Climate Change SCIENCE INSTITUTE

# Newsletter

JULY 2010 VOLUME 1, ISSUE 3

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

## LETTER FROM CCSI LEADERSHIP

We continue to transition CCSI from our initial concept almost a year ago to full reality.

This summer witnessed the acquisition of the NOAA HPC system, the addition of several new staff members, and the appointment of formal leads for two of the four CCSI Research Themes. Peter Thornton was named as the Lead for Terrestrial Ecosystem and Carbon Cycle Research Theme, and Ben Preston was named Lead for Climate Impacts, Adaptation, and Vulnerability Science. In addition, we await the arrival of Danny McKenna, who will become the Computational Earth Sciences Group Lead.

The next two months will bring more exciting changes to the CCSI including our consolidation of approximately 85 staff into the new Pro2Serve building at 1st and Bethel Valley Road. A key goal in this consolidation is to alleviate any remaining confusion for our staff, partners and stakeholders regarding the role of the Institute at ORNL. The space was specifically designed to enhance multi-disciplinary collaboration and creativity, which will generate new opportunities in climate change science as well as excitement about our work.

As was announced in the last newsletter, we will host the CCSI's Science Advisory Board (SAB) in late September to obtain feedback from a cross-disciplinary team of experts on our strategy and plans. This will also be a great opportunity for the SAB to meet many of our scientists during the poster session that is planned to showcase CCSI's work.

## MIKE KUPERBERG VISIT

***Figure 1.*** *Paul Hanson (center) explains the various features and functions of the SPRUCE prototype for Mike Kuperberg (far right) and Sharlene Weatherwax (back right). Also participating in the tour was Martin Keller (Associate Lab Director for Biological and Environmental Sciences Division)*

On July 9, 2010, Paul Hanson hosted a site visit by Sharlene Weatherwax and Mike Kuperberg, both with DOE's Biological and Environmental Research program, to the SPRUCE prototype (Spruce and Peatland Responses Under Climatic and Environmental Change). This was the first visit to the prototype when the air-circulation system was functioning. Paul also invited all the contributing ORNL staff, including engineers and computational scientists who modeled the air flow within the structure to help with design parameters. This allowed Paul to thank them for their successes with our BER sponsors present. Earlier, Paul hosted Paul Sloan and some of his staff from the Tennessee Department of Environment and Conservation. There will be an opportunity for CCSI staff to visit the prototype at the end of the Science Advisory Board meeting this September. Look for an upcoming announcement with more details.

During Mike's visit, he also explored the PiTS site (Partitioning in Trees and Soil ). PiTS is a field research facility for developing dynamic C and N partitioning representations for global models and applications, led by Rich Norby, Colleen Iversen, and Jeff Warren. Look for additional information on PiTS in a future newsletter. Mike spent time with staff across all the Science Forcing Areas (Forcing, Response, and Mitigation).

***Figure 2.*** *Paul Hanson demonstrates for Mike Kuperberg the deployment of temporary walkways to access vegetation in a repeated yet non-destructive manner.*

**MEETING REMINDER**

**Science Plan Meeting, Next-Generation Ecosystem Experiments (NGEE – Arctic)**
Friday, August 20th from 1-2 PM in Building 1059, Room 110
For additional information, contact Stan Wullschleger (574-7839 ).

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# Highlighted Researcher PETER THORNTON

*Peter's interests originally lay outside of the climate arena as he received his bachelor's in Biomedical Engineering from The Johns Hopkins University, leading to an interest in physiological feedback systems. Undergraduate courses in plant geography led to a summer field program in ecology in the Rocky Mountains, where the notion of merging feedback research with ecological modeling began to take root. Peter went on to earn his master's in Geography and Environmental Engineering at Johns Hopkins, studying the paleoecology of Chesapeake Bay salt marshes under Professor Grace Brush. He moved to the University of Montana and received his PhD under Professor Steven Running in the School of Forestry, applying his numerical modeling skills to the development of new land biogeochemistry and biometeorology models. Prof. Running was an important influence in introducing Peter to climate modeling, and after 10 years in Montana, Peter and his family moved to Colorado to work at NCAR on land biogeochemistry model development. According to Peter, "I could never have predicted this path as an engineering student analyzing amplifier circuits, but it has turned out to be very satisfying – I'm glad to be able to make useful contributions to a community research effort like CCSM." That work continues as a theme of Peter's research efforts in his new position in ORNL's CCSI.*

*Peter has two children and is married to Michele who supports the NASA-DAAC project at ORNL. In his free time, Peter enjoys a wide variety of interests including skiing, hiking, camping and woodworking as well as guitar, voice and piano.*

Peter Thornton works at the intersection of climate science and terrestrial ecosystems, integrating current knowledge on the carbon cycle and biogeochemical dynamics with predictive models of climate dynamics and climate change.

Peter is part of the Ecosystem Simulation Science group and was also appointed earlier this year as Lead for CCSI's Terrestrial Ecosystem and Carbon Cycle Research Theme.

Peter has been honored as a National Merit Scholar and as a Global Change Research Fellow (National Aeronautics and Space Administration [NASA]). He recently shared the Community Climate System Model (CCSM) Distinguished Achievement Award as part of the Land Model Working Group. Peter serves on science advisory boards for the North American Carbon Program, the AmeriFlux Network, and the Carbon Dioxide Information Analysis Center, and was recently selected as a Lead Author on the upcoming Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report.

Peter's current work includes several collaborative, cross-disciplinary projects, for some of which he is the principal investigator (PI).

**PI for Climate Change Forcing Science Focus Area (FY10-12)** The goal of this project is to understand and predict the global terrestrial ecosystem forcing of the Earth's climate, focusing on how terrestrial ecosystem processes vary with climate change, and how those processes interact to affect atmospheric $CO_2$. The project team's approach is to integrate observation, experimentation, and modeling to evaluate and improve terrestrial ecosystem components of climate change predictions. They use multi-scale model evaluation and data assimilation methods to identify sensitive and poorly-constrained model parameterizations or process representations, then design and implement observations and experimentation to provide the data critical to resolving these uncertainties. This is an iterative process, and they are in the midst of the first data-model evaluation cycle.

An experiment is underway, led by Rich Norby and Colleen Iversen, to provide information on uptake and allocation of carbon and nutrients. Leaf and stand-level measurements of photosynthesis and carbon exchange are being made at a deciduous forest site, and synthesized for a large number of similarly instrumented sites (efforts led by Lianhong Gu). Isotope studies are being carried out to track the fate of above- and below-ground litter inputs through multiple forest ecosystems (work led by Paul Hanson and Chuck Garten). Multiple observational data streams are being integrated in a data assimilation framework to provide quantitative uncertainty estimates and optimized parameter values for models of varying complexity (led by Mac Post and Dan Ricciuto). Gregg Marland is leading an effort to increase spatial and temporal resolution in fossil fuel emissions, a critical component for running and evaluating global-scale coupled carbon-climate simulations.

**Local PI for Improving the Representations of Human-Earth Interactions (FY09-14)** The goal of this project is to strengthen the coupling between Earth System Models (ESMs) and Integrated Assessment Models (IAMs). The project team's long term vision is to integrate the economic and human dimension modeling of IAMs within fully coupled ESMs. By doing so, they will improve scientific understanding of the human-Earth system dynamics such as the interactions and feedbacks leading to the timing, scale, and geographic distribution of emissions trajectories and other human influences, corresponding climate effects, and the subsequent impacts of a changing climate on human and natural systems. This project is lead by Pacific Northwest National Laboratory (PNNL) and includes collaboration with Lawrence Berkeley National Laboratory (LBNL). The ORNL effort is focused on integration of prognostic land use and land cover change components from an IAM into the CCSM. This research will identify and quantify the inconsistencies in future climate change trajectories introduced by the standard approach of uncoupled land use change prediction, and then demonstrate the effects of eliminating those inconsistencies. Later in the project, the team will address similar inconsistencies arising from off-line calculation of energy supply and demand. Results will be critical in establishing uncertainty bounds for climate change trajectories considered in the upcoming IPCC Fifth Assessment Report.

**Lead PI for Quantification and Reduction of Critical Uncertainties Associated with Carbon Cycle-Climate System Feedbacks (FY10-13)** The objectives of this recently funded project are to quantify critical uncertainties in global climate prediction associated with carbon-climate feedbacks, to improve understanding of critical feedback processes in the tropics, temperate, and arctic zones, and to extend our data-based evaluation capabilities to quantify carbon-climate feedbacks in a large population of models contributing to the IPCC Fifth Assessment Report. LBNL and Los Alamos National Laboratory (LANL) are partners on this project.

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**Prognostic Land-Use and Land-Cover for a Coupled Climate-Biochemisty Model (FY09-10)** The purpose of this project was to explore the coupling of an integrated assessment model to the land component of CCSM. The team has performed a series of partial coupling experiments, with final fully-coupled experiments underway now. This Laboratory Directed Research and Development (LDRD) project laid the foundations for the successful multi-laboratory proposal that resulted in ORNL's current IAM-ESM integration project with PNNL and LBNL (Improving the Representations of Human-Earth Interactions).

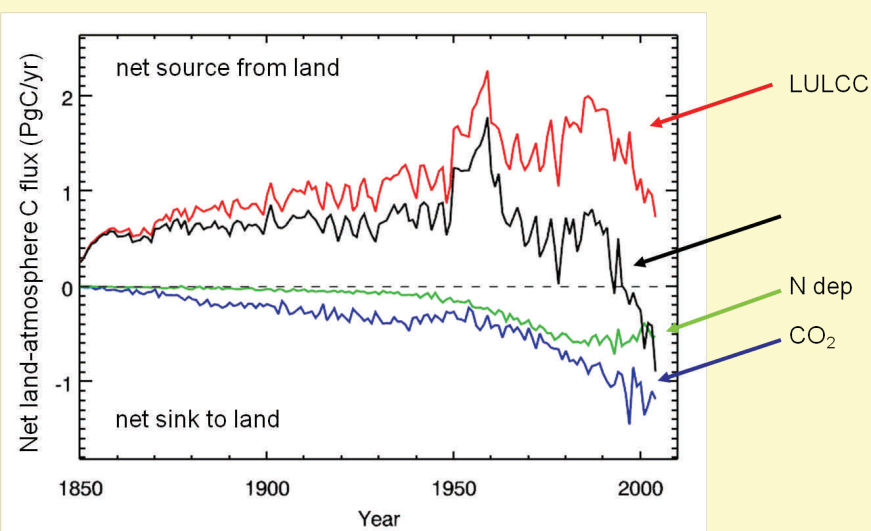
***What role does your research play in climate change research?*** "I'm working at the intersection of biogeochemistry, land-atmosphere interactions, and human modification of land use and land cover. My most important contribution to our understanding of climate change is to show, through modeling, that interactions among climate, the carbon cycle, nutrient cycles, and land use can exert significant control over the trajectory of atmospheric $CO_2$ concentration in predictions of likely climate change over the coming century. Building on that finding, I am now developing collaborations with experimentalists and observationalists to help evaluate and constrain the representation of ecological processes which seem to be required for accurate future climate change predictions."

***Who is the customer for your research?*** "My research serves two communities. First, I bring expertise in the synthesis of ecological process knowledge and its representation in numerical models to the climate change modeling community. Second, I provide a conduit for new ecological knowledge to find appropriate application in climate and Earth system models. My efforts in both of these directions have supported national-scale model development and knowledge synthesis priorities at DOE, the National Science Foundation, NASA, and the U.S. Department of Agriculture."

***Why is it important to you, personally, to become involved in climate change research?*** "I feel a growing urgency about understanding and addressing our influence, as a species, on the climate system. I feel fortunate to have a combination of interests, skills, and experience that make it possible for me to contribute directly to improved understanding of likely future climate change. I think that people are willing to make changes to ensure a safe and healthy world for their kids and future generations, but there is still a lot of uncertainty about what outcome we should expect from a given course of action. Part of the responsibility for filling that gap belongs to the Earth science community, with increasing overlap with social sciences and the policy realm. I think that by working at the intersection of climate and biogeochemistry, and collaborating with social science and policy experts, I can make a positive contribution and provide the kind of information that will help people make responsible decisions."

***In what direction do you see the future of climate change research going?*** "As the human-caused climate change signal continues to emerge, to become more obvious in the face of natural variation, climate change research is likely to shift from diagnosis and attribution towards prognosis, impacts assessment, adaptation, and mitigation. We now know with a high degree of certainty that humans are causing the climate system to change. We must quickly improve our predictions of the spatial and temporal details of those changes, and place them in the context of simultaneous internal climate system variations. And we must accelerate our efforts to connect these predictions of the physical and biogeochemical aspects of the climate system to humans, socio-economics, and decision-making. Multiple research and policy communities which have worked mostly in isolation are converging on the same point. Sometimes, I think the future of this research looks like a six-way intersection in a crowded city – the occasional fender-bender, but with practice, good will, and a few brave souls with orange vests and whistles, people get where they need to go."

## Single-factor experiments with CLM4




Individual influences can be tracked separately through simulations to help explain the overall human influence in terms of net carbon fluxes between land ecosystems and the atmosphere. Positive values indicate a net loss of carbon from land (tending to increase atmospheric $CO_2$), and negative values indicate a net accumulation of carbon on land (tending to decrease atmospheric $CO_2$). The individual factors shown here are the influence of rising $CO_2$ concentration on land biosphere ($CO_2$), the influence of increasing mineral nitrogen deposition (N dep), and the influence of land-use and land-cover change (LULCC). Simulation results from all factors considered together are also shown.

***Figure 3.*** *Global effects of human influences on the climate system*

# Highlighted Research

## IMPACTS, ADAPTATION AND VULNERABILITY

Of the various scientific endeavors associated with global climate change, perhaps the one that is the most societally-relevant, but least well-defined, is that of impacts, adaptation and vulnerability (IAV). The growing international investments in both climate science and climate policy are ultimately a function of concern for the potential consequences that climate change poses to human and ecological systems. Yet effective methods for building a robust understanding of such consequences in a manner that is relevant to decision-makers are often elusive.

Generally, IAV research focuses on understanding the consequences of climate change (impacts), the factors that make systems more or less susceptible to those consequences (vulnerability), and the available policies and measure for reducing adverse consequences and/or capitalizing on potential opportunities (adaptation). Such knowledge also informs the national and international discourses on greenhouse gas mitigation policy, as future emissions and climate impacts are inextricably linked. As such, IAV research tends to be inherently interdisciplinary as it attempts to link biophysical sciences with social sciences and economics within a broader context of decision-making. Nevertheless, continual innovation and discovery within individual disciplines is necessary for ensuring new tools and methods are available for IAV applications.

At the moment, demand for insights regarding the implications of climate change is expanding rapidly, necessitating investments in IAV science and its delivery to keep pace with the needs of end users. The federal Office of Management and Budget recently identified IAV research as a critical science and technology challenge to be addressed within the 2012 budget. Other recent federal developments including the National Academy of Sciences' *America's Climate Choices* study and the Interagency *Climate Change Adaptation Task Force* have highlighted the importance of IAV research for the development of a climate-resilient nation.

CCSI is well-placed to lead national IAV research efforts. ORNL has and will continue to play a prominent role in national and international IAV assessment efforts including contributions to U.S. national, regional, and sectoral assessments of the implications of climate change as well as the Intergovernmental Panel on Climate Change's assessment reports. Furthermore, ORNL has a critical mass of world-class scientific capabilities in global and regional climate modeling, environmental informatics, geography, and scenario development that are critical for effective IAV research.

In coming years, the ORCCSI's IAV theme aims to continue to develop these capabilities and apply them in IAV studies across a range of domains. Of particular interest at the moment is research to better characterize climate extremes, including methods for simulating extreme events in a changing climate and the quantification of uncertainty in such simulations. Figure 4, for example, illustrates work by ORNL researchers examining the projected effects using a particular emission scenario for driving global circulation models. Understanding climate impacts to critical systems and infrastructure, such as energy, water resources,

*(Continued on page 5)*

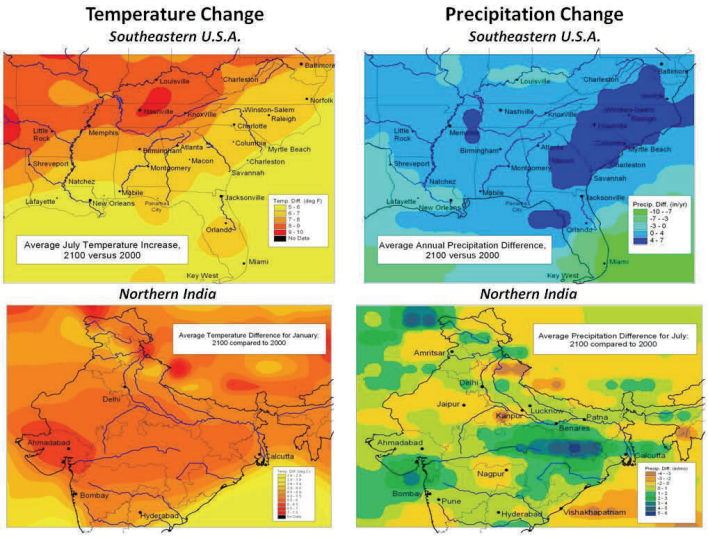



***Figure 4.*** *Projected effects of the Special Report on Emissions Scenarios (SRES) A1fi scenario on two regions by 2100. SRES was prepared by the Intergovernmental Panel of Climate Change for the Third Assessment Report in 2001.*

## CCSI WELCOMES NEW STAFF

**Dr. Willis Shem** joined ORNL in August as a postdoctoral fellow in the Environmental Sciences Division after previously working as a postdoctoral research associate at the University of Georgia's (UGA) Department of Geography Climate Research Program. Shem's most recent research at UGA was focused on dynamical downscaling of Atmosphere Ocean General Circulation Mode climate products with the aim of assessing climate change impacts on selected United States Forest Service sites in the southeastern United States. Prior research at UGA included evaluations of the impact of land use change on convective precipitation over the Atlanta metropolitan region.

Shem holds a BS in meteorology from the University of Nairobi, a Master of Engineering in water resources technology from Vrije Universiteit Brussels, as well as an MS and PhD in Earth and Atmospheric Sciences from the Georgia Institute of Technology. Other activities in his career have included participation in the building of a decision support system for the Lake Victoria Water Resources Management through the Georgia Water Resources Institute and hydrological modeling work for the Nile Basin Initiative. Shem will be assisting CCSI in building research tools that will maintain focus on high-resolution climate forecasting that can be applied in climate change impacts analysis.

**Dr. Gautam Bisht** received his PhD from Massachusetts Institute of Technology in Environmental Hydrology, and his MS in Environmental Hydrology from the University of Cincinnati, and Bachelor of Technology from the Indian Institute of Technology, Kanpur. Bisht's research focuses on regional scale feedbacks between the atmosphere and vegetation, controlled by topography and soil moisture. As a part of his PhD., he coupled a physically-based ecohydrology model with the Weather Research and Forecasting model while utilizing high-performance computing. Additionally, he has developed methodology to estimate the surface net radiation budget using remotely sensed data. Over the next two years, Bisht will be working on evaluating modeled carbon fluxes using the Carbon Land Model-CN model, as a part of NACP Interim Site Synthesis project. He will also be working on the development of the Integrated Earth System Model by incorporating the Global Climate Change Model within CCSM/CLM.

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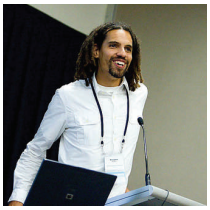
## IAV *(Continued from page 4)*

and transport, is another key focus of the IAV theme. ORCCSI is partnering with PNNL on a DOE grant to develop a regional integrated assessment model for the Gulf Coast region to simulate the dynamic interactions among climate, water, land, and energy systems. CCSI has also seen strong interest from the Department of Defense in IAV applications related to human and national security implications of climate change. ORNL's contribution to the Quadrennial Defense Review is just one example of the lab's accomplishments in delivering relevant science to the defense community. Finally, ORCCSI will also continue to leverage the laboratory's expertise in ecosystem science to better understand the consequences of climate change for ecosystem productivity, biodiversity, and land use.

CCSI is actively exploring new pathways through which ORNL's scientific capabilities can support novel IAV research of national significance. Strategic planning is underway to define CCSI's research niche in the IAV arena and identify opportunities for greater collaboration within ORNL as well as in partnership with external institutions.

# Recent Conferences and Workshops

### CLIMATE ADAPTATION GOES MAINSTREAM



Climate change adaptation researchers from around the world recently gathered in Queensland, Australia for the 2010 International Climate Change Adaptation Conference, organized by the National Climate Change Adaptation Research Facility and the CSIRO's Climate Adaptation Flagship. With nearly 1,000 individuals in attendance, the conference represented the largest gathering to date of researchers working in the impacts, adaptation, and vulnerability arena. The conference sessions spanned diverse topics, from climate data delivery systems to risk communication to the economics of adaptation. CCSI was represented by Dr. Benjamin Preston, leader of the CCSI's Impacts, Adaptation and Vulnerability Research Theme. Preston convened a session with Dr. Roger Jones of Victoria University entitled 'New Concepts in Adaptation', which featured several presenters from the U.S., U.K., and Australia on cross-cutting challenges associated with adaptation science and policy. Preston also gave a talk in a separate session entitled "Partner or Perish: Regional Governance for Local Adaptation", which focused on the role of regional institutions for delivering climate information and facilitating climate adaptation at the local level. Given the success of the conference, a follow-up event is being planned for 2012 in Phoenix, which will provide an opportunity for greater participation of CCSI researchers.

www.nccarf.edu.au/conference2010/

### SUCCESSFUL ESIP MEETING IN KNOXVILLE

The 12th summer meeting of the Federation of Earth Science Information Partners (ESIP Federation) was held at the University of Tennessee Conference Center in Knoxville, July 20-23. The meeting had a record attendance of over 200, which is 40 more than the previous summer meeting attendance record last year in Santa Barbara. The meeting featured a plenary presentation by ORNL's Tom Wilbanks, followed by a presentation by Eileen Shea from NOAA. At least 25 ORNL staff participated in the meeting, many presenting in various sessions, with Bruce Wilson and Chris Lenhardt serving as ORNL's local hosts for the meeting. This meeting was the launch for the Energy Cluster within ESIP, which is intended as a collaboration focal point for data and information projects broadly relating to energy applications. Many positive comments have been received, and the meeting was an excellent opportunity to highlight ORNL science for a wide range of collaborators, potential collaborators, and agency representatives from NASA, NOAA, EPA, and USGS.

### CCSM CONFERENCE

The Community Climate System Modeling (CCSM)/CESM held its 15th Annual Workshop this June in Breckenridge, CO where ORNL was well represented. The CCSM project is now the Community Earth System Model project, to more accurately reflect the modeling system's simulation capabilities brought to fruition in the most recent model release this spring. ORNL's terrestrial carbon cycle modeling research, described at the meeting by Peter Thornton, was a major contributor to the newest Community Land Model release. Kate Evans and Jim Hack described plans by a multi-lab partnership led by ORNL to dramatically increase the atmospheric model's horizontal resolution to faithfully simulate weather-scale phenomena, a major goal of the project. Pat Worley and others from the multi-lab SciDAC CCSM Consortium project were instrumental in completely restructuring the model's framework to execute efficiently on leadership class computers, such as Jaguar. The meeting further highlighted ORNL's role as a valued and reliable partners in the CESM enterprise.

### SciDAC CONFERENCE

The SciDAC 2010 Conference, this year's annual meeting of scientists participating in DOE's Scientific Discovery through Advanced Computing Program, was held July 11-15 in Chattanooga, Tennessee. As in previous years, climate research was a prominently featured application area, and ORNL's contributions were highlighted in both oral and poster presentations. In the HPC Performance session, CCSI's Pat Worley discussed performance portability and optimization for strong scaling using the Community Earth System Model (CESM) as a case study. Three oral presentations made up the technical session on climate, chaired by Phil Jones of LANL. First, Esmond Ng of LBNL described the Ice Sheet Initiative for Climate Extremes (ISICLES), a new SciDAC project to which CCSI's Kate Evans contributes. Second, CCSI's Peter Thornton presented preliminary results of single-forcing factor experiments performed with CESM to evaluate climate-biogeochemistry feedbacks in the model. Third, Todd Ringler of LANL gave a talk on a multi-resolution approach to climate modeling, which is the focus of the Model for Prediction Across Scales project. Among climate-focused poster presentations were two DOE lab-based projects, one from Rao Kotamarthi of ANL about scaling ARM surface energy flux measurements, and one describing the HOMME Cubed-Sphere Atmospheric Dynamical Core presented by Kate Evans.

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## RECENT PUBLICATIONS

Wang, D., W. M. Post, B. E. Wilson (in press). Several Computational Opportunities and Challenges Associated with Climate Change Modeling. Computing in Science and Engineering.

Mahowald, N., K. Lindsay, D. Rothenberg, S.C. Doney, J.K. Moore, P.E. Thornton, J.T. Randerson, I. Fung, C.D. Jones (in press). Desert dust and anthropogenic aerosol interactions in the Community Climate System Model coupled-carbon-climate model. Biogeosciences Discussions.

Marland, G. (submitted). Invited commentary on geoengineering. Issues in Science and Technology.

Yang B., S.G. Pallardy, T.P. Meyers, L.H. Gu, P.J. Hanson, S.D. Wullschleger, M. Heuer, K.P. Hosman, J.S. Riggs and D.W. Sluss (2010) Environmental controls on water use efficiency during severe drought in an Ozark Forest in Missouri, USA. Global Change Biology 16:2252 2271 DOI: 10.1111/j.1365-2486.2009.02138.x

Gunderson, C.A., K.H. O'Hara, C.M. Campion, A.V. Walker, and N.T. Edwards (2010) Thermal Plasticity of photosynthesis: The role of acclimation in forest responses to a warming climate. Global Change Biology 16:2272-2286 DOI: 10.1111/j.1365-2486.2009.02090.x

Kardol P., D.E. Todd Jr., P.J. Hanson, and P.J. Mulholland (2010) Long-term successional forest dynamics: species and community responses to climatic variability. Journal of Vegetation Science 21:627-642.

## RECENT DATA PRODUCTS

Blasing, T.J., updated a very popular atmospheric database, the AGAGE database, in the CDIAC data collection through September 2009.

Kaiser, D. and B. Jackson updated CDIAC's data files and user interface for NOAA's United States Historical Climatology Network (USHCN) Database through 2009.

**Coming in August!**

Data Archives—strategic vision for the future
Highlighted Researcher: Galen Shipman
Update on NOAA Computer Installation

*Developing and executing programs for the multi-agency, multi-disciplinary climate change research partnerships at Oak Ridge National Laboratory.*

## CALENDAR

PROMITHEAS, The Energy and Climate Change Policy Network (Athens) ..…….. 7-8 October 2010
17th AMS Conference on Air-Sea Interaction (Annapolis, MD) ……...….. 27 Sept-1 Oct 2010
Climate Adaptation in the Nordic Countries: Science, Practice, Policy (Stockholm) …8 -10 Nov 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
Amer. Assoc. for the Advancement of Science Annual Meeting (Washington, DC)…...17-21 Feb 2011
Fifth Intl. Conf on Flood Management (Tsukuba, Japan)…..……27-29 September 2011

## CURRENT CCSI JOB OPPORTUNITIES

We seek motivated individuals across a range of educational and professional experience including M.S. through Ph.D. academic qualifications at junior, as well as senior levels of experience to address some of the most pressing questions in global climate change science. You can view complete position descriptions and apply at http://jobs.ornl.gov .

- Deputy Division Director— Environmental Sciences
- Climate Computational Scientists
- Postdoctoral Research Associates