Purdue Climate Change Research Center

ANNUAL REPORT 2007




PURDUE UNIVERSITY
Discovery Park

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

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Cover photos from left to right: Graduate student Kendra Castillo (EAS) at the New Delhi Conference on Sustainability and Climate Change with new colleagues from around the world; graduate student Phil Tackett (Chem) setting up experiments onboard the *Amundsen* research icebreaker; Jill Jankowski (undergraduate honors student in Biological Sciences) with a resplendent quetzal in the Monteverde Cloudforest Reserve, Costa Rica; Prof. Tim Filley and undergraduates from Bemidj State University setting up long-term experiments to study forest structure in the northern hardwood forests of the Red Lake Nation.

Paul B. Shepson

Professor and Director

Message from the Director

Please join me in celebrating another great year of growth and development at the PCCRC. As you can see from the Annual Report, we continue to make substantial progress in all the key areas by which we measure the success of a Center. Our level of sponsored research continues its upward trajectory and is such that we are an important component of the overall University strength in the discovery endeavor. We are doing high profile research, which has garnered a great deal of media attention.

There is great strength and breadth in our membership which expands our opportunities and enables us to leverage synergies between disciplines. Our new members section shows that while the PCCRC was borne out of an effort within the College of Science, our new members this year represent the Departments of Building and Construction Management, Forestry and Natural Resources, Agronomy, and Political Science.

We are publishing at a fantastic rate in some of the highest impact journals. We have developed new courses at the graduate and undergraduate levels, and this, along with our research activities enables us to fully engage our students in the new arena of multidisciplinary problem solving.

PCCRC members have been very active this year in engagement, from local scale talks to a variety of community groups, to analysis of legislation impacts in support of the work of our state's senators. We have begun putting all this together, and pursuing the paths that great Centers should pursue, i.e. organizing large scale collaborative federally funded research efforts. For the PCCRC, all the indicators are up.

So, with these successes, it is appropriate to return to the initial question – what is it that will truly distinguish the PCCRC as a unique and highly valued national resource? To me, the answer is a clear one – we should be real leaders. We should effectively connect Purdue's combined strengths in the fundamentals of climate science and energy management with the social sciences to better inform the national and international decision-making process regarding how to develop sensible national policy that simultaneously addresses our needs for secure and sustainable energy sources, as well as mitigation of and adaptation to the impacts of long term climate change. To deal with the range and complexity of these issues requires expertise in a vast array of disciplines – atmospheric science, carbon cycle science, ecology, energy technologies and engineering, agriculture, political science, economics, and sociology, to name several.

What a fantastic opportunity we have to leverage the combination of expertise that uniquely sits within universities! Can we do it? The answer rests with how well we organize our efforts within the University setting, and the extent to which we can break down barriers to collaborative research across Departments and Colleges. So, why not start at Purdue? Why not ask Purdue to be the leader? Do we have what it takes? How could we demonstrate that? I believe we can best demonstrate that by expressing our leadership locally. We could develop and commit to a new campus plan for sustainability. We could continue our efforts to build LEED certified buildings. We could build showcase buildings that act as living laboratories, about how to better manage our limited resources. Such activities will in the long run save the University money, attract and retain the best students and faculty, and convey to the world that Purdue University is an intellectual leader.

I have heard that dealing with our energy management issues will be very difficult, and a very great challenge. Well, how exciting for us! We should welcome a great challenge. Throughout U.S. history we have met very great challenges with a spirit of commitment and a positive attitude. We put a man on the moon in 1969, against unbelievable odds. We loved the challenge. It is time to get back to that spirit. I challenge Purdue to be a real leader. The time is now.

Sincerely,

Paul B. Shepson

Professor and Director

This experiment at the Smithsonian Environmental Research Center was designed to measure how invasive earthworm activity impacts carbon and nitrogen in soils. Tim Filley and Cliff Johnston have recently discovered that these invasive macroinvertebrates fundamentally alter the chemical mechanisms of litter and soil organic matter decomposition, changing the balance and chemical nature of organic matter stored on and below the forest floor.

This research is the focus of a new NSF grant to Filley and Johnston along with Co-PIs from the Smithsonian Institution and The Johns Hopkins University.

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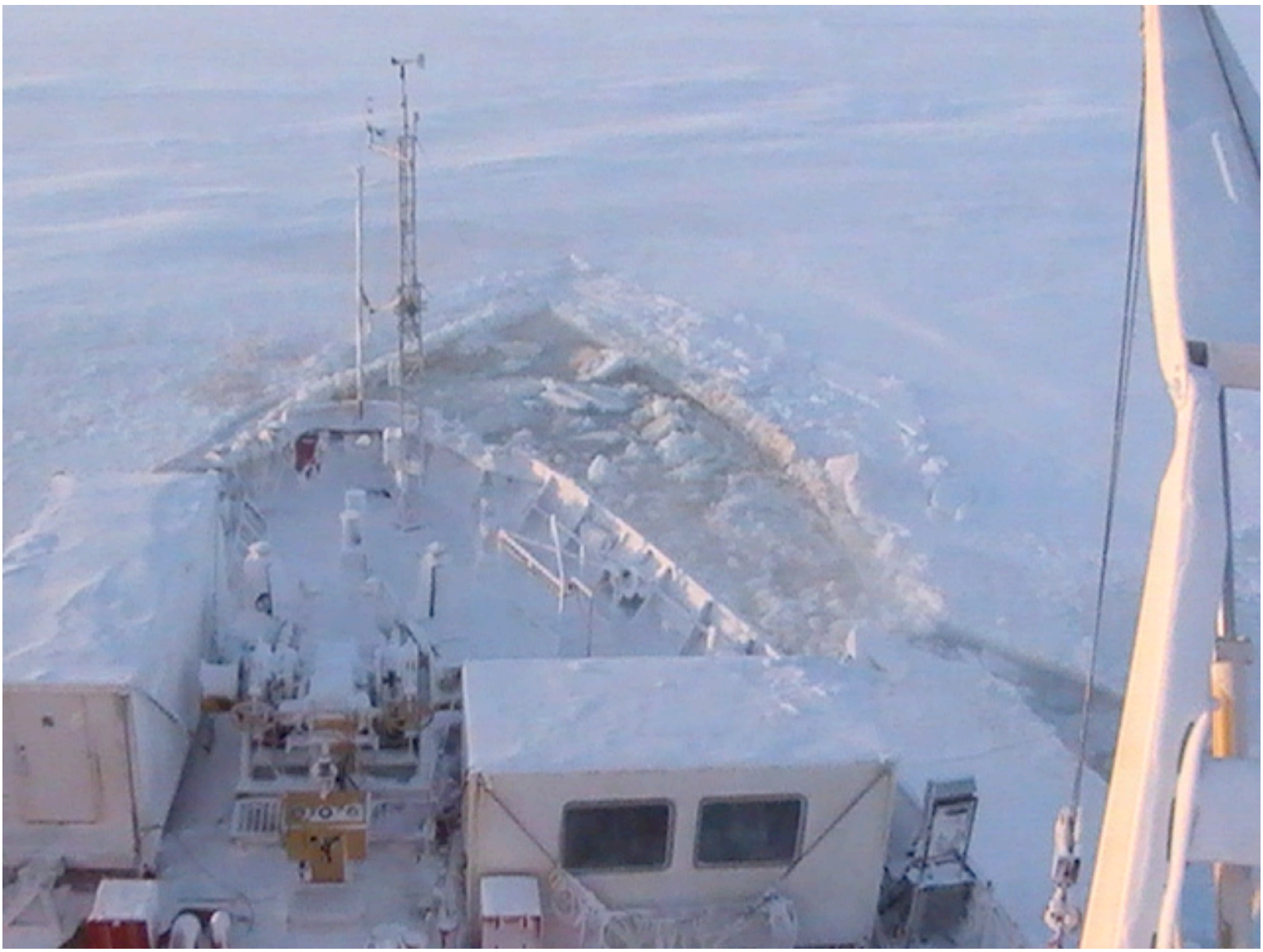


This photo shows the bow of the icebreaker, CCGS Amundsen. In thick ice, as shown, the ship repeatedly moves forward, crushing ice with the keel, and then backs up to enable repeated runs at the ice. Typically, the ship pitches up slightly during such a run, so that the weight of the ship sitting on top of the ice is able to crush it. The ship is able to move continuously through ice as thick as 1m.

With a grant from the National Science Foundation, Paul Shepson and graduate student Phil Tackett were onboard the Amundsen this spring to study the relationship between sea ice and cloud cover in the Arctic.

DISCOVERY

As part of the the new research environment created in Purdue's Discovery Park, the PCCRC continues to build and strengthen interdepartmental relationships to promote new ideas and discoveries that only interdisciplinary research can provide. The following pages provide a summary of our research programs and how they are being applied in innovative ways to solve climate change issues.

Sponsored Research

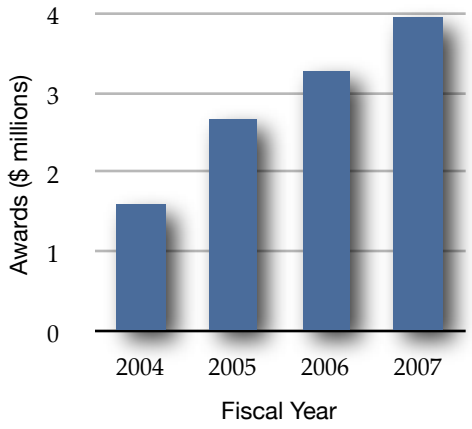
The Center facilitates and supports cross-disciplinary collaborations, assisting our faculty as they initiate new projects and compete for funding. In this section, read about our newest research grants.

Summary

PCCRC research projects sponsored by external funding totaled over $3.8 million in FY2007. Federal funding comprised the majority of the total, which included support from the National Science Foundation, U.S. Department of Energy, U.S. Environmental Protection Agency, and the U.S. Agency for International Development.

Non-federal sponsors of our work included the World Bank and the Camille and Henry Dreyfus Foundation.

Research Grant Activity



The PCCRC continues on its trajectory of growth, building and enhancing a vital research program in the pursuit of local, national, and often global, goals related to climate change.

In this section we describe our faculty's new sponsored research projects and provide an early look at the kinds of activities underway.

Experimental Testbeds for New Applications of Environmental Trading Programs

Timothy Cason, *Department of Economics,* with collaborators John Stranlund and John Spraggon, *University of Massachusetts;* James Murphy, *University of Alaska*; David Porter , Stephen Rassenti and Vernon Smith, *Chapman University* (Funded by the U.S. Environmental Protection Agency)

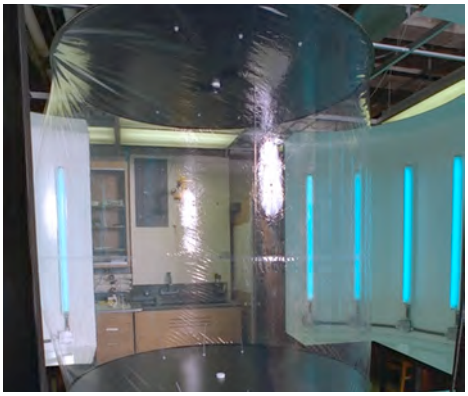
The proposed testbed experiments will provide policy guidance for several important emissions trading design issues. The first experimental testbed will study how emissions permit markets function when governmental authorities conduct international (or interstate) trading, and do not allow unrestricted trading between individual firms in different countries and states. The second testbed will examine simultaneous trading for multiple related pollutants, such as different greenhouse gases, and will compare market performance to alternative designs that combine the different pollutants in the same market by employing trading ratios based on their global warming potential. The third experiment will study how banking incentives are affected by emissions uncertainty and alternative banking policy rules that may depreciate banked allowances or cap withdrawal rates to reduce temporal and geographic "hot spots."

The overall project results should provide practical answers and advice to improve management of local environmental problems, such as those where banking considerations may be very important, as well as national and global problems featuring inter-jurisdictional enforcement challenges and multiple related pollutants.

Carefully designed emissions trading systems have the flexibility to confront these and other challenges, but only if they are guided both by economic theory and by empirical evaluation in controlled settings.

Building resiliency in the world's poorest communities.

Incorporating relationships between weather extremes and the energy sector into energy planning.



Photochemical reaction chamber in the Shepson Lab.

Natural Capital and Poverty Reduction

Gerald Shively, *Department of Agricultural Economics* with collaborators Charles Jumbe, *University of Malawi*; Disk Sserunkuuma, *Makerere University*, *Uganda*; Pam Jagger, *Indiana University*; Monica Fisher, *Oregon State University*; and Arild Angelsen, *CIFOR and Norwegian University of Life Sciences* (Funded by the U.S. Agency for International Development)

This 4-year project provides an opportunity to study the potential impacts of climate change on agricultural producers and explore policy options for mitigating the economic and environmental impacts of climate change in low-income settings. Activities will center on strengthening capacity for policy analysis and deriving policy lessons regarding two topics: (i) the role of natural insurance among the rural poor, including the degree to which environmental income serves as a safety net in the face of economic and environmental shocks and (ii) the potential for poor rural households to sustainably use environmental income as a means to accumulate physical and human capital, and move out of poverty.

In addition, the research team will look at the long term sustainability of resource extraction, and look to inform policies in directions that improve both economic and environmental outcomes. The project will work to highlight ways to ensure that a larger share of resource rents go to local people, and articulate ways to enhance poverty alleviation without increasing environmental degradation.

Impacts of High Resolution Extreme Events on U.S. Energy Demand and CO_2 Emissions in the 21st Century

Noah Diffenbaugh, *Department of Earth & Atmospheric Sciences* and Kevin Gurney, *Departments of Earth & Atmospheric Sciences and Agronomy* (Funded by the U.S. Department of Energy)

Enhanced greenhouse forcing is likely to intensify extreme climate regimes. Because energy demand is highly sensitive to extreme temperature and precipitation events and their fine-scale space/time patterns, intensification of extreme climate regimes is likely to impact energy demand and related CO_2 emissions. These impacts and their subsequent feedbacks could be a key contributor to the net damage or benefit associated with climate change. However, even the most sophisticated studies of the potential impacts of climate change on the energy sector have failed to capture the effects of climate change at the scales at which energy use decisions are driven and made: the scale of local weather and extreme weather events. Further, due to limited data, computational restrictions, and conceptual modeling barriers, Integrated Assessment (IA) models have to-date required a "macro" or "top-down" approach, necessarily excluding interactions between weather extremes and the energy sector. The objective of this work is to build fundamental knowledge regarding the impact of weather extremes on particularly sensitive portions of the energy sector, in service of the next generation of IA models.

Production of Secondary Organic Aerosol from Multiphase Terpene Photooxidation

Paul Shepson, *Department of Chemistry* (Funded by the U.S. Environmental Protection Agency)

A major area of uncertainty for air quality as well as climate change research is the role of secondary organic aerosol (SOA). Recently it has become clear that there is a large unknown source of SOA in the free troposphere. A wide variety of studies have implicated the oxidation of biogenic volatile organic compounds (BVOCs), and in particular the terpenes, α- and β-pinene, in aerosol production in the boundary layer. We believe there is evidence that a significant part of SOA production from BVOCs is derived

from organic nitrates that derive from OH reaction with the BVOC in the presence of NOx. This three year field and laboratory project is aimed at improving quantitative understanding of the photooxidation of α- and β-pinene, and the extent and nature of the production of SOA from their NOx-, O_3-, and NO_3-induced photooxidations.

Climate Variability and the Poor in Southern and Eastern Africa

Tom Hertel, *Department of Agricultural Economics* and Noah Diffenbaugh, *Department of Earth & Atmospheric Sciences* (Funded by the World Bank TFESSD).

The world's poor are particularly sensitive to changes in the agricultural sector, both because the majority of the poor rely on agriculture for their livelihood, and because they spend a disproportionate share of their income on food. Because the agricultural sector is particularly influenced by weather extremes, changes in extreme climate regimes could have substantial impacts on the poorest populations. In order to develop policies and infrastructure to cope with increased frequency of extreme climate events, we must understand how global warming affects climate volatility (both globally and locally); how changes in climate volatility affect agricultural yields and land use (as well as other economic opportunities, including trade and migration); and finally, how all of these changes affect poverty. This effort to bridge climate, land use, and poverty analyses will help to develop a framework for quantifying the impacts of climate variability and change on the world's poor on seasonal-to-decadal time-scales. Because the framework to be developed through this project will be general and flexible, it will be readily applied to other regions of the world.

Exploration of the Mechanistic Relationship Between Improved Regional North American Inverse Carbon Fluxes and Climate Variability/Trends

> *The Tanzania National Strategy for Growth and Reduction of Poverty highlights "weather extremes (droughts and floods)" as one of the primary factors underlying vulnerability of poor populations.*
>
> *--Republic of Tanzania, 2005, p. 14.*

Kevin Gurney, *Departments of Earth & Atmospheric Sciences and Agronomy* (Funded by the U.S. Department of Energy NICCR Program)

This project will use improved time-dependent net carbon exchange results from the TransCom intercomparison to advance quantitative understanding of the feedbacks between net carbon exchange and climate variability/change for the United States. The project will improve upon recent inverse work through expansion and extension of observations, a state-of- the-art fossil fuel CO_2 flux product, and sensitivity to inter-annually varying transport. The regional carbon-climate relationships will be further explored mechanistically through process datasets (NDVI, fire, drought) and terrestrial biosphere model results.

Soil-Earthworm-Litter System Controls on the Stabilization of Organic Matter in Forests

Timothy Filley, *Department of Earth & Atmospheric Sciences*, and Cliff Johnston, *Department of Agronomy* with collaborators Melissa McCormick, *Smithsonian Environmental Research Center*; Kathy Szlavecz, *The Johns Hopkins University* (Funded by the National Science Foundation)

Soil organic matter (SOM) and associated litter represent the largest actively cycling pool of organic carbon and nitrogen. Because soil acts as both a sink and a source for carbon, a detailed, mechanistic understanding of what controls the conversion of litter to SOM, and its stability in soil is critical to accurately account for the changing balance between the atmospheric, terrestrial plant, and soil carbon reservoirs. In mid-continent and northern North American forests there is an increasing awareness of the effect that detritivore macroinvertebrates, specifically earthworms (EW), have on litter decay dynamics and the associated nature of stabilized SOM. The earthworm-litter-soil system is particularly relevant today as most identified earthworm species in this region's forests are non-native, and it is anticipated that over the next few decades they will expand farther into northern forests driven by rising surface temperatures, and local factors such as soil transport, discarded fishing bait, and land use change. This work will employ detailed molecular, isotopic, mineralogical, ecological and microbiological methods to develop a mechanistic understanding of the processes that control soil organic matter storage in a system with an intense gradient in earthworm activity.

Computational and Laboratory Studies of Arctic Sea Ice Halogen Chemistry

Paul Shepson, *Department of Chemistry* (Funded by the Camille and Henry Dreyfus Foundation)

The prediction of future global climate change is fraught with difficulties associated with feedbacks. Among the most important feedbacks are those associated with changing sea ice cover. Sea ice is believed to release reactive halogen species (Br_2 and BrCl) into the atmosphere; those halogens then photolyze to impact the radiative (and ecological) balance in the lower atmosphere by consuming ozone and producing particulate matter. However, the fundamentals of the reactions that lead to halogen release are poorly understood. With funding from the Foundation, Shepson has created a unique postdoctoral opportunity that will combine molecular dynamics simulations, associated computer modeling studies, and laboratory studies to improve our

understanding of the nature of the ice surface and sea ice surface chemistry that will enable us to develop more reliable predictive models of the atmosphere in Polar regions.

Brown-rot Fungal Mechanisms as a Model for Biomass Saccharification

Timothy Filley, *Department of Earth & Atmospheric Sciences,* with Jonathan Schilling and Robert Blanchette, *University of Minnesota* (Funded by the U.S. Department of Energy).

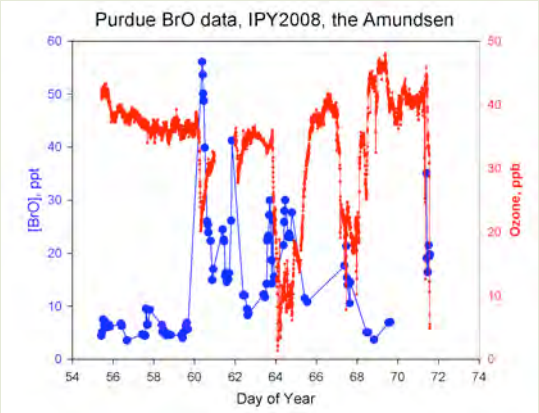
Brown rot wood-degrading fungi accomplish naturally what bioconversion technologies currently do not: complete removal (>99%) of plant polysaccharides from lignocellulosic tissues without removing or extensively damaging lignin. The lignin modifications that are seen in residues from brown rot fungi may be an important link to understanding fungal mechanisms of sugar release (saccharification). While the predominant theory has been that modifications increase pore size and in doing so, allow enzymes to penetrate the plant cell wall, most brown rot fungi cannot degrade crystalline cellulosics if lignin is absent. This observation remains unresolved and characterizing this dynamic has significant implications for commercial biorefining. Successfully utilizing an approach similar to that of brown rot fungi may offer an alternative to current efforts focused on engineering plants to have low lignin content, or on delignification of feedstocks prior to processing.

Halogen Chemistry and Ocean-Atmosphere-Sea Ice-Snowpack (OASIS) Chemical Exchange During IPY

Paul B. Shepson, *Department of Chemistry* (Funded by The National Science Foundation)

The Arctic is currently undergoing widespread and significant change that includes rising surface temperatures and declining sea ice extent. There are a variety of feedbacks between the changes at the Arctic Ocean surface and the drivers of climate change. Among them is the relationship between the sea ice and cloud cover in the Arctic. This project will explore the role of halogen atom chemistry derived from salt associated with the surface of sea ice on the oxidizing power of the Arctic atmospheric boundary layer, which in turn results in production of cloud condensation nuclei, which in turn influences cloud cover. The proposed three-year research effort will develop a novel method for ultra-trace level determination of the halogen atom (Cl, Br, and I, as well as ClO, BrO and IO) concentrations in the air above the Arctic Ocean. This work will be coordinated with several IPY projects including OASIS, CFL, SEARCH, and ASCOS.

Early results from the International Polar Year (IPY) field campaign



In the photo at left, chemistry graduate student, Phil Tackett, stands next to the analytical equipment that he designed to take measurements of the free radical, bromine monoxide (BrO). Simply, air enters a tube where a reagent gas is added that reacts with BrO to make a product that is detected using a gas chromatograph (GC). The GC is cooled by drawing in ambient air, but the roughly -20°F temperatures were not cold enough! Here, Phil is supplementing the cold Arctic air by adding liquid nitrogen to the GC inlet. The figure to the left shows Phil's BrO measurements (BrO is produced in the atmosphere only as a result of Br atom reaction with O_3.) As shown in the figure, BrO (blue) inversely correlates with ozone (red). The maximum measured BrO concentration, 55 ppt, is enough to destroy ozone in a matter of hours in the absence of air mass mixing.

Project updates

Our previously funded (FY04-06), active projects (19), with select examples of recent results and work in progress.

1. Collaborative Research: Water Balance of western North America: Dynamics of the Miocene Summer Monsoon - **Noah Diffenbaugh** and **Matt Huber**; M. Lyle and A. Olivarez Lyle, *Boise State University*; and C. Ravelo, *University of California, Santa Cruz* (NSF)

2. Collaborative Research: Investigation of Holocene Seasonality and Inter-annual Variability Along the California Current System - **Noah Diffenbaugh**; P. Koch *University of California, Santa Cruz* and S. Schellenberg, *San Diego State University* (NSF).

3. Surface-Atmosphere Feedbacks and Holocene Climate Variations in Eastern North America: Linkages, Impacts, and Governing Mechanisms - **Noah Diffenbaugh**; J. Williams, *University of Wisconsin*; B. Shuman, *University of Minnesota*, and L. Sloan, *University of California, Santa Cruz* (NSF)

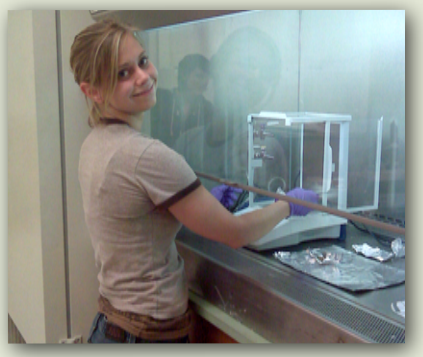
4. Soil Carbon Responses to Atmospheric CO_2 Enrichment - **Timothy Filley**; J. Jastrow, *Argonne National Laboratory*; T. Boutton, *Texas A&M*; M-G. Meler and R. Matamala, *University of Illinois, Chicago* (DOE)

5. Key Role of Nitrogenous Compounds in Soil Organic Matter Stabilization via Interactions with Mineral Surfaces - **Timothy Filley**; P. Sollins, K. Lajtha, B. Caldwell and M. Kleber, *Oregon State University*; C. Swanston, *U.S. Forest Service*; M. Kramer, *University of California, Riverside*; and R. Bowden, *Allegheny College* (USDA).

6. Developing Activities for Conceptualizing Climate and Climate Change - **Dan Shepardson** and **Dev Niyogi** (NSF)

7. Collaborative Research: Synthesis of Arctic System Carbon Cycle Research through Model-Data Fusion Studies Using Atmospheric Inversion and Process-Based Approaches, **Qianlai Zhuang**; D. McGuire, *University of Alaska, Fairbanks;* J. Melillo, *Marine Biological Laboratory, Woods Hole;* and M. Follows, *Massachusetts Institute of Technology* (NSF).

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



Courtney setting up respiration experiments in the lab.

In 2007-2008 this grant supported several undergraduates and one doctoral student, Courtney Creamer. Courtney, a new graduate student in EAS coming from the PULSE program, is working on a project to quantify how various biological, chemical, and physical processes act as protective mechanisms for soil organic carbon following a major vegetation change from grassland to woodland. A chronosequence (120 yrs) of woody plant invasion into a subtropical grassland will be utilized as a model system to investigate the storage or release (as respired CO_2) of organic matter from specific soil physical and chemical fractions. In the photo to the right, Courtney is preparing micro respiration experiments with soil from the woodlands to analyze the amount and stable carbon isotope composition of evolved CO_2 as microbes progressively degrade the organic matter. Two manuscripts from this grant have been published this year that document how these systems accrue both above and below ground organic matter, and speculate on the role that soil structure and plant chemistry have in soil carbon stabilization.

✶ Filley, T. R., T. W. Boutton, J. D. Liao, J. D. Jastrow, and D. E. Gamblin, Chemical changes to nonaggregated particulate soil organic matter following grassland-to-woodland transition in a subtropical savanna (2008), Journal of Geophysical Research, doi: 10.1029/2007JG000564.

✶ Boutton T.W., J.D. Liao, T.R. Filley, S.R. Archer (2008) Belowground carbon storage and dynamics accompanying woody plant encroachment in a subtropical savanna. Soil Carbon Sequestration and the Greenhouse Effect (R. Lal and R. Follett, eds.). Soil Science Society of America, Madison, WI.

The PROPHET tower at the University of Michigan Biological Station.

Sectioning ice cores in West Antarctica.

Prof. Gabe Bowen measuring sections in the Wasatch Plateau, Utah.

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

Results of this study, a collaborative effort between the Shepson, Filley and Rhodes (Horticulture) groups, showed that plants can uptake (through stomata) and utilize atmospheric organic nitrogen. This was done by exposing aspen seedlings to a ^{15}N labeled organic nitrate and detection of ^{15}N in the plant amino acids. The work is important in addressing how trees can use atmospheric nitrogen when in nitrogen-limited conditions.

✳ Lockwood, A.L., T.R. Filley, D. Rhodes, P.B. Shepson, Forest canopy uptake of atmospheric organic nitrogen (2008), Geophysical Research Letters 35, L15809, doi:10.1029/2008GL034714.

10. Cosmogenic Nuclides on the West Antarctic Ice Sheet - **Marc Caffee** (NSF)

During the last year the team has measured cosmic-ray-produced ^{10}Be in several test cores from Antarctica (the Ross Ice Drainage System core, RIDS-95A; and Bentley Shot Hole cores, BSH-2 and BSH-5). These analyses were done to test methods in preparation for core samples from the West Antarctic Ice Sheet.

Evidence of the 11-year solar cycle is visible in the depth profiles of both BSH cores, while it is less pronounced in RIDS-95A. Some of the scatter in ^{10}Be contents in the BSH cores may be due to variations in annual precipitation. The average ^{10}Be concentration of $(20\pm5) \times 10^3$ at/g in the BSH-5 core is ~10% higher than in RIDS-95A, while the average ^{10}Be concentration of $(26\pm7) \times 10^3$ at/g in BSH-2 is ~40% higher than in RIDS-95A. The average ^{10}Be contents in the three cores do show a negative correlation with the annual precipitation rate determined over the past 40 years.

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

The aim of this project is to develop an Arctic Ocean-rugged and autonomous buoy capable of measuring atmospheric O_3, BrO, and CO_2 for a period of up to two years to ensure a full year cycle of high quality data. The first "O-buoy", that will conduct continuous measurements of O_3, BrO, and CO_2 from the Arctic Ocean surface has been built and will be installed this November in the Beaufort Sea area.

12. Sub-daily Scale Extreme Precipitation in Future Climate-Change Scenarios: a Pilot Study- **Jeff Trapp, Noah Diffenbaugh, Alexander Gluhovsky, Matthew Huber, Sonia Lasher-Trapp** (NSF)

This pilot study has resulted in two publications and provided the proof-of-concept for a more comprehensive project recently funded by the NSF entitled, "The Response of Convective Precipitating Storms to Anthropogenically Enhanced Global Radiative Forcing."

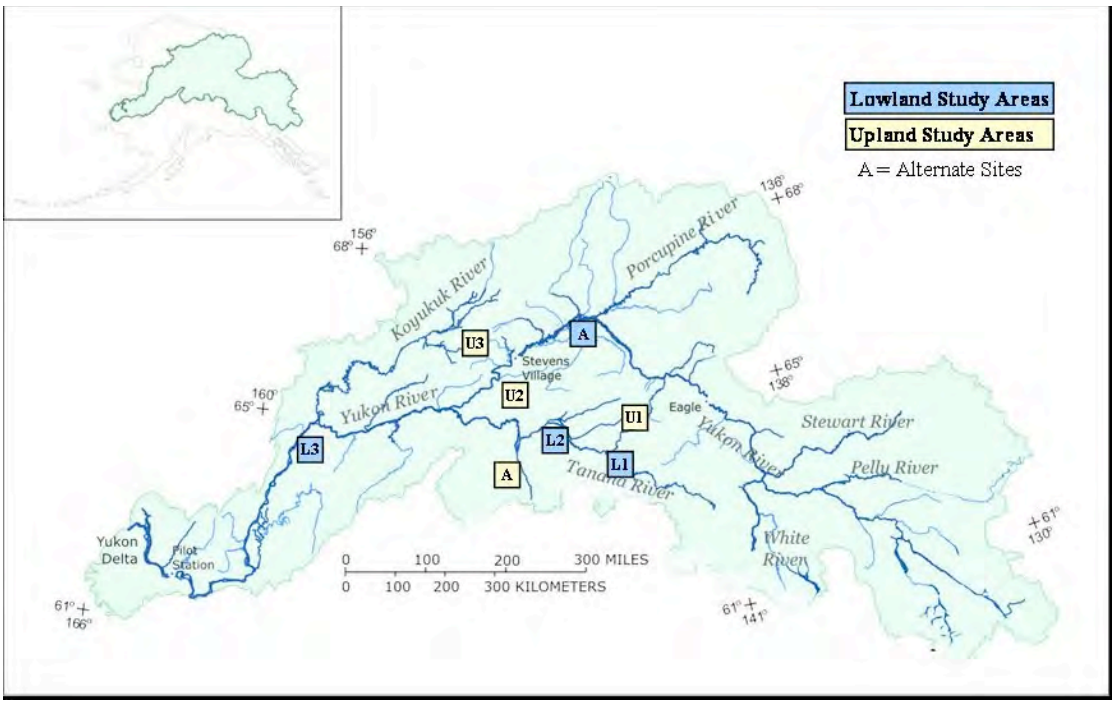
✳ Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal, Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing (2007), Proceedings of the National Academy of Sciences of the United States of America 104 (50): 19719-19723.

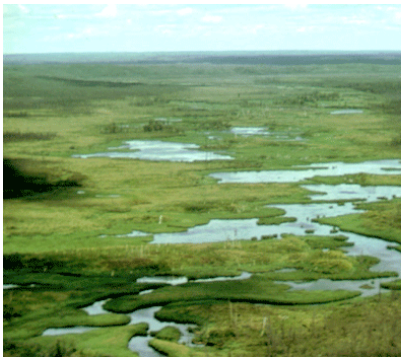
✳ Trapp, R. J., B. A. Halvorson, and N. S. Diffenbaugh, Telescoping, multimodel approaches to evaluate extreme convective weather under future climates (2007), Journal of Geophysical Research-Atmospheres 112, D20109, doi:10.1029/2006JD008345.

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

This large, $1.7M effort seeks to assess the interactive effects of climate change and fire on permafrost stability; to quantify how varying modes of permafrost degradation initiate various thaw regimes on the boreal landscape; to determine how these thaw regimes affect carbon loss or accumulation in biomass and soils; and, to characterize the export of dissolved organic carbon (DOC) from watersheds in an effort to fingerprint the various thaw regimes induced by permafrost degradation.

The 2007 field campaign was conducted at Twelve Mile Lake in late August in the Yukon Flats National Wildlife Refuge, in interior Alaska (see map below). The research team described successional plant communities, collected samples for measuring carbon storage, and assessed permafrost along three transects that extended laterally from the current lake margin, through the drained lake basin, to the adjacent uplands. Five distinct vegetation communities were established along each transect and a suite of permafrost degradation sites and surface waters in the Hess Creek drainage basin were also sampled. To date, the following preliminary results were made: 1) It appears that permafrost degradation has played a minor, albeit important role in lake shrinkage, 2) relative to sites with intact permafrost formed in historically cool climates, thawed soils with enhanced drainage likely lost carbon since the 1950s as a result of enhanced decomposition, and 3) permafrost degradation will likely result in increased water infiltration and DOC mineralization in soil and in the unsaturated zone in upland areas. This will reduce DOC in runoff relative to areas where permafrost persists and will increase groundwater contribution to streamflow.





The study area within the Yukon River Basin. Upland and Lowland field study areas are identified in boxes, along with two alternative study sites. The photos to the right show the Porcupine River (top) and Koyukuk Reserve wetlands (bottom).

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

Work in this fiscal year has focused on generating better estimates of local ranges and population variability, and better projections of range shifts and community change in response to climate change. Masters theses were completed in Biological Sciences at Purdue by Matt Gasner and Keiller Kyle, resulting in the manuscripts below being submitted for publication. Collaboration with botanist William Haber of the Missouri Botanical Garden has also resulted in preliminary estimates of significant parallel change in tree and bird communities; this is a first for tropical systems. Also unique for tropical systems are simulations of statistical power to detect population change given four-year measurement of population variability over a 40km^2 area, and regression models of local ranges that permit projections of future population sizes given projections for reduced rainfall and higher temperatures. Collaborators at the University of Alabama and the National Aeronautics and Space Administration have improved imaging from satellite data of cloud immersion and local climate models that will permit more detailed niche mapping for bird and tree species and better projections of the ecological impacts of climate change. Educational materials were provided to local schools and conservation organizations.

✶ Kyle,K.O., A.L. Ciecka, M.R. Gasner, and K.N. Rabenold. Response of avian communities to edges of tropical montane forests: harbinger of future impacts of climate change? (to Conservation Biology).

✶ Gasner, M.R., A.L. Ciecka, J.E. Jankowski, K.O. Kyle and K.N. Rabenold. Projections of local range shifts of birds in a montane rainforest in response to climate change (to Biological Conservation).

Studying the cloud forest lee margin in Costa Rica - Miravalles volcano.

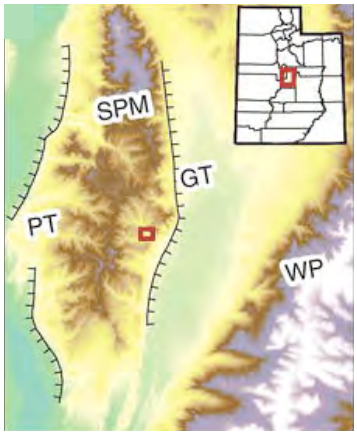
✶ Gasner, M.R., A.L. Ciecka, J.E. Jankowski, K.O. Kyle and K.N. Rabenold. Population variability and power to detect change in tropical bird communities (to Ecological Applications).

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

A postdoctoral researcher and several undergraduate students were supported by this grant. Initial results from this project suggest a pattern of extreme aridification in the American southwest during paleo-warming. Summaries of the work, published in *Geology* and the *Journal of Sedimentary Research*, follow.

Climate change during Paleocene-Eocene thermal maximum (PETM) was forced by the release of several thousand petagrams of carbon to the ocean/atmosphere system, producing a climatic perturbation that represents one of the best potential geological analogues to modern, anthropogenic global climate change. The paper, "Mechanisms of PETM global change constrained by a new record from central Utah" describes new records of the PETM from previously unstudied sites in central Utah (see map at right), which, in comparison with other study sites, suggest a broad pattern of aridification across western North America associated with PETM climate warming, with more intense drying in the southwestern part of the continent. This suggests northward diversion of atmospheric circulation systems and precipitation during the PETM, consistent with some models of carbon-induced hydroclimate change.

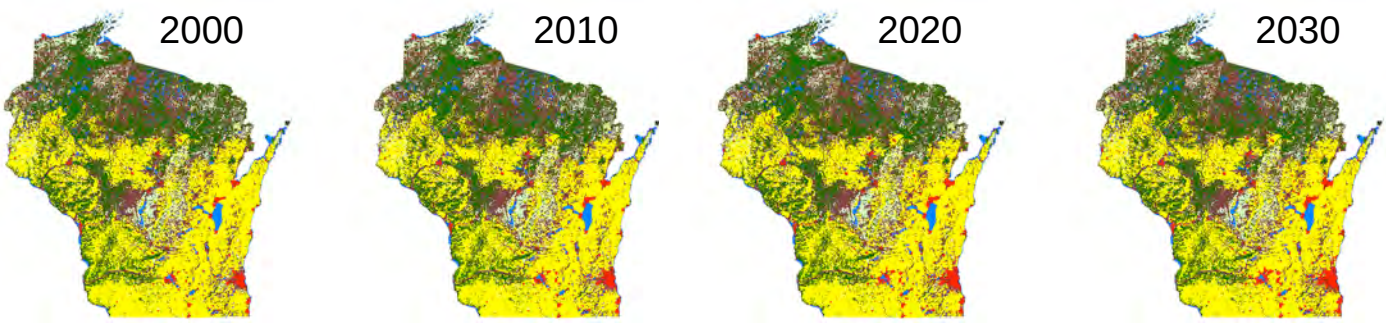
✶ Bowen, G. J. and B. B. Bowen, Mechanisms of PETM global change constrained by a new record from central Utah (2008), *Geology* 36(5): 379-382; doi: 10.1130/G24597A.1.



Geological and geographic setting of the study area. SPM—San Pitch Mountains; PT—Pavant thrust system; GT—Gunnison thrust system; WP—Wasatch Plateau.

In a complementary study, Bowen et al., note that lacustrine rocks in central Utah reveal dramatic environmental fluctuations in association with million-year changes in global climate during the early Paleogene (65 - 33 million years ago). Their paper has demonstrated that the stable isotope geochemistry of these rocks provides a high-fidelity recorder of these environmental changes and a means to link them to coeval global changes in climate and biotic evolution.

✶ Bowen, G. J., A. L. Daniels, and B. B. Bowen, Paleoenvironmental isotope geochemistry and paragenesis of lacustrine and palustrine carbonates, Flagstaff Formation, central Utah, U.S.A. (2008), *Journal of Sedimentary Research* 78: 162-174.



Land cover projections for Wisconsin from the Land Transformation Model using historic land-cover training data from the state of Michigan. Yellow=cropland, blue=water, red=urban, green=forest.

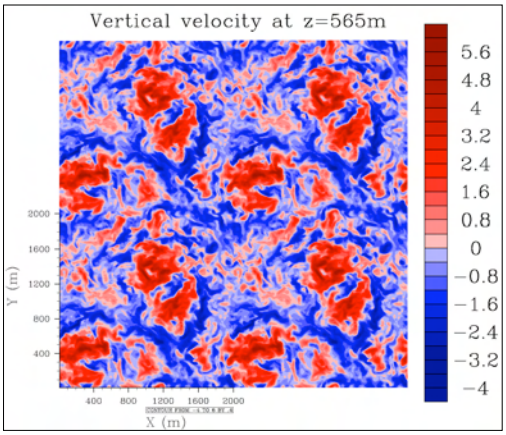
16. Multisensor/Multiscale Assessment of Urban Impacts in the Great Lakes Region. NASA LCLUC Program - **Laura Bowling**, **Keith Cherkauer**, **Bryan Pijanowski**, and **Dev Niyogi** (NASA)

The central objective of this project is to study the interactions between land cover/land use change (in particular urban growth), weather, and surface hydrology for a four-state study area (Indiana, Illinois, Wisconsin and Michigan) in the Great Lakes region. The study uses land use forecasts (see above) as well as pre-settlement land use reconstructions. Some of the preliminary work on this project has focused on the state of Wisconsin, where the Variable Infiltration Capacity (VIC) macroscale hydrology model, enhanced to represent impervious area, has been calibrated to reproduce observed streamflow for several large watersheds. The model was then used to simulate the relative influence of land cover change and climate change for streamflow and other hydrologic variables. Conversion from the preexisting forest to modern cropland results in an increase in streamflow during the high flow period (March-July) due to increased snow accumulation and melt. In contrast, the climate change scenarios result in decreased snow accumulation and a reduction in streamflow between the months of March and July.

To investigate the simultaneous influence of land use/land cover change on regional weather, the Regional Atmospheric Modeling System (RAMS-LEAF2) was used with the same land use maps for single events under clear sky and rainy conditions. It was found that both daytime sensible and latent heat fluxes were about 10 Wm^2 higher with historic land cover for both conditions, but there was no significant change in precipitation. The final phase of the project will extend simulations to the entire study domain using the simulated weather from the RAMS-LEAF2 as input to the VIC hydrology model, to investigate the relative influence of precipitation changes and impervious area on urban flood magnitudes.

17. Modeling Coherent Structures in Convective Boundary Layers - **Alexander Gluhovsky** and **Ernest Agee (NSF)**

Large Eddy Simulation models provide an excellent platform for the study of convective boundary layers (CBL). This project has funded research on the evolution of coherent structures in the CBL that develop in wintertime cold air outbreaks over the Great Lakes region of the USA and Canada. The air-lake interaction produces microscale structures of various 2-D and 3-D geometries that evolve within the surface boundary layer and are responsible for heat, momentum and water vapor transport from the lake to the atmosphere (as done in similar cold air outbreaks over warm ocean currents, such as the Kuroshio and the Gulf Stream). These microscale structures self-organize at higher levels into a spatially-coherent 3-D pattern as illustrated in the figure to the right.



From VULCAN to HESTIA

18 -19. Funded by NASA (CARBON/04-0325-0167) and DOE (DE-AC02-05CH11231), Vulcan constitutes a high resolution inventory of fossil fuel CO_2 emissions for the U.S. (www.purdue.edu/eas/carbon/vulcan). Through collaboration with Lawrence Berkeley National Laboratory, Colorado State University, and Purdue's Rosen Center for Advanced Computing, Vulcan inventories CO_2 emissions at a 10 km-gridded scale every hour for the year 2002. The CO_2 emissions are subdivided by sector and by industrial classification for greater resolution and flexibility.

Vulcan was created to greatly improve our scientific understanding of the North American carbon budget, support the upcoming launch of a remote sensing platform (the Orbital Carbon Observatory) aimed at space-based CO_2 monitoring, and act as a backbone to new carbon forecasting research.

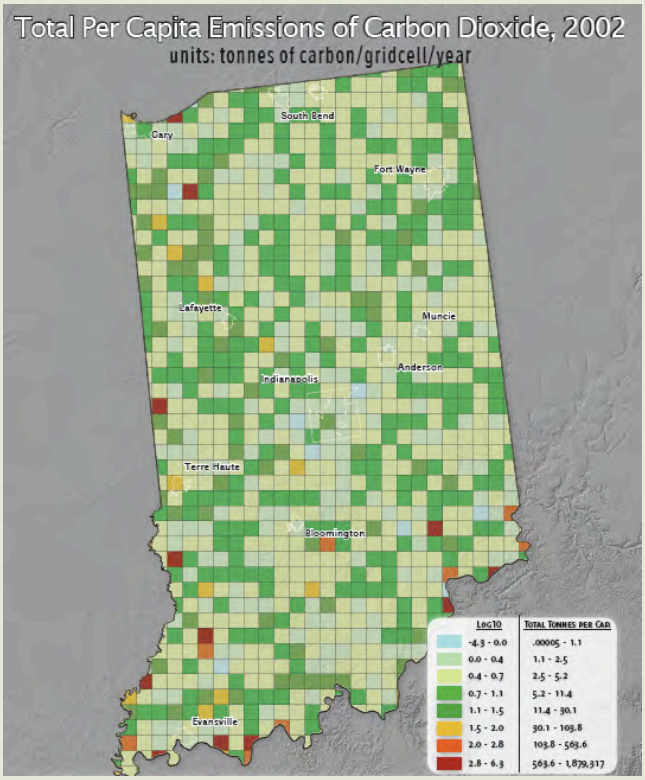
"This type of mapping technology will be critical to a vibrant carbon trading market in the future, and to efforts to quantify the benefits of preserving forest lands."

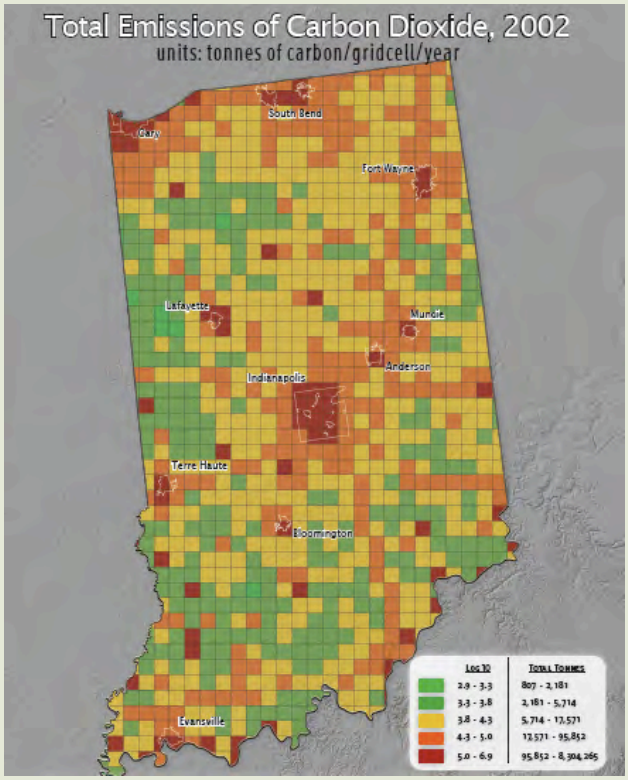
-- Senator Richard Lugar (IN)

Kevin Gurney's vision for next steps with Vulcan is the creation of a model/data system offering a real-time estimation of fossil fuel CO_2 emissions at a building-by-building and road-by-road scale across the planet (The Hestia™ Project). This information will be placed within a visually realistic Google™ Earth-like platform allowing anyone, anywhere to access emissions information at these readily recognizable scales. However, Hestia will go far beyond a simple inventory of emissions. The project will embed a suite of related information and simulation tools such that users can analyze emissions information within the context of energy, economics, behavioral choices, and urban/regional planning.

With seed funding from the Showalter Trust and from Knauf Insulation, Inc. (the project's first corporate sponsor), a pilot study of the greater Indianapolis region is underway.

✳ Gurney, K. R., D. Baker, P. Rayner, and S. Denning (2008), Interannual variations in continental-scale net carbon exchange and sensitivity to observing networks estimated from atmospheric CO_2 inversions for the period 1980 to 2005, *Global Biogeochem. Cycles*,doi:10.1029/2007GB003082, in press.





Publications

A listing of this year's peer-reviewed publications and selected highlights from these studies.

- Pal, J. S., F. Giorgi, X. Bi, N. Elguindi, F. Solmon, X. Gao, S. A. Rauscher, R. Francisco, A. Zakey, J. Winter, **M. Ashfaq**, F. S. Syed, J. L. Bell, **N. S. Diffenbaugh**, J. Karmacharya, A. Konare, D. Martinez, R. P. da Rocha, L. C. Sloan and A. Steiner, Regional climate modeling for the developing world: The ICTP RegCM3 and RegCNET (2007), *Bulletin of the American Meteorological Society* 88, (9): 1395-1409.

- **Bowen, G. J.**, A. L. Daniels, and **B. B. Bowen**, Paleoenvironmental isotope geochemistry and paragenesis of lacustrine and palustrine carbonates, Flagstaff Formation, central Utah, U.S.A. (2008), *Journal of Sedimentary Research* 78: 162-174.

- **Bowen, G. J.**, Spatial analysis of the intra-annual variation of precipitation isotope ratios and its climatological corollaries (2008), *Journal of Geophysical Research* 113, D05113, doi:10.1029/2007JD009295.

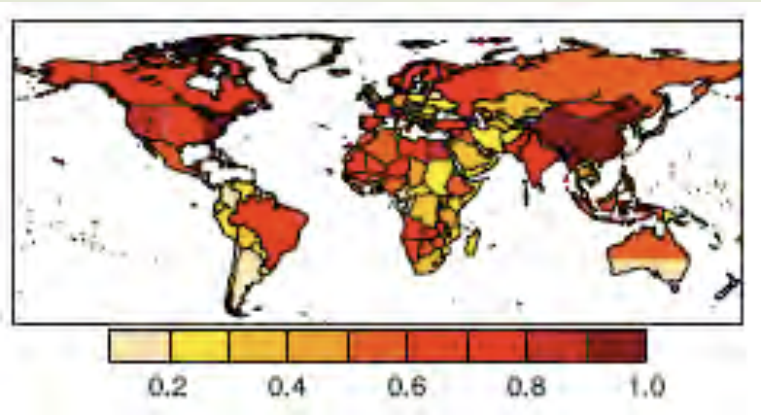
- **Bowen, G. J.** and **B. B. Bowen**, Mechanisms of PETM global change constrained by a new record from central Utah (2008), *Geology* 36(5):379-382; doi: 10.1130/G24597A.1.

- Ehleringer, J. R., **G. J. Bowen**, L. A. Chesson, A. G. West, D. W. Podlesak, and T. E. Cerling, Hydrogen and oxygen isotope ratios in human hair are related to geography (2008), *Proceedings of the National Academy of Sciences of the United States of America* 105(8): 2788-2793.

- Bohn, T.J., D.P. Lettenmaier, K. Sathulur, **L.C. Bowling,** E. Podest, K.C. McDonald, and T. Friborg, Methane emissions from western Siberian wetlands: heterogeneity and sensitivity to climate change (2007), *Environmental Research Letters*, 2, doi: 10.1088/1748-9326/2/4/045015.

- **Cavender, A. E.**, T. A. Biesenthal, J. W. Bottenheim, and **P. B. Shepson**, Volatile organic compound ratios as probes of halogen atom chemistry in the Arctic (2008), *Atmospheric Chemistry and Physics* 8, 1737–1750, 2008.

- **Diffenbaugh, N. S.,** F. Giorgi, **L. Raymond,** and X. Bi, Indicators of 21st century socioclimatic exposure (2007), *Proceedings of the National Academy of Sciences of the United States of America* 104 (51): 20195-20198.



Policies that attempt to curb greenhouse gas emissions, allocate emissions rights, or distribute compensation to those most damaged by climate change must explicitly incorporate the international heterogeneity of the climate change threat. In this paper, the research team has developed a novel integration of climate change projections and poverty, wealth, and population metrics. They have shown that the patterns of socioeconomic variables interact with spatial heterogeneity in projected climate change to determine the overall international pattern of socioclimatic exposure. Their synthesis provides a critical missing piece to the climate change debate, and should facilitate the formulation of climate policies that account for international variations in the threat of climate change across a range of socioeconomic dimensions. The figure above is a summary of 21st century socioclimatic exposure. The summary shows that most nations face substantial socioclimateic exposure from the interaction of climate change with some combination of population, poverty and wealth.

- **Chaubey, I**. and M. Matlock, Teaching undergraduate students to manage aquatic ecosystems at the watershed level: an ecological engineering approach (2007). *International Journal of Engineering Education* 23(4):723-727.

- Srivastav, R.K., K.P. Sudheer, and **I. Chaubey**, A simplified approach to quantify predictive and parametric uncertainty in artificial neural network hydrologic models (2007). *Water Resources Research* 43, W10407, doi: 10.1029/2006RW005352.

- Sudheer, K.P., **I. Chaubey**, V. Garg, and K.W. Migliaccio, Impact of time scale of calibration objective function on the performance of watershed models (2007), *Journal of Hydrological Processes*, doi: 10.1002/hyp.6555.

- Giorgi, F. and **N. Diffenbaugh**, Developing regional climate change scenarios for use in assessment of effects on human health and disease (2008), *Climate Research* 36(2): 141-151. doi: 10.3354/cr00728.

- Rauscher, S. A., F. Giorgi, **N. S. Diffenbaugh**, and A. Seth, Extension and intensification of the Meso-American mid-summer drought in the twenty-first century (2008), *Climate Dynamics* http://dx.doi.org/10.1007/s00382-007-0359-1.

- **Filley, T. R.**, M. K. McCormick, **S. E. Crow**, K. Szlaveca, D. F. Whigham, **C. T. Johnston**, and R. N. van den Heuvel, Comparison of the chemical alteration trajectory of Liriodendron tulipifera L. leaf litter among forests with different earthworm abundance (2008), *Journal of Geophysical Research: Biogeosciences* 113, G01027, doi: 10.1029/2007JG000542.

- Olchin, G., S. Ogle, S. Frey, **T. Filley**, K. Paustian and J. Six, Residue carbon stabilization in soil aggregates of no-till and tillage management of dryland cropping systems (2008), *Soil Science Society of America Journal* 72: 507-513.

An emerald toucanet

"Who can explain why one species ranges widely and is very numerous, and why another allied species has a narrow range and is rare?

-- Charles Darwin (1859)

- **Jankowski, J. E.** and **K. N. Rabenold**, Endemism and local rarity in birds of neotropical montane rainforest (2007), *Biological Conservation* 138:453-463.

The causes and consequences of rarity are fundamental issues in ecology and conservation biology, in part because species with small geographical ranges (endemics) could be at risk of extinction in changing landscapes. If such globally rare species also had narrow ecological distributions and low local densities, then they could have very small global populations. The highlands of Costa Rica and Panamá harbor the greatest avian species richness in Central American montane forests and one of the highest levels of avian endemism in the world. In a study of 100 species in the Tilarán mountains, we found a positive correlation between abundance and distribution at the smallest spatial scale: ecological specialists that occupy few forest types over a complex mountainside also had low abundances where they occur. At larger scales, geographical distribution was correlated with local ecological amplitude (ecological zones occupied). Within families with endemics and cosmopolitan species, 72% of narrow endemics were among the rarest species. Little is known about most tropical species, but a companion study ("Beta diversity along environmental gradients: implications of habitat specialization in tropical montane landscapes") has shown that high species diversity in the landscape results from species' ecological specialization, and such specialization increases vulnerability to population declines because of the effects of climate change. Endemism globally is concentrated in tropical mountains, and endemics are locally concentrated at high elevations. Changes in temperature and rainfall consistent with model projections would be sufficient to extirpate some endemic species from the Tilarán mountains. In tropical mountains generally, many endemics are threatened at several spatial scales by climate change and other anthropogenic habitat degradation.

Photo credit: Aaron Spalding

- **Filley, T. R.**, T. W. Boutton, J. D. Liao, J. D. Jastrow, and D. E. Gamblin, Chemical changes to nonaggregated particulate soil organic matter following grassland-to-woodland transition in a subtropical savanna (2008), *Journal of Geophysical Research*, doi: 10.1029/2007JG000564.

- **Gluhovsky, A**. and **E. Agee**, On the analysis of atmospheric and climatic time series (2007), *Journal of Applied Meteorology and Climatology* 46, (7): 1125-1129, DOI: 10.1175/JAM2512.1.

- **Gurney, K. R**. and **L. Raymond**, Targeting deforestation rates in climate change policy: a 'Preservation Pathway' approach (2008), *Carbon Balance and Management* 3 (2), doi: 10.1186/1750-0680-3-2.

- Goetz, S. J., M. C. Mack, **K. R. Gurney**, J. T. Randerson and R. A. Houghton, Ecosystem responses to recent climate change and fire disturbance at northern high latitudes: observations and model results contrasting northern Eurasia and North America (2007) *Environmental Research Letters* 2, 045031 (9pp) doi: 10.1088/1748-9326/2/4/045031.

- Butler, A, D. Thompson, **K.R. Gurney**, Observed relationships between the Southern Annular Mode and Carbon Dioxide, *Global Biogeochemical Cycles*, 21, GB4014, doi: 101029/2006GB002796, 2007.

- Lyle, M., J. Barron, T. J. Bralower, **M. Huber**, A. Olivarez Lyle, A. C. Ravelo, D. K. Rea, and P. A. Wilson (2008), Pacific Ocean and Cenozoic evolution of climate, Reviews of Geophysics, 46, RG2002, doi: 10.1029/2005RG000190.

- Garman, K. E., P. Wyss, M. Carlsen, J. R. Zimmerman, B. H. Stirm, T. Q. Carney, R. Santini, and **P. B. Shepson**, The contribution of variability of lift-induced upwash to the uncertainty in vertical wind determined from an aircraft platform (2008), Boundary Layer Meteorology 126, 461-476, DOI 10.1007/s10546-007-9237-y.

- **Trapp, R. J.**, **B. A. Halvorson**, and **N. S. Diffenbaugh**, Telescoping, multimodel approaches to evaluate extreme convective weather under future climates (2007), *Journal of Geophysical Research-Atmospheres* 112, D20109, doi: 10.1029/2006JD008345.

- **Xiao, J**. and **Q. Zhuang**, Drought effects on large fire activity in Canadian and Alaskan forests (2007), *Environmental Research Letters* 2 044003, doi: 10.1088/1748-9326/2/4/044003.

- **Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin,** E. D. Robinson, and J. S. Pal, Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing (2007), *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19719-19723.

Severe thunderstorms comprise an extreme class of deep convective clouds, and produce high-impact weather such as destructive surface winds, hail and tornadoes. This study addresses the question of how severe thunderstorm frequency in the U.S. might change due to enhanced global radiative forcing associated with elevated greenhouse gas concentrations. The authors use global climate models and a high-resolution regional climate model to examine the larger-scale (environmental) meteorological conditions that foster sever thunderstorm formation. Across the model suite, they find a net increase during the late 21st century in the number of days in which these environmental conditions occur. The largest increases are shown during the summer season, in proximity to the Gulf of Mexico and Atlantic coastal regions.

This is an image of a severe thunderstorm that occurred on June 7, 2005, near Murdo, S.D. (Karen A. Kosiba photo courtesy of the Trapp research group).

Facilities

Examples of our research equipment and infrastructure.

The Airborne Laboratory for Atmospheric Research (ALAR)

ALAR was designed to develop the capability to measure fluxes of volatile organic compounds from a light aircraft, a twin-engine Beechcraft Duchess. This past year, the ALAR team worked on improving measurements of CO_2. They have been collaborating with the NOAA ESRL Carbon Cycle Group to incorporate a cavity ringdown instrument for simultaneous determination of methane and carbon dioxide from the aircraft, in flux mode. In early 2008, this instrument was applied to determine CO2 and CH4 flux measurements for the City of Indianapolis.

ALAR director Paul Shepson preparing the aircraft for flight.

Computational Resources

PCCRC researchers have access to a large array of computational resources at Purdue. These include the new 812-node dual-quad-core cluster known as Steele, which is the largest campus computer in the Big 10; a new 3200 processor SciCortex 5832; and a 150-node quad-core cluster half-owned by investigators in the EAS Department. Purdue researchers also have allocations at national computing centers, including an allocation of 399,000 GAUs on NCARs new bluefire IBM supercomputer, through the Accelerated Scientific Discovery initiative. Additionally, PCCRC researchers have access to dozens of terabytes of spinning storage as well as a petabyte tape storage system.

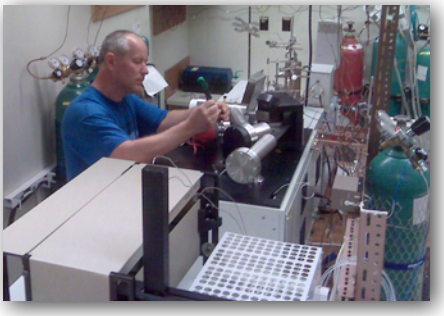
Indian Pine Research Station (IPFS)

IPFS was organized in January 1989 and encompasses 50km^2 in the prairie-forest transition zone of west-central Indiana. Two primary watersheds are included within the station boundaries: Indian Creek and Little Pine Creek. Three properties form the nucleus of ecological research, teaching, and outreach efforts: (1) Martell Forest, operated by the Department of Forestry and Natural Resources (FNR), is near the confluence of Indian Creek and the Wabash River; (2) the Purdue Wildlife Area, also operated by FNR, is on a tributary of Indian Creek near its headwaters; (3) the Ross Biological Reserve (photo below) operated by the Department of Biological Sciences borders the Wabash River and two Tippecanoe County Parks Department properties. Research and education within these three core facilities of IPFS have concentrated on the effects of land use on habitat distribution and quality, and on the population dynamics of native flora and fauna using long-term datasets. These facilities all include laboratories and staff, and are available for research related to climate change.

Aerial photo of the forests of the Ross Biological Reserve on the Wabash River.

The Purdue Stable Isotope (PSI) Facility

PSI is a state-of-the-art multi-user, stable isotope laboratory housed in the Department of Earth & Atmospheric Sciences. PSI is co-directed by Professors Tim Filley, Gabe Bowen, Greg Michalski Yuch Ning Shieh. PSI houses three gas Isotope Ratio Mass Spectrometers (IRMS), each accompanied by peripheral devices for conversion of various compounds into analyzable gases. Areas of specialty include modern and paleo-hydrology, N cycling in the upper and lower atmosphere, ice core records of climate change, biogeochemical cycling of C, N in forests and grassland, paleosol environment and climate reconstruction, and molecular proxies for ecosystem and environmental dynamics in soils and lake sediments. This past year, many of the PSI lab's services were made available to researchers at Purdue and elsewhere on a contract basis.



Sergey Oleynik, PSI lab manager maintains 3 IRMS systems, trains students and visiting scientists in mass spectrometry techniques, and is co-instructor in a stable isotopes methods course.

Graduate student Keiller Kyle befriends a collared peccary in the Santa Elena Cloudforest Reserve in Costa Rica. Keiller's master's thesis (Advisor, Kerry Rabenold) compared forest-interior bird communities to those at the edges of forests bordering pastures. Temperatures are elevated and humidity reduced at these edges so that they provide a window on what the effects of predicted regional climate change could be. Populations of peccaries and others like monkeys and big cats are growing in expanding protected reserves, but climate change could alter the species composition even there.

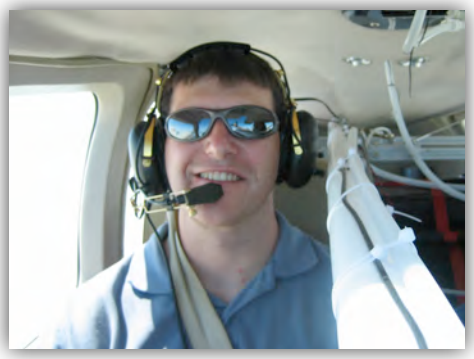
LEARNING

The PCCRC strives to create a learning environment that strengthens existing programs and encourages the development of new, cross-disciplinary learning initiatives.

Enriching Experiences

Many PCCRC students participate in field research involving travel to places ranging from the cloudforests of Costa Rica to the Arctic Ocean.

Leanna in the dunes of the Navajo Nation, Arizona.



Doug in Purdue's ALAR, preparing to fly over the Iowa "ring of towers."

Phil and colleagues playing ice hockey on the Arctic Ocean.

Graduate student **Leanna Begay** (master's student in the Department of Biological Sciences) is shown above in her study area on the Navajo Nation, Arizona. Increased sand dune activity is associated with the ongoing drought in the southwestern US, and Leanna is investigating the impact of dunes on plant communities and adaptations of plants to drought and mobile soil.

Last summer EAS doctoral student **Doug Martins** (pictured above) participated in the North American Carbon Program Mid-Continent Intensive Field Campaign. The work will determine fluxes of carbon between the land surfaces and the atmosphere by comparing "top-down" atmospheric budgets with "bottom-up" ecosystem stocks. Doug's project was aimed at capturing regional scale fluxes of CO_2 by taking measurements from an aircraft, the Purdue Airborne Laboratory for Atmospheric Research (ALAR). With his advisor, Paul Shepson, Doug flew a series of vertical profiles in the vicinity of what is called the "ring-of-towers," a sensor network measuring CO_2 from tall towers, surrounding Iowa. Among the experiments that Doug designed and participated in was a Lagrangian profile experiment, in which a series of vertical profile measurements and horizontal transects were made while following an air mass over the course of a day. The work was a collaborative effort between Purdue, the NOAA Global Monitoring Division (which funded the effort), and Atmospheric Observing Systems, Inc., a small company in Boulder, Colorado which supplied the CO_2 measurement instrumentation.

In the spring of 2008, Chemistry Ph.D. candidate **Phil Tackett** spent nearly 2 months aboard the CCGS Amundsen, a dedicated polar research vessel and icebreaker re-commissioned in 2003 and operated by the Canadian Coast Guard. Phil's work is a part of a large international project studying the impact of sea ice on the health of the Arctic environment. It has been shown that sea ice, itself documented to be reducing in coverage and in intensity, plays a critical role in the composition of the atmosphere. Phil's work is focused on investigating halogen chemistry in the lower Arctic troposphere through the measurement of halogen oxides and halocarbons using a new analytical technique developed at Purdue (see page 9).

Biological Sciences graduate student **Keiller Kyle** and research associate Anna Ciecka in the Santa Elena Cloudforest Reserve, Costa Rica.

New Courses

Six new courses were developed this year by PCCRC faculty.

Topics in Paleoclimatology (EAS 591B)
Instructor: Gabe Bowen

Course Description: The study of past climate change helps earth scientists understand what the climate system can do and why. How hot and how cold has the Earth been in the past? How wet and how dry? How quickly can Earth's climate change? Why do these changes happen, and how do they affect the chemistry of Earth's atmosphere, oceans, and soils, the structure and composition of Earth's ecosystems? By seeking to answer these questions, paleoclimatologists help us understand the bounds of variability in the climate system, factors that cause climate change, and potential trajectories of future climate. By the end of the semester, participants will have developed a broad understanding of how past climate change is studied and an in-depth understanding of several key problems that motivate current paleoclimate research.

Ecohydrology (ABE 591S)
Instructor: Indrajeet Chaubey

Course Description: Ecohydrology links hydrological and ecological processes at various spatiotemporal scales and is considered to be one of the most exciting frontiers of future research. Movement and storage of water are integral parts of landscape and ecosystem functioning. Hydrological processes in individual ecosystems and the role of water in linking the myriad components of the landscape are explored in this course. Interactions between hydrological and biological processes and factors that regulate and shape these interactions are covered. The ecohydrology principles covered will include integration of water and biota at a catchment scale, evolutionarily established resilience and resistance of ecosystems to stress, and how ecosystem properties can be used as a management tool for biodiversity, water quality, and water quantity improvement.

Climate Analysis I (EAS 591C)
Instructor: Noah Diffenbaugh

Course Description: Students will undertake a research project to understand the mechanisms or impacts of past, present, or future climate dynamics. The core of this project will consist of analyzing existing observational, reanalysis and/or climate model data. Lectures will address tools for climate analysis and topics in climate dynamics.

Terrestrial Biogeochemistry (EAS 591B/AGRY 589T)
Instructors: Tim Filley (EAS) and Cliff Johnston (AGRY)

Course Description: This interdisciplinary course provides an introduction to the physical and microbial processes governing the cycling of photosynthetically produced organic matter on land and in streams and rivers. Organic geochemical transformations in the soil will be highlighted along with methods of characterizing soil organic constituents. Biogeochemical concepts are reinforced through hands-on modeling assignments using the CENTURY model. Additionally, transformations controlled by temperature and pressure under geological conditions are discussed.

Models in Climate Change Science and Policy (POL 520A/EAS 591Y)
Instructors: Matt Huber (EAS) and Leigh Raymond (PolSci)

Course Description: The proper use of models is controversial in both science and policy making. Nowhere is this controversy more apparent today than over the issue of climate change. This course will provide students a better understanding of the role of political, economic, and scientific models in the study of climate change. Team-taught by instructors from Political Science and Earth and Atmospheric Sciences, the course partners students across disciplines to work on applying models to distinct aspects of the climate change problem.

Applied Spatial Statistics (STAT/FNR 598Z)
Instructor: Hao Zhang

Course Description: This course covers a wide range of statistical models and methods for data that are collected at different spatial locations and perhaps at different times. These data are called spatial or spatio-temporal data, which arise in many scientific disciplines such as agronomy, plant pathology, forestry and natural resources, environmental and health studies, climatology, geology, biosecurity, etc. This course introduces the classical methods as well as some newly developed ones, and provides ample hands-on activities. The programming language R and a few packages for analyzing spatial data are introduced. One objective of the course is for students to be able to identify appropriate methods and analyze spatial data in their own research.

Fellow updates

Each year PCCRC awards up to two fellowships to recruit outstanding doctoral students to Purdue. Read about our Fellows' progress below.

Charlotte Kendra G. Castillo, 2007 Fellow

This last year, Kendra (Department of Earth & Atmospheric Sciences, Prof. Kevin Gurney, advisor) was part of an interdisciplinary team that initiated a project to measure Boilermakers' attitudes on sustainability. The project involved creating and implementing a survey, "The Boilermaker Lifestyle Survey," which was pilot-tested during the Fall Semester, 2007. The team presented their findings at the Ecological Sciences and Engineering Student Research Symposium in November, 2007 and won a 2nd place award. The project was also entered in Purdue's "Idea-to-Product Competition for Environmental and Social Entrepreneurship" in March 2008.

Kendra attended the 2008 Delhi Sustainable Development Summit (Sustainable development and climate change) as one of the international graduate student delegates. Upon her return, she presented her experiences at the spring semester Graduate Students Seminar Series. Most recently, Kendra has been developing a research project aimed at understanding the climate impacts of applying the "preservation pathway" to tropical forests. She is also a Fulbright Scholar and a PEO International Peace Scholar.

Kendra Castillo at the 2007 Delhi Sustainable Development Summit on climate change.

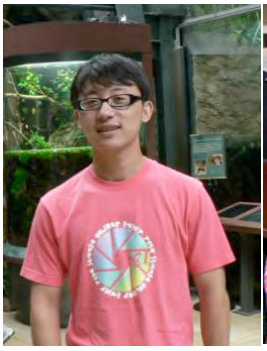
Vimal Mishra, 2006 Fellow

Vimal joined Purdue in the fall of 2006 as a PhD student in the Department of Agricultural & Biological Engineering (Prof. Keith Cherkauer, advisor). His doctoral research is focused on understanding the role of historic climate variability and future climate change on lakes in the Great Lakes Region. He is using in-situ data, remote sensing observations and a land surface model to address (i) how have lakes changed historically in the Great Lakes Region; (ii) how are they likely to change in the future within the perspective of projected climate change; and (iii) how might the regional hydrology (water and energy balance) be affected due to changes which have occurred or changes which are likely to occur in future. Over the last year Vimal has given the following presentations:

- Mishra, V. K. A. Cherkauer, M. M. Crawford, and L. C. Bowling (2008), Sensitivity study of lakes/wetlands processes using remote sensing data and a land surface model. American Society of Agricultural and Biological Engineering (ASABE), Rhode Island
- Mishra, V., K. A. Cherkauer, and L. C. Bowling (2008), Impacts of climate variability and change on inland lakes in Michigan, 88th Annual Meeting of American Meteorological Society (AMS), New Orleans, LA.
- Sinha T., K. A. Cherkauer, and V. Mishra (2008), Historic climate impacts on seasonal soil frost in the Midwestern US, 88th AMS Annual Meeting, New Orleans, LA, Abstract 135102
- Mishra, V., K. A. Cherkauer, T. Sinha, and M. Huber (2007), Variation of surface soil moisture and its implications under changing climate conditions, 2nd Graduate Climate Conference, University of Washington, Seattle, WA.

Vimal also participated in the Virginia Coastal Reserve 2007 Field Campaign to collect remotely sensed and in-situ data related to coastal wetland water quality along with representatives from agencies such as NRL, NASA, NOAA and USGS.

Vimal Mishra, *Agricultural & Biological Sciences*



Jinyung Tang, *Earth & Atmospheric Sciences*

Avantika Regmi, *Forestry & Natural Resources*

Joseph Alfieri, *Agronomy*

Jinyung Tang, 2006 Fellow

During the 2007-2008 academic year, with support from a NASA Earth System Science Fellowship, Jinyung has further developed the Terrestrial Ecosystem Model (TEM) to account for the effects of soil moisture and nitrogen deposition on methane dynamics. In March, 2008, he attended a workshop, "Toward an adequate quantification of CH_4 emissions from land ecosystems: Integrating field and in-situ observations, satellite data, and modeling," sponsored by the National Center for Ecological Analysis and Synthesis, Santa Barbara, CA.

This year, Jinyung has given the following presentations:

- Zhuang, Q., Xu, K., Tang, J., Responses of global soil methane consumption to changes of climate, land-use and land-cover, and atmospheric chemistry deposition during the 20th century, European Geosciences Union, General Assembly 2008, Vienna, Austria, 13 – 18 April 2008
- Tang, J., Q. Zhuang, Incorporating a snow model into soil thermal dynamics modeling, 2008 Graduate Student Research Expo. Purdue University, Feb. 23, 2008.
- Tang, J. and Q. Zhuang, Modeling the growing season change in Alaska during the 20th centuray, ESA 93rd annual meeting, Milwaukee, WI, 5 Aug. 2008
- Zhuang, Q., K. Xu, and J. Tang, Responses of global soil CH_4 consumption to changes of climate, atmospheric CH_4 concentration, and atmospheric chemistry deposition during the 20th century. ESA 93rd annual meeting, Milwaukee, 5 Aug. 2008

Jinyung has two manuscripts in review:

- Tang, J. and Q. Zhuang ,A Global Sensitivity and Bayesian Inference Framework toImprove the Parameter Estimation and Prediction of Process-Based Terrestrial Ecosystem Models. In review at J. Geophys. Res. - Atmos.
- Tang, J. and Q. Zhuang, Equifinality in Parameterization of Process-Based Biogeochemistry Models: A Significant Uncertainty Source to Regional Carbon Dynamics. In review at J. Geophys. Res. - Biogeoscience

Avantika Regmi, 2005 Fellow

Avantika Regmi is a student in Forestry and Natural Resources (Prof. Bryan Pijanowski, advisor). Her dissertation research includes developing a human-demographic model-Watu written in the C-programming language. This is a spatio-temporal model that takes into consideration the bio-physical, socio-economic and ethno-cultural variables that affect the main components of demography -fertility, survivorship and migration. Avantika is currently working on developing the migration component of the model. The model is country-specific and her focus is on Kenya. Avantika presented a poster on the development of the model at the Fall 2007 "Center for the Environment's Ecological Sciences and Engineering Graduate Research Showcase" and was awarded the 1st place tie. Since last year her research has also taken a new direction, she has combined spatial econometric models into the demographic model. Avantika is in the process of writing the first paper, "The spatial determinants of fertility in Kenya."

Joseph Alfieri, 2005 Fellow

Collaborating with scientists at Purdue University and the National Center for Atmospheric Research, Joseph was invited to NCAR during the summers of 2006, 2007, and 2008 through the Advanced Study Program and the Mesoscale and Microscale Meteorology Visiting Scientist Program. He has been investigating the linkages between the heterogeneity of surface characteristics and the spatial variability of surface fluxes. Using a combination of surface, remotely sensed, and modeled data, in conjunction with flux footprint and spatial statistical analysis techniques, Joseph's work seeks to clarify the influence of surface properties, such as land use and vegetation density, on land-atmosphere exchange processes. In 2007, he was awarded a NASA Earth and Space Science Fellowship. He was also recognized as the Outstanding Ph.D. Student in Research and the recipient of the Wayne P. Rothgreb Memorial Scholarship awarded through the Department of Agronomy, Crop, Soil, and Environmental Sciences. Joseph was the author or co-author of six papers published during 2007.

In the spring of 2008, the Rotary Club of Fort Wayne, Indiana hosted a World Affairs Conference on Climate Change. Over 300 high school students from the northwest Indiana region were in attendance for a presentation and discussion session on climate change led by PCCRC members Kirk Alter, Tim Filley, and Paul Shepson.

The presentation, ***Climate change: realities, impacts, and opportunities****, was filmed and sent to 9 other locations throughout northern Indiana where 2,000 additional high schoolers and their teachers had the opportunity to see the presentation and participate in local discussions. At the Hammond, IN session, Keith Cherkauer focused the discussion on climate change impacts to water resources in the Great Lakes region.*

ENGAGEMENT

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

Part of the community

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

Nurturing the Next Generation of Science Leaders

During his junior and senior years at Harrison High School, Russell Conard participated in the on-going research in Prof. Tim Filley's lab. With Filley's guidance, Russell studied how native and invasive earthworm activity changes the chemistry of decomposing forest litter. The work was part of an NSF-funded project investigating the implications of invasive earthworm species on organic matter budgets in forest litter and soil.

In the spring of 2008, Russell presented his findings at the Purdue Regional and Indiana State Science fairs placing first in both competitions. He was then invited to participate in the Intel International Science and Engineering Fair (ISEF) in Atlanta, Georgia. Russell did spectacularly well, receiving a 1st place award in biochemistry and Best in Class - Overall Winner. In December, Russell will travel to Sweden to represent the ISEF and the United States at the Stockholm International Youth Science Seminar, one of only 25 students from around the world invited to attend. Recently graduated from HHS, Russell will be attending the Rose-Hulman Institute of Technology this fall to study software engineering and biochemistry. He will continue his research in the Filley lab on various projects related to application of new chemical methods to track carbon cycling.

Russell Conard addressing a panel of Nobel Laureates at the International Science and Engineering Fair in Atlanta, Georgia.

Facilitating Knowledge Transfer

Moetasim Ashfaq's (Ph.D. candidate, *Earth & Atmospheric Sciences*) first exposure to climate science was in a collaborative RegCNET workshop in Pakistan in 2004. The RegCNET, short for Regional Climate Network, was established 5 years ago during the First ICTP Workshop on the theory and use of regional climate models. It was connections with the RegCNET that led Moetasim to Purdue to work with his thesis advisor, Prof. Noah Diffenbaugh. Diffenbaugh has been a part of the network since it was initiated. The RegCNET mission is to foster scientific interactions between developing and developed nations on the topic of regional climate dynamics and impacts research, and much of Moetasim's work with RegCNET has gone toward building scientific networks. For example, with the Abdus Salam International Centre for Theoretical physics, he helped establish RegCNET-South Asia. This regional network has supported government meteorological departments and climate research centers in Bangladesh, Nepal, and Pakistan to kick-start research on the assessment of climate change and its impacts on water resources, food security, and agriculture.

While at Purdue, Moetasim has been involved in the development and maintenance of new GCM-RegCM3 and RegCM3-hydrology couplers, and RegCM3-paleoclimate capability. He is also responsible for the improvement and maintenance of RegCM3 postprocessing codes and a key provider of RegCM3 user support over the RegCNET listserv.

Moetasim's doctoral work on the response of South Asian monsoon dynamics to changes in radiative forcing has also benefited from RegCNET relationships. Most practically, RegCNET connections have led to collaboration with scientists at the National Climate Center in Beijing, which has enabled computationally expensive high-resolution climate change experiments for South Asia.

Examples of our outreach activities

Alter, Kirk; Tim Filley, and Paul Shepson, March 2008, presentation to Indiana public high school students at the Fort Wayne Rotary Club World Affairs Conference, Fort Wayne, IN: *Climate change: realities, impacts, and opportunities.*

Cason, Tim, March 2008, Emissions trading "experts" workshop, Canberra, Australia: *Laboratory experiments inform emissions permit market design.*

Cherkauer, Keith, February 2008, Indiana Sea Grant seminar series, Purdue University Calumet, Hammond, IN: *The impact of changing climate and precipitation in the Great Lakes basin, Illinois.*

Diffenbaugh, Noah, October 2007, NSF Climate Over Landscapes Workshop, Boulder, CO: *High-resolution paleoclimate modeling.*

Diffenbaugh, Noah, March 2008, Fourth ICTP Workshop on the Theory and Use of Regional Climate Models, Trieste, Italy: *The importance of fine-scale feedbacks in regional climate change projections.*

Filley, Timothy April 22, 2008 Tim Filley, NICHES Land Trust, West Lafayette, IN: *Climate change and forest ecosystems*.

Filley, Rose, February 2007, YWCA Spring Luncheon Series, Lafayette, IN: *Climate change challenges and opportunities (and an introduction to a local resource: the PCCRC).*

Gluhovsky, Alexander, July 2007, presentation at the XXIV IUGG General Assembly "Extreme Weather and Climate Events: Past Occurrences and Future Likelihoods" symposium, Perugia, Italy: *Advances in subsampling methodology for analysis of nonlinear atmospheric time series.*

Grant, Richard, Dec 2007, Estimación de Emisiones de Gases Efecto Invernadero: Actualización de Conocimientos, Colegio de Postgraduados, Campus Montecillo, Mexico: *Methodologies of the National Air Emissions Measurement Study with applications to greenhouse gas emissions measurements.*

Gurney, Kevin, November 2007, Indiana University, Bloomington, IN: *From Tara to Hestia: Connecting the missing sink and fossil fuels through carbon science.*

Gurney, Kevin, September 2007, Heinz Center's Business Council for Economics and the Environment, Sustainability Retreat, Invited participant.

Huber, Matthew, Oct 2007, Purdue University, SISI meeting (teaching teachers), West Lafayette, IN: *A glance in the rearview mirror and the view ahead: Using climate models.*

Huber, Matthew, September 2007, featured on Earth & Sky Radio Series: *Global warming and tropical cyclones.*

Lasher-Trapp, Sonia, August 2007, Oxford Roundtable "Global Warming and Sustainable Development: Governing a Crisis", Oxford, England: *Clouds in a Warmer Environment: Friend or Foe?*

Michalski, Greg, September 2007, plenary speaker at the 7th Annual Association of Isotope Geochemists, in Stellenbosch South Africa: *Theory and Applications of ^{17}O anomalies in Biogeochemistry.*

Nies, Larry, May 2008, Unitarian Church, Lafayette, IN: *Sustainable Development*.

Pijanowski, Bryan, June 2008, Keynote address at Accuracy2008, Shanghai, China: *Sustainability, climate change, and uncertainty*.

Rabenold, Kerry, March 2008, Wabash Area Lifetime Learning Association lecture, West Lafayette, IN: *Vulnerability of tropical biological diversity to climate change.*

Rabenold, Kerry, June 2007, Arenal Tempisque Conservation Area Symposium, Ministry of Environment & Energy, Costa Rica: *La Distribución Espacial de la Biodiversidad y las Implicaciónes para las Especies Endémicas Amenazadas*.

Raymond, Leigh, December 2007, Harvard Electricity Policy Group Quarterly Seminar, Invited presenter: "Allocation of Carbon Emissions Allowances" session, Los Angeles, CA: *Allocating emission allowances: learning from EU and US experiences*.

Raymond, Leigh, November 2007, Purdue University Seminar Series in Bioethics, West Lafayette, IN: *The Ethics and Politics of Climate Change.*

Rochon, Gilbert, July 2007, presentation for HRH Princess Ncengencenge Dlamini and HRH Prince Lethuthando Dlamini of the Kingdom of Swaziland. Purdue University, West Lafayette, Indiana: *Remote Sensing in Support of Public Health & Disaster Mitigation in Swaziland.*

Rochon, Gilbert and Joseph Quansah, September 2007, Keynote Address, International Conference on Natural Disasters: Challenges for Better Forecasting and Hazard Assessment, Sponsored by the Thailand Commission on Higher Education, Mae Fah Luang University Chiang Rai, Thailand: *Methodology: Worldwide Experience and Assessment of the Application of Space Technologies to Forecasting and Hazard Assessment of Natural Disasters.*

Rowe, Helen, May 2008, co-convener of "Tallgrass Prairie Research, Indicators and Monitoring Workshop" for science directors and project directors for the central US region of the Nature Conservancy.

Shao, Guofan, October 2007, Indiana Department of Natural Resources for Forest Planners: *Roles of Forests in Offsetting CO_2 Emissions.*

Shao, Guofan with Liu, Y., and Martin, B., November 2007, 1st Xiamen International Forum on Urban Environment held at the Institute of Urban Environment, Chinese Academy of Sciences, in Xiamen: *Diminishing the Role of Urbanization in Raising Atmospheric CO_2 Concentrations: Think Globally, Act Locally*.

Shepson, Paul, September, 2007, Juniata College, Huntingdon, PA: *Atmospheric chemistry and climate change in the Arctic*.

Shepson, Paul, November 2007, presented the 17th annual Harold I. Schiff Lecture at York University, Toronto, Canada: *Climate Change, and Atmosphere-Surface Interactions in the Arctic.*

Trapp, Jeff, November 2007, University of Illinois, Department of Atmospheric Science: *Connections between global climate change and severe thunderstorms.*

Tung, Wen-wen, October 2007, special seminar at the Dept. of Geophysical Sciences, University of Chicago and in May, 2008 at the Shanghai Typhoon Institute, Shanghai, China: *Quantifying dynamical predictability: the pseudo-ensemble technique*.

Zhuang, Qianlai, June 2008, Northern Eurasia Earth Science Partnership Initiative (NEESPI) Science Team meeting, Helsinki, Finland: *Modeling CO_2 and CH_4 emissions in the Arctic.*

Zhuang, Qianlai, October 2007, Keynote speaker at "Towards a process-based description of trace gas emissions in land surface models" Workshop, Marina Plaza, Helsingborg, Sweden: *Current issues on methane modeling.*

Informing Policy

PCCRC members work to bring objective, science-based information to the policy making process.

In December 2007, delegates from over 180 countries gathered in Bali, Indonesia for the annual event known as the ***Conference of the Parties (COP) to the UN Framework Convention on Climate Change***. The COP is a two-week meeting of negotiations and information sharing regarding the challenge of global climate change. This year, for the first time, two representatives from the PCCRC attended the negotiations as part of the Center's new, official "observer" status. With observer status, the PCCRC can participate in the COPs and other, related processes. PCCRC Associate Director Kevin Gurney is a veteran of the UN climate negotiation process, having attended as an observer since the early days of the meetings in the 1990s. He was joined by first-time attendee, Leigh Raymond, the Center's other Associate Director. In the near future, the Center plans to establish travel scholarships for students so they may gain an inside look at the complexity of international climate policy.

PCCRC member and Purdue Professor of Economics, Tim Cason, met in March 2008 with Australian policy makers in Canberra to ***discuss plans for implementing market-based regulations for controlling greenhouse gas emissions.*** His presentation was part of an emissions trading "expert workshop" for the Departments of Climate Change, Treasury, Natural Resources and Environment, and other state and federal agencies.

Kevin Gurney at the UNFCCC COP13 held in Bali, Indonesia.

Sonia Lasher-Trapp, Assistant Professor of Earth & Atmospheric Sciences, was invited to present a paper at the ***Oxford Round Table on "Global Warming and Sustainable Development: Governing a Crisis"***, held at Oxford University from Aug 12-17, 2007. For 20 years, Oxford University has hosted discussions to consider public policy issues as they relate to education in the U.S., England, and other selected countries. Other participants included individuals from private industry and government as well as lawyers and other academics. Sonia's participation was funded in part by the PCCRC, and she presented the paper "*Clouds in a Warmer Environment: Friend or Foe?*" Papers presented at the round table were reviewed and then published in Oxford's *Forum on Public Policy*, Vol. 3, No. 4.

On Earth Day, April 22, 2008, Kevin Gurney provided ***testimony before the U.S. Senate Foreign Relations Committee*** about proposed international deforestation and climate change policy. Included in his testimony was a new approach (developed in collaboration with Leigh Raymond) that would provide carbon credits for developing countries that set aside a portion of existing forests and slow the rate at which the remaining forests are cut down. A key point in the approach is its call for a deceleration of deforestation.

Washington D.C. briefings

In October, 2007, the PCCRC, College of Science, and the Office of Foundation Relations held two days of outreach events to introduce the Hestia project (see page 15) to business leaders, foundations, and NGOs in the D.C. metro area. In addition, Kevin Gurney, presented the project to congressional staff at a Capitol Hill briefing.

2007 PCCRC Distinguished Lecture

The Center welcomed Dr. Barry Rabe, Professor of Public Policy, University of Michigan, to campus on October 4, 2007, to present the PCCRC Distinguished Lecture: "***States on Steroids: the Intergovernmental Odyssey of American Climate Policy.***" Dr. Rabe shared his insights and experiences in climate policy development, noting in particular that in the United States, federal level disengagement on climate policy coincides with an unexpected and growing body of state and local government policy innovation. Dr. Rabe examined what has fostered such state subnational involvement and considered lessons from early stages of state climate policy development and implementation. The PCCRC and Department of Political Science co-hosted Dr. Rabe's visit.

New interdepartmental collaborations related to climate change policy issues

Greenhouse Gas Pricing Policy: A More Integrated, Realistic Analysis

Analysis of greenhouse gas pricing policy currently relies on optimizing economic outcomes in the face of unrealistic assumptions about environmental consequences and human decision-making. Such analysis would benefit from an additional dose of realism. For instance, the statement that the U.S. will be significantly affected by climate change overlooks recent work indicating that some areas face significantly more serious risks than others (Diffenbaugh et al., 2005). The statement that economic actors will reach an efficient price for greenhouse gases in a cap and trade system ignores recent work indicating that human behavior can undermine those efficiencies in many surprising ways (Cason and Gangadharan, 2006). The statement that greenhouse gas offsets are a useful policy tool ignores the uncertain economic and environmental implications of shifting greenhouse gas emissions or storage around the globe. Further, policy analysts tend to treat the greenhouse gas pricing challenge in the abstract, when in fact governments around the world have been in the business of pricing and distributing natural resources for centuries (Raymond, 2003).

The Purdue approach will provide an in-depth assessment of the political, economic, and environmental benefits and weaknesses of a variety of policy options available in a cap-and-trade system. Specifically, the research team will evaluate the environmental, economic, and political viability of five initial allocation principles (auction, grandfathering, per capita, per unit GDP, and vulnerability), and five trading rules (banking, enforcement, liability, equity-based limits, and swapping of weather risks). Team: Tim Cason, *Economics*; Noah Diffenbaugh, *EAS*; Kevin Gurney, *EAS* and *Agronomy*; Tom Hertel, *Agricultural Economics*; Leigh Raymond, *Political Science*; Jerry Shively, *Agricultural Economics*; and Wally Tyner, *Agricultural Economics*.

Responding to Climate Change: Measuring Vulnerability and Building Resilience

Regardless of greenhouse gas mitigation measures, it is now apparent that some adaptation to climate change will be required in the coming decades. However, different communities almost certainly face different climate change vulnerabilities. For instance, physical effects of climate change will not be uniform between nations or within individual nations. Further, the ability of an individual community to adapt to climate change will depend not only on the physical effects of climate change that it faces, but also on its unique social and economic dynamics. Thus, general prescriptions for adaptation will fail to prepare communities for more costly localized consequences of future climate change. Rather, successfully building resilience to climate change requires rigorous identification of the local climate exposure, deep understanding of the local community dynamics, and careful consideration of the local geography and infrastructure.

The Purdue approach will integrate detailed, local-scale projections of climate change with historical case studies of community response to severe climatic events. The analysis will provide a deeper understanding of what makes communities vulnerable and resilient to climate variations, a quantitative assessment of the climate change risks faced by different areas, and specific recommendations for building resilience to those risks. Team: Daniel Aldrich, *Political Science*; Noah Diffenbaugh, *EAS*; Leigh Raymond, *Political Science*; and Jerry Shively, *Agricultural Economics*.

Reports

The PCCRC encourages and coordinates multidisciplinary analysis to provide science-based information tools for researchers, students, elected officials, and the public. We are pleased to include four new reports in our toolbox this year.

In the spring semester of 2007, an interdisciplinary class of 29 students and 6 instructors calculated the annual carbon emissions of Purdue University and generated a series of ideas to reduce those emissions over time to the point of "carbon neutrality," or zero net carbon emissions. Their efforts are documented in a new report, "***Carbon Neutrality at Purdue***."

In this report, the group has provided a model for calculating the university's carbon footprint and a baseline analysis to use in monitoring future energy conservation efforts. For this study, the class defined Purdue's "carbon footprint" as the net amount of carbon (in the form of carbon dioxide) released to the atmosphere as a result of Purdue University's activities which include energy production and consumption, building construction, land management, business travel, and purchasing decisions for the 2005-2006 fiscal year. The geographic boundaries encompassed the Purdue West Lafayette campus and land holdings throughout Tippecanoe County.

While true carbon neutrality is, by any standard, an ambitious goal, the report outlines specific steps the university can

take towards that end. For example, there are opportunities for developing and utilizing renewable energy sources, improving energy transmission methods, adopting energy efficient technologies, increasing energy conservation efforts, and creating or purchasing carbon offsets. The wide assortment of emissions reductions options identified in the report are meant to facilitate activity at a variety of speeds and initial investment.

Locally, this work has served to put the concept of carbon neutrality on the Purdue map and has sparked the interest of campus administration, faculty, students, and the surrounding community. In addition, the work has catalyzed formation of the Purdue Sustainability Council. Led by Dr. Robin Mills Ridgway (Purdue's environmental regulatory consultant), the Council brings together students, faculty, and staff to identify issues, discuss options, educate the campus community, and make recommendations on the future direction of sustainability initiatives. This includes consideration of many facets of the University's impact, including greenhouse gas emissions, water use, non-renewable material use, transportation, and more.

Through monthly meetings, an email listserv, and a new website, the Council is generating excitement, sharing knowledge, and securing the commitments needed to move forward with implementing sustainable best practices on campus. You can learn more about campus sustainability activities at: www.purdue.edu/sustainability.

Purdue Climate Change Research Center

PURDUE UNIVERSITY

Policy Brief

PB 0701 · SEPTEMBER 2007

A Primer on Market-Based Approaches to CO_2 Emissions Reductions

By Leigh Raymond and Gerald Shively

Recent political developments have brought to the political fore the issue of controlling emissions of greenhouse gases. In the United States, numerous proposals have surfaced promoting policies to limit domestic emissions of gases like carbon dioxide (CO_2), a primary contributor to climate change. Many of these proposals embrace "market-based" approaches, including the creation of a new tax or a new trading program for carbon emissions. In this flurry of political advocacy and activity, a fair amount of ambiguity and confusion has arisen concerning what these policy options might entail, and how their impacts might differ. The purpose of this policy brief is to describe some of the basic features of carbon taxes and carbon-based emissions trading. Our goal is to aid decision makers to more effectively weigh the advantages and disadvantages of these approaches.

The brief proceeds in five sections. First, we review how *cap and trade* emissions trading systems work. Second, we outline the history of emissions trading as a policy option in the United States and elsewhere. Third, we review the similarities and differences between a cap and trade system and an *emissions tax*. We then discuss some critical issues for policymakers contemplating either approach. After concluding we offer a few suggestions for further reading.

Carbon dioxide emissions in Indiana have increased 13% since 1990.

I. What is cap and trade?

Cap and trade systems draw on the ideas of economic thinkers like Ronald Coase, who argued that a clear specification of property rights can improve environmental conditions in many instances more effectively than a tax on undesired behavior. Cap and trade systems rely on two instruments to create these private property rights: the "cap," a ceiling on total allowable emissions (typically defined within a given industry or geographical region); and "trade," or creation of exchangeable emissions permits (often called "allowances") that grant the right to emit one unit of pollution in a given year. The cap appeals to those seeking environmental protection because it firmly limits total pollution loading regardless of additional economic growth: new facilities seeking to emit the pollutant typically must buy or otherwise obtain sufficient allowances from those in possession of permits to maintain the total cap.

At the same time, the system appeals to those seeking to limit the overall costs of meeting the environmental target for several reasons. The first is that allowances are tradable among emitters, allowing them to equalize their costs of compliance at the margin, and thereby achieve the overall environmental goal at least total cost to society. Meeting strict standards is often more difficult and costly for older facilities, for instance, than for newer ones. With a cap and trade system, emissions trading directly addresses this problem. In other words, firms facing very high pollution control costs can continue to emit high levels of pollution

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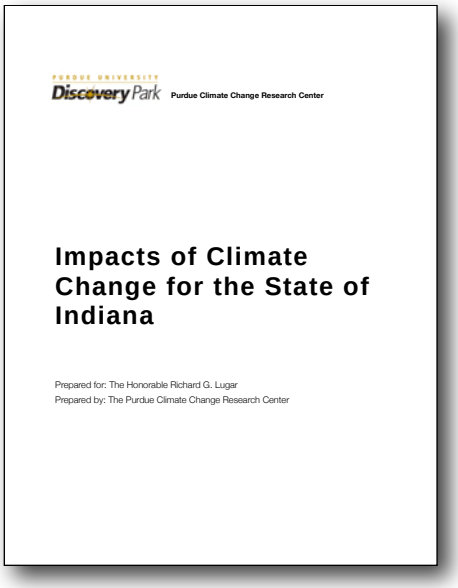
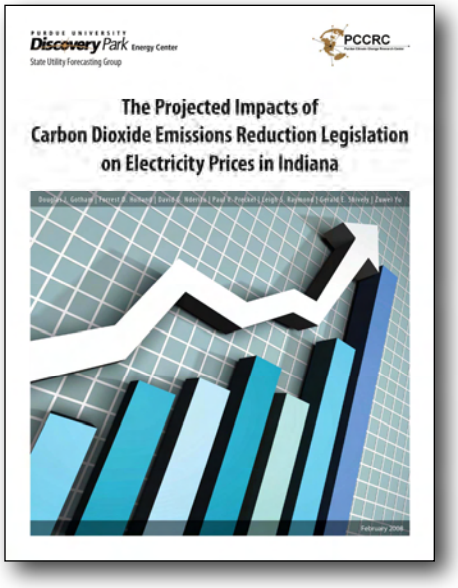


PURDUE UNIVERSITY Discovery Park Purdue Climate Change Research Center

Impacts of Climate Change for the State of Indiana

Prepared for: The Honorable Richard G. Lugar
Prepared by: The Purdue Climate Change Research Center



PURDUE UNIVERSITY Discovery Park Energy Center
State Utility Forecasting Group

PCCRC

The Projected Impacts of Carbon Dioxide Emissions Reduction Legislation on Electricity Prices in Indiana

February 2008

Market-Based Approaches to CO_2 Emissions Reductions

Recent political developments have brought to the political fore the issue of controlling emissions of greenhouse gases. In the United States, numerous proposals have surfaced promoting policies to limit domestic emissions of gases like carbon dioxide (CO_2), a primary contributor to climate change. Many of these proposals embrace "market-based" approaches, including the creation of a new tax or a new trading program for carbon emissions. In this flurry of political advocacy and activity, a fair amount of ambiguity and confusion has arisen concerning what these policy options might entail, and how their impacts might differ.

Written by Dr. Leigh Raymond, PCCRC Associate Director and Associate Professor of Political Science, and Dr. Gerald Shively, Professor of Agricultural Economics, this policy brief describes some of the basic features of carbon taxes and carbon-based emissions trading to aid decision makers to more effectively weigh the advantages and disadvantages of these approaches.

Impacts of Climate Change on the State of Indiana

PCCRC faculty have analyzed the potential "no-action" impacts of climate change on Indiana, as well as the potential opportunities and consequences of climate change mitigation in the State. Most of the analyses of no-action impacts assume future greenhouse gas concentrations at the high end of the IPCC SRES illustrative emissions scenarios, although some analyses also consider low emissions trajectories. Further, some of the analyses are quantitative, based on published and unpublished work that is ongoing at Purdue; other analyses are qualitative based on "expert opinion." While additional research will always bring further clarity, these initial analyses are meant to provide a reliable indication of the direction and magnitude of important climate change impacts and opportunities in Indiana.

The report, prepared for Senator Richard Lugar, considers projected climate changes in the State, impacts to water resources, agriculture, plants and animals, soils, human health, and heating and cooling demand. It also explores carbon management opportunities and consequences.

The Projected Impacts of CO_2 Emissions Reduction Legislation on Electricity Prices in Indiana

A report by the Indiana State Utility Forecasting Group (a part of Discovery Park's Energy Center) and the PCCRC have estimated the impact of proposed federal regulations aimed at reductions in carbon dioxide emissions on the projected prices of electricity and the use of electric energy in the State of Indiana. Prepared at the request of Senator Evan Bayh, the analysis is based on the Lieberman-Warner Climate Security Act (S. 2191), which places a declining cap on greenhouse gas emissions; however, it does not attempt to model the full details of the proposed legislation.

Although the bill places limits on six greenhouse gases (CO_2, methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons) from a number of producers, this report solely focuses on CO_2 emissions from Indiana's electric utility industry. The analysis focuses on the impacts of the legislated limitations on CO_2 emissions on the electric energy sector of the economy and does not address the benefits of reduced emissions.

People

As a faculty-led center, we know that our strength derives from the scholarship, creativity, and energy of our members. The PCCRC was founded by a group of 12 faculty members representing 8 academic units across campus and has since grown to include 46 active members from 13 departments.

Welcome our newest members

Kirk Alter, Associate Professor, Department of Building and Construction Management

Prof. Alter has been a full-time participant in the mechanical and electrical construction industries since the early 1970s. The past 13 years Prof. Alter has created curricula specializations in environmental systems in buildings, sustainable construction, and international development. More recently, his research and teaching efforts have focused on green building and sustainability best practices. In 2007-08 he spent the year in Europe as a Fulbright Scholar exploring European approaches to sustainable building practices and adaptation to climate change. Prof. Alter is also president of Fast Management, Inc.

Reuben Goforth, Assistant Professor of Forestry & Natural Resources

Prof. Goforth is a broadly trained aquatic ecologist with particular interest in stream and Great Lakes nearshore ecology Within these ecosystems, he is particularly interested in conducting research to better understand the mechanisms that drive changes in biological community structure. He currently has great interest in the potential role of increased biofuel-related crop production as a factor driving stream biological community structure in affected watersheds. His lab is also beginning to focus on research to better understand the mechanisms of stream communities response to changing environmental properties related to climate change (e.g., increased carbon dioxide concentrations, increased and more variable water temperatures, etc).

Cliff Johnston, Professor, Department of Agronomy

Prof. Johnston's research interests are focused on the surface chemistry of natural particles and the biogeochemical processes they regulate. Much of his group's work is in soils; however, they are broadly interested in the properties of natural particles found in a variety of aquatic and subsurface environments. The group seeks to develop an understanding of how molecules (e.g., contaminants, water, nutrients) interact with natural particles, as well as studying the particles themselves. Dr. Johnston's research is focused on the nano- and molecular- scales with application to larger scales.

COALESCE Climate Change Hiring Initiative

With support from the Colleges of Science, Agriculture, and Liberal Arts, the COALESCE climate change faculty searches in "policy and science" and "ecological impacts" successfully recruited two outstanding researchers, Dr. Elizabeth McNie and Dr. Jeffrey Dukes.

Dr. Elizabeth McNie will join Purdue this fall as Assistant Professor in the Department of Political Science and the Department of Earth & Atmospheric Sciences. Elizabeth's research interests relate to climate policy and how to facilitate the development of stronger linkages between scientists and policy makers so that scientists produce information that is both needed and used by policy makers in their decision processes. Her research also explores the concept of 'useful' scientific information and seeks to develop evaluative tools for determining whether scientific information is useful, and how it is useful, for policy makers. She is also interested in the institutional design, organizational dynamics and social capital needed for successful scientist – policy maker interactions regarding the production of useful information.

Dr. Jeffrey Dukes joins the Department Forestry & Natural Resources and Department of Biological Sciences. Jeffrey has carried out research across a wide range of ecological disciplines including invasion biology, plant physiological ecology, community, ecosystem, and global ecology, and biogeochemistry.

The majority of Jeffrey's work has been related to environmental changes and he currently leads a broad research program that centers on drivers and effects of species composition change. His overarching professional goal is to study and promote understanding of how the human enterprise affects terrestrial ecosystems.

PCCRC Membership

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

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

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

Biological Sciences: Kerry Rabenold

Building & Construction Management: Kirk Alter

Chemistry: Paul Shepson

Civil Engineering: Larry Nies

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

Economics: Timothy Cason

Forestry and Natural Resources: Reuben Goforth, Bryan Pijanowski, Linda Prokopy, Helen Rowe, Guofan Shao, and Rob Swihart

IT Discovery Resources: Gilbert Rochon[2]

Mechanical Engineering: Greg Shaver

Political Science **:** Leigh Raymond

Sociology: Martin Patchen

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Kerry Rabenold, Biological Sciences
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Jerry Shively, Agricultural Economics
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[1] joint appointment in Civil Engineering; [2] joint appointment in Earth & Atmospheric Sciences; [3] joint appointment in Statistics; [4] joint appointment in Agronomy

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