

Purdue Climate Change Research Center

2011-2012 ANNUAL REPORT



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 learning and engagement.

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Cover photos: From left to right: A snapshot from Purdue's Ross Biological Reserve where graduate student Asya Robertshaw is studying the effects of climate change on phenology and reproductive success in the spring ephemeral herbaceous plant community; graduate student Lindsey Payne at Machu Picchu, Peru - Lindsey's research is focused on the integration of transdisciplinary knowledge into decision-making processes; the northern lights over the tundra observation site in Barrow, Alaska, where Purdue Chemistry graduate student Kyle Custard and postdoctoral fellow Dr. Kerri Pratt studied halogen chemistry this spring, 2012.

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Message from the Director



Many are beginning to realize the pervasive impact of climate change on the world around us and recognize the potential future impact of this change. Whether one is dealing with environmental

concerns, the provision of food, fiber and clean water or our transportation or built infrastructure, the impacts from climate change are entering the public consciousness. One does not have to be a climate change “believer” to recognize what is going on. There is increased understanding that we have to make our future world and society more resilient to the impacts of climate change. Those who work in agriculture and forestry and produce our food and fiber are increasingly aware of this as are those who are concerned with our infrastructure and those concerned with human and animal health. Suffering two or three “hundred year” floods in a decade and tracking the climate induced movement of vector borne diseases changes the perception of what is going on and what is required to cope. Landscapes and movement of species are changing at increasing speeds. The growing season for crops in the Upper Midwest has increased seven to ten days in the last several decades. Temperature changes and related events like fires are changing the more arid landscapes of the United States in irreversible ways.

All of this makes what we do in Purdue’s Climate Change Research Center even more meaningful. Most of our faculty believe that climate changes are taking place and that human activity contributes to it. However, our major effort has not been trying to move public opinion in this direction. Our major effort has been to undertake the basic work that will allow us to better understand and adapt to or mitigate what is going on in the future. A good example is the work on carbon that is going on across our schools and departments at Purdue. Carbon, like nitrogen, is slippery. It moves in different forms between media, so the carbon lost from soils moves elsewhere – often into the atmosphere. Conversely, increases in soil carbon can reduce atmospheric carbon. If the speed, magnitude and direction of these movements change, then the balance of carbon between land, air and water can change

across the globe. We have similar potential exchanges with methane in the permafrost and our work in the Arctic reflects this important science. Our work with methane and with carbon, highlighted in this report, give us the basic knowledge we need to gain to understand what is going on and allow us to better identify some alternative paths these compounding changes might take. This gives us the ability to explain the consequences we will face along the different potential paths that human interaction with nature might take us. We are not the policy makers, but we do have the obligation to help define climate change problems and assess alternative paths and their consequences for decision makers. If we fail in this, we have not played one of science’s most important public roles.

As I look at efforts like the Purdue Climate Change Research Center, I find myself questioning what are the best metrics for success. Standard administrative metrics include things like increased faculty membership, level of grants, involvement of students, etc. The Center does extremely well with these conventional metrics. Beyond that, I ask myself if we are more successful in making a difference for society when we compare ourselves with other similar efforts? There are certainly other climate centers with equal horsepower in climate science. However, I believe what Purdue brings to the table that is almost unique is the combination of good climate science together with the broad scope of the chemical, biophysical, engineering, agricultural, health, and other applied sciences. These are then complemented by strength in the social sciences that informs the decisions society will have to make about the costs and social impacts of decisions to increase resilience and sustainability in the face of climate change. It is this encompassing package that is our strength. This combination of strengths only functions effectively because of the excellent connections Purdue faculty members tend to form with their colleagues within and outside of their disciplines. Purdue has had a tradition of collegiality and working together that allows and encourages constructive collaboration. The strength of the Center is in such faculty. We do contribute greatly to developing the science base that must undergird much of what we or others might say on the broader issues of where changing climate and increased climate variability may be leading us. We are key providers in

the science that should ultimately frame our climate adaptation and mitigation choices.

Where should we go in the future? We are going to have to continue to improve our basic scientific core – especially in those areas where we already have or nearly have a critical mass. Purdue is hiring another climate modeler who will be working with the center and expanding our capacity in that area that then ultimately links to the other sciences. There are other areas where we should be strengthening as well. We need to find ways to increasingly improve the linkages between the different basic sciences, the studies of their impacts under climate change, and the policy implications for adaptation or mitigation. We should be in a better position than most other institutions to have well-grounded alternatives for decision makers that could lead to increased resilience and sustainability for our food supply, our fiber resources and our built environment that also take account of the economic and social imperatives that surround such decisions. We have the opportunity not only to do the basic

science but also provide the linkages between the sciences and provide the context for considered decisions that flow from the science. We need to do it, do it better, and develop increasing capacity to do so.

A handwritten signature in dark ink, appearing to read "Otto C. Doering, III". The signature is fluid and cursive, with a prominent flourish at the end.

Otto C. Doering, III
Professor and Director

Purdue Chemistry Ph.D. student Kyle
Custard exploring the sea ice in Barrow,
Alaska.



DISCOVERY

We pursue climate change research at Purdue to improve our understanding of the causes and consequences of the Earth's changing climate system and to enhance the capacity of decision makers to develop effective mitigation and adaptation strategies. These endeavors are critical as the pace of change is accelerating and the broad-reaching effects of climate change are becoming more apparent. The following pages provide an update on the tremendous advances being made by Purdue researchers who are working to expand our knowledge of the rate, magnitude and patterns of change.

SPONSORED RESEARCH

WHAT IS THE ARCTIC TELLING US ABOUT CLIMATE CHANGE ?

The cryosphere, regions of the earth in which the surface is perennially frozen, is an important component of the Earth's climate system that is particularly vulnerable to global warming. Temperatures in the Arctic are warming twice as fast as they are for the planet as a whole and global climate models project the highest future warming in the high latitudes. Higher air temperatures and changes in snow conditions are expected to initiate widespread permafrost thawing and this thawing could lead to large changes in natural emissions rates of greenhouse gases, methane and carbon dioxide in particular. Two new grants awarded this year to Purdue researchers explore the implications of permafrost thawing on the global carbon cycle and the feedbacks to climate change.

The striking pace of change in the Arctic is also reflected in the dramatic loss of Arctic sea ice over the last several decades; both the extent and thickness of the Arctic ice cap has rapidly declined, even faster than climate models have predicted. Important chemical exchanges occur between polar air, snow, frost, brine, and sea ice, and there is an urgent need to track how climate change is impacting this chemistry. A third new grant investigates how thinner spring-time ice is altering the atmospheric chemistry in the region, potentially increasing the amount of toxic mercury accumulating in the Arctic.

Permafrost Thawing and Vegetation Change Effects on Cryoturbation Rates and C and CH₄ Dynamics

Timothy Filley, *Earth, Atmospheric & Planetary Sciences* with Miquel Gonzales-Meler and Neil Sturchio, *University of Illinois, Chicago*; Kunda Taneva and Jeffrey Wekjer, *University of Alaska, Anchorage* (Funded by the Department of Energy).

Permafrost soils cover 22% of the Earth's surface in the Northern Hemisphere and contain at least one third of the global pool of soil organic carbon (C) in the upper 1 meter of the surface. Under a warming climate this perennially frozen organic C reservoir becomes increasingly vulnerable to microbial decomposition, which could potentially transfer huge quantities of C into the atmosphere. Climate change can also impact other aspects of ecosystem dynamics in the Arctic such as the amount of snow cover, growing season length, plant growth rates and species composition. These interrelated changes confound our understanding of the processes and mechanisms influencing the global permafrost carbon cycle. For example, greater snow cover and higher air temperatures in the Arctic are likely to expose C stored over millennia to accelerated microbial decomposition, resulting in a major release of C from permafrost into the atmosphere. However, greater winter snow cover is also likely to contribute to the expansion of shrubs into tundra ecosystems, thus increasing net primary production, making the overall net result to the C budget unknown.

Because the mechanisms governing permafrost C cycling in response to climate and ecosystem changes are not well understood, the primary objective of this project is to determine how increasing soil thaw depth and changes in plant composition contribute to C storage capacity in permafrost soils. The research team will investigate a range of interacting processes including soil mixing (cryoturbation) rates, soil C cycling rates (methane and carbon dioxide), microbial

community composition, and the relative importance of different soil organic matter stabilization mechanisms. Experiments will be conducted at two existing long-term snow manipulation experiments at Toolik Lake, located in the foothill region of the Brooks Range, North Slope of Alaska.

Collaborative Research: Quantifying Climate Feedbacks of the Terrestrial Biosphere under Thawing Permafrost Conditions in the Arctic

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

The thawing of permafrost with climate warming is expected to lead to widespread changes in the terrestrial Arctic landscape. This project posits that there exists a climate warming threshold beyond which permafrost degradation becomes widespread and stimulates large increases in methane emissions from thermokarst lakes and poorly-drained wetland areas and large increases in carbon dioxide emissions from well-drained areas. In addition to affecting a range of biogeochemical responses, climate change will also impact global energy dynamics. These changes would outweigh any increased uptake of carbon (e.g. from peatlands and higher plant photosynthesis) and would result in a strong, positive feedback to global climate warming. The research team will use a suite of numerical experiments that encapsulate the fundamental processes governing methane emissions and carbon exchanges - as well as their coupling to the global climate system - to quantify the threshold dynamics (for methane and carbon dioxide) and landscape-level changes in terrestrial Arctic ecosystems that would result from permafrost thawing and to understand the feedback of permafrost thawing to climate change.

Studies of the Production of Molecular Halogens in Arctic Snowpacks and on Sea Ice Surfaces

Paul Shepson, *Chemistry* (Funded by the National Science Foundation).

When the spring sun rises in the Arctic, there occurs a dramatic phenomenon characterized by the complete loss of ozone from the lowest layer of the atmosphere, along with near-complete loss of atmospheric elemental mercury. Researchers have discovered that unique photochemistry of bromine from the sea surface triggers reactions that destroy ground-level ozone in the atmosphere, and transforms airborne elemental mercury into more reactive forms. While the destruction of ground-level ozone is good for air quality, the transformation of largely unreactive elemental mercury into more reactive forms that then deposit to the surface results in the accumulation of mercury toxins in the snow and ice.

During the last several decades, ozone depletion events in the Arctic have increased, but our understanding of the chemical reactions and physical processes leading to

ozone and mercury depletion events is incomplete. It is thought that the processes that release molecular halogens into the atmosphere are related to the presence of seasonal, or first-year (relatively thin and relatively saline) sea ice.

Long-term measurements of Arctic ice indicate a rapid decrease in the extent of multi-year sea ice, with associated increases in the extent of first-year sea ice. This project hypothesizes that as loss of the permanent ice pack continues, the springtime halogen chemistry in the Arctic region, and associated impacts on atmospheric composition and deposition of mercury, will increase. This project will use laboratory experiments and field-based experiments in Barrow, Alaska to develop a detailed photochemical model to understand and predict the chemistry of the atmosphere during ozone and mercury depletion events. The model will be incorporated into larger scale Earth System climate and chemistry models to help enable reliable simulations of the future state of the Arctic atmosphere.



ABOVE: The map shows the extent of sea ice for September, 2012 (shaded white) relative to the median extent (orange line) which is based on the period 1979-2000. Compared to September conditions in the 1980s and 1990s, this represents a 45% reduction in the area of the Arctic covered by sea ice. From the National Snow & Ice Data Center.



LEFT: View of inlet to Toolik Lake, Alaska (a part of the Arctic LTER) taken during the Filley group's June 2012 field campaign. **ABOVE:** Excavated block of permafrost from under moist acidic peats near Toolik Lake. Purdue researchers are studying how snowpack thickness could change the average annual depth to permafrost and the nature of organic matter stored in the soil.

WHAT WILL HAPPEN TO THE CARBON CYCLE AS TEMPERATURES INCREASE AND CLIMATE CHANGES?

The flow of carbon (C) between the atmosphere, oceans, rocks, and the biosphere is known as the carbon cycle. While much is known about the various processes (e.g., photosynthesis and decomposition) that shift carbon between these reservoirs, there remain many unanswered questions about how the global carbon cycle is changing through time, and how the changing carbon cycle is altering our climate.

Two new grants will focus on what these changes will look like in temperate forest ecosystems. One project will investigate the role of plant-generated volatile organic compounds in the formation of tropospheric ozone and secondary organic aerosol formation (both having important impacts on air quality and climate), and how emissions of these biologically produced volatile organic compounds impact carbon sequestration in forests. The second project will address gaps in our understanding of how black carbon affects carbon sequestration in fire-prone forests. A third grant will examine how plant biopolymer structural composition changes with climate stress, and how these changes affect decomposition rates and C and N cycling in a New England old-field ecosystem.

Collaborative Research: Biogenic Volatile Organic Compounds and their Impacts in a Changing Temperate Forest

Paul Shepson, *Chemistry* with collaborators John Seeley, *Oakland University*, Steven Bertman, *Western Michigan University*, and Timothy Starn, *Westchester University of Pennsylvania* (Funded by the National Science Foundation).

This project is a part of long-term research initiative designed to test the hypothesis that the impact of biogenic volatile organic carbon (BVOC) emissions on climate depends on the structures of the BVOC; specifically, isoprene can impact ozone production and terpenes are more effective at nitrogen sequestration and aerosol production, thus the change to terpene-dominated BVOC emissions in forests will lead to more carbon sequestration, other factors remaining the same.

The research team will construct an automated system to measure mixing ratios of speciated BVOCs and their reaction products. They will then deploy this novel measurement system at the Program for Research on Oxidants, PHotochemistry, Emissions, & Transport (PROPHET) site at the University of Michigan Biological Station to test the instrument's performance in reliably measuring a broad suite of heavy alkanes, alkenes, aromatics, isoprene, monoterpene, sesquiterpenes, aldehydes, ketones, alcohols, and organic nitrates in ambient air within and above the forest canopy. These high-resolution measurements will increase the ability of researchers to address questions related to the interactions among forest dynamics, oxidation processes, aerosol production, nitrogen and carbon sequestration, and associated feedbacks on climate. Results from the project will also extend the PROPHET data archive, a valuable community resource for investigation of forest-atmosphere interactions.

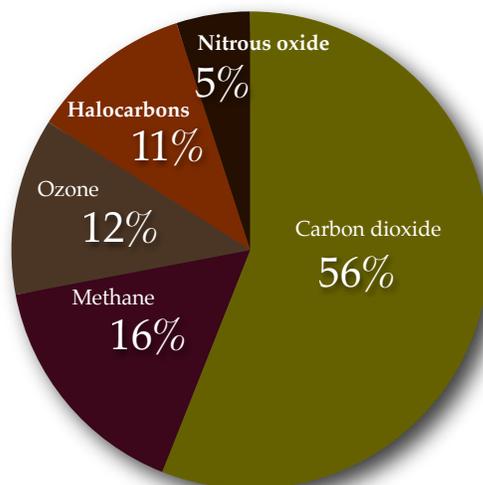
RIGHT: Approximate contribution of the main greenhouse gases (carbon dioxide, methane, tropospheric ozone, halocarbons, and nitrous oxide) to positive radiative forcing of the atmosphere post 1750.

Collaborative Research: Linking the Chemical Structure of Black Carbon to its Biological Degradation and Transport Dynamics in a Northern Temperate Forest Soil

Timothy Filley, *Earth, Atmospheric & Planetary Sciences* with collaborators Jeff Bird, *City University of New York*, and Knute Nadelhoffer, *University of Michigan* (Funded by the National Science Foundation).

Fires are an important component of the global carbon cycle, contributing large fluxes of CO₂ into the atmosphere and incompletely-combusted biomass (black carbon) to soils. Climate models project that temperate and boreal forests will experience greater fire frequency under a warmer future climate, thereby increasing the amount of black carbon (BC) in soils.

Through integrated laboratory and field studies, the research team will explore fundamental biological, chemical, and physical controls on BC degradation and transport processes in a northern forest soil. This experimental approach will produce the first direct, in-situ measurements of BC degradation rates in a temperate forest soil, in this case, a sandy Spodosol, which is representative of large forested regions of eastern North America. Moreover, the team will quantify the role and impact of the main faunal and microbial degraders of BC materials produced at 300°C and 450°C, and of the BC precursor-wood. The project will provide a quantitative description of the source-carbon stabilization mechanisms and chemical transformations in soil over time, as well as measure the effects of BC and wood additions on turnover rates of natural soil organic carbon.



Collaborative Research: Characterizing Climate-Induced Qualitative Changes in Plant Biopolymer Composition and their Influence on Soil Processes

Jeffrey Dukes, *Forestry & Natural Resources and Biological Sciences* with collaborators Nishanth Tharayil, *Clemson University*, Baoshan Xing, *University of Massachusetts Amherst*, and Carol Adair, *University of California Santa Barbara* (Funded by the National Science Foundation).

The productivity of an ecosystem depends on the recycling of nutrients through the process of decomposition. Decomposition is primarily governed by climate and the chemical composition of plant litter. Traditionally, decomposition rates have been estimated using concentrations of carbon, nitrogen, and lignin in the litter. However, the structural characteristics of many hard-to-degrade compounds (biopolymers), including lignins, tannins, and cuticular matrices, can dictate overall decomposition rates. The climate in which plants grow can strongly influence the structural properties of these compounds. Climate change thus has the potential to alter decomposition both directly, by changing temperature and moisture, and also indirectly, by changing the structural attributes of biopolymers in plant litter in ways that are not factored into traditional nutrient cycling models.

This project has three long-term goals. The first goal is to learn how growing season temperature and moisture availability affect the diversity and chemical properties of biopolymers that govern decomposition of plant litter. The second goal is to understand how environmental conditions interact with the chemical composition of litter to affect decomposition and nutrient cycling. The third goal is to develop and test models of decomposition that incorporate new

knowledge of the roles of climate and biopolymer properties. The investigators will test these hypotheses using six plant species from the Boston-Area Climate Experiment, which exposes patches of old fields with tree seedlings to twelve possible future climates.

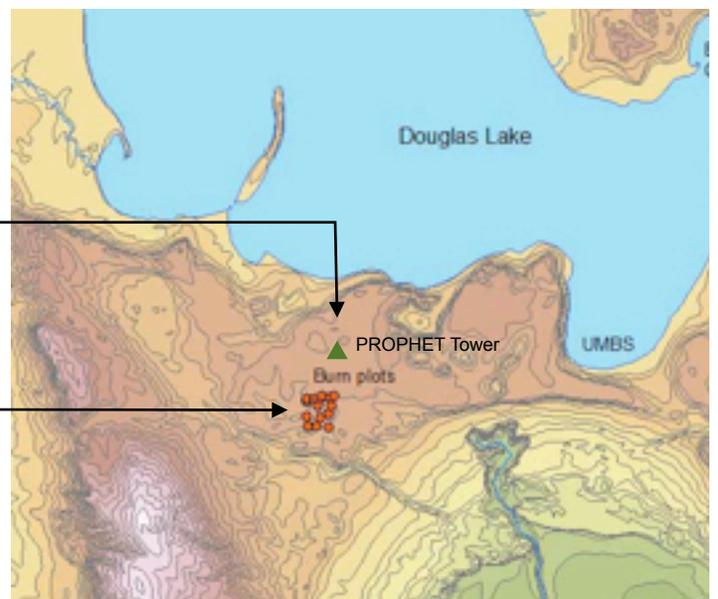


ABOVE: Researchers from ten institutions work at the Boston-Area Climate Experiment, which exposes plots of a New England, old-field ecosystem to twelve possible future climates.

University of Michigan Biological Station (UMBS)

The UMBS is home to the Program for Research on Oxidants, PHotochemistry, Emissions, & Transport (PROPHET) tower. It was constructed in 1996 as a coordinated research effort aimed at investigating forest-atmosphere interactions. The BVOC measurement system will be installed on the PROPHET tower.

Also located on the UMBS property is a unique set of experimental burn plots that form a a hundred year chronosequence of plant succession after fire. These plots will be used for the long-term black carbon decomposition study.



CAN WE CREATE MORE EFFECTIVE ONLINE TOOLS AND RESOURCES FOR CLIMATE CHANGE ANALYSIS?

Data on all aspects of climate change are needed to support and improve our understanding of the causes and consequences of the Earth's changing climate system and to improve the capacity of decision makers to develop effective mitigation and adaptation strategies. Decades of investment in measurement and monitoring technologies has resulted in thousands of databases and millions of observations, but these datasets are often incomplete, are not interoperable, and their use often requires specialized knowledge. Furthermore, access to data remains a problem for many scientists, decision makers, and other stakeholders, especially in developing countries.

These factors inhibit our ability to adequately address important climate change issues such as emissions reduction strategies, environmental impacts of biofuels, offsite pollution from agriculture, and the preservation of biodiversity, among others. Two new grants seek to improve the state of our information infrastructure. The GEOSHARE project aims to create a new cyberinfrastructure to support the global research community as it seeks to understand the long-run sustainability of our agricultural systems. A second grant will focus on developing a training program that will integrate stable isotopes with other datasets and computer models to address ecological challenges at regional to continental scales.

GEOSHARE: Geospatial Open Source Hosting of Agriculture, Resource and Environmental Data

Thomas Hertel, Nelson Villoria, *Agricultural Economics*, and Carol Song, *Rosen Center for Advanced Computing* with collaborators Navin Ramankutty, *McGill University*; Stanley Wood, *IFPRI*; Wolfgang Britz and Stefan Siebert, *University of Bonn*; Noah Diffenbaugh, *Stanford University*; Glenn Hyman, *CIAT*; Andrew Nelson, *IRRI* (Funded by the UK Department for International Development (DFID); the US Department of Agriculture Economic Research Service; UK Department for Environment Food and Rural Affairs (DEFRA); and the CGIAR CCAFS initiative).

Agriculture is likely to be one of the sectors most sharply affected by climate change. The distribution of effects depends on a combination of factors, but is likely to shift the pattern of global comparative advantage in agriculture, and may reduce the productivity of farming in precisely those regions of the world where malnutrition is most prevalent, while increasing yield variability. Furthermore, agriculture and forestry are increasingly envisioned as key sectors for climate change mitigation policy. Farming and land use change currently account for nearly thirty percent of global greenhouse gas emissions, and any serious attempt to decrease these emissions will involve changes in the way agricultural land is used, as well as limits on expansion of farming into areas currently under forest cover. These factors point toward the need for a better understanding of the spatial distribution of agricultural production, resource use, and the associated greenhouse gas emissions. The goal of this project is to make available to the world's research community an open source, spatially explicit, global data base on agriculture and the environment to advance research on the long run sustainability of the world's food system and its impact on poverty.

To satisfy the critical need for globally consistent information on agriculture and resource use, the research team will create a cyber-infrastructure that coordinates the work of the most prominent data producers in the world in order to achieve interoperability of the datasets as well as their

long run sustainability. GEOSHARE has a nodal structure which is easily expandable as additional policy needs are identified and new research groups come forward to meet these needs. Three of the nodes are global, focusing on land use, irrigation and climate, while the other three are regional nodes. The role of the regional nodes is to inform the global datasets, as well as provide more in-depth information on variables not available at the global scale – of which poverty intensity is the focal point in the pilot project. By focusing on Africa, Asia, and Latin America, the regional nodes will also be in a position to engage regional stakeholders, thereby informing GEOSHARE about current and future policy issues.

The initiative will be hosted by Purdue University, through the HubZero platform. HubZero is a collaborative environment with a web interface that allows sharing data analysis and modeling tools, which has great potential for overcoming some of the most serious constraints to effective utilization of geospatial information in developing countries.

Collaborative Research: Integrated Training for Continental Ecology (ITCE): Bridging Scales and Systems with Isotopes

Gabe Bowen, *Earth, Atmospheric & Planetary Sciences*, Chris Miller, *Library Sciences*, and Eric Riggs, *Texas A&M University* (Funded by the National Science Foundation).

This project will provide training and network building opportunities to more than 150 graduate students and post-doctoral researchers over five years, preparing future generations of ecologists to use existing and new isotopic data streams from regional to continental scale ecology programs. Data and model synthesis efforts will greatly increase the accessibility of existing large-scale isotopic datasets and data analysis tools within and beyond the ecological research community. Key themes to be addressed include biodiversity loss, gas exchange between ecosystems and the atmosphere, and ecohydrology.

COUNTING CARBON: A Possible GEOSHARE Application

Just as the absence of consistent land use data for agriculture and forestry presents a barrier to global analysis of land-based climate policies, it also poses a challenge for those countries attempting to move forward aggressively with national policies. The REDD+ or Reducing Emissions from Deforestation and Degradation Plus, is a strategy to mitigate climate change that emerged from the United Nations Framework Convention on Climate Change. The idea behind REDD+ is to provide incentives for developing countries to reduce emissions from the forestry sector, including actions to reduce deforestation and degradation, to foster sustainable management of forests, and to enhance and conserve forest carbon stocks. With funding from the Norwegian government and technical assistance from Conservation International, an important REDD+ initiative is currently underway in Indonesia.

Indonesia hosts the world's third largest tropical rainforest, with forests covering approximately 70% of the country. The UN-REDD National Program aims to facilitate the development of a REDD+ architecture in Indonesia that will allow a fair, equitable and transparent REDD+ implementation program, contributing to a sustainable reduction in forest-related GHGs. The basis for allocation of carbon payments aimed at preventing deforestation is

based on spatially explicit data on agriculture, forests, and potential productivity of land in different uses. By estimating the probability of deforestation at any given site, as well as the value of that land in alternative uses, researchers are able to target REDD+ payments in a manner which maximizes their impact (Busch et al., 2011). In order to support this work, the Government of Indonesia is developing the Forest Resource Information System with bilateral support from the Government of Australia.

While such national efforts are uniquely situated to navigate the local political landscape and respond to specific national needs, they miss the opportunity for realizing the scale economies from a global effort. The wheel needs to be "re-invented" for each country, with each group often returning to the same global or regional data bases for common variables. In addition, the scope for global harmonization of standards and approaches to this important problem is significantly hindered. GEOSHARE aims to fill these gaps.

Busch, J., R. N. Lubowski, F. Godoy, M. Steininger, A. A. Yusuf, K. Austin, J. Hewson, D. Juhn, M. Farid, and F. Boltz (2012). Structuring economic incentives to reduce emissions from deforestation within Indonesia. *Proceedings of the National Academy of Sciences*, 109(4), pp.1062–1067.

The GEOSHARE mission is to develop and maintain a freely available, global, spatially explicit database on agriculture, land use, and the environment accompanied by analysis tools and training programs for scientists, decision makers, and development practitioners.

RIGHT: The map shows the expected spatial distribution of land-cover response in Indonesia to a carbon price of \$10 tCO₂e paid for emission reductions below business-as-usual levels. Darker blue areas represent greater voluntary abatement of emissions from deforestation in response to incentive payments.



WORK IN PROGRESS

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

-- Leigh Raymond, *Political Science*; Benjamin Gramig, *Agricultural Economics*; and Rosalee Clawson, *Political Science* (USDA-ERS)

In the second year of this project to investigate non-economic factors motivating farmers to adopt no-till practices consistent with carbon offset programs, the research team followed-up on some surprising initial findings. A national mail survey experiment found that describing no-till in terms of the increased profit to farmers actually lowered interest in the practice among those who had not already adopted it. This “counter-framing” effect was a surprise to the researchers and their primary non-profit partners, the Conservation Technology Information Center, whose national board of directors were briefed on the results of the first year of research in an April 2012 presentation by the investigators. The research team also presented these initial findings at the annual research conference of the Association for Public Policy Analysis and Management in Washington, DC in November 2011.

As a result of this finding, the research team designed a second field experiment testing the influence of three different frames promoting no-till given to farmers attending the Fort Wayne, Indiana farm show in January 2012. Over three days researchers operating out of the Purdue Extension booth at the show recruited nearly 200 farmers to receive one of three “treatments” describing the benefits of no-till: one using a similar frame about enhancing “profit,” and two alternative frames describing the technique in terms of its advantages for the land and ecosystems (a “stewardship” frame), or for local community residents (a “community” frame). Farmers were randomly assigned to one of the three treatment groups, and asked a series of questions about their reasons for adopting or not adopting no-till, a battery of questions measuring their environmental values in general, as well as questions measuring their interest in no-till both before and after receiving the framed treatment. Preliminary results indicate that the profit frame remained relatively ineffective among non-adopters, with better results for the alternative frames promoting the technique for other reasons. Work continues to explore the interaction between farmers’ environmental values and beliefs about no-till and the different frames for promoting the technique.



PCCRC researchers are investigating what factors affect farmers' interest in no-till cropping systems that reduce emissions of greenhouse gases. No-till farming leaves the soil undisturbed from harvest to planting.

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

3. 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)

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

5. 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, & Planetary Sciences and Agronomy* (NASA)

6. Taming Complexity of Mesoscale Dynamics with Low-Order Models -- Alexander

Gluhovsky and Ernie Agee, *Earth, Atmospheric, & Planetary Sciences* (NSF)

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

8. 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)

9. Can trade liberalization help countries adapt to climate change impacts on agriculture?

Wallace E. Tyner, *James and Lois Ackerman Professor of Agricultural Economics* and graduate student Ismail Ouraich are studying the extent to which trade liberalization might be a means of helping countries adapt to climate change. They use a data set that provides global yield estimates for 17 regions/countries, 14 crop categories and 4 SRES scenarios spanning 2010-2100. In other words, they have projections under 4 climate scenarios for all major crops and global regions. Tyner and Ouraich ran simulations of these yield impacts using the GTAP model under alternative trade liberalization scenarios and assessed the extent to which trade liberalization helps countries adapt to adverse crop yield impacts that are different across global regions. What they have learned is that some countries and regions will find trade liberalization is a good means of helping to adapt to adverse agricultural impacts of climate change. However, for other countries and regions, trade liberalization does not help reduce the negative impacts of climate change.

Tyner and Ouraich's analysis is focused on North Africa with special attention to Morocco and Tunisia as case study countries. They have also developed a country economic model for Morocco to estimate how agricultural development policies could help the country adapt to negative crop yield shocks. This research was presented at the international conference, "Climate Change and Development Policy," September 26-29, 2012, in Helsinki, Finland. Funding for this project was provided by the United Nations University World Institute for Development Economics Research.

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

11. 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, & Planetary Sciences*, with Mark Pagani, *Yale University* (NSF)

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

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

14. 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, & Planetary Sciences and Agronomy*, with A. David McGuire, *University of Alaska, Fairbanks*; Jerry Melillo, *Marine Biological Laboratory*; and Michael Follows, *MIT* (NSF)

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

16. The Isotope Networks Portal: Data Integration for Biogeochemistry and Ecology Through Web-based Geospatial Modeling -- Gabe Bowen, *Earth, Atmospheric, & Planetary Sciences*, Lan Zhao, *Rosen Center for Advanced Computing*; Chris Miller, *Libraries*; Tonglin Zhang, *Statistics*; and Jason West, *Texas A&M University* (NSF)

17. Collaborative Research: The O-Buoy Network of Chemical Sensors in the Arctic Ocean -- Paul Shepson, *Chemistry* with Jan Bottenheim, *Environment Canada*; Francisco

Global Trade Analysis Project (GTAP)

GTAP is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. GTAP is coordinated by the Center for Global Trade Analysis, which is housed in the Department of Agricultural Economics at Purdue. While the GTAP Models and Database have become common place in global trade analysis, GTAP is increasingly used to analyze the economic impact of global environmental issues, including the costs of abatement and to assess the spill-over effects of GHG abatement policies via international trade and sectoral interaction. GTAP's goal is to improve the quality of quantitative analysis of global economic issues within an economy-wide framework.

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* (NSF)

18. Collaborative Research: A New Reconstruction of the Last West Antarctic Ice Sheet Deglaciation in the Ross Sea -- Nathaniel Lifton, *Earth, Atmospheric, & Planetary Sciences and Physics* with Peter Clark, *Oregon State University*; David Pollard, *Pennsylvania State University*; and Mark Kurz, *Woods Hole Oceanographic Institution* (NSF)

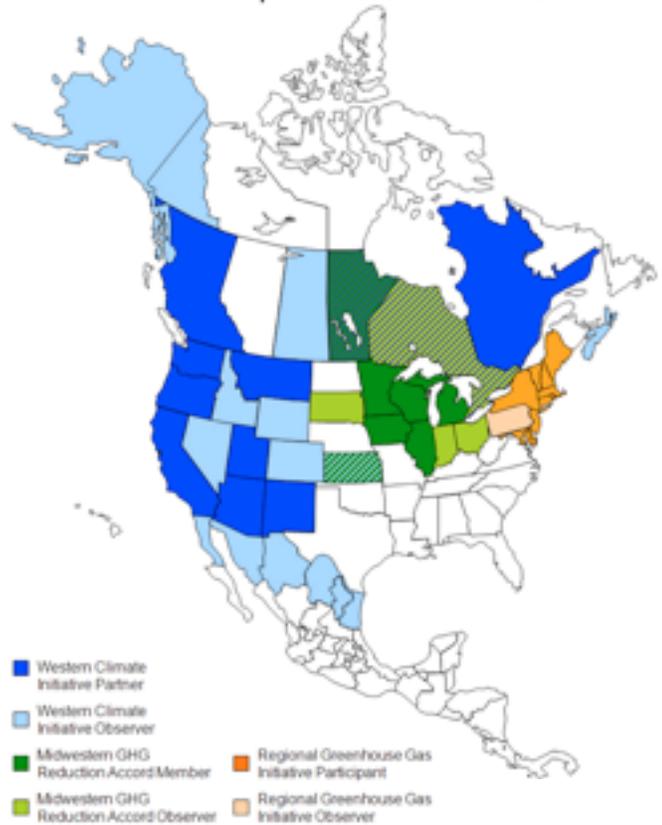
19. A Paradigm Shift in Ecosystem and Environmental Modeling: An Integrated Stochastic, Deterministic, and Machine Learning Approach -- Qianlai Zhuang, *Earth, Atmospheric, & Planetary Sciences and Agronomy*; Melba Crawford, *Civil Engineering and Agronomy*; Hao Zhang, *Statistics*; Dongbin Xiu, *Mathematics*; and Jian Zhang, *Statistics*; with collaborators Jerry Melillo at *Marine Biological Laboratory, Woods Hole*; and John Reilly, *MIT* (NSF)

20. Experimental Testbeds for New Applications of Environmental Trading Programs

Early emissions trading programs have obtained a very high rate of compliance, in part by using continuous emissions monitors that automatically record emissions data on a 24-hour basis. As they expand into a wider range of pollutants and sources, however, such policies will have to rely on less automated forms of self-reporting. A component of this project, led by Professor Timothy Cason, *Economics* and Leigh Raymond, *Political Science*, asks if improved “affirmative motivations” for compliance based on perceptions of a policy’s fairness could reduce the likelihood of under-reporting, thereby lowering verification costs without jeopardizing environmental integrity. Cason and Raymond implemented a computerized laboratory emissions trading market in which human subjects buy and sell assets that correspond to emissions permits that allow them to avoid incurring costs of emissions abatement. Subjects then self-report their emissions, with different probabilities of inspection to verify the accuracy of their reports. The data indicate that many subjects reported emissions honestly in situations where dishonest reporting would have been more profitable, as well as a statistically significant association of affirmative motivations based on perceptions of a policy’s fairness with honest reporting. These results suggest that designing an emissions trading program to increase its perceived fairness among users has the potential to increase accurate emissions reporting and reduce monitoring costs.

Leigh Raymond and Timothy Cason, "Can Affirmative Motivations Improve Compliance in Emissions Trading Programs?" *Policy Studies Journal*, 39 (2011), pp. 659-678.

North American Cap-and-Trade Initiatives



Map adapted from the Pew Center for Climate and Energy Solutions

21. Developing an Earth System Science Teacher Professional Development Toolkit for Climate Science

Dan Shephardson, *Curriculum & Instruction and Earth, Atmospheric, & Planetary Sciences* and Dev Niyogi, *Earth, Atmospheric, & Planetary Sciences and Agronomy* (NSF)

The development team implemented three professional development programs as a pilot and field test during the 2011-12 academic year, involving 46 formal and informal educators. The professional development program and toolkit will be modified based on the evaluation data during the fall 2012. A dissemination conference will be held May 15-17, 2013 at Purdue University. The conference will prepare formal and informal educators to use the toolkit as a means to deliver professional development. The PCCRC will co-sponsor the dissemination conference. The conference will have invited speakers, panel sessions, breakout sessions for modeling the program, and work sessions for planning future professional development programs.

The professional development program takes a climate system approach to learning about global warming and climate change. In general, the professional development program introduces participants 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 data, 5) adaptations and mitigation, and 6) actions and impacts. The program is data and visually driven, incorporating small group activities. The toolkit consists of: 1) Professional Development Manual, 2) Administrative Packet, 3) Presenters Guide, 4) Program PowerPoint, 5) Materials Packet, and 6) Teacher Lesson Plan Document.

The pilot and field test evaluation data indicate that the team has developed an effective professional development program and toolkit that provides a model for preparing teachers and other professionals to teach about climate change in the context of a climate system. The average overall program quality rating was 4.5 (5.0 scale; 1 low, 5 high) and 4.0 for developing participants understanding. The professional development program and toolkit aligns nicely with the National Research Council’s (2012) *A Framework for K-12 Science Education: ESS2.A Earth Materials and Systems, ESS2.D Weather and Climate, and ESS3.D Global Climate Change*. Thus, the program and toolkit provide a foundation for the preparation of formal and informal educators in addressing the core science concepts and practices, linking to the Next Generation Science Standards.

22. 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* (DOE and NSF)

Scientists agree that Earth's climate is changing. However, there remains uncertainty about the rate at which temperatures will rise, how precipitation will change, and for how long the warming will continue. To date, several experiments have advanced our understanding of how ecosystems will respond to changes in temperature or precipitation, but few have studied both factors simultaneously. In addition, almost all experiments that have warmed ecosystems have examined the effect of one sudden and sustained temperature increase. In reality, climate will change gradually, and the endpoint of this change is unknown. Will the processes and properties of communities and ecosystems respond linearly to changes in temperature, or are there important threshold temperatures that could be reached? To what extent does an ecosystem's response to warming depend on precipitation patterns? Professor Jeff Dukes, *Forestry and Natural Resources and Biological Sciences*, designed the Boston-Area Climate Experiment to answer these questions. Using overhead heaters and sprinklers, the experiment simulates twelve possible future climates; it warms plots of an old-field ecosystem by four different amounts (up to 7 degrees Fahrenheit), while subjecting groups of plots to three different precipitation regimes (by either allowing all rain and snow to fall on the plots, removing half of incoming precipitation, or supplementing incoming precipitation during the growing season). Researchers from ten institutions now collaborate at the site, including three smaller, local, non-research-intensive institutions.

With funding from the National Science Foundation and the Department of Energy, Professor Dukes and his research team have measured responses of several variables, including growth of herbs, grasses, and tree seedlings, and the processing of dead organic matter by microorganisms. Postdoctoral researcher Dr. Susanne Hoepfner found that, on their own, warming and changes in precipitation led to changes in the composition of the herbaceous plant community, but had relatively little effect on the overall growth of herbaceous plants.

However, in the driest treatment, warming suppressed plant growth and reduced the number of plant species present. This result suggests that, in a warmer world, plant production will become more sensitive to interannual changes in precipitation. In general, the results indicated that old-field ecosystems in this region are unlikely to produce more forage in response to climate change, and are also unlikely to slow climate change by storing additional carbon.

Warming is known to accelerate decomposition of organic matter under most conditions. Graduate student Vidya Suseela found that warming affected the microbial decomposition of organic material in soils differently depending on the season. In some seasons, particularly when the soils were quite dry, warming had little effect on decomposition rates. In other seasons, warming had a much larger effect. To accurately represent the release of carbon from soils under future conditions, models of the Earth system must be able to replicate this pattern.

Another pattern that models should replicate (although most do not) is the attenuation of the temperature response of plants over time. Currently, the Earth system models used for climate change projections accurately represent short-term responses of photosynthesis and respiration to temperature, but most do not have the capability to simulate commonly observed longer-term adjustments. Graduate student Nick Smith's work on this topic led to recommendations for how to implement longer-term plant responses to temperature and CO₂ increases into these models.

BELOW LEFT: Graduate student Nick Smith (center) and technician Carol Goranson (right) collect data at the Boston-Area Climate Experiment. **BELOW RIGHT:** Milkweed blooms in the shadow of an infrared heater (background) that simulates a future warmer climate.



23. A New Regional Paleo-Precipitation Proxy: Oxygen Isotopes in Desert Nitrate -- Greg Michalski, *Earth, Atmospheric, & Planetary Sciences and Chemistry* (NSF)

Professors Greg Michalski and Brenda Beitler-Bowen, PCCRC fellow Fan Wang, and Purdue undergraduates Ji-Hye Soe and Liesl Elison spent two weeks in the Atacama Desert completing fieldwork for this project examining long term climate change in the desert. They were accompanied by Devon Burr and Robert Jacobson of the University of Tennessee who were studying Mars-like inverted stream channels.

In the photo to the right, Purdue students Jihye Soe (Chemistry) and Liesl Elison (EAPS) look on as Professor Brenda Beitler-Bowen (now with the University of Utah) points out features on a volcanic debris flow deposit to University of Tennessee scientists while PCCRC fellow Fan Wang (EAPS PhD candidate) collects samples at the base of the deposit. Photo credit: Greg Michalski.



24. Useful to Usable (U2U): Transforming Climate Variability and Change Information for Cereal Crop Producers -- Linda Prokopy (PI), Patrick Freeland, Amber Mase, Melissa Widhalm,

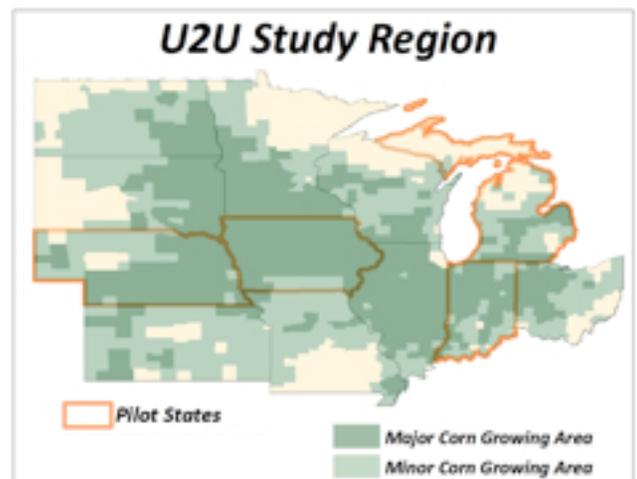
Forestry & Natural Resources; Dev Niyogi, Ani Elias, Olivia Kellner, Xing Liu – *Earth, Atmospheric, & Planetary Sciences and Agronomy*; Otto Doering, Ben Gramig, *Agricultural Economics*; Larry Biehl, Carol Song, Lan Zhao, *Rosen Center for Advanced Computing*; with over 35 additional collaborators from 9 other universities.

Weather and climate patterns are a driving force behind the success or failure of cropping systems. With U.S. corn and soybean production accounting for nearly one-third of global supplies and contributing \$100 billion annually to the national economy, the ability to successfully produce crops under more variable climate conditions is critical. U2U is an integrated research and extension project working to improve farm resilience and profitability by transforming existing climate information into usable knowledge for the agricultural community.

Under development are decision support tools that will allow farmers and agricultural advisors to examine the financial, production, and environmental outcomes of short-term farm management decisions and long-term investment planning. Using “what if” scenarios, U2U tools will deliver a range of management options, climate scenarios, and potential outcomes to help farmers choose strategies that fit their capabilities and acceptable levels of risk. Researchers are currently investigating the impact of past and future climate conditions on key topics that include crop yield estimations, the number of calendar days suitable for a farmer to work in their field, nitrogen management, and the cost-effectiveness of irrigation and tiling.

Additionally, the U2U social science team is using a number of techniques to integrate stakeholder interests, needs, and concerns into U2U research and products. In partnership with the Climate and Corn-Based Cropping Systems CAP (CS-CAP)*, over 18,000 corn producers were surveyed in 22 HUC6 watersheds across the Corn Belt. In a separate, but related effort, nearly 8,000 formal and informal agricultural advisors were surveyed in four states (IA, IL, IN, MI). These two unprecedented efforts are providing critical insights on the perceived usefulness of climate information, climate change concerns and beliefs, risk management strategies, and trusted sources of climate change information. Survey results and publications will be publicly available in 2013.

This project is supported by the USDA National Institute of Food and Agriculture (NIFA), AFRI competitive grant no. 2011-68002-30220. More information about U2U is available at www.AgClimate4U.org. *CS-CAP is a USDA-NIFA-funded project led by Iowa State University. More information is available at www.sustainablecorn.org.



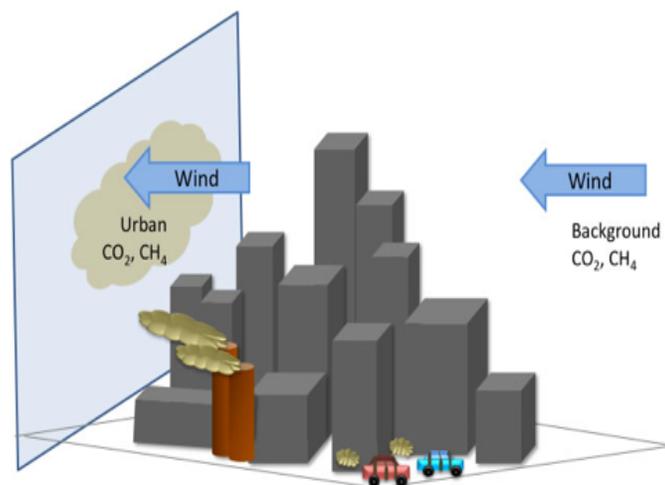
25. Studies of the uncertainties in determining the urban area-wide fluxes of greenhouse gases

-- Paul Shepson, *Chemistry*, with collaborators Kevin Gurney, *Arizona State University*; Ken Davis, Scott Richardson and Natasha Miles from *The Pennsylvania State University*; and Colm Sweeney and Jocelyn Turnbull, *NOAA/ESRL*, and Laura Iraci, *JPL (NIST)*

The fossil fuel emissions component of the global carbon budget is well-constrained in some regions of the globe, but less so in others, revealing a critical need for better emissions flux measurements and models, as well as better evaluation of measurement uncertainty. The Indianapolis flux experiment ("INFLUX") focuses on development and evaluation of measurement strategies to better constrain uncertainties in urban greenhouse gas emissions, using the City of Indianapolis as a case study. In particular, the team designed a series of experiments to assess the uncertainty in aircraft-based mass balance flux measurements in Indianapolis.

The research group measured CO₂ and CH₄ from an aircraft-based platform — Purdue University's Airborne Laboratory for Atmospheric Research (ALAR) — equipped with a Picarro cavity ring-down CO₂/CH₄ spectrometer, a flask sampling system, and a Best Air Turbulence probe for high-resolution wind measurements. The flight plan was designed based on the experimental theory depicted in the figure to the right. Wind (from the right) carrying background concentrations of CO₂ and CH₄ blows over the city, where it picks up greenhouse gas emissions from anthropogenic sources such as cars, power plants, etc. By flying perpendicular to the wind direction in downwind horizontal transects in which the imaginary plane from the surface to the top of the boundary layer is rastered, the on-board aircraft sampling system is able to intercept, detect, and quantify enhancements over background concentrations that arise from the multitude of urban sources.

Initial findings indicate that the precision of this particular aircraft-based greenhouse gas flux method is on the order of $\pm 30\%$ for point sources and small area sources, and $\pm 40\%$ for urban area sources. This can be significantly improved through improved acquisition of background data, e.g., from towers, and boundary layer height information from remote sensing. Both of these enable improvements in the sampling coverage, and uncertainties on the order of 20% should be possible. For megacities, capturing this emission information would require measurements from multiple aircraft.



ABOVE: Wind carrying background concentrations of CO₂ and CH₄ blows over the city, where it intercepts and picks up greenhouse gas emissions from anthropogenic sources such as cars, power plants, land fills, etc. Flux across the downwind perpendicular plane is measured. **BELOW LEFT:** The ALAR platform, developed for Prof. Paul Shepson, is a Beechcraft Duchess Light Twin Engine airplane, equipped with an air flow measurement probe, a BAT probe (Best Air Turbulence probe) and dual air sample intakes. Fossil fuel emissions of CO₂ and CH₄ from Indianapolis are quantified using a combination of flask measurements, cavity ring-down spectroscopy (CRDS), and a mass balance approach. In flight calibrations for CO₂ and CH₄ are conducted using a computer-controlled calibration system and three reference cylinders from the National Oceanic and Atmospheric Administration.



PCCRC SEED GRANT PROGRAM

ENCOURAGING NEW IDEAS

The breadth of climate change research at Purdue is tremendous; ranging from the complex dynamics of the Earth's climate system to the multidimensional impacts of an altered climate state, from analysis of benefits and losses to mitigation and adaptation strategies. Each year, the PCCRC allocates a modest amount of funding to catalyze innovative, interdisciplinary projects and activities.

This year, the PCCRC provided funding to initiate a local field study aimed at improving our understanding of how ecosystems are responding to changing climatic conditions. The center also focused on the need to enhance our international collaborations and partnerships. With this in mind, we provided support to four researchers to participate in the Planet Under Pressure conference. Conference delegates were charged with helping to create a new platform for trans-disciplinary research; one based on broader partnerships that link global-change science with business, investors, and the development agenda to create a new environment for tackling global sustainability challenges.

Effects of Warming on the Spring Ephemeral Plant Community and its Pollinators

Nancy Emery, *Biological Sciences and Botany & Plant Pathology* and Asya Robertshaw, *graduate student, Botany & Plant Pathology*.

Climate change is already impacting the timing of biological events within natural communities, which could lead to dramatic changes in community dynamics if tightly interacting species exhibit different responses to temperature variation. Professor Nancy Emery and her research team are conducting a series of experiments with the goal of quantifying the consequences of changing temperatures on the mutualistic interactions between plants and their pollinators, using the spring ephemeral wildflower community at Purdue's Ross Biological Reserve as the study system. Early spring wildflowers in deciduous forests are predicted to be particularly sensitive to climate change because their life cycles are closely linked to various climate-related events, and many rely on temperature-sensitive pollinators for seed production.

The current research project consists of three interrelated studies. First, the team has been monitoring natural-occurring patches of the spring ephemeral herbaceous plant community to identify the relationships between temperature, plant phenology and pollen limitation (i.e., the reduction in seedset due to the lack of pollination). Second, in collaboration with Dr. Jeffrey Holland (Department of Entomology), the insect pollinators and their responses to local temperature and plant flowering dynamics are being documented. Finally, the team has initiated a manipulative warming experiment to isolate the direct effects of elevated air and soil temperatures on plant flowering time and seedset of three different plant species that have been transplanted into the experimental plots. Collectively, these studies will help determine how changes in temperature affect the flowering time of several spring ephemeral plant species, and how these responses in turn affect plant-pollinator dynamics.

The project will continue over several years, but early results are already providing surprising insights into the effects of temperature on plant-pollinator interactions in the focal community. For example: despite the exceptionally early onset of warm temperatures, forest canopy development and flowering this past spring, pollinators were just as effective as they were in 2011 in maximizing seed set for *Claytonia virginica* (Spring Beauty), a dominant member of the spring ephemeral plant community. Specifically, providing supplementary pollen to these flowers did not increase the number of seeds they produced in either year, indicating that the pollinators are providing sufficient—and consistent—pollination services for this plant population, even across years with significantly different climatic regimes. This project has facilitated the graduate training of Ms. Asya Robertshaw, a Ph.D. student in the Department of Botany & Plant Pathology, and 8 different undergraduate students from the Departments of Biological Sciences, Botany & Plant Pathology, and Entomology.

LEFT: PhD candidate Asya Robertshaw instructs Ashley Visek (former undergraduate in Biological Sciences) how to collect data on plant phenology and fruit production and provide supplementary pollen to experimental plants, while Nicholas Goldsmith (former undergraduate in Plant Science) patiently waits to record the data. Photo taken at the Ross Biological Reserve by Ashley Holmes. **RIGHT:** Emerging shoot and inflorescence of *Sanguinaria canadensis* (Bloodroot), a relatively common spring ephemeral at Ross Biological Reserve. The leaves remain wrapped around the plant until the flower opens. Photo credit: Asya Robertshaw.



A student's perspective...

In the introductory remarks, it was said that "science and scientists by themselves cannot save the world," and it is "social and institutional failures, not technological failures, that are contributing to unsuccessfully addressing today's environmental pressures in sustainability." These remarks set the tone for a conference that was focused upon cross-scale solutions and innovative partnerships toward addressing today's pressing environmental problems.

During the conference I was highly focused on interpreting messages that arose from the delegates, specifically investigating the understanding of and potential for transdisciplinary research. This new approach to problem solving links scholarship and practice by integrating knowledge from scientists, communities, and practitioners, which allows for connections and linkages between multiple ways of interpreting the world. Transdisciplinary research, in its essence, is well-suited to address the broad issues related to global sustainability research that are beyond the scope of any one discipline and cut across traditional academic and societal boundaries. As a participant observer, I inferred two key themes and subsequent continued justification emerging in delegate dialogue specific to transdisciplinary research: 1) participation must be increased across scales and 2) training is needed in universities to do cross-boundary work.

I also had the honor of serving on a Youth Committee to draft a response (Annex 3) to the delegates' State of the Planet Declaration. Nearly 400 graduate students participated in the process, creating a network of engaged peers in which I will continue to collaborate. Lobbying for the inclusion of transdisciplinary research resulted in the following call-to-action in our response: "expand transdisciplinary research and engage with user communities in efforts to develop integrative solutions for sustainability."

-Lindsey Payne, PhD student in Ecological Sciences and Engineering.

**PLANET UNDER PRESSURE**

During the week of March 26-29, 2012, the International Human Dimensions Programme of Global Environmental Change, convened the Planet Under Pressure Conference to focus the scientific community's and the wider world's attention on climate, ecological degradation, human well-being, planetary thresholds, food security, energy, governance across scales and poverty alleviation. In addition to providing an update on the state of our knowledge of the Earth system, conference themes included discussion of solutions, at all scales, to move societies on to a sustainable pathway.

The conference was attended by over 3,000 participants representing 105 countries. Advocating an "all hands on deck" approach, participants included scientists, social scientists, industry leaders, and policy makers.

For Professor Benjamin Gramig, participating in the Planet Under Pressure conference provided an opportunity to engage with international scientists working across disciplines to address climate change adaptation and mitigation challenges faced by society.

"Interacting with leading scholars and practitioners in this setting helped to expose the global scientific community to social science research involving different dimensions of climate change that is ongoing at Purdue. Personally, I made connections with leading researchers on the economics of ecosystem services and catalyzed collaboration with the agriculture-climate change group within Australia's CSIRO," said Gramig.

Professor Jacob Ricker-Gilbert attended the meeting at the invitation of Dr. Bruce Campbell, Director of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). In addition to attending sessions, Ricker-Gilbert established collaborations for a project related to climate change impacts in Sub-Saharan Africa.

For Professor Thomas Hertel, the conference provided an opportunity to participate in discussions related to integrated data management of global datasets and to meet with GEOSHARE team members and sponsors.

"These face to face meetings were critical for finalizing the contracts with the UK government, as well as connecting to the Global Land Use community," said Hertel.



ABOVE: Members of the Youth Committee work on drafting a response (Annex 3) to the delegates' State of the Planet Declaration.

JOURNAL ARTICLES

Scholarship

Each year center researchers publish dozens of climate-change related articles in peer-reviewed journals. Their contributions focus on improving our understanding of a broad-range of scientific, technological, social, and humanitarian issues, and this knowledge is helping to better define what we know and what we do not know about climate change.

While the big picture is becoming increasingly clear, there remains much to learn about our climate system, climate change, and related impacts and our researchers continue to observe, analyze and refine our knowledge base. This year, Purdue research has shed light on the role of carbon dioxide during the onset of glaciation in Antarctica, explored the implications of a permanent El Nino to precipitation over North America, and demonstrated the importance of local culture in community participation. These examples of our findings, along with a wide array of additional research results appeared in the 48 peer-reviewed journal articles listed in this section.

- Agee, E., K. Kiefer, and E. Cornett (2012). Relationship of Lower-Troposphere Cloud Cover and Cosmic Rays: An Updated Perspective. *J. Climate* 25, 1057–1060.
- Agee, E. and A. Hendricks (2011). An Assessment of the Climatology of Florida Hurricane-Induced Tornadoes (HITs): Technology versus Meteorology. *J. Climate*, 24, 5218–5222.
- Aldrich, D. (2012). Post-Crisis Japanese Nuclear Policy: From Top-Down Directives to Bottom-Up Activism. *AsiaPacific Issue No. 103*.
- Bianchi, T., L. Wysocki, K. Schreiner, T. Filley, D. Corbett, and A. Kolker (2011). Sources of Terrestrial Organic Carbon in the Mississippi Plume Region: Evidence for the Importance of Coastal Marsh Inputs. *Aquat Geochem* 17:431–456.
- Bowen, G., C. Kennedy, Z. Liu, and J. Stalker (2011). Water balance model for mean annual hydrogen and oxygen isotope distributions in surface waters of the contiguous United States. *J. Geophys. Res.* 116, G04011.
- Bowers, M., W. Tung, and J. Gao (2012). On the distributions of seasonal river flows: Lognormal or power law? *Water Resour. Res* 48, W05536.
- Brzostek, E.R., Blair, J.M., Dukes, J.S., Frey, S.D., Hobbie, S.E., Melillo, J.M., Mitchell, R.J., Pendall, E., Reich, P.B., Shaver, G.R., Stefanski, A., Tjoelker, M.G. and Finzi, A.C. (2012). The effect of experimental warming and precipitation change on proteolytic enzyme activity: positive feedbacks to nitrogen availability are not universal. *Global Change Biology* 18: 2617–2625.
- Charusombat, U., D. Niyogi (2011). A Hydroclimatological Assessment of Regional Drought Vulnerability: A Case Study of Indiana Droughts. *Earth Interact* 15, 1–65.
- Chen, M., O. Zhuang, D. Cook, R. Coulter, M. Pekour, R. Scott, J. Munger, and K. Bible (2011). Quantification of terrestrial ecosystem carbon dynamics in the conterminous United States combining a process-based biogeochemical model and MODIS and AmeriFlux data. *Biogeosciences* 8, 2665–2688.
- Chen, M., Q. Zhuang (2012). Spatially Explicit Parameterization of a Terrestrial Ecosystem Model and Its Application to the Quantification of Carbon Dynamics of Forest Ecosystems in the Conterminous United States. *Earth Interactions* 16, 1–22.
- Fall, S., A. Watts, J. Nielsen-Gammon, E. Jones, D. Niyogi, J. Christy, R. Pielke Sr. (2011). Analysis of the impacts of station exposure on the U.S. Historical Climatology Network temperatures and temperature trends. *J. Geophys. Res.* 116, D14, D14120.
- Goldner, A., M. Huber, N. Diffenbaugh, and R. Caballero (2011). Implications of the permanent El Niño teleconnection "blueprint" for past global and North American hydroclimatology. *Clim. Past*, 7, 723–743.
- Herold, N., M. Huber, R. Müller (2011). Modeling the Miocene Climatic Optimum. Part I: Land and Atmosphere. *J. Climate* 24, 6353–6372.
- Herold, N., M. Huber, R. Müller, and M. Seton (2012). Modeling the Miocene climatic optimum: Ocean circulation. *Paleoceanography*, 27, PA1209.

• Pagani, M., M. Huber, Z. Liu, S. Bohaty, J. Hendriks, W. Sijp, S. Krishnan, R. M. DeConto (2011). The Role of Carbon Dioxide During the Onset of Antarctic Glaciation. *Science* 334, 6060, 1261-1264.

When glaciers began covering Antarctica about 34 million years ago, atmospheric carbon dioxide (CO₂) was declining, according to a recent study led by scientists at Yale and Purdue universities. This drop in CO₂ appears to be the driving force that led to the Antarctic ice sheet's formation, and aligns with scientific theories on the role of greenhouse gases during climate change. The study resolves a major paradox surrounding the complex links between CO₂, Antarctic glacier growth and climate. In doing so, it further validates the theories and models that we use to understand and predict climate change. Matthew Huber, PCCRC associate director, is an author of the paper.

Previously published data suggested a possible increase in CO₂ during this time of global cooling. The increase would have led to global warming, not the global cooling associated with Antarctic glacier advancement. Because the earlier data conflicted with theoretical expectations of CO₂ levels, a multi-institution team re-evaluated the long-term data records used to reconstruct CO₂ levels. The data was derived from marine organic molecules known as alkenones that were preserved in deep ocean sediment cores recovered by the Integrated Ocean Drilling Program.

The research team showed that alkenones obtained in the high latitudes of the Southern Hemisphere overestimated global CO₂, whereas those collected closer to the equator provided a more accurate global estimate. Once the team excluded the overestimated data from the long-term records, they found a substantial decline in CO₂ leading up to and during this major cooling episode.

"The evidence falls in line with what we would expect if carbon dioxide is the main dial that governs global climate; if we crank it up or down there are dramatic changes," Huber said. "We went from a warm world without ice to a cooler world with an ice sheet overnight, in geologic terms, because of fluctuations in carbon dioxide levels."



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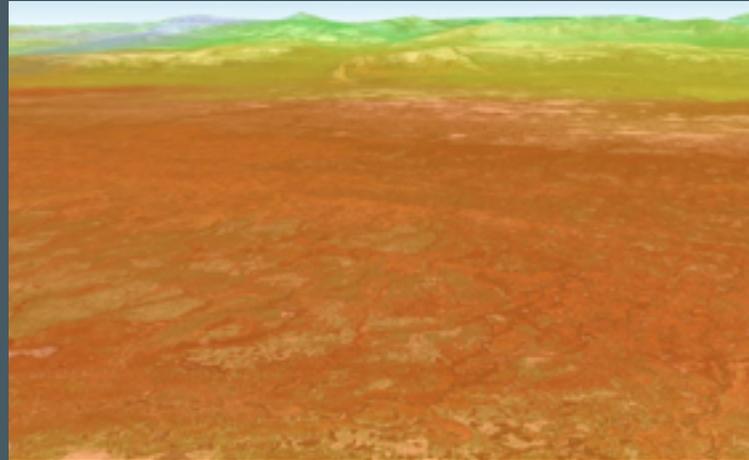
Recent price spikes have raised concern that climate change could increase food insecurity by reducing grain yields in the coming decades. However, commodity price volatility is also influenced by other factors which may either exacerbate or buffer the effects of climate change. In this paper, the authors show that US corn price volatility exhibits higher sensitivity to near-term climate change than to energy policy influences or agriculture-energy market integration, and that the presence of a biofuels mandate enhances the sensitivity to climate change by more than 50%. The climate change impact is driven primarily by intensification of severe hot conditions in the primary corn-growing region of the United States, which causes US corn price volatility to increase sharply in response to global warming projected to occur over the next three decades. Closer integration of agriculture and energy markets moderates the effects of climate change, unless the biofuels mandate becomes binding, in which case corn price volatility is instead exacerbated. However, in spite of the substantial impact on US corn price volatility, the researchers find relatively small impact on food prices. The findings highlight the critical importance of interactions between energy policies, energy-agriculture linkages and climate change.

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Drastic reductions in Arctic sea ice over the last decade are increasing the chemical release of bromine into the atmosphere. The connection between changes in the Arctic Ocean's ice cover and bromine chemical processes appears to be determined by the interaction between the salt in sea ice, cold temperatures, and sunlight. When these mix, the salty ice releases bromine into the air and starts a cascade of chemical reactions called a "bromine explosion." These reactions rapidly create more molecules of bromine monoxide in the atmosphere. Bromine then reacts with a gaseous form of mercury, turning it into a pollutant that falls to Earth's surface. Bromine also removes ozone from the lowest layer of the atmosphere where it is a ground-level pollutant.

The research team, which includes Paul Shepson, PCCRC founding director, combined data from six NASA, European Space Agency, and Canadian Space Agency satellites, field observations, and a model of how air moves in the atmosphere to link Arctic sea ice changes to bromine explosions in the high Arctic. They used the topography of mountain ranges in Alaska and Canada as a "ruler" to measure the altitude at which the explosions took place. In short, during the spring of 2008 satellites detected increased concentrations of bromine, which were associated with a decrease of gaseous mercury and ozone. After verifying the satellite observations with field measurements, the researchers used an atmospheric model to study how the wind transported the bromine plumes across the Arctic. The model, together with satellite observations, showed the Alaskan Brooks Range and the Canadian Richardson and Mackenzie mountains stopped bromine from moving into Alaska's interior.

The research team concludes that if sea ice continues to be dominated by younger, saltier ice, and Arctic extreme cold spells occur more often, bromine explosions are likely to increase in the future.



ABOVE: Bromine explosion on March 13, 2008 across the western Northwest Territories in Canada looking toward the Mackenzie Mountains at the horizon, which prevented the bromine from crossing over into Alaska. The bromine explosion is depicted in the foreground by the red-orange areas, while the green shades at high altitudes on the mountains represent areas where there was no increase in bromine. (Credit: NASA/JPL-Caltech/University of Bremen)

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PCCRC FACULTY

66
Affiliated
Faculty

7 million in new
sponsored grants
awarded

34
Research
Projects

9 Symposia,
workshops, conferences,
and lectures hosted on
campus

Academic units **8**
represented by our
faculty

48 Publications

PCCRC Membership by Department

Aeronautics & Astronautics: Jim Garrison

Agronomy: Laura Bowling, Sylvie Brouder, Melba Crawford¹, Richard Grant, Cliff Johnston, Dev Niyogi², Ronald Turco, Jeffrey Volenec

Agricultural & Biological Engineering: Indrajeet Chaubey², Keith Cherkauer, and Rabi Mohtar

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

Biological Sciences: Kerry Rabenold

Botany & Plant Pathology: Nancy Emery

Building & Construction Management: Kirk Alter

Chemistry: Paul Shepson

Civil Engineering: Larry Nies, Suresh Rao⁴

Earth & Atmospheric Sciences: Ernest Agee, Michael Baldwin, Gabriel Bowen, Noah Diffenbaugh, Timothy Filley, Alexander Gluhovsky³, Jennifer Haase, Jon Harbor, Harshvardhan, Matthew Huber, Sonia Lasher-Trapp, Nathaniel (Nat) Lifton, Greg Michalski, R. Jeffrey Trapp, Wen-wen Tung, Qianlai Zhuang⁴

Economics: Timothy Cason

Forestry and Natural Resources: Jeffrey Dukes⁵, Songlin Fei, Reuben Goforth, Bryan Pijanowski, Linda Prokopy, Guofan Shao, and Robert Swihart

Health & Human Sciences: Jennifer Freeman, James McGlothlin

Information Technology: Carol Song, Lan Zhao

Libraries: Christopher Miller

Mechanical Engineering: Jay Gore, Greg Shaver

Political Science: Daniel Aldrich, Elizabeth McNie², Leigh Raymond, and Mark Tilton

Sociology: Martin Patchen

Statistics: Bo Li, Frederi Viens⁷, Hao Zhang⁶

Executive Committee: Kirk Alter, Laura Bowling, Gabriel Bowen, Timothy Filley, Richard Grant, Matthew Huber, Elizabeth McNie, Larry Nies, Dev Niyogi, Leigh Raymond, Gerald Shively, and Ronald Turco

Administrative Staff

Otto C. Doering, III, Director
Cindy Fate, Administrative Assistant
Rose Filley, Managing Director
Matthew Huber, Associate Director
Leigh Raymond, Associate Director

¹joint appointment in Civil Engineering; ²joint appointment in Earth & Atmospheric Sciences; ³joint appointment in Statistics; ⁴joint appointment in Agronomy; ⁵joint appointment in Biological Sciences; ⁶joint appointment in Forestry & Natural Resources; ⁷joint appointment in Mathematics.

Daniel Aldrich's paper, "Social, Not Physical, Infrastructure: The Critical Role of Civil Society in Disaster Recovery," received the Best Paper Award from the Public Policy Section of the American Political Science Association. The article illuminates four factors—damage, population density, human capital, and economic capital—that are thought to explain the variation in the pace of population recovery following disaster; it also explores the popular but relatively untested factor of social capital. These findings suggest new approaches for research on social capital and disasters as well as public policy avenues for handling catastrophes.

Indrajeet Chaubey was presented with the 2012 Purdue University Agricultural Research Award. This is the highest honor awarded to mid-career faculty members through the office of the Associate Dean of Research, College of Agriculture. Chaubey receives the award in recognition of the exceptional contributions he has made in the field of soil and water engineering.



Jeffrey Dukes and **Matthew Huber** were named Purdue University Faculty Scholars. This program was established by the University to recognize the outstanding accomplishments of faculty who are on an accelerated path for academic distinction. Faculty are nominated by committees from their academic areas and the appointment is approved by the provost.

Timothy Filley was awarded a Chinese Academy of Sciences (CAS) Visiting Professorship for Senior International Scientists. Filley spent three months at the CAS Institute for Applied Ecology in Shenyang, China, promoting scientific and educational collaborations that address issues in the earth sciences. Research projects that focus on the human impacts to terrestrial ecosystems and their influence on global change issues related to soil and water use were initiated.

In May, 2012, Filley was appointed Purdue Director of the US-China Ecopartnership for Environmental Sustainability (USCEES). The USCEES was established by the U.S. State Department with the primary focus of creating networks of private sector investment, state and local expertise, and high-level policymakers in both the U.S. and Chinese government to advance energy security, economic growth, environmental sustainability, and address climate change, by encouraging voluntary, cooperative partnerships at the sub-national level.

Paul Shepson was appointed as a fellow of the American Geophysical Union at the 2011 Fall AGU Meeting in San Francisco. To be elected a Fellow is a special tribute for those who have made exceptional scientific contributions. This designation is conferred upon not more than 0.1% of all AGU members in any given year. New Fellows are chosen by a Committee of Fellows. Shepson was honored for his "exceptional creativity in the study of the atmospheric chemistry of isoprene and of the role of snow and ice surfaces in the atmospheric chemistry of the Arctic."



Frederi Viens, completed his appointment in the Franklin Fellows Program, Bureau of African Affairs' Economic Policy Staff. Viens served as an advisor on issues related to climate change, energy, and environmental diplomacy. His work included assessing and helping develop material for the special envoys for climate change and for international energy. On a personal level, his work as a Franklin Fellow changed his own views on how scientific information is used, and gave him additional motivation to develop a new research focus on climatology and environmental statistics.

"I realized how intelligent and competent people can be and how very little they understand about science," Viens says. Since returning to Purdue, Viens is focused on engaging colleagues interested in studying deforestation issues and sustainable, low-emissions agricultural practices in Africa

LEFT: Indrajeet Chaubey, recipient of Purdue's Agricultural Research Award, tests the waters of Wildcat Creek east of campus. (Purdue Agricultural Communication photo/Tom Campbell). **ABOVE:** Paul Shepson, at the AGU awards ceremony for newly appointed Fellows. **BELOW** Timothy Filley standing at the shores of DaLi Lake nature preserve in Inner Mongolia. He visited this site during a trip to the Inner Mongolian Grassland Ecosystem Research Station, Chinese Academy of Sciences.



Gypsum crystals in a pool of saline water in the Salar de Llamara - Lagunas. Professors Greg Michalski and Brenda Beitler-Bowen led a group of researchers to the Atacama Desert to study long-term climate change.



LAUNCHING TOMORROW'S LEADERS

The PCCRC supports a learning environment that emphasizes interdisciplinary thinking, collaboration, and a vibrant academic experience. 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.

PCCRC DOCTORAL FELLOWS

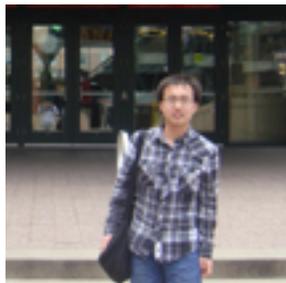
Casey Beel is a 2012 PCCRC Fellow. Casey hails from New Zealand, earning his BSc and MSc in Geography (specifically, sediment transfer processes) from Otago University. Before arriving at Purdue, he worked as a hydrological technician for the West Coast Regional Council, New Zealand. Here, he was responsible for the installation of 10 telemetered hydrometeorological sites and the maintenance of over 20 flood warning sites. Casey is working with advisor Prof. Nathaniel Lifton in the Department of Earth, Atmospheric, & Planetary Sciences.



Wendell Walters joined the Department of Earth, Atmospheric, & Planetary Sciences in the fall of 2012 and is a 2012 PCCRC Fellow. This past May, he graduated from the University of Maryland, College Park with a B.S. in Chemistry and received the American Institute of Chemists' award. His undergraduate research under Dr. Amy Mullin focused on studying the dynamics of inelastic collisions of highly excited molecules. A paper on this work entitled, "Using a frequency stabilized CW mid-IR OPO for high resolution transient IR absorption spectroscopy," will soon be submitted for publication in *Optics Express*. Wendell is working with advisor Prof. Greg Michalski in the Department of Earth, Atmospheric, & Planetary Sciences.



Linyuan Shang - 2011 PCCRC Fellow. Linyuan is working with advisor Prof. Qianlai Zhuang to address questions related to the exchange of carbon between the biosphere and atmosphere. This last year, Linyuan has focused on improving the representation of leaf phenology (spring leaf emergence, growing season, and fall senescence) in the Terrestrial Ecosystem Model (TEM). He is incorporating satellite data from the Advanced Very High Resolution Radiometer into the phenology component of the TEM, and choosing spatially explicit



parameterization methods to improve the accuracy of the model simulations. Linyuan is a graduate student in the Department of Earth, Atmospheric, & Planetary Sciences.

Ruoyu Wang - 2011 PCCRC Fellow. Ruoyu is a graduate student in the Department of Agricultural and Biological Engineering working with Prof. Keith Cherkauer with Prof. Laura Bowling, Department of Agronomy, serving as a co-advisor. His current research involves exploring the ability of an existing hydrology and crop growth model (SWAT2009) to simulate yield variability for traditional crops in the Midwestern U.S. with respect to observed climate and soil moisture variability. The model has been set up and will be calibrated and evaluated. The calibrated model will then be used to extend the observational record to study the effects of climate variability on crop yield. Ruoyu will present his research at the ASA, CSSA and SSSA International Annual Meetings in October, 2012 in Cincinnati, Ohio.



Paul Schmid - 2010 PCCRC Fellow. Paul is a student in the Department of Earth, Atmospheric, & Planetary Sciences, working with advisor Prof. Dev Niyogi, in conjunction with the Indiana State Climate Office. His current research includes mesoscale modeling the combined land-surface and urban aerosol effects on thunderstorms. Projects include idealized and real simulations of urban-thunderstorm interaction, seasonal regional mesoscale simulations, and adapting satellite data to improve model performance. In 2012 he accepted the NASA Earth and Space Science Fellowship to continue his research. Paul has recently published some of his results in the *Journal of Atmospheric and Oceanic Technology*:



Schmid, P. & D. Niyogi, 2012: A Method for Estimating Planetary Boundary Layer Heights and Its Application over the ARM Southern Great Plains Site. J. Atmos. Oceanic Technol., 29, 316-322.

Since 2006, the PCCRC Graduate Fellowship Program has helped recruit outstanding doctoral-seeking students interested in pursuing interdisciplinary climate change research.

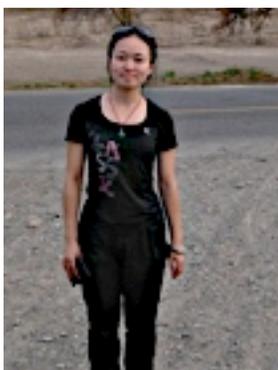
Clay Davis - 2009 PCCRC Fellow.

Clay Davis' current work focuses on the impacts of wind generation on other generation resource needs and their effects on electricity markets. He is also looking at the impacts of wind forecasting errors on electricity market operations. Clay has presented to Indiana Utility Regulatory Commission staff members. This summer, he completed an internship with the Federal Energy Regulatory Commission in Washington, DC. In this internship he worked in the Office of Enforcement's Surveillance Group, which monitors electricity and natural gas market trading. Clay is working with advisor Prof. Paul Preckel in the Department of Agricultural Economics.



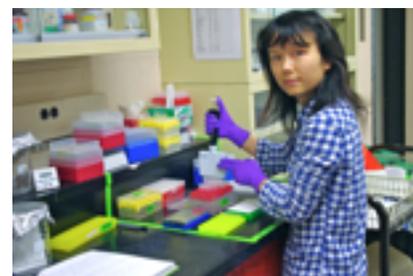
Fan Wang - 2009 PCCRC Fellow.

Fan Wang focused her attention this last year on data collection, both out in the field and in the laboratory. She collected samples from field sites in Xinjiang, China in August, 2011 and the Atacama Desert, Chile in December, 2011. These samples will be used to address soil formation mechanisms in hyper-arid regions and to track nitrogen pollution in the Yellow River, China. This year Fan had the opportunity to present a talk entitled, "A ^{36}Cl chronology for salt accumulation in the hyper-arid Atacama Desert, Chile" at the Geological Society of America Annual Meeting in Minneapolis, MN. She received a grant award from the Mineralogical Society of America for her research. Fan also passed her preliminary exam in April, 2012 to become a doctoral candidate in the Department of Earth, Atmospheric, & Planetary Sciences; advisor, Prof. Greg Michalski. She recently received a grant award from the Mineralogical Society of America for her work on the mineralogy of the Atacama Desert, which may serve as a terrestrial analog for aqueous-derived mineral formation on Mars. Fan is now concentrating her efforts on writing manuscripts and her dissertation.



Yini Ma - 2008 PCCRC

Fellow. Yini Ma's research focuses on the combined influences of past land use, litter type and addition rate, and invasive earthworms on soil organic carbon and litter decay in eastern deciduous forests. She uses a combination of natural products chemistry, soil particle fractionations, and stable isotope geochemistry to track the flow of carbon and nitrogen from litter to soil organic matter. In the past academic year, she worked at the Smithsonian Environmental Research Center (SERC) as a graduate fellow where she used soil respiration experiments to investigate the temperature sensitivity of accumulated soil organic carbon in SERC forests. By measuring the CO_2 respired from soil samples through 6 months incubation, she found that litter type and earthworm activity interact to control the proportion of labile (active) and stable (passive) carbon. She will be presenting this work at the 2012 Fall American Geophysical Union meeting. Yini is a PhD candidate in the Department of Earth, Atmospheric, & Planetary Sciences, working with advisor Prof. Timothy Filley.



ENRICHING EXPERIENCES for our STUDENTS

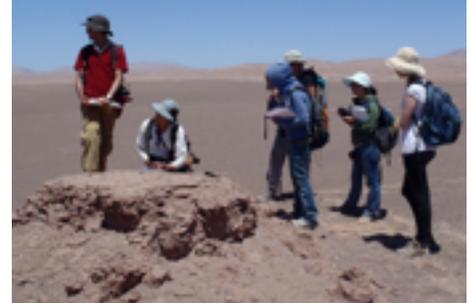


Asya Robertshaw, a PhD candidate in the Department of Botany & Plant Pathology (Professor Nancy Emery, advisor), collects samples from the Ross Biological Reserve in the photo above. Located about ten miles from Purdue's West Lafayette campus, the Ross Biological Reserve contains 92 acres of mature forest along with the Alton A. Lindsey Field Lab. Asya's work examines the effects of climate change on phenology and reproductive success in the spring ephemeral herbaceous plant community. This year she gave a poster presentation of her research at the Sigma Xi Annual Meeting and received a first place award for the "Best Graduate Student Poster" in her division. Asya also presented a talk at



the Indiana Academy of Science and the Botanical Society of America Annual Meetings.

Olivia Miller, a new graduate student in the Department of Earth, Atmospheric, & Planetary Sciences, is working with Professor Timothy Filley on the impacts of climate change on soil carbon cycling of the Alaskan North Slope. At the Toolik Lake Arctic Long-Term Ecological Research (ARC-LTER) field station, Olivia, pictured above, is studying how snow pack thickness changes plant community composition and permafrost depth and relating these changes to the decomposition of old, stable carbon pools. This summer, Olivia visited the field sites along with her advisor and collaborators from University of



Anchorage and University of Illinois Chicago to collect plants and soil samples for biogeochemical analysis.

In the photo above, Liesl Elison and Fan Wang (Department of Earth, Atmospheric, & Planetary Sciences), Jihye Soe (Department of Chemistry) and Professor Brenda Bowen, examine a relict tree mound in the Atacama Desert as Professor Devon Burr and graduate student Robert Jacobsen of the University of Tennessee take notes.

How to convey science and its uncertainty to policy makers? Choose brief & simple.



Aaron Goldner a PhD candidate in the Department of Earth, Atmospheric, & Planetary Sciences, attended a Policy Colloquium in Washington, DC organized by the American Meteorological Society and American Geophysical Union. The Policy Colloquium brings together scientists from academia, government, and the private sector for ten days of training on how to more effectively communicate scientific topics to politicians and the media.

The ten day Policy Colloquium took place at the American Association for the Advancement of Science (AAAS) building, and included trips to Congress and the Senate to meet with Congressional and Senate staffers. Throughout the week the participants were able to meet with leaders in all levels of government, including the National Oceanic and Atmospheric Administration, National United States Geological Survey, the National

Aeronautics and Space Administration, the U.S. Agency for International Development, Federal Emergency Management Agency, and the White House National Security Staff.

The AMS and AGU Policy Colloquium is offered every year and funding applications are open to graduate students in early January.

"This course is a fantastic starting point for a graduate student interested in science policy or for students who are interested in learning more about how to interface their science with policy decisions," said Aaron. In the photo to the left, Aaron stands in front of the Environmental Protection Agency Ariel Rios Building.

ALUMNI UPDATE



Courtney Creamer (PhD '12; seed grant recipient) is currently a postdoctoral fellow at the Commonwealth Scientific and Industrial Research Organization's (CSIRO) Land and Water division in Adelaide, South Australia. She is working in the soil carbon and nutrient cycling group along with

Evelyn Krull, Jeff Baldock, Jonathan Sanderman, Mark Farrell, and Lynne Macdonald.

In her postdoctoral position, she will be investigating the impacts of altered climate (temperature, precipitation) and soil organic matter quality upon soil carbon turnover in Australian soils, with a focus on compound-specific stable isotope analysis. The dry and variable climate of Australia has presented challenges for land and water management, and frequent long-term droughts and increasing soil salinity create issues for long-term sustainable agriculture. Temperature increases in Australia during the last century have been slightly higher than the global average, and future climate scenarios in South Australia predict higher temperatures, increased drought frequency and severity, and decreased average rainfall in agricultural regions. Courtney's work seeks to understand how these climatic changes will impact the productivity of natural and managed ecosystems in Australia.



After completing his doctoral studies in 2009, Joseph Alfieri (2006 PCCRC Fellow) joined the Hydrology and Remote Sensing Laboratory at the US Department of Agriculture, Agricultural Research Service in Beltsville, Maryland. Since that time, his research has focused largely on improving methods of measuring and modeling evaporative water loss via remote sensing. With a growing population, evolving societal preferences, and changing climate, it has become increasingly more challenging in recent

years to manage scarce water resources to meet the competing demands of agricultural, industrial, and urban consumers. Joe's work ensures that the most accurate scientific data and information is available to the resource managers and policy makers seeking to meet that challenge.

Working with both U.S. and international scientists, Joe is exploring the impacts of spatiotemporal variability in the ambient environmental conditions on both the structure of the surface boundary layer and the mechanisms of land-atmosphere exchange. He is particularly interested in how these processes influence measurement uncertainty and upscaling when evaluating numerical and remote sensing-based models over heterogeneous terrain. Joe is also an active participant in several projects exploring such diverse issues as the role of surface properties in regulating pesticide volatilization and the effects of wind farms on crop productivity.

Castillo joins the faculty at Ateneo de Manila University

C. Kendra Gotangco Castillo (PhD '11; 2007 PCCRC Fellow) has taken a position as assistant professor in the Department of Environmental Science at the Ateneo de Manila University, Philippines. Kendra maintains her affiliation with the Manila Observatory as a research scientist working on climate change adaptation and disaster risk management projects.

Boiler UP
PURDUE RECEPTION
at the AGU Fall Meeting

The PCCRC sponsors an annual reception at the American Geophysical Union (AGU) fall meeting to provide an opportunity for prospective students to meet our faculty and current students - it is also a great opportunity for our alumni to stay connected with our programs!

NEW COURSES

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. This wide-lens approach is exemplified in the range of interconnected topics explored in the fall literature club focused on the water-climate nexus:

Hydrological and biotic change in the 'way back': Eocene greenhouse climates (Gabe Bower)

Global Warming: It's not the heat, it's the humidity (Matthew Huber)

Skating on thin ice: the role of the cryosphere in hydrologic change (Laura Bowling)

Soil moisture: the main regulator of plant and microbial processes in a changing world? (Jeff Dukes)

Changing farmers' behaviors in a changing climate (Linda Prokopy)

Plant responses to variable hydrology in California ephemeral wetlands (Nancy Emery)

Evaluating extremes in precipitation and in the precipitation-generating weather systems (Jeff Trapp)

Estimating climate change impacts on streamflow in the Lake Michigan basin using the USGS PRMS watershed model (Special presentation by John F. Walker, U.S. Geological Survey)

Water and Climate Seminar

Instructors: Ron Turco, *Agronomy* and Gabe Bower, *Earth, Atmospheric, & Planetary Sciences*

EAS 54143 and AGRY 54144

In a collaborative merger of the PCCRC and PWC literature clubs, this 1-credit seminar series focused on reviewing and synthesizing active research on the physical, biological, and societal dimensions of the water-and-climate problem, encouraging the broad participation of graduate students, postdoctoral researchers, and faculty from across campus. The seminar offered an opportunity to review research at the intersection of water cycle and climate change research, consider Purdue's strengths and weaknesses in this area, and further develop our collective thinking about these systems that are so critical to global sustainability.

The format included lectures by faculty from across 6 different departments as well as guest speakers. Discussion and synthesis sessions provided a venue for reflecting on and integrating information from speaker presentations. The literature club continues to be a successful platform for thinking creatively about research trends and opportunities and has served as a launching pad for new collaborations and research within and beyond the Purdue community.

Advanced Topics in Energy, Resource, and Environmental Economics

Instructors: Juan Sesmero and Nelson Villoria, *Agricultural Economics*

AGEC 69000

This seminar was designed to create a platform to explore research on energy, resource and environmental economics (EREE). The interactive format allowed for all participants to present their own research (or research interests) and receive critical feedback from peers, faculty participants, and course instructors. Some of the topics discussed included energy (biomass, grain ethanol, oil, natural gas, coal, oil shale, wind and solar energy, and policy analysis for these sources), climate change (including land use change and GHG emissions, the interface between climate and international trade patterns, and the role of agriculture as a source or sink of carbon dioxide), assessment of agricultural and natural resource policy, markets for environmental goods and services, invasive species management, and spatial dimensions of environmental and natural resource management.

One of the most attractive aspects of the EREE topic is the wide range of methodological tools that can be applied to this subject area. Methods include econometrics (micro, spatial, and time-series), non-market valuation, decision analysis and mathematical modeling, game theory and information economics, applied general equilibrium theory, and interdisciplinary research that integrates economics with natural or physical sciences to analyze applied problems. The course provided an excellent opportunity for both established and incoming students to learn about a wide array of research interests, projects, and opportunities.

SUMMER SHORT COURSES OFFERED IN CHINA

The economies of the US and China are inextricably linked to the challenges of climate change, food security, and sustainable development. In the face of dwindling natural resources, increasing population, and changing consumption patterns, these two nations share responsibility for developing realistic goals and effective strategies for the best solutions to these challenges.

The Purdue-led **U.S.—China EcoPartnership for Environmental Sustainability (USCEES)** was established by the U.S. State Department with the primary focus of addressing environmental challenges that are common to both the United States and China. Through a variety of programs, the USCEES brings together academic, government and business spheres to develop and apply innovative, solutions-oriented approaches to help move the trajectory of our nations, and the world, toward sustainable management of our natural resources and living environment in the face of our common vulnerability to climate and land use change.

This year the USCEES offered two short courses in Beijing, China in May 2012, attracting 50 students and postdoctoral researchers from 4 different Chinese academic institutions. The short courses were hosted by Professor Wenshen Ge of the China University of Geosciences and Professor Dong Shikui of Beijing Normal University. Professors Greg Michalski and Timothy Filley (*Department of Earth, Atmospheric, and Planetary Sciences*) introduced a range of topics focused on the dynamics of soil organic matter and advanced mass spectrometry tools to help students gain a better understanding of the biogeochemistry of modern and ancient systems.

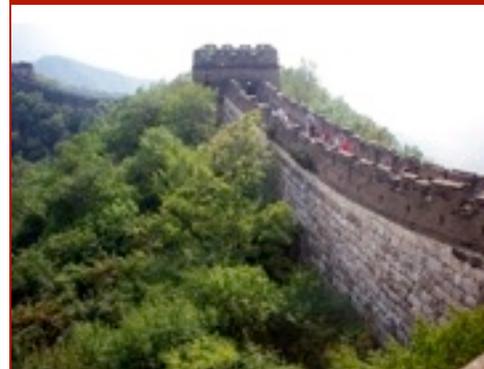
One session emphasized the mechanisms of stabilization and destabilization of soil organic matter using examples from specific ecosystems to teach how plant chemistry, input rate, microbial community, soil mineralogy, soil texture, and the local environment interact to control soil organic matter dynamics. Specific biogeochemical methods to assess organic



matter input type, decay mechanisms, and dynamics were discussed. The course included detailed presentations and homework on topics ranging from the organic chemistry of plant and microbial biopolymers, black carbon formation and reactivity, stable isotope fractionation and modeling, and the use of cosmogenic and stable isotopes for mean residence time calculations.

A second session focused on exploring how stable isotopes can be used to understand biogeochemical cycling of nitrogen, carbon, and sulfur in contemporary and ancient geologic systems. The lectures emphasized how mass-independent isotope compositions in oxygen and sulfur can be used to assess the importance of atmosphere-surface interactions and how they are manifest in soils and the geologic record. Examples of the topics covered include the fundamentals of stable isotope biogeochemistry; disturbances to soil organic matter such as ecosystem engineering, ecosystem shifts, and climate change; the rise of O₂ two billion years ago inferred from Achaean sulfides and sulfates; and origins of the nitrate deposits found in the world's deserts.

Professors Michalski (pictured above with some of the students attending the summer short course) and Filley then accompanied Prof Dong and selected students from the class to field sites in the Qinghai Tibetan Plateau to discuss application of isotope and biomarker techniques to land degradation issues at the sites. The USCEES will offer similar short courses in the summer of 2013.



Third graders from the Ipalook Elementary School in Barrow, Alaska learn about snow research on the tundra during the BROMEX field season.



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.

A RESOURCE FOR SCIENCE-BASED INFORMATION

Doering chairs EPA's Science Advisory Board Integrated Nitrogen Committee

In August, 2011, the Environmental Protection Agency's (EPA) Science Advisory Board's Integrated Nitrogen Committee released their findings in a new report entitled, *Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences and Management Options*. Professor Otto Doering chaired the team of science advisors leading the five-year study which is the first to quantify the sources and risks of nitrogen pollution (reactive nitrogen) in the United States. The report finds that in the U.S., "human activities across multiple sources currently introduce more than five times the reactive nitrogen into the environment than natural processes." When released into the environment in large quantities, reactive nitrogen can severely damage ecosystems, impact our climate system, and adversely affect health.

While it is well known that the primary sources of nitrogen pollution are agriculture and the burning of fossil fuels, the report highlights that, unlike other pollutants, once reactive nitrogen makes it into the environment, it causes a "cascading sequence of events, resulting ultimately in harm to the natural balance of our ecosystems," said University of Virginia environmental sciences professor James Galloway, a co-author of the report.

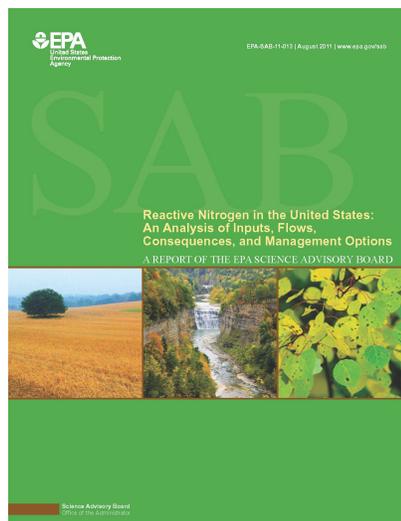
For example, NO_x emissions from a tailpipe will contribute to the formation of ozone, then smog, and then acidify soil when it settles out of the atmosphere. From the soil, it can be washed into rivers and streams, causing algal blooms and ultimately evaporating back as the greenhouse gas nitrous oxide which warms the troposphere, and also destroys stratospheric ozone.

Findings from the report show that a 25% reduction in excess reactive nitrogen is achievable in the coming decade with available technology, if there is the will to do so. The report urges government agencies to

take action and set goals for controlling excess reactive nitrogen. Doering has recently served on several committees for the National Academies that have made similar recommendations after investigating the nutrient problems in the Mississippi River Basin.

The Integrated Nitrogen Committee's report is having a profound impact on the way EPA and other agencies are approaching the nitrogen problem. The board recommends more integrated approaches to researching and regulating nitrogen in part to prevent nitrogen-cutting "solutions" in one program from causing inadvertent problems in another. They also recommend improved communication between its researchers who study air and water, and better communication with colleagues at the U.S. departments of agriculture and energy, who also work on nitrogen pollution.

The Integrated Nitrogen Committee's leadership team, including Jim Galloway from the University of Virginia and Tom Theis from the University of Illinois, Chicago, has participated in numerous briefings and meetings to highlight this issue and suggest alternative approaches that might be utilized successfully to reduce excess reactive nitrogen.



POST-CRISIS JAPANESE NUCLEAR POLICY: FROM TOP-DOWN DIRECTIVES TO BOTTOM-UP ACTIVISM

by Daniel P. Aldrich

Over the past fifty years, Japan has developed one of the most advanced commercial nuclear power programs in the world. This is largely due to the government's broad repertoire of policy instruments that have helped further its nuclear power goals. These top-down directives have resulted in the construction of 54 plants and at least the appearance of widespread support for nuclear power. By the 1990s, however, this carefully cultivated public support was beginning to break apart. And following the earthquake and tsunami of March 2011 and resulting nuclear crisis in the Fukushima nuclear complex, the political and social landscape for energy in Japan has been dramatically altered. The crisis has raised and reinforced environmental concerns and health fears, as well as skepticism about information from government and corporate sources. A civil society that for decades has appeared weak and non-participatory has awakened and citizens are carrying out bottom-up responses to the accident, effecting change with grassroots science and activism.

The full paper is available in *AsiaPacific Issues*, No. 103.

INFORMAL INSTITUTIONS & INTRACTABLE GLOBAL PROBLEMS WORKSHOP

The 2012 Purdue University Workshop on Informal Institutions and Intractable Global Problems brought together a diverse group of scholars and practitioners to discuss how greater attention to informal institutions, such as social and ethical norms or other “unwritten” rules of behavior, might improve policy responses to global grand challenges. Participants applied theoretical insights from the latest work on informal institutions in political science, psychology, philosophy, economics, and anthropology on three “intractable” problems that have confounded policy makers for decades: climate change, food security, and women’s human rights.

By synthesizing work across disciplines and policy issues, the workshop aimed to create new perspectives on old problems, and new theoretical insights on the importance of informal institutions.

Workshop co-organizers Leigh Raymond and Laurel Weldon will edit a print symposium in the journal, *Political Research Quarterly*, featuring several papers from the workshop and an overview paper on informal institutions and public policy. In addition, four policy briefs distilling lessons from the workshop for the public and stakeholders will be available at the end of 2012.

The multidisciplinary planning committee included: Ximena Arriaga, Associate Professor of Psychology; Ann Marie Clark, Associate Professor of Political Science; Rose Filley, Managing Director, PCCRC; Daniel Kelly, Associate Professor of Philosophy; Leigh Raymond, Professor of Political Science; and S. Laurel Weldon, Professor of Political Science.

The two-day workshop included four sessions with presentations by the following speakers:

Cross-disciplinary Perspectives on Norms

Joe Henrich, *University of British Columbia*
Stephen Stich, *Rutgers University*
Georgina Waylen, *University of Manchester*

Climate Change

Kathryn Hochstetler, *University of Waterloo*
Breena Holland, *Lehigh University*
Leigh Raymond, *Purdue University*
Janet Swim, *The Pennsylvania State University*

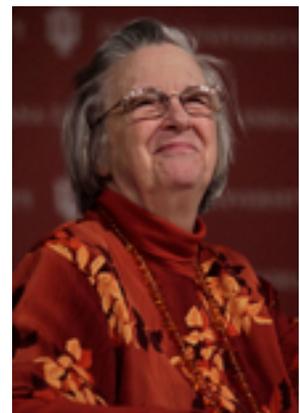
Food Security

Marc Cohen, *Oxfam America*
Lauren MacLean, *Indiana University*
Ellen Messer, *Brandeis University*

Women's Human Rights

Olga Avdeyeva, *Loyola University Chicago*
Louise Chappell, *University of New South Wales*
Elisabeth Jay Friedman, *Univ. of San Francisco*
S. Laurel Weldon, *Purdue University*

The workshop was sponsored by: The National Science Foundation, Global Policy Research Institute, Purdue Climate Change Research Center, Discovery Lecture Series, Global Sustainability Institute, and Purdue’s College of Liberal Arts.



The late Elinor Ostrom presented the workshop’s keynote lecture. Ostrom, an American political economist and distinguished professor at Indiana University, won the 2009 Nobel Prize in Economic Sciences for her groundbreaking research demonstrating that ordinary people are capable of creating rules and institutions that allow for the sustainable and equitable management of shared resources. She shared the prize with Oliver Williamson, a University of California economist.

Ostrom was the Arthur F. Bentley Professor of Political Science and Senior Research Director of the Workshop in Political Theory and Policy Analysis at Indiana University in Bloomington. She also served as founding director of the Center for the Study of Institutional Diversity at Arizona State University in Tempe.

HOTHOUSE EARTH

World Without Ice

Central to understanding, predicting and mitigating the impact of climate change is understanding how the Earth's climate changed in the past. The Paleocene-Eocene Thermal Maximum (PETM) was a period in Earth's history (around 56 million years ago) that is characterized by an exceptionally large release of carbon into the atmosphere and the highest global temperatures of the Cenozoic Era; it was a "world without ice." How much carbon was transferred to the atmosphere? Scientists estimate that it would be roughly the amount released if we burned through the Earth's entire reserve of conventional fossil fuels (oil, coal, natural gas). The PETM lasted more than 150,000 years, until the excess carbon was reabsorbed. A recent (October 2011) National Geographic article, "Hothouse Earth," by Robert Kunzig explores this time in Earth's history and considers how it relates to current climate warming. An excerpt highlighting the research of PCCRC associate director and professor, Matthew Huber, is given below:

Matt Huber, a climate modeler at Purdue University who has spent most of his career trying to understand the PETM, has also tried to forecast what might happen if humans choose to burn off all the fossil fuel deposits. Huber uses a climate model, developed by the National Center for Atmospheric Research in Colorado, that is one of the least sensitive to carbon dioxide. The results he gets are still infernal. In what he calls his "reasonable best guess at a bad scenario" (his worst case is the "global-burn scenario"), regions where half the human population now lives become almost unbearable. In much of China, India, southern Europe, and the United States, summer temperatures would average well over 100 degrees Fahrenheit, night and day, year after year.

Climate scientists don't often talk about such grim long-term forecasts, Huber says, in part because skeptics, exaggerating scientific uncertainties, are always accusing them of alarmism. "We've basically been trying to edit ourselves," Huber says. "Whenever we see something really bad, we tend to hold off. The middle ground is actually much worse than people think."

"If we continue down this road, there really is no uncertainty. We're headed for the Eocene. And we know what that's like."



Inuit Johnny Issaluk holds a recent photo of a South Carolina swamp. That's what his home, near the Arctic Circle on Baffin Island, would have looked like 56 million years ago, when summer water temperatures at the North Pole hit 74°F. Photograph by Ira Block



Now you can stay up-to-date on the latest news, events, and activities from the PCCRC via our Facebook page. Join us and be a part of the conversation.

www.facebook.com/PurdueClimateChangeResearchCenter



PART OF THE COMMUNITY

DISPATCHES FROM THE ICE

Dr. Kerri Pratt blogs from Barrow, Alaska during the BROMEX field campaign

From February through April 2012, Professor Paul Shepson's lab headed to Barrow, Alaska for the NASA sponsored BROMine, Ozone, and Mercury EXperiment (BROMEX), an international, multi-year project studying the implications of Arctic sea ice reduction on tropospheric bromine, ozone and mercury chemical processes, transport and distribution. During the 2012 field campaign, Prof. Shepson, aircraft technician Brian Stirm, postdoc Dr. Kerri Pratt, and graduate student Kyle Custard conducted ground-, buoy-, and aircraft-based measurements.

Dr. Kerri Pratt, a National Science Foundation Postdoctoral Fellow in Polar Regions Research, documented their 2012 field campaign with detailed blog posts, maps, photos, and video clips (<http://shepsonbromex.blogspot.com>). This incredible resource provided an opportunity for engagement with many audiences, including school-aged children who were able to follow along on their adventures and see what it's like to be a research scientist in the Arctic. Classrooms across the country emailed questions to Kerri, who posted answers on the blog. The fantastic questions ranged from "Do scientists have snowball fights?" to "How does the ice affect the gases in the air?" Kerri and Kyle also enjoyed describing their research to a Barrow 3rd grade class who visited their lab on the tundra (photos to the right).

Highlights from the two-month field campaign included: outfitting and flying Purdue's Airborne Laboratory for Atmospheric Research (ALAR) a twin-engine Beechcraft Duchess from West Lafayette to Barrow, and back; many nights of amazing views of the Aurora Borealis while working out at the tundra lab; learning about whaling from a native Iñupiat whaling captain; snowmobile rides onto the sea ice to collect snow and ice samples; flying over open leads and tundra on ALAR; watching beautiful sunrises and sunsets that moved drastically in time each day; and feeling what -30°F plus a wind chill feels like.



ENGAGING LOCAL STUDENTS: Purdue graduate student Kyle Custard and postdoc Kerri Pratt, together with other BROMEX grad students, hosted a class of 3rd graders from the Barrow elementary school at the project's tundra site.

