Climate Change SCIENCE INSTITUTE

Newsletter

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

LETTER FROM CCSI LEADERSHIP

Although we are just starting a new fiscal year, we want to look ahead even now. Next month, Dr. Gary Geernaert will be visiting ORNL. Gary is the Director of BER's Climate and Environmental Sciences Division. He will receive a comprehensive overview of the climate change research at ORNL and also the subsurface biogeochemical research program. The SERDP (Strategic Environmental R&D Program) has a solicitation out that for the first time includes climate change. The guidelines and statements of need can be accessed at the SERDP website (www.serdp.org). Greg Zimmerman of ESD coordinates the submission process of ORNL pre-proposals to DOE. If you are developing ideas, please communicate to Greg early and more importantly; please communicate to Mary so that she can alert CCSI leadership about the interest in this solicitation. We will want to arrange review of both pre-proposals and any full proposals that are encouraged. DOE/BER reviews pre-proposals and either discourages or encourages full proposals to the DOD/SERDP process.

There is a summary piece on LDRD in this newsletter. This is the time for you to be thinking about ideas for the next round of LDRD proposals. We anticipate reviewing pre-proposals in all four research themes, so you should now start developing innovative concepts. The time in the spring is usually short and hectic. LDRD is an important part of positioning ORNL for future opportunities. We encourage you to discuss ideas with the Research Theme leads.

Congratulations to Rich Norby and his team for the publication of FACE results in PNAS (see article below). We encourage all of you to seek opportunities to publish in high-impact journals. Such publications are time consuming (just ask Rich!) but offer important avenues for communication of important scientific results.

FY11 CLIMATE LDRD PORTFOLIO

For FY11, CCSI has seven LDRD (lab directed research and development) projects of which three are continuations, and four are new for a combined funding of $1.95 M. This year, there will be an in-house review of all climate LDRD projects in January 2011 to discuss progress, issues, etc. Approval of these LDRD projects have created some opportunities for new postdoctoral research associates, as identified below. Additional information on how to apply for the postdoctoral positions can be found on the back page of this newsletter.

Enabling Plant System Biology Investigations for Carbon Cycling and Biosequestration Research ($268k) PI– Udaya Kalluri

Enhancing Climate Impact Integrated Assessment for Water Through Climate Informatics ($350k) PI– Chris Lenhardt [Postdoc opportunity: application of informatics and information science to climate change science in the domain of water issues; applications and decision support]

Uncertainty Assessment and Reduction for Climate Extremes and Climate Change Impacts ($29k) PI– Auroop Ganguly

Investigating Climatic/Socioeconomic Interactions at the Local Scale ($363k) PI– Ben Preston

Modeling Long-Term Population Resettlement Under Climate Change Scenarios ($300k) PI– Budhendra Bhaduri

Characterization and Modeling of Permafrost Microbial Community Diversity and Metabolism During Simulated Global Warming ($370) PI– Dwayne Elias [Postdoc opportunity: Model integration of the microbial and geochemical data]

Incorporating Molecular Scale Mechanisms Stabilizing Soil Organic Carbon into Terrestrial Carbon Cycle Models ($270k) PI– Melanie Mayes [Postdoc opportunity: experiments and modeling designed to interrogate rates and mechanisms governing cycling of plant and microbial compounds at the soil mineral interface, and for incorporating results into soil carbon cycling models]

ORNL PUBLICATION MAKES COVER OF PNAS

Results from the Oak Ridge Free-Air CO_2 Enrichment (FACE) experiment were featured in the November 9th edition of the Proceedings of the National Academy of Sciences. Results show that the growth response of the forest to CO_2 is diminished over time, and the team attributes the loss of response to a nitrogen limitation. The team hopes that this quantified data will improve the accuracy of carbon cycles within climate models.

Congratulations to Rich Norby and his team on this notable achievement! Read more on this project on page 2, "Highlighted Researcher—Rich Norby."

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Highlighted Researcher

RICHARD NORBY

As a young boy growing up in a suburb of Chicago, Richard Norby was a self-proclaimed "science nerd", enjoying a home chemistry set and eventually participating in his high school's chemistry club—winning prizes for a science experiment on protein decomposition in putrefactive meat. He headed off to Carleton College in Minnesota in 1968 with a clear vision—he would study chemistry and find a job with a company like DuPont Chemical.

But like most undergraduate students, Rich's notion of an ideal career path changed by the time he received his BA in chemistry in 1972. He jokingly blames it on "p-chem" (or physical chemistry for those outside of the chemistry coil), but in reality it was a mixture of finding new interests and a shift in American consciousness in the late 60s. "In that era we were all demanding relevance—everything had to be relevant. That lead me to have more interest in doing things that I thought would serve the public interest."

After graduation, Rich spent time in southern Oregon as a fire lookout for the Forest Service. It was four years before he went back to school for his graduate degree, but this time he focused on forestry and botany. He began his career at ORNL in 1981 as a post-doctoral researcher studying the effects of acid rain on soybean growth.

The separation between work and play is not all that distinct for Rich—he enjoys visiting friends and colleagues across the globe in work-related travel.

Richard Norby is a Corporate Fellow in the Ecosystem Observations and Experiments group of ORNL. He is a physiological ecologist with interests in tree growth, forest ecology, carbon and nitrogen cycling, and global change. Norby has been conducting experiments on the responses of trees and forests to elevated atmospheric carbon dioxide (CO2) since 1982 with an emphasis on belowground responses.

Through his involvement in the National Center for Ecological Analysis and Synthesis working group, "Benchmarking Ecosystem Response Models with Experimental Data from Long-term CO_2 Enrichment Experiments," the Global Change and Terrestrial Ecosystems project of the International Geosphere-Biosphere Programme, and the National Science Foundation (NSF) network project Terrestrial Ecosystems Response to Atmospheric and Climatic Change, Norby has had a strong interest in fostering cross-disciplinary global change research and improved communication between experimentalists and modelers.

He is a member of the Ecological Society of America and, in 1995, was elected fellow of the American Association for the Advancement of Science. Norby serves as the Environment Section editor of New Phytologist, is a member of the Board of the New Phytologist Trust, and is on the editorial board of the Journal of Plant Ecology. He also is an adjunct professor in the Department of Ecology and Evolutionary Biology at the University of Tennessee-Knoxville. He was recognized with an Outstanding Mentor Award by the U. S. Department of Energy's Office of Science in 2007, the UT-Battelle Award for Outstanding Accomplishment in Science and Technology in 2004, and the Scientific Achievement Award of the Environmental Sciences Division, Oak Ridge National Laboratory in 1992.

Rich's current work includes several collaborative, cross-disciplinary projects.

Rich is married to ORNL environmental scientist Ellen Smith. The two have a son who is currently living in Chicago and working as a computer programmer.

PI for Free-Air CO_2 Enrichment (FACE) Experiment (FY96-11)

The general objective for FACE is to understand how the eastern deciduous forest is affected by elevated CO_2 and what the feedbacks are from the forest to the atmosphere. It is intended to address the interaction between rising CO_2 and forest productivity in the global carbon cycle as CO_2 is a forcing factor in climate change. An important activity involves bringing the data from the Duke and Oak Ridge FACE experiments to a suite of ecosystem and global models and challenging the modelers to reproduce the observational results. The team hopes to improve the models with insights from the experiments.

CCSI members involved in this project include Colleen Iversen, who focused on root and soil responses; Jeff Warren, focused on water relations; Joanne Childs, who analyzed root images and runs the lab; and Charles Garten who has done work on stable isotopes in nitrogen cycling.

Co-PI for Partitioning In Trees and Soil (PITS) (FY10-12)

PITS is intended to improve the carbon partitioning routines in existing ecosystem models based on the concepts gathered from plant partitioning models and tested against field observations and manipulations. The team uses short-term, comprehensive field measurement of processes related to carbon partitioning from leaves to roots and roots to soil. The experiment focuses on belowground carbon partitioning. An improved understanding of the relative amount and fate of belowground partitioning will lead to improvements in model representation of carbon partitioning and the fate of carbon under elevated $CO_2$and other climate perturbations.

Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) (FY10-23)

SPRUCE is an experiment being implemented to assess the response of northern peatland ecosystems to increases in temperature and exposures to elevated atmospheric CO_2 concentrations. The experimental work will be conducted in a *Picea mariana* [black spruce]

bog forest in northern Minnesota. Questions to be addressed include the identification of thresholds for organism decline or mortality, environmental limitations to regeneration, biogeochemical limitations to productivity, and the cycling and release of CO_2 and CH_4 to the atmosphere. Direct and indirect effects of these experimental perturbations will be tracked and analyzed over a decade to develop and refine models needed for full Earth system analyses.

What role does your research play in climate change research?

"Reliable predictions of future climate requires knowledge of the trajectory of the forcing factors, including, of course, the concentration of CO_2 in the atmosphere. Predictions of atmospheric CO_2 depend in turn on all of the social, political, and economic factors that affect the burning of fossil fuels and land use change, as well as on the natural processes of the global carbon cycle. The terrestrial biosphere, and forests in particular, play a prominent role in the uptake, storage, and release of atmospheric CO_2, so it is important to understand the underlying physiological and ecological processes that control carbon exchanges between forests and the atmosphere and how those processes might change in the future. There has long been an expectation that as atmospheric CO_2 increases, the rate of uptake and storage of carbon in forests will also increase, and this 'CO_2 fertilization' effect will provide a negative feedback on the rate of accumulation of CO_2 in the atmosphere and the climate change that follows.

This long-winded description is meant to emphasize that my research on the response of trees and forests to elevated CO_2 is just a small sliver of the complex and multidisciplinary activity called climate change research. Although CO_2 fertilization can be considered one of the few favorable responses in the climate change arena, it will never 'solve' the problem of climate change, nor provide society an excuse to ignore it, but I do strongly believe that policy decisions need to be based on solid science wherever that may lead us."

Who is the customer for your research?

"The primary customer for our research is DOE's Biological and Environmental Research Program. DOE has supported our research for almost 30 years. It is primarily through DOE that experimental studies such as ours become integrated with other information on the global carbon cycle to address the larger climate change issues. Secondarily, our customer is the international climate change research community. No one experiment can answer all the questions we have, and the community of elevated CO_2 researchers has made a lot of progress in working together to synthesize responses across sites and to learn from each other as next-generation experiments are planned. I have been especially pleased with the enthusiasm that many modelers have received our data sets and their appreciation for our having made our data so accessible. Another set of customers of sorts are other researchers from around the world who have taken advantage of the opportunity to conduct their research on our research sites. Interactions with our many collaborators have been one of the highlights of our research."

Why is it important to you, personally, to become involved in climate change research?

"When I was in college in the late 60's, early 70's, one of the mandates we tried to impose, with revolutionary zeal, on our institutions and ourselves was for 'relevance'. For me this meant seminars on topics such as 'Science and Society' and 'Technology and Nature', as I abandoned my naïve notions of a career at a big chemical corporation. As I completed graduate school, I was inclined toward research that would meet the public's need, and a job at ORNL seemed to fit that desire well. Although in 1981, it had just been a year or two since I had heard a prominent ecologist lecture that 'some say global cooling, some say global warming; I guess it's a wash', the new research that Bob Luxmoore (now retired from ESD) had proposed to DOE on feedbacks between elevated CO_2 and nutrient cycles was intriguing to me, and it has remained intriguing ever since. It is easy to become cynical about our inability to respond to the serious challenges of climate change, and I know that my research is only a small sliver of climate change research. However, I do feel satisfied that we are doing our best to provide the science needed for making informed decisions."

In what direction do you see the future of climate change research going?

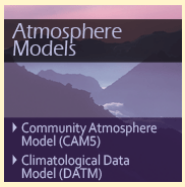
"I wish we could say that everyone now recognizes that climate change is real, and we should be focusing on solutions—but apparently that is not the case. Nevertheless, options for responding to climate change have huge economic implications and, therefore, must be based on solid science and continued improvement in the predictions of future climate. The trend toward increasing integration of multiple data streams into comprehensive models will continue. In the experimental world, we need to be tackling the responses of the more difficult-to-study ecosystems—the high-latitude peatlands and tropics, in particular—because the uncertainties are large and so are the potential consequences for global carbon and climate. All new climate change experiments are likely to involve a close integration of models, data, and observations—of which the CCSI can be proud to be providing the leadership. I hope there will be increasing emphasis on how atmospheric and climatic change affect plant community structure and dynamics—another area of large uncertainty with potentially large consequences that are meaningful not only to carbon-climate feedbacks, but also to quality of life for many people.

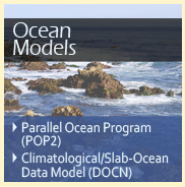
Highlighted Research

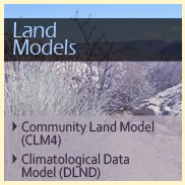
EARTH SYSTEM MODELING

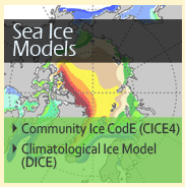
What is CESM?

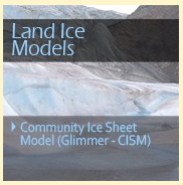
The Community Earth System Model (CESM) is one of about a dozen climate models worldwide that can be used to simulate the many components of Earth's climate system, including the oceans, atmosphere, sea and land ice, and land cover. The CESM is unique among these models in that it is developed by a broad community of scientists. The model is freely available to researchers worldwide, and it allows them to conduct fundamental research into the earth's past, present and future climate states.*

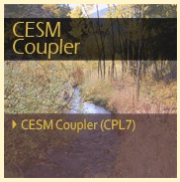












*Text and images courtesy of the National Center for Atmospheric Research. www.cesm.ucar.edu/models/cesm1.0/

Much of what we can foresee about the Earth's climate comes from Climate Model and Earth System model simulations. The Community Earth System Model (CESM) is one of the most widely used Earth system models, with a vibrant community of developers in the U.S. and a significant and expanding national and international user community. The CESM's predecessor, the Community Climate System Model (CCSM), was one of the global models whose simulations contributed to the IPCC Fourth Assessment Report. As part of a DOE-National Science Foundation partnership, ORNL has been a member of the core development team for the CCSM/CESM system for over a decade. ORNL researchers continue this involvement through further development of several of the CESM component models such as the Community Atmosphere Model (CAM), the Community Land Model (CLM), and the Community Ice Sheet Model (Glimmer-CISM).

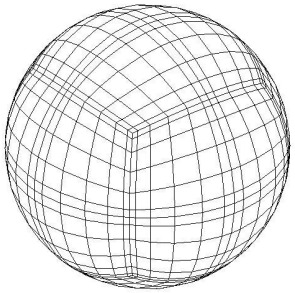


Figure 1. *Depicts cubed sphere geometry, where the transformation between the inscribed cube and the sphere is determined by the gnomonic (center) projection from the sphere to each face of the cube. This geometry is used for spectral element methods that have been demonstrated to be scalable dynamic cores (HOMME).*

ORNL is working with the National Center for Atmospheric Research and three other DOE laboratories to develop an ultra-high resolution version of the CAM and couple it to similar ultra-high resolution versions of the ocean (POP – Parallel Ocean Program) and land-surface (CLM) to resolve fine scale features. Closely related projects include work by CCSI researchers to improve model scaling and efficiency on Leadership Class computing platforms, like Jaguar. As model resolution increases to take advantage of Leadership systems, future versions of CAM will rely on a radically different numerical approach to simulating atmospheric fluid dynamics, which will combine spectral element algorithms implemented on cubed sphere grids (HOMME—High Order Method Modeling Environment) (Figure 1). CAM will be developed to take advantage of the 20 petaflop computer that will be delivered to ORNL a few years from now and the exascale computing capability that will push beyond current capabilities at ORNL by a factor of 1,000. Figure 2 is a visualization using the newest version of CAM, CAM4.

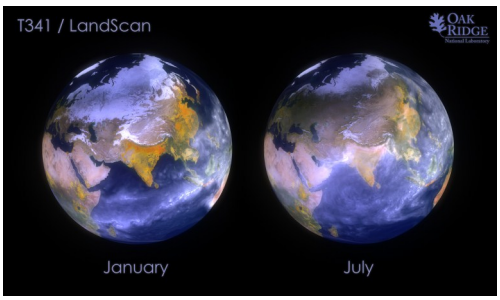


Figure 2. *This visualization uses the new CAM4, for the preindustrial 1850 period, spectral dynamic core at T341 truncation, which is about a 37km horizontal grid resolution. This configuration is currently under development by climate scientists at ORNL and NCAR in order to quantify the benefits and costs of climate simulation using higher resolution models.*

ORNL scientists participate in the development, parameterization, evaluation, and application of the CLM, with an emphasis on the representation of the carbon cycle and other biogeochemical cycles such as nitrogen and phosphorus (Figure 3). New model development efforts include the incorporation of prognostic land use and land cover change, improved representation of soil organic matter dynamics, and introduction of phosphorus cycling. ORNL scientists are leading efforts to estimate uncertain model parameters from a wide range of observations and experimental results, using data assimilation and multivariate nonlinear optimization approaches. Model evaluation is a critical component of the climate science enterprise, and ORNL scientists have developed quantitative metrics to make objective assessments of model performance, and which are now being adopted by the broader national and international land modeling communities. A major area of model application is the analysis of climate-carbon cycle feedback characteristics, based on the output of fully-coupled CESM simulations that make climate change projections out to the year 2100 and beyond. Policy-relevant questions about the likely climate changes associated

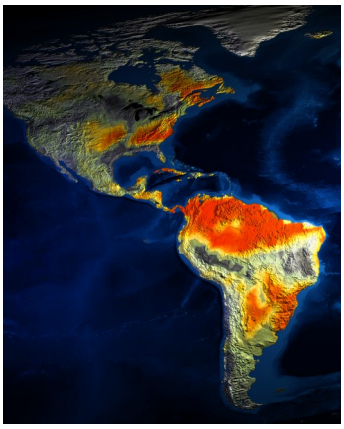


Figure 3. *The instantaneous Net Ecosystem Exchange (NEE) a measure of the atmospheric-terrestrial exchange of carbon as simulated with a version of the CCSM3 model that includes a terrestrial carbon modeling capability.*

with various trajectories of fossil fuel emissions depend strongly on the quantification of these feedbacks, and the integration of observational, experimental, and modeling knowledge and expertise to answer these questions is a major focus for the ORNL CCSI.

ORNL collaborates on CISM through the DOE ISICLES (Ice Sheet Initiative for Climate ExtremeS) initiative aimed at better inclusion of dynamic ice sheet modeling. In particular, ORNL is adapting ice sheet models developed at Los Alamos National Laboratory to run on massively parallel architectures efficiently with good scalability on increased numbers of processors. One of the project's goals with far reaching implications is to prototype the approaches deployed in developing a scalable CISM as a template scaling other CESM components.

ORNL will continue to leverage its capabilities as an integrator through regular interactions and feedbacks between various disciplines and models. CESM's success is based not only on the fidelity of the individual model components when tested against observational data, but also on the ability to simulate the combined behavior of all the model components working in concert and demonstrating high quality simulations of past and present climates.

CCSI RESEARCHERS HOST JASON PROJECT ARGONAUTS

Several CCSI researchers had the opportunity to roll up their sleeves and rub elbows with four up-and-coming scientists in early October through National Geographic's Jason Project. The Jason Project was founded in 1989 by Dr. Robert Ballard after discovering the wreck of the RMS Titanic and the ensuing outpouring of interest from students to participate in his explorations. The Jason Project is named after Jason, the mythological Greek explorer and is part of the STEM (Science, Technology, Engineering and Mathematics) education initiative aimed at highly talented or motivated students who have the potential to become future innovators in STEM areas.

Each year, a few dozen students are selected to be Jason National Argonauts, traveling around the U.S. to work with Jason Host Researchers covering a variety of research topics. This October, ORNL was host to four of these Argonauts focused on Forces and Motion, and Climate and Space. This was the second visit by Jason Argonauts to ORNL since ORNL's involvement began in 2009. As part of the climate portion of their visit, Jim Hack had the Argonauts average temperatures over the course of a day at the same location to demonstrate how weather data, sampled at various intervals over time, impacts the accuracy of the resulting climate data. They also had the opportunity to go into the field to tour and discuss projects that demonstrate how terrestrial ecosystems would adapt to changes in the environment. Jason Argonauts had the chance to view the prototype warming chamber to be used in SPRUCE. They also visited the PITS project to see a wide range of ecological measurement approaches.

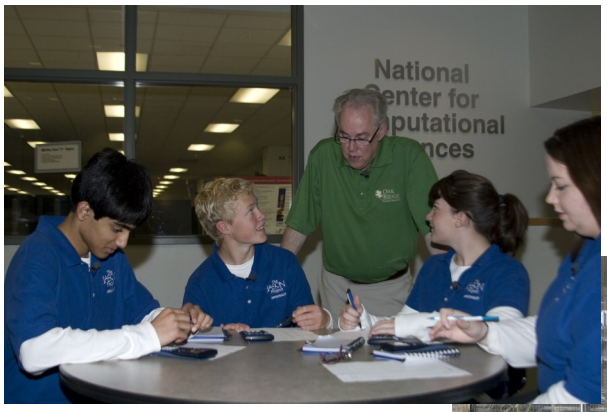


Figure 4. (top left) *Jim Hack and Jason Argonauts calculate average temperature over time.*

Figure 5. (below) *Argonauts conduct field measurements with ORNL scientists.*

Figure 6. (top right) *Argonauts on tour at the National Center for Computational Sciences.*

(Images courtesy of the Jason Project.)

CALENDAR

Strategic Environmental R&D Program Annual Symposium (Washington, DC)...30 Nov—2 Dec 2010
American Geophysical Union Fall Meeting (San Francisco, CA) ……....13-17 December 2010
91st Annual Amer. Meteorological Society Meeting (Seattle, WA)…..……...…….. 23-27 January 2011
AmeriFlux Science Meeting & 3rd NACP All-Investigators Mtg (New Orleans)…. 31 Jan—4 Feb 2011
Amer. Assoc. for the Advancement of Science Annual Meeting (Washington, DC)…...17-21 Feb 2011
Colorado Conference on Earth System Governance (CSU, Fort Collins, CO)…….17-20 May 2011
Fifth Intl. Conf on Flood Management (Tsukuba, Japan)…..…….27-29 September 2011

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RECENT DATA PRODUCTS

LBA-ECO LC-09 Landsat TM and ETM+ Data, Sites in Rondonia and Para, Brazil: 1985-2004. Data set prepared by E.S. Brondizio and E.F. Moran. http://dx.doi.org/10.3334/ORNLDAAC/987.

LBA-ECO LC-09 Natural, Infrastructure, and Boundary Features, Amazonian Sites, Brazil. Data set prepared by E.S. Brondizio, M. Batistella, and E.F. Moran. http://dx.doi.org/10.3334/ORNLDAAC/986.

ORNL DAAC has added the following data sets to its Spatial Data Access Tool (SDAT):
'LBA-ECO CD-06 Land Use/Land Cover Time Series, Ji-Parana Basin, Brazil: 1986-2001'.
'ISLSCP II Continuous Fields Of Vegetation Cover, 1992-1993'
Nitrogen deposition onto the United States and Western Europe

Coming in November

Highlighted Researcher: Bruce Wilson
Highlighted Research: North American Carbon Program (NACP)

RECENT PUBLICATIONS

Angly F.E., D. Willner, A. PrietoDavo, R.A. Edwards, R. Schmieder, R. Vega Thurber, D.A. Antonopoulos, K. Barott, M.T. Cottrell, C. Desnues, E.A. Dinsdale, M. Furlan, M. Haynes, M.R. Henn, Y. Hu, D.L. Kirchman, T. McDole, J.D. McPherson, F. Meyer, R.M. Miller, E. Mundt, R.K. Naviaux, B. Rodriguez Brito, R. Stevens, L. Wegley, L. Zhang, B. Zhu, F. Rohwer. 2009. The GAAS Metagenomic tool and its estimations of viral and microbial average genome size in four major biomes. PLoS Computational Biology 5(12): e1000593.

Bailey VL, SJ Fansler, S Bandyopadhyay, JL Smith, KM Waters, and H Bolton, Jr. (2010). Direct detection of soil mRNAs using targeted microarrays for genes associated with lignin degradation. Soil Biology and Biochemistry 42:1793-1799.

Bailey VL, SJ Fansler, H Bolton, Jr, and JL Smith (2010). Modifications of soil- and purified-enzyme activities by biochar. Soil Biology and Biochemistry (in press).

De Graaff M-A, AT Classen, HF Castro and CW Schadt. Labile soil carbon inputs mediate the soil microbial community composition and plant residue decomposition rates. New Phytologist (in press).

Devarakonda, R., Palanisamy, G., Green, J.M,. Wilson B.E., (2010) "Scientific data searching, sharing and retrieval" Earth Science Informatics Accepted for publication.

Garten CT, Iversen CM, Norby RJ. 2010. Litterfall 15N abundance indicates declining soil nitrogen availability in a free air CO2-enrichment experiment. Ecology, (in press).

Garten Jr CT, Wullschleger SD, Classen AT. (2010) Review and model-based analysis of factors influencing soil carbon sequestration under hybrid poplar. Biomass and Bioenergy (in press).

Gassman, P.W., J.R. Williams, X. Wang, A. Saleh, E. Osei, L.M. Hauck, R.C. Izaurralde, J.D. Flowers (2010). The Agricultural Policy Environmental EXtender (APEX) model: An emerging tool for landscape and watershed environmental analyses. Trans. ASABE (in press).

Hanson PJ, Childs KW, Wullschleger SD, Riggs JS, Thomas WK, Todd DE and Warren JM (in press) A method for experimental heating of intact soil profiles for application to climate change experiments. Global Change Biology ??:???-???, doi: 10.1111/j.1365-2486.2010.02221.x

Iversen CM, Hooker T, Classen AT, Norby RJ. Net mineralization of N at deeper soil depths as a potential mechanism for sustained forest production under elevated [CO2]. Global Change Biology DOI: 10.1111/j.1365-2486.2010.02240.x.

Kardol P, Campany CE, Souza L, Norby RJ, Weltzin JF, Classen AT (2010) Climate change effects on plant biomass alter dominance patterns and community evenness in an experimental old-field ecosystem. Global Change Biology 16:2676-2687 doi: 10.1111/j.1365-2486.2010.02162.x

Lee JW, Kidder M, Evans BR, Paik S, Buchanan III AC, Garten CT, Brown RC. (2010) Characterization of biochars produced from cornstovers for soil amendment. Environmental Science and Technology 44: 7970-7974.

Marland, G., 2010. Accounting for carbon dioxide emissions from bioenergy systems, Journal of Industrial Ecology, in press

Miller, R.M., M.S. Fitzsimons (2011). Fungal growth forms in soil. In: Architecture and Biology of Soils. (ed. K. Ritz, I.M. Young), CABI publishers (in press).

Miller, R.M., Wilson, GWT, Johnson, NC. Grassland Mycorrhizas. In: D. Southworth, editor. Plant-fungal interactions--interdependence between plants and fungi. Wiley-Blackwell, New York (in press).

Norby RJ, Warren JM, Iversen CM, Medlyn BE, McMurtrie RE. 2010. CO2 enhancement of forest productivity constrained by limited nitrogen availability. Proceedings of the National Academy of Sciences 107: 19368-19373. (published online in October, in print in November)

Shirley, K., E. Marland, J. Cantrell, and G. Marland, 2010. Managing the costs of carbon for durable, carbon-containing products. Mitigation and Adaptation Strategies for Global Change, in press

Smith JL, HP Collins, and VL Bailey (2010). The effect of biochar on soil respiration.Soil Biology and Biochemistry 42: 2345-2347.

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