows’

‘Doppler radars help increase monsoon rainfall prediction accuracy’

‘How much should the public know about climate science?’

‘Indiana, Illinois climate trending toward fewer droughts’

‘U.S. does not have infrastructure to consume more ethanol’

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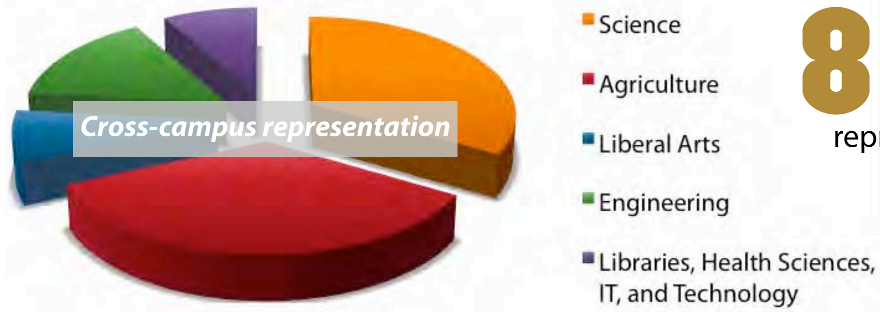
PCCRC FACULTY

Our core: the scholarship, creativity, and energy of our faculty is simply the lifeblood of the center. Unmatched in breadth, our cross-college faculty teams focus on interdisciplinary approaches to the "wicked problem" of climate change.

62 Affiliated Faculty



8 The number academic units represented by our faculty.

29 Research Projects

20 Percentage increase in this year's annual sponsored grant dollars.

41 Publications

11 The number of symposia, workshops, conferences, and lectures hosted on campus.

PCCRC Membership by Department

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

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

Agricultural Economics: Otto Doering, Alla Golub, Ben Gramig, Thomas Hertel, Jacob Ricker-Gilbert, Juan Sesmero, Gerald (Jerry) Shively, and Wally Tyner

Biological Sciences: Kerry Rabenold

Botany & Plant Pathology: Nancy Emery

Building & Construction Management: Kirk Alter

Chemistry: Paul Shepson

Civil Engineering: Larry Nies, Suresh Rao[4]

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Economics: Timothy Cason

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

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Cindy Fate, Administrative Assistant
Matthew Huber, Associate Director
Rose Filley, Managing Director
Leigh Raymond, Associate 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; [7] joint appointment in Mathematics.

Documenting the last ~8,000 years of water cycle history as recorded in the sediments of the Great Salt Lake to investigate the response of the water cycle to climate change.

Building and deploying a network of rugged, autonomous buoys in the Arctic Ocean to study global change in the region.

Improving the resilience of Midwest farms to climate change by providing enhanced decision support tools to the region's farmers and land managers.

Quantifying the exchange of methane between the terrestrial ecosystems of northern Eurasia and the atmosphere.

Investigating how overgrazing and climate change influence the expansion of leguminious woody plants through the grasslands of Inner Mongolia, China.

GLOBAL REACH

As these examples highlight, in pursuit of a better understanding of Earth's changing climate, the activities of our faculty span the globe.

Improving our understanding of warm tropical paleoclimate dynamics to study the potential impact of a large warming anomaly on the Earth's modern general circulation.

Documenting the paleoclimate history of the Atacama Desert in northern Chile, the oldest and driest desert in the world, to understand long-term climate variability in South America.

Improving our understanding of the response of the Western Antarctic Ice Sheet to climate change by reconstructing the region's last deglaciation.

Assessing the impact of climate change on agriculture in Tunisia and Morocco with the aim to create a framework that can be applied in other countries and regions.

Detailing the glacial history of the Kyrgyz Tian Shan range to improve model simulations of past climates which will improve the ability of models to simulate future climate states.

GEOSHARE

A warming planet combined with population growth and rising incomes is increasing the vulnerability of our agricultural systems. Those grappling with the complex, dynamic nature of the relationships among climate change, resource use, and agricultural production are faced with the added challenge of incompatible datasets, which limits analysis that integrates across these domains. In a simple example, analysis of future crop prospects do not consider the projected rise in extreme weather events like heatwaves and floods. Recognizing that there is a critical need for improved database infrastructure to support state-of-the-art, spatially explicit modeling of land use/land cover change, agricultural production, and climate change, Professor Thomas Hertel and Dr. Nelson Villoria (*Agricultural Economics)*, working with partners from across the globe have proposed a new cyberinfrastructure to support the global research community as it seeks to understand the long-run sustainability of our agricultural systems. Read more about the project on page 30.

Former Purdue visiting professor Wenshen Ge, PCCRC Fellow and EAS graduate student Fan Wang, and Professor Greg Michalski collecting samples near the Turpan oasis, in western China. They are trying to understand the origin of massive nitrate deposits in the Turpan-Hami basin and their connection to the onset of aridification in the Tarim Basin.

LAUNCHING TOMORROW'S LEADERS

The PCCRC supports a learning environment that emphasizes interdisciplinary thinking, collaboration, and a sense of open possibility. Our faculty encourage students to see the larger implications and connections of their work, challenging them to dig deeper into issues, broaden their perspective, and question assumptions. In this section of our report, we present a sampling of the intellectual contributions of our students and highlight examples of our faculty's teaching programs.

DOCTORAL FELLOWS

Since 2006, the PCCRC Graduate Fellowship Program has helped recruit outstanding doctoral-seeking students interested in pursuing interdisciplinary climate change research. On the next couple of pages, read about our Fellows and the focus of their work.

Linyuan Shang joined the Department of Earth & Atmospheric Sciences in the fall of 2011. He came to us from China, earning his B.S. degree from Wuhan University and his M.S. from the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. In his first year at Purdue, Linyuan is taking courses in Atmospheric Physics and Atmospheric Chemistry. He is currently working with Prof. Qianlai Zhuang's group on a project that focuses on terrestrial biogeochemistry, specifically, interactions between the atmosphere and biosphere.

Ruoyu Wang joined the Department of Agricultural and Biological Engineering in the fall of 2011. Ruoyu earned his B.S. degree in Environmental Engineering from Beijing University of Chemical Technology and his M.S. in Forestry (specifically, forest hydrology) from Auburn University, Alabama. In his first year at Purdue, he is taking courses in Environmental Informatics, Eco-hydrology and Soil Genesis, and classification and survey methods. Ruoyu is currently working with advisors Profs. Keith Cherkauer and Laura Bowling on a DOE project that focuses on improving plant growth models. His research also estimates how future climate change will affect cereal crop/bio-fuel crop production.

Paul Schmid, Department of Earth & Atmospheric Sciences, is a 2010 PCCRC Fellow. Paul works with advisor Prof. Dev Niyogi, in conjunction with the Indiana State Climate Office. His current research includes modeling land surface interaction with thunderstorms, specifically in urban areas and statistical and model representation of surface-subsurface-atmospheric flux coupling.

OUR RECENT GRADUATES

Jinyun Tang, 2007 PCCRC Fellow. Jinyun successfully defended his PhD thesis in spring, 2011. Along with his published work (see Journal Articles section of this report) Jinyun developed a 4D-Var method using GEOS-Chem to invert surface fluxes for atmospheric methane by assimilating different types of measurements, including in-situ time measurements of atmospheric methane concentrations and satellite data. Jinyun is now working as a postdoctoral researcher in the Department of Climate Science, Earth Sciences Division at the Lawrence Berkeley National Laboratory (LBNL). His goal at LBNL is to develop a biogeochemical transport and reaction model for CLM4 (CLM4BeTR) - a first effort towards improving the next generation ecosystem model for earth system modeling. The work is expected to provide a testbed for further developments in our understanding of ecosystem dynamics, and to provide an efficient framework to investigate the possible feedbacks between terrestrial ecosystems and the atmosphere.

Charlotte Kendra Gotangco Castillo, 2007 PCCRC Fellow. Kendra has finished her Ph.D. in Earth & Atmospheric Sciences and is now working as Program Manager of the Klima Climate Change Center of the Manila Observatory where her work centers on the climate change science-policy nexus and human-nature dynamics. Her most recent research focused on modeling different tropical forest deforestation rates, analyzing both the carbon and non-carbon or physical impacts on climate, and exploring the policy implications, particularly with regards to the United Nations Reducing Emissions from Deforestation and forest Degradation program (REDD) in developing countries. She has also worked on the co-benefits aspect of managing climate change, such as synergizing climate change adaptation with disaster risk management, and integrating climate change mitigation into sustainable development. Kendra is interested in the concept of "science management," approaching complex environmental problems with a big-picture perspective and harnessing interdisciplinary knowledge, methods, and skills.

Clay Davis is a 2009 PCCRC Fellow. His current work focuses on the impacts of wind generation on other generation resource needs and their effects on electricity markets. He is also looking into the potential benefits of including energy storage with intermittent generation resources, such as wind generation. Clay has presented to Indiana Utility Regulatory Commission staff members. This last July, he presented a paper at the Agricultural and Applied Economics Association annual meeting in Pittsburgh, PA. Clay is working with advisor Prof. Paul Preckel in the Department of Agriculture Economics.

Fan Wang is a 2009 PCCRC Fellow. She is currently working on the origin and evolution of nitrate deposits in the hyper-arid regions. She has conducted field work in the Atacama Desert, Chile (Dec. 27-Jan 18) and Kumtag Desert, China (Mar 12-Apri 9). During the 2010 Goldschmidt conference, she gave a poster presentation entitled, "Role of water availability in source partitioning for desert nitrate: New evidence from mass-independent oxygen isotopic compositions". Fan was awarded a 2011 Geological Society of America Graduate Student Research Grant. Fan is working with advisor Prof. Greg Michalski in the Department of Earth & Atmospheric Sciences.

Yini Ma is a 2008 PCCRC Fellow, and a 2011 CIC Smithsonian Fellow. Yini is working on a project that focuses on past land use change and current invasive earthworm impact on soil carbon and nitrogen cycling in deciduous forest ecosystems. This year she presented her work at the 2010 American Geophysical Union annual meeting and at the China-US Joint Symposium "Energy, Ecosystem, and Environmental Change" Annual Meeting, Beijing, 2010. In the spring of 2011, Yini was also awarded a Geological Society of America Graduate Student Research Grant. Yini is working with advisor Prof. Timothy Filley in the Department of Earth & Atmospheric Sciences.

Yini Ma Awarded CIC-Smithsonian Fellowship

BIOLOGICAL INVASION AND CLIMATE CHANGE

PhD candidate, Yini Ma, was awarded a Committee on Institutional Cooperation and Smithsonian Institution fellowship for the 2011-2012 academic year for her proposal entitled, "The influence of invasive and native earthworm activity on microbial community structure and carbon cycling dynamics in an eastern US deciduous forest". This national award is presented to only six students annually to support research in-residence at Smithsonian Institution facilities. The fellowships carry a stipend of $30,000 plus an additional $4,000 for research expenses.

This next year, Yini will travel to the Baltimore area to work with collaborators Kathy Szlavecz at Johns Hopkins University and Melissa McCormick and Patrick McGonigal at the Smithsonian Environmental Research Center in Edgewater, Maryland. A goal of the project is to determine if invasive earthworm activity stabilizes or destabilizes soil carbon pools and alters soil microbial community structure and function. Yini will combine field and laboratory experiments to measure gas fluxes from forest soils undergoing disturbance by this biological invasion and study the feedbacks to climate change drivers such as soil carbon sequestration, loss of forest floor litter, and greenhouse gas emissions.

EVALUATING THE IMPACTS OF CLIMATE CHANGE

Examples of our students' scholarly contributions

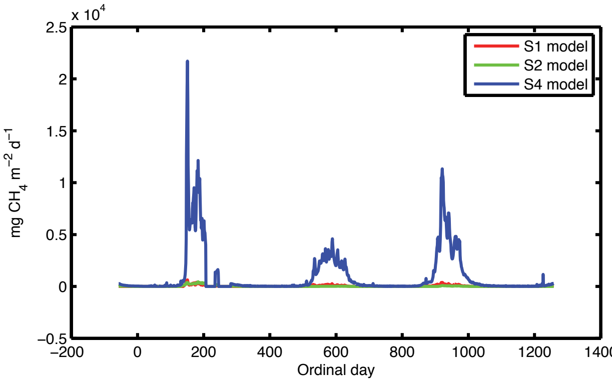
Migration and Land Rental as Risk Response in Rural China

Recent graduate Patrick Ward (*PhD, Agricultural Economics*) and his advisor Professor Gerald Shively, have been studying migration and land transactions as responses to weather risk in rural China. Using a longitudinal data set comprised of households in nine provinces in China from 1991 through 2006, they measure the effects of transitory idiosyncratic and covariate income shocks, household labor shocks, and unanticipated expenditure shocks on household behavior. In addition, they have also analyzed responses to spatially heterogeneous rainfall shocks, which are viewed as affecting the productivity of households' land holdings. They find that idiosyncratic income shocks increase labor migration while simultaneously increasing land rented-out. Positive rainfall shocks alter household expectations about future rainfall and cause households to release excess farm labor. Patrick presented this research at the 2011 Agricultural and Applied Economics Association annual meeting in Pittsburgh, PA.

In fall, 2011 Patrick will be a postdoctoral visiting researcher with the International Center for Climate Governance (ICCG) in Venice, Italy. During this period, he will conduct independent research on social vulnerability to natural disasters, asset-based measures of socioeconomic status and inequality, and the use of market-based instruments as a potential tool for flood risk management, as well as contributing to two worldwide observatories evaluating research and practices for dealing with climate change. In April 2012, Patrick will begin a two-year position as a postdoctoral fellow with the International Food Policy Research Institute (IFPRI) in New Delhi, India. Patrick's research with IFPRI will contribute to the Environment and Production Technology Division's objectives of identifying the most appropriate technological and institutional changes and policies for sustainable and equitable agricultural production, with a geographic focus on South Asia.

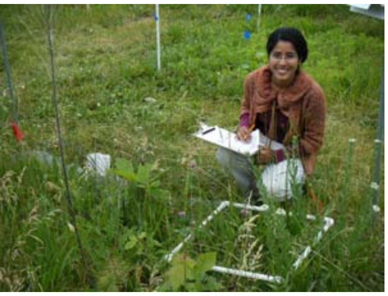
Understanding Global Methane Emissions

Jinyun Tang's (*PhD, Earth & Atmospheric Sciences*) dissertation research has broadly focused on improving quantification of greenhouse gas fluxes (e.g., methane and carbon dioxide) to the atmosphere. Emissions from wetlands are an important source of methane to the atmosphere, and are often observed "bubbling" from the land surface. Many different models can be used simulate methane emissions and, if they are properly calibrated, most of them can generally reproduce fluxes reasonably well. These models, however, do not adequately capture methane fluxes from ebullition, or "bubbling." In a recent paper published in the journal, *Biogeosciences*, Jinyun and co-authors address this issue by introducing a pressure-based ebullition algorithm in processed-based models in a comprehensive sensitivity analysis study. They demonstrate that the inclusion of the ebullition algorithm improves the models' ability to capture fluxes of methane from wetland ecosystems. This is particularly evident in simulations of ecosystems with little or no surface vegetation, where the models that do not consider ebullition greatly underestimate methane effluxes from bubbling. (Source: Tang, J., Zhuang, Q., Shannon, R. D., and White, J. R. (2010), Quantifying wetland methane emissions with process-based models of different complexities, *Biogeosciences*, 7, 3817-3837).



ABOVE: Methane effluxes through ebullition at the Buck Hollow site when no vegetation is present to support plant aided transport.

Linking the Carbon Cycle to Climate Change



Quantifying the effect of temperature, moisture and substrate availability on soil respiration and its components is critical to predict the fate of soil carbon under changing climate scenarios. Since soils have large reserves of carbon, any increase in soil respiration due to climate change could accelerate global warming. To determine how warming and altered precipitation affect the rate and temperature sensitivity of soil respiration (Rs), rhizosphere respiration (Rr) and heterotrophic respiration (Rh), doctoral student Vidya Appukuttan-Suseela, *Forestry & Natural Resources*, and her advisor, Professor Jeffrey Dukes, *Forestry & Natural Resources* and *Biological Sciences*, subjected a New England old-field ecosystem to four levels of warming (up to 4ºC) and three levels of precipitation (ambient, drought (-50%) and wet (+50%) treatments). They also removed aboveground vegetation in small patches of experimental plots to evaluate the effect of substrate availability. In this mesic ecosystem, they find that Rs and its components responded strongly to precipitation. Their results suggest that the response of soil respiration to warming was modified by soil moisture variability. The study also showed that the response of soil respiration was largely driven by rhizosphere respiration. The results highlight the annual, seasonal and diel variability of Rs, Rr, and Rh in response to soil moisture, temperature and substrate availability and emphasize the importance of adequately simulating these responses when modeling trajectories of soil carbon stocks under climate change scenarios. Vidya presented this research at the 2011 annual meeting of the Ecological Society of America in Austin, TX.

CROSS-COLLEGE TEACHING

Developing critical thinkers: our faculty strive to create innovative courses that introduce students to interdisciplinary thinking and foster the development of cross-disciplinary, collaborative solutions to the complex, critical issues of our time for the benefit of all society. This inquiry-based approach is exemplified in courses like the ones described here.

Models in Climate Change Science and Policy

Instructors: Matthew Huber, *Earth & Atmospheric Sciences* and Leigh Raymond, *Political Science*

Models play an increasingly important role in scholarship across many disciplines. Atmospheric scientists model patterns of carbon cycling and radiative forcing in order to better understand past changes in climate and better predict future changes. Economists model changes in consumption and production of goods and services across regional, national, and international scales. Political scientists explain and predict changes in public policy influencing these economic and environmental impacts using models of individual choice and collective action. All of these models are increasingly common and indispensable tools in the worlds of research and policymaking, and educators in many fields are paying more time and attention to working with and explaining these tools. Yet models remain controversial and subject to criticism despite their prevalence.

Modelers in all disciplines are accused of oversimplifying the world, illegitimately presenting their results as "reality," or even manipulating their equations so as to produce biased outcomes. All of these concerns are intensified as models become more and more complex, seeking to integrate the output from one complicated system as input for another. Thus, global circulation model results are now being entered into economic models to predict the financial impacts of climate change, for example, compounding the potential for criticism and error. Unfortunately, students still tend to learn the details of modeling within a single discipline, rather than the broader range of experiences needed to integrate models more effectively, and to better avoid the criticisms and problems leveled at the modeling process by its critics.

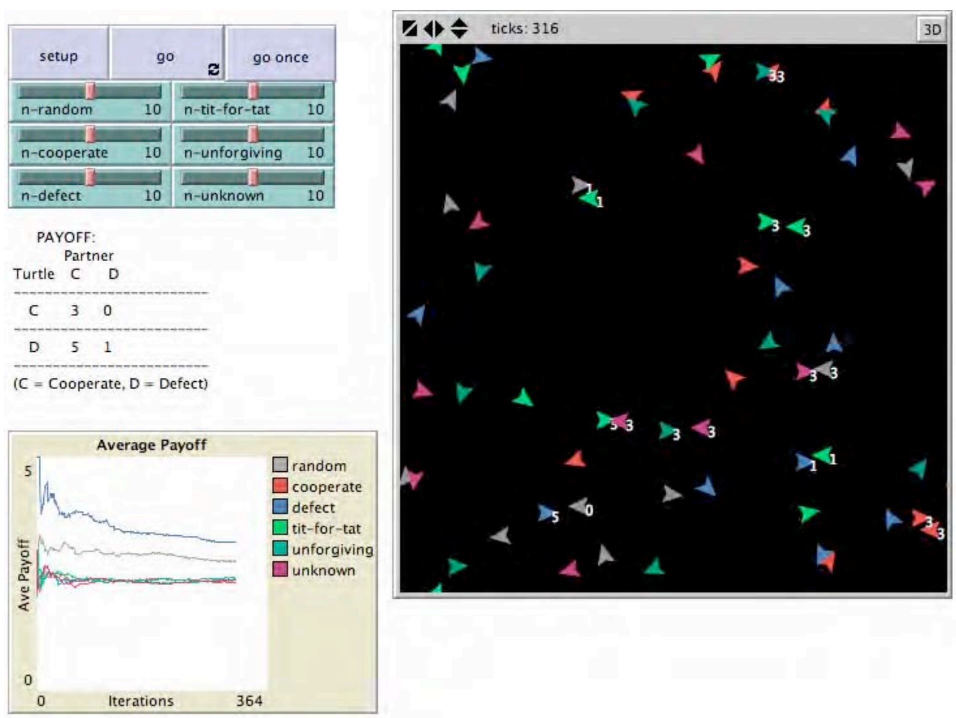
The goal of Huber and Raymond's course is to better educate students in the use and misuse of modeling across disciplines, so that they will be better builders and consumers of integrated, complex models of coupled human/natural systems in their own careers. A key part of the class has students working in interdisciplinary teams (including at least one College of Liberal Arts student and one College of Science student in each team) on semester-long projects to generate policy recommendations based on their own analysis of output from a suite of scientific, economic, and political models of climate change impacts.

A "GREAT ISSUES" COURSE

Through the lens of abstract models of complex social and physical processes, course instructors Dr. Matthew Huber and Dr. Leigh Raymond explore one of the most critical issues of our time, climate change. As a part of the College of Science "Great Issues" program, the course considers the impact of climate change science on society.

Students examine the role of scientific models in understanding how human and natural systems relate to climate change and they consider a range of related ethical issues including: the appropriate distribution of burdens among nations; political vs. individual responsibility; the role of ethical norms in promoting social cooperation; and the proper role of scientific information in the political process.

RIGHT: An image capture of an "agent-based model" of cooperation and an n-person iterated prisoners dilemma, used by students to explore likely outcomes for different mixes of altruistic and selfish individuals. The image shows one time step in the model, including payoffs for different types of individuals meeting in this particular round. If both cooperate, they produce a mutually beneficial outcome of 3 and 3, as with the green and red individuals near the top of the screen. If both choose not to cooperate, they receive lower payments of 1 and 1, whereas if one chooses to cooperate and the other defects, the defector is able to take advantage of the cooperator by gaining 5 with the cooperator getting nothing. Students can manipulate the initial conditions of the model, including the number of people playing different "strategies"--including some that only cooperate contingently such as "tit-for-tat"--in order to understand how different strategies are more or less likely to win out over time.



Terrestrial Biogeochemistry

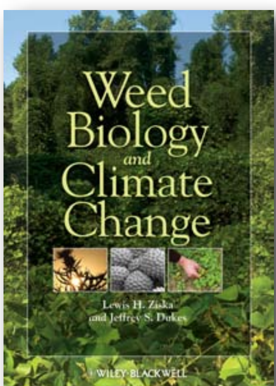
Instructors: Timothy Filley, *Earth & Atmospheric Sciences* and Cliff Johnston, *Agronomy*

This interdisciplinary graduate-level or senior undergraduate level course blends distinct perspectives and tools in stable isotope biogeochemistry, ecology, soil mineralogy, and geochemistry to provide students with a holistic understanding of the transformation and cycling of carbon, nitrogen, and other elements through Earth's ecosystems, with an emphasis on formation and decomposition of soil organic matter. The dynamics of soil organic matter takes a central role in the course because this is such an important source and sink for carbon; there is more carbon in soil organic matter than in the atmosphere and living plants combined, and changes - even small changes- to the rate of formation or decomposition of soil organic matter can have a large impact on the global carbon cycle.

In this course, students take a leading role in guiding the learning process as biogeochemical concepts are reinforced through inquiry-based class projects. These projects focus on evaluation of soil organic matter in ecosystems that are undergoing transition. Filley and Johnston provide background and biogeochemical datasets related to a particular site, then assign student teams specific components of the datasets (e.g., microbial, mineralogical, chemical, isotopic) with which they formulate and test hypotheses about the major drivers for change in the system. The teams present their analyses in open class discussion, and compare and debate the various lines of evidence for change in the ecosystem.

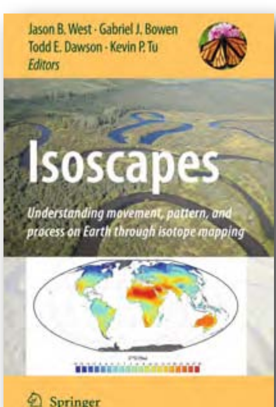
By the end of the course, students gain a fundamental understanding of what makes soil organic matter vulnerable to land use and climate change and what are the cutting-edge metrics used by experimentalists and modelers to measure and predict environmental change.

HOT OFF THE PRESS



Weed Biology and Climate Change

A new book co-authored by Professor Jeff Dukes, *Forestry & Natural Resources*, with Lewis H. Ziska, a plant physiologist in the Crop Systems and Global Change Laboratory of the U.S. Department of Agriculture presents a current and global synthesis of scientific findings for researchers, land managers, and policy makers who are interested in the impact of climate change on weed biology. The book opens with overviews of climate change and weed biology and continues with chapters on climate's effect on weed growth and reproduction, weed management, invasive species, ecosystem functioning, and food security. It also addresses how practices will need to adapt to address a changing climate.



Isoscapes: Understanding movement, pattern and process on Earth through isotope mapping

Stable isotope ratio variation in natural systems reflects the dynamics of Earth systems processes and imparts isotope labels to Earth materials. Carbon isotope ratios of atmospheric CO2 record exchange of carbon between the biosphere and the atmosphere; the incredible journeys of migrating monarchs is documented by hydrogen isotopes in their wings; and water carries an isotopic record of its source and history as it traverses the atmosphere and land surface. Through these and many other examples, improved understanding of spatio-temporal isotopic variation in Earth systems is leading to innovative new approaches to scientific problem-solving. Edited by Gabe Bowen, *Earth & Atmospheric Sciences*, with Jason West, Todd Dawson and Kevin Tu, the volume provides a comprehensive overview of the theory, methods, and applications that are enabling new disciplinary and cross-disciplinary advances through the study of "isoscapes": isotopic landscapes.

Improving Climate Literacy in our Schools

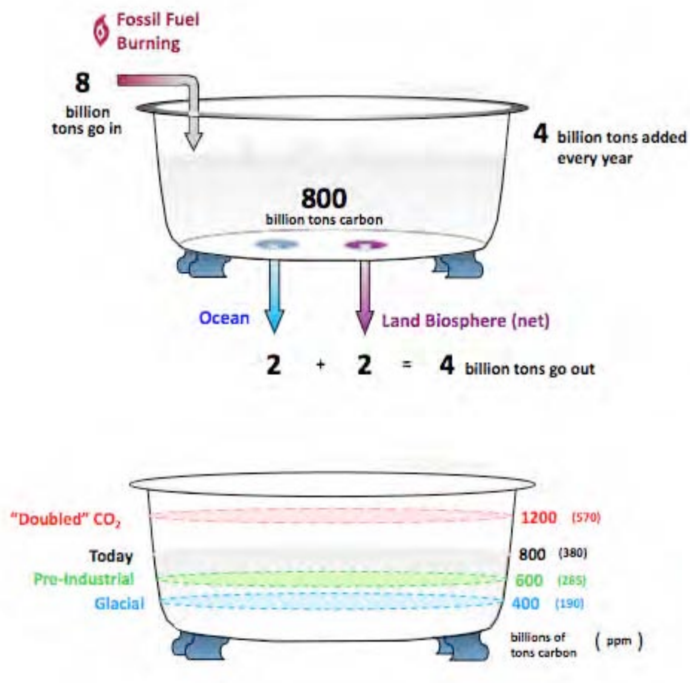
Our faculty and their research partners work to expand and improve understanding of climate change by providing educators with the tools and strategies they need to help their students develop evidence-based thinking skills.

A team of teachers, scientists and professional educators led by Professors Daniel Shepardson, *Curriculum & Instruction and Earth & Atmospheric Sciences* and Dev Niyogi, *Agronomy and Earth & Atmospheric Sciences*, are developing a professional development program designed to prepare teachers to both understand the science of climate and climate change and the pedagogy for effectively teaching about climate and climate change. The program takes a climate system approach to learning about global warming and climate change. Participants are introduced to: 1) the climate system and how the system has changed, 2) greenhouse gases and the greenhouse effect, and how humans enhance the greenhouse effect, 3) the Earth's energy budget and the climate system, 4) global warming, climate variability, and climate change, 5) adaptations and mitigation, and 6) actions and impacts. The program is data and visually driven (see figure to the right) and incorporates small group activities.

The team's approach promotes active learning, viewing participants as active thinkers who construct their own understandings to be able to fluently answer:

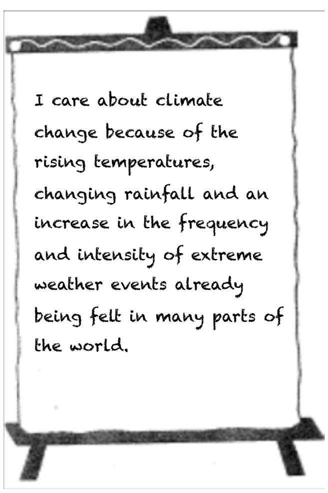
- What is a climate system and its components?
- What are causes and effects of component change?
- What are the impacts of these changes?
- What can we do about it?

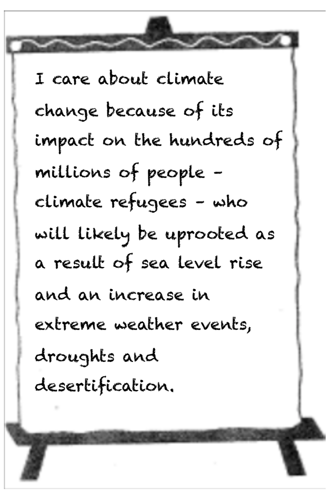
Shepardson and Niyogi are joined in this effort by Adam Baker, *Indianapolis Weather Service*, Hans Schmitz, *Purdue Cooperative Extension*, Jan Sneddon, *Earth Force*, Mary Cutler, T*ippecanoe Parks and Recreation,* and teachers Ted Leuenberger and Mark Koschmann. This project is funded by the National Science Foundation.

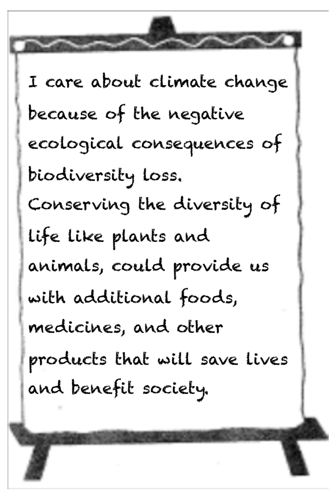


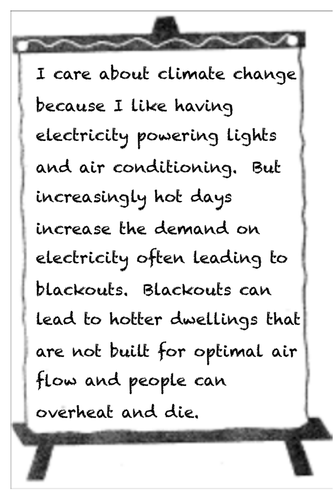
ABOVE: The team uses easy-to-understand graphics to describe the climate system; the atmosphere is represented by a bathtub. In the top tub, carbon emissions are like water coming out of the tap and the ocean and land biosphere act as "drains" taking a fraction of carbon out of the atmosphere. The bottom tub depicts past, present, and potential future levels of carbon in the atmosphere. (Figure from Stabilization Wedges: A Concept & Game, R. Socolow, S. Pacala, R Hotinski)

BELOW: The "I care" flipcharts are used as an icebreaker activity, encouraging participants to interact and share why they relate to that perspective, as well as introduce themselves to the group.









The driving ambition of our work is to serve the citizens of Indiana, the United States, and the world through discovery that expands the realm of knowledge, learning through dissemination and preservation of knowledge, and engagement through exchange of knowledge.

ENGAGEMENT

Defined by a spirit of collegiality and collaboration, the PCCRC works to expand partnerships, share our collective knowledge, and encourage an openness that helps generate innovative solutions to the challenges of climate change. In this section, read examples of how we help connect the scientific community with policy makers, federal agencies, industry, the public, and other stakeholders.

INFORMING POLICY

Our faculty serves as a resource of science-based information for our elected officials, the business community, and resource managers. We work with representatives, and industry and community leaders to promote synergistic solutions that focus on addressing the long-term, global problem of climate change.

PCCRC Participates in First 'Climate Science Day' on Capitol Hill

In February 2011, climate specialists from across the country, representing an array of disciplines, convened on Capitol Hill to meet with new members of Congress. Organized by the American Association for the Advancement of Science (AAAS), the idea behind the 'Climate Science Day' program was to build relationships between policy-makers and scientists. PCCRC Associate Director, Professor Matthew Huber was one of 35 scientists invited to participate in the program. The team of scientists had an afternoon of training in how Congress works. The next day, they paired off to meet with members of Congress and aides representing 22 states. The focus of the non-partisan visits were on topics such as coastline erosion, agricultural pests, climate models, drought, and other issues where the representatives' concerns and the scientists' expertise were likely to overlap. Huber met with several legislators from the Midwest region, including the State of Indiana, offering to share information and keep an open line of communication.

The AAAS partnered with 10 other science groups to organize the first Climate Science ay on Capitol Hill including: American Chemical Society; American Geophysical Union; American Meteorological Society; American Society of Agronomy; American Statistical Association; Crop Science Society of America; Geological Society of America; National Ecological Observatory Network; Soil Science Society of America; University Corporation for Atmospheric Research.

Beyond Additionality in Cap-and-Trade Offset Policy

Perhaps no element of recent cap-and-trade proposals has been as controversial as provisions for offset credits, which allow "capped" sources to increase their emissions in exchange for reducing emissions from an unregulated source outside the cap. At the heart of nearly all offset programs is the requirement of "additionality"—offset credits should only be given for emissions reductions that would not have happened in the absence of the offset program. In an invited paper for the Brookings Institution (Issues in Governance Studies #36), PCCRC Associate Director, Professor Leigh Raymond, questions the usefulness of additionality as a standard on both practical and moral grounds. Practically speaking, the paper argues that additionality requires verifying what a potential offset seller would have done without the offset program. The difficulty of establishing such counterfactuals hamstrings existing offset programs by raising transaction costs. The paper also describes how additionality often calculates offset credits against a weak, Business As Usual (BAU) baseline. By favoring larger historical emitters, this approach is morally disquieting and a threat to environmental integrity under the cap. Ironically, even as recent cap-and-trade programs such as the Regional Greenhouse Gas Initiative (RGGI) have stopped rewarding higher emitters through free allocations of allowances based on prior emissions levels, Raymond concludes, they are creating the same perverse incentives rewarding high emissions baselines and poor environmental performance for emitters outside the cap. For these reasons, Raymond's paper argues that offset policy designers should consider going "beyond additionality" to focus on other standards creating fair, practical, and environmentally effective offset credits. The paper, "Beyond Additionality in Cap-and-Trade Offset Policy," is downloadable from the Brookings website, or by contacting the PCCRC office (pccrc@purdue.edu).

Symposium on Climate Change in the State of Indiana

Federal, state, and local conservation organizations are increasingly incorporating climate change information into their planning, practice and decision-making roadmaps. Members of the Indiana Natural Resources Climate Change Response Team, representing a range of conservation organizations from around the State, are working together to develop and implement climate change response priorities, planning, and practice. To assist the Team with their efforts, the PCCRC hosted a symposium focused on climate change in Indiana. Faculty experts from across campus presented the latest science from their respective fields and participated in an open discussion session with the Response Team members on how to reduce the impacts of climate change on Indiana's natural resources. Presentations drew from the expertise of Professors Jeff Trapp, *Earth & Atmospheric Sciences,* Laura Bowling, *Agronomy*, Keith Cherkauer, *Agricultural and Biological Engineering*, Jeff Dukes, *Forestry and Natural Resources and Biological Sciences,* Barny Dunning, *Forestry and Natural Resources,* Tomas Hook, *Forestry and Natural Resources,* Dev Niyogi, *Agronomy and Earth & Atmospheric Sciences, IN State Climatologist* and Sara Pryor, *Indiana University,*

LEFT: Matthew Huber (on the right) with Mark Berliner, *The Ohio State University,* on Capitol Hill for Climate Science Day.

GEOSHARE

Agriculture presents a trilema. Per capita increases in food production over the last few decades have lifted millions of people out of starvation. At the same time, we acknowledge that agricultural expansion and intensification is a major driver of global change, and is, in turn, vulnerable to the impacts of a changing climate system. Shocks from extreme weather events, energy markets, and obstruction of the smooth functioning of commodity markets via export bans and other measures designed to force instability onto global markets underscore the vulnerability of our global food system.

Defining the Challenge Balancing the tradeoffs between the need to increase agricultural production while minimizing its environmental impacts is a major challenge of the 21st century. Can these interacting challenges be reconciled as we look to the future? What are the data requirements for making informed investment, regulatory and policy decisions in the context of this trilemma? How can we ensure that the information used to make such decisions is valid and fit for the job at hand?

The Problem Those grappling with the complex, dynamic nature of the relationships among climate change, resource use, and agricultural production are faced with the added challenge of incompatible datasets, which limits analysis that integrates across these domains. Most spatial datasets are are not practically accessible; they tend to be regional or national, while many of the problems are global in scope; they often require specialized IT knowledge; and, generally, they are incompatible.

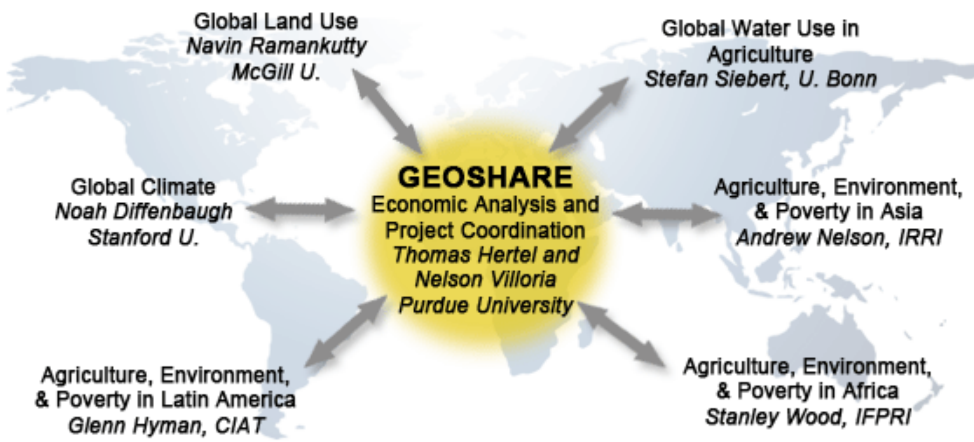
The Proposed Solution Working with colleagues from across the globe, Professors Thomas Hertel and Nelson Villoria, *Agricultural Economics*, and colleagues from across the world have proposed new infrastructure to support researchers working in this area, called GEOSHARE for Geospatial Open Source Hosting of Agriculture, Resource & Environmental Data. GEOSHARE will be a consistent, open-source, spatially explicit global data set, along with regional companion information on agriculture, resources, and the environment that is maintained by a network of research nodes.

GEOSHARE Workshop

With funding from Purdue's GPRI and the PCCRC, Hertel and Villoria organized an international workshop on May 23, 2011, to bring together interested participants to discuss the use of geospatial data for analysis of the global agricultural system, and to consider the GEOSHARE concept. The workshop allowed for exchange of information among researchers, industry leaders, NGOs, and government agencies about what data are currently available (or attainable in the near-term) and which pressing research and policy questions can be addressed with the data flowing out of this type of global spatial data base infrastructure, discuss issues of institutional design and the long-run sustainability of a shared, global, spatial database architecture.

GEOSHAREPROJECT.ORG

The project website, geoshareproject.org, provides an overview of the history of the effort to date and detailed information from the GEOSHARE Workshop including: streaming archive video, a list of speakers and panelists, and downloads of presentation slides.



PART of the COMMUNITY

The complex problem of climate change cannot be solved by any one group. The PCCRC offers a variety of programs and opportunities designed to open dialogue between groups who are interested in making progress towards sustainable solutions to reverse the declining health of our environment.

Resilience and Adaptation in the Face of Climate Change

During Purdue's 2010 Green Week, the PCCRC hosted a panel discussion to offer an objective, non-partisan look at how we might reduce the negative impacts of climate change and take advantage of new opportunities to improve global sustainability. Moderated by Laura Bowling the discussion highlighted the need to start thinking in new ways about how we manage and protect our resources, infrastructure, and people, and adjust our decisions and activities because of observed or expected changes in climate. Speakers include Professor Daniel Aldrich, *Political Science*; Professor Rabi Mohtar, *Agricultural & Biological Engineering* and *Director of the Global Engineering Program*; and Professor Dev Niyogi (*Agronomy and Earth & Atmospheric Sciences; Indiana State Climatologist*). Highlights from the program's topical areas are described below.

WATER RESOURCES: It is evident that changes across nearly all sectors of the economy are expected as a result of water shortages, which are compounded by climate changes and ecological zone shifts. However, to a large extent, integrated multi-scale tools for water decisions and water footprints are lacking, and even more so in a changing climate. We need to better understand the water system under changing climate conditions and to establish measures for linkages between water and other systems that affect water security such climate, trade, food, and energy to name a few. Rabi Mohtar explored the linkages between the water and related systems such as energy, food, trade, and climate, as well as the need for a comprehensive framework for integrating these linkages into a decision making process, and the role of the academic community in creating this framework.

DISASTER RECOVERY: Disasters remain among the most critical events which impact residents and their neighborhoods; they have killed far more individuals than high salience issues such as terrorism. Daniel Aldrich calls for a re-orientation of disaster preparedness and recovery programs at all levels away from the standard fixes focused on physical infrastructure towards ones targeting social infrastructure. The reservoirs of social capital and the trust (or lack thereof) between citizens in disaster-affected communities can help us understand why some neighborhoods in cities like Kobe, Japan, Tamil Nadu, India, and New Orleans, Louisiana displayed resilience while others stagnated.

AGRICULTURAL SYSTEMS: Agriculture is extremely vulnerable to climate change. In his presentation, Dev Niyogi discussed what the different assessments say about how climate change can affect agricultural systems. He also presented information about agricultural feedbacks to climate that need to be considered in an integrated assessment, including some efforts already underway at Purdue. Dev concluded his presentation with suggestions for a vulnerability study to get a better "what if"assessment of climate change and agriculture.

The 2010-2011 Distinguished Lecture Series Speakers

Professor Henry Shue, Senior Research Fellow at Merton College, University of Oxford, and Professor of Politics and International Relations: *Climate Change, Human Rights, and the Trillionth Ton of Carbon*

Dr. Joshua Elliott, The University of Chicago Computation Institute: *Integrating the Socio-economic and Physical Drivers of Land-use Change at Climate relevant Scales: an Example with Biofuels*

Dr. Jonah Busch, Climate and Forest Economist with Conservation International: *Creating incentives for REDD in Indonesia*

Professor Jeff Andresen, Associate Professor and State Climatologist for Michigan, Department of Geography, Michigan State University: *Dynamic Interactions among People, Livestock, and Savanna Ecosystems under Climate Change: The East Africa Climate-Land Interaction Project in Savanna Ecosystems*

A recent episode of the program, **NAKED SCIENCE** (on the National Geographic Channel) explored the topic of man-made disasters. It featured a segment on urban tornados that highlighted Dev Niyogi and colleagues' work on the 2008 tornado in Atlanta, including the impact of urban landscapes on weather.

BEYOND 'CLIMATEGATE'

What Role for Science and the Media in the Making of Climate Policy?

A special event sponsored by the PCCRC and GPRI

Over the past couple of decades, governments around the world have spent $Billions researching past and present climate variability and change, its impact to our environment, and likely future climate scenarios. In 2007 the Intergovernmental Panel on Climate Change published its 4th Assessment Report, proclaiming that, "The warming of the climate system is unequivocal", stating with 'very high confidence' that human activity has contributed significantly to the observed changes. A recent poll indicated that well over 90% of climate scientists agree with findings of anthropogenic global warming.

As robust debates continue within the scientific community concerning the magnitude of human influence, the rate of, and likely future impacts of climate change, public opinion - across all demographics - about the certainty of global warming and humanity's role in climate change has decreased significantly over the past two years. The 'Climategate' controversy has raised additional questions not just about the legitimacy of climate science, but about the credibility of climate scientists themselves. A growing segment of the American population now believes that warnings about climate change are part of an elaborate hoax. To some observers, the climate change science community has failed in its public relations efforts. To others, the climate change science community has not been active enough in politics.

The "Beyond Climategate" forum, moderated by Professor Elizabeth McNie, *Political Science and Earth & Atmospheric Sciences*, examined why such a contradiction between growing scientific certainty and decreasing public belief in climate science exists. The PCCRC partnered with Purdue's Global Policy Research Institute to convene a discussion with speakers Judith Curry, *Professor, Georgia Institute of Technology,* Roger Pielke, Jr., *Professor, University of Colorado, and* Andrew Revkin, *The New York Times and Pace University*. Elizabeth challenged the group to consider:

- *Have scientists become 'too political' in their advocacy of particular climate change mitigation and adaptation policies? Do the benefits of engaging in political advocacy outweigh the risks of losing their credibility as scientists?*
- *What role has the media, including the blogosphere and the Internet, played in this growing contradiction? How has the media shaped the way that climate science is debated, disputed, and created? Is there a 'better' way for climate scientists to work with the media?*
- *Moving forward, is there an 'idealized' role for climate scientists in political and policy debates, and if so, what would it look like?*

Free and open to the public, the event drew over 400 people from campus as well as the Greater Lafayette Community.