CLIMATE CHANGE SCIENCE INSTITUTE

FY 2013 Annual Report

Climate Change Science Institute
AT OAK RIDGE NATIONAL LABORATORY

OAK RIDGE National Laboratory

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MISSION STATEMENT

Advancing knowledge of the Earth system, describing the consequences of climate change, and evaluating and informing policy responses to climate change.

For more information, please go to http://climatechangescience.ornl.gov/.

Oak Ridge National Laboratory conducts basic and applied research and development to create scientific knowledge and technological solutions that strengthen the nation's leadership in key areas of science; increase the availability of clean, abundant energy; restore and protect the environment; and contribute to national security.

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6283, is managed by UT-BATTELLE, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

Major funders of CCSI research projects include the Department of Energy Office of Science's Biological and Environmental Research Program and its Advanced Scientific Computing Research Program; the U.S. Geological Survey; the National Aeronautics and Space Administration; the National Oceanic and Atmospheric Administration; and the Environmental Protection Agency.

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Collaborators of the Climate Change Science Institute at Oak Ridge National Laboratory

Strategic collaborations are critical in achieving the vision of the Climate Change Science Institute at Oak Ridge National Laboratory. Through collaborations, institute scientists leverage knowledge and resources to accelerate insights about the Earth system that can guide policy and action. Collaborators include:

Department of Energy National Laboratories

Argonne National Laboratory
Brookhaven National Laboratory
Los Alamos National Laboratory
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Pacific Northwest National Laboratory
Sandia National Laboratories
National Renewable Energy Laboratory

Universities

Boise State University
Duke University
Florida International University
Florida State University
Georgia Institute of Technology
Harvard University
Iowa State University
Johns Hopkins University
Lund University (Sweden)
Massachusetts Institute of Technology
New York University
Purdue University
Rutgers University
San Diego State University
Texas A&M University
University of Alaska–Fairbanks
University of Alberta (Canada)
University of California–Berkeley
University of California–Davis
University of California–Irvine
University of Florida
University of Guelph (Canada)
University of Illinois–Chicago
University of Michigan
University of Minnesota
University of Nebraska–Lincoln
University of New Hampshire
University of Oregon
University of Prince Edward Island (Canada)
University of Puerto Rico
University of Sydney (Australia)
University of Tennessee–Knoxville
University of Utah
University of Virginia
University of Victoria (Canada)
University of Wisconsin–Baraboo/Sauk County
University of the Sunshine Coast (Australia)

National Agencies

National Aeronautics and Space Administration
National Center for Atmospheric Research
National Oceanic and Atmospheric Administration
National Science Foundation
U.S. Army Cold Regions Research and Engineering Lab
U.S. Department of Agriculture
USDA Forest Service
USDA Land Management and Water Conservation Research
U.S. Global Change Research Program
U.S. Geological Survey

Other Partners

Barrow Arctic Science Consortium
DuraSpace

Letter from the Director

Community Matters

User-inspired research can advance discovery and innovation and serve society

Greetings, and welcome to the Climate Change Science Institute's Annual Report. The report highlights CCSI accomplishments over the past year. It was my great privilege to become the first full-time CCSI director in October 2013. I was drawn to this position by ORNL's long-term commitment to environmental and climate research and the caliber of CCSI's people and their focus on both advancing climate science and helping society. In my brief time here, that commitment to excellence and service continues to be evident, and I'm honored to be here. Before getting to the report, I would like to thank the Oak Ridge National Laboratory leadership for the opportunity to help lead CCSI into the future, in particular James Hack. In addition to his duties as the director of ORNL's National Center for Computational Science, Jim led CCSI from 2009 until I came on board. I'm grateful for the world-class cross-disciplinary research organization that Jim and Gary Jacobs created, for Jim's recruiting me and trusting me with its legacy, and for his continued generosity of time and energy.

With respect to the climate, this is an uncertain time. This report covers a period during which the atmospheric carbon dioxide concentration reached a milestone of 400 parts per million—a level exceeding both the 350 ppm posited as safe by many prominent climate scientists and above the worst-case scenarios explored by the Intergovernmental Panel on Climate Change. Elevated atmospheric carbon dioxide drives a warmer world and possibly weather extremes like this past year's deadly destruction from Sandy, the second-costliest hurricane in U.S. history, and Haiyan, one of the most intense tropical cyclones ever, which devastated parts of Southeast Asia. Despite positive developments in the U.S. federal government during this period—notably President Obama's Climate Action Plan and Department of Energy Secretary Moniz's focus on domestic climate and energy policy—much remains to be done.

People who operate companies and oversee communities are struggling to plan for reliable and resilient access to food, water, housing, transportation, health services, national security, and energy in the face of a changing climate. Stakeholders in the financial and relief sectors at all levels struggle to keep up with losses and changes that are happening at a speed and scope that tax our ability to recover. Frustration continues to grow among our citizens, including a group of young people who have filed a lawsuit against the federal government for negligence in not adequately addressing the impact of climate change on our nation (www.ourchildrenstrust.org).

Jack D. Fellows, director, Climate Change Science Institute at Oak Ridge National Laboratory

I step into my new role as CCSI director against a backdrop of impending change for which society has yet to fully develop effective paths of response. The fact that the global climate situation is not improving underscores the critical nature of CCSI's work. CCSI's ecosystem-process work spans the microbial to global scales and feeds data into world-class modeling and simulation efforts. It curates thousands of diverse environmental and climate data sets and tools for their management. It is home to leading analysts who study the impacts of climate change on human and natural systems. Colocation and integration of these capabilities within CCSI create great potential to advance the science and provide accessible information and tools to help people deal with the consequences of climate change. At CCSI, we call this balance of advancing the science and service to society "user-inspired" research, and it permeates all that we do.

While CCSI serves primary sponsors, such as the Department of Energy and the National Aeronautics and Space Administration, it is committed to developing models and simulations, data sets, field experiments, and analytical resources that are accessible to the broader scientific community and other federal sponsors as well. A classic example is the Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) project, a long-term partnership of DOE, the U.S. Forest Service, and universities to collect, share, and model data about how boreal lands respond to a range of elevated carbon dioxide and temperature levels. Where possible, the SPRUCE site is made available to members of the ecosystem science community. We also expect our research products to provide value to societal stakeholders beyond the scientific community, whether private citizens, mayors or governors, or the President. There has never been a better time for user-inspired science-based solutions to the broad range of climate change challenges.

As you will see in the report, CCSI has been very active in DOE's Scientific Discovery through Advanced Computing program, which employs computationally advanced methods for component algorithms, software, performance, validation, and verification, typically involving collaboration between climate and computational scientists. This opportunity is designed to support university researchers collaborating with DOE laboratory scientists. University researchers can allocate up to 20 percent of their project support to national lab collaborators incorporating the academic science into the DOE model. DOE prioritizes development and analysis of high-fidelity and predictive models representing Earth and climate system variability and change, with a focus on the response of systems to natural and anthropogenic forcing. CCSI is also working with DOE in its development of an advanced climate model in support of DOE's energy mission, including effectively running that model on a broad range of supercomputers. These supercomputers are critical to answering questions that require very-high-resolution models.

As we continue to support DOE's mission needs, we intend to remain a solid partner for the climate science community, which includes modeling groups of the National Science Foundation's National Center for Atmospheric Research; NASA's Goddard Institute for Space Studies; and the Geophysical Fluid Dynamics Laboratory at Princeton University, a collaboration with the National Oceanic and Atmospheric Administration. We will continue collaboration on the development of the Community Earth System Model, a strong partnership of academia and government, and find the best way to design our respective models so both are useful to our users.

CCSI research integrates four fields—Earth system modeling; data integration, dissemination, and informatics; terrestrial ecosystem and carbon cycle science; and impacts, adaptation, and vulnerability science. Individually, these fields are crucial in meeting our mission. Collectively, they have the potential for great synergy in service to society. Our hope is that all of our sponsors feel they're getting a very high return for their investments in CCSI because of this integrative research environment. CCSI has not revised its strategic plan since its formation in 2009. Sponsor interests are changing, and so is the world. Thus we are revising our strategic plan and will be working with our sponsors and the CCSI Scientific Advisory Board to ensure we are focused on the highest priorities and needs facing the climate science community and the nation.

Just as our research is on the move, so are we—literally. In March 2014, CCSI researchers move to a brand new collaborative space at the center of the ORNL campus. We hope this move will catalyze interactions within CCSI and with other groups at ORNL that result in knowledge and tools for our generation and the next.

We hope you enjoy the report but, more important, that it sparks some ideas and partnership opportunities. The very best from all of us at CCSI.—*Jack Fellows*

CCSI Scientific Advisory Board

Theme 1: Earth System Modeling

Forrest Hoffman, Theme Leader

Venkatramani Balaji

Modeling Systems Group
Geophysical Fluid Dynamics Laboratory
Princeton University

Venkatramani Balaji heads the Modeling Systems Group serving developers of Earth system models at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory and Princeton University.

William Lapenta

Environmental Modeling Group, National Oceanic and Atmospheric Administration

William Lapenta is the director of the National Weather Service's National Centers for Environmental Prediction at NOAA. Lapenta's research interests include numerical modeling of the Earth/atmosphere system with specific interest in land–atmosphere interactions, land–surface data assimilation, and energy–water budgets associated with regional climate simulations.

David Williamson

Climate and Global Dynamics Division, National Center for Atmospheric Research

David Williamson is a senior scientist in the Climate and Global Dynamics Division at NCAR. His work focuses on analysis and initialization methods for numerical weather prediction.

Theme 2: Data Integration, Dissemination, and Informatics

Giri Palanisamy, Theme Leader

Robert Chen

Center for International Earth Science Information Network
Lamont-Doherty Earth Observatory
Earth Institute, Columbia University

Robert Chen is the director of the Center for International Earth Scientific Information Network, The Earth Institute, Columbia University.

Mike Frame

Scientific Data Integration and Visualization
Core Science Analytics and Synthesis
U.S. Geological Survey

Mike Frame is chief of Scientific Data Integration and Visualization, USGS. He is responsible for geospatial, informatics, and technology research and oversight within the organization.

Sara James Graves

Information Technology and Systems Center
Computer Science Department, University of Alabama in Huntsville

Sara James Graves is the director of the Information Technology and Systems Center, a University of Alabama System Board of Trustees university professor, and a professor of computer science at the University of Alabama in Huntsville.

Theme 3: Terrestrial Ecosystem & Carbon Cycle Science
Peter Thornton, Theme Leader

Peter Curtis

Department of Evolution, Ecology, and Organismal Biology, The Ohio State University

Peter Curtis is a professor and chair of the Department of Evolution, Ecology, and Organismal Biology at The Ohio State University. His research focuses on plant and ecosystem responses to global change, including rising atmospheric carbon dioxide, altered climatic drivers such as temperature and precipitation, and changes in land use and community composition.

Anna Michalak

Department of Global Ecology, Carnegie Institution for Science, Stanford University

Anna Michalak is a faculty member in the Carnegie Institution for Science's Department of Global Ecology at Stanford University. Her research interests focus on characterizing complexity and quantifying uncertainty in environmental systems with the goal of improving our understanding of these systems and our ability to forecast their variability.

Sasha Reed

Southwest Biological Science Center
U.S. Geological Survey

Sasha Reed is a scientist with the USGS and a member of the Southwest Biological Science Center. Her research interests are centered within the fields of biogeochemistry and ecosystem ecology.

Theme 4: Impacts, Adaptation, and Vulnerability Science
Ben Preston, Theme Leader

Virginia Burkett

SAB Chair 2014
Climate and Land Use Change
U.S. Geological Survey

Virginia Burkett is the chief scientist for Climate and Land Use Change at the USGS. Her research focuses on global change and low-lying coastal zones.

Noah Diffenbaugh

Stanford Woods Institute for the Environment
Department of Environmental Earth System Science, Stanford University

Noah Diffenbaugh is a center fellow in the Stanford Woods Institute for the Environment and an assistant professor in the Department of Environmental Earth System Science at Stanford University. His research interests are centered on the dynamics and impacts of climate variability and change, including the role of human activity in the climate system.

Anthony Janetos

Pardee Center for the Study of Longer-Range Future
Boston University

Anthony Janetos is the director of the Frederick S. Pardee Center for the Study of the Longer-Range Future and a professor of Earth and Environment at Boston University. His former affiliations were with the Joint Global Change Research Institute with the Pacific Northwest National Laboratory at University of Maryland. His research focuses on high-impact global change science and policy.

CCSI Board of Directors

Martin Keller, Associate Laboratory Director, Energy and Environmental Sciences Directorate, Oak Ridge National Laboratory

Jeff Nichols, Associate Laboratory Director, Computing and Computational Sciences Directorate, ORNL

Jay Gulledge, Director, Environmental Sciences Division, ORNL

James Hack, Director, National Center for Computational Sciences, ORNL

Director Biography

Meet Jack Fellows: Director of the Climate Change Science Institute at Oak Ridge National Laboratory

In October Jack D. Fellows, who oversaw a $110 billion federal science portfolio under two U.S. presidents and co-founded the U.S. Global Change Research Program integrating all federal Earth system science research programs, joined Oak Ridge National Laboratory to direct its Climate Change Science Institute. Martin Keller and Jeff Nichols, leaders of the Energy & Environmental Sciences Directorate and the Computing & Computational Sciences Directorate respectively, announced Fellows' appointment.

"Jack Fellows is a welcome addition to our climate change science program," said ORNL Director Thom Mason. "His extensive experience in directing research and education programs, most recently as vice president for the University Corporation for Atmospheric Research, will be particularly valuable as CCSI moves forward in its work of advancing the understanding of the Earth system, describing the consequences of climate change, and evaluating and informing policy on the potential outcomes of responses to climate change."

Fellows succeeds founding CCSI director James J. Hack, who came to ORNL in 2008 to direct the National Center for Computational Sciences and since 2009 has been directing both organizations. In 2013 UT-Battelle recognized Hack with its Director-Level R&D Leadership Award for exemplary leadership of both organizations. Hack will maintain his position as NCCS director. His CCSI involvement will continue as a new member of the institute's board of directors and as a scientist engaged in climate modeling and simulation studies. Moreover, he will remain a strong advocate for the institute's mission.

"We are extremely pleased that Jack has joined ORNL to take on the leadership of CCSI," Hack said. "He brings decades of high-quality experience in developing and leading large programs and interacting at the highest levels across government agencies engaged in the study of the climate system."

Career path

In 2012 Fellows founded G2Groups, LLC, to provide organizations with tools to improve their ability to lead and manage their organizations, and the Envirogen International Foundation to create the next generation of environmental leaders and citizen scientists. He currently serves as president of both and plans to remain active in the two organizations. "I'm hoping to incorporate some of EIF into the [ORNL] climate institute," he said.

Jack D. Fellows

In 1993 Fellows worked with Vice President Al Gore to create The Globe Program, which continues to operate in more than 112 countries and teaches children to take and analyze environmental measurements and use the data to address pressing environmental problems. From 2002 to 2012 Fellows served as the program's executive director and principal investigator.

From 1997 to 2012, he was vice president of the University Corporation for Atmospheric Research, a private, non-profit consortium of more than 100 universities that study weather and climate and embrace national- and community-level issues.

Fellows co-led the 2010 National Climate Adaptation Summit, which fostered a national-level discussion of effective adaptation strategies to respond to climate change and its impacts.

From 1984 to 1997 he served as branch chief in the Executive Office of the President for the Office of Management and Budget, where he oversaw budget, programs, and policy related to federal research and development programs including those of the National Aeronautics and Space Administration, the National Science Foundation and the Smithsonian. (Department of Energy programs were not in his purview.)

Fellows received doctorate (1984), master's (1976), and bachelor's (1975) degrees in civil engineering from the University of Maryland.

The author of 25 publications or presentations in fields including water resources, remote sensing, geographical information systems, and science and space policy, he is a member of the American Geophysical Union, American Meteorological Society, and National Academy of Science's Space Studies Board and Land Remote Sensing Committee.

His honors include a lifetime achievement award from the National Council for Science and the Environment and the 1997 Edward A. Flinn III Award, bestowed by the AGU for "unselfish cooperation in research." In 1983 and 1984 he advised members and committees of the U.S. Congress as an AGU Congressional Science Fellow.—*by Dawn Levy*

At a staff meeting to pass the baton of CCSI leadership, outgoing director James Hack, right, introduces his successor, Jack Fellows. Photo credit: Curtis Boles

FY 2013 Metrics for the Climate Change Science Institute at Oak Ridge National Laboratory

139	Scientific publications
291	Scientific presentations and seminars
177	Conferences or workshops attended
116	Community outreach, committee service, and service-to-the-profession activities
44	Leadership in national and international planning activities

Intergovernmental Panel on Climate Change Activities

Oak Ridge National Laboratory Scientists Contribute to Global Climate Assessment

Lab researchers instrumental in understanding causes, consequences of climate change

In 2013 and 2014 the United Nations' Intergovernmental Panel on Climate Change will issue reports detailing what the scientific community knows to date about global climate change. The first report, by Working Group I, detailed the current state of knowledge about the physical science basis of climate change. The second report, by Working Group II, will analyze impacts of and adaptation and vulnerability to climate change, and the third report, by Working Group III, will investigate mitigation. The fourth report will synthesize the findings in the Fifth Assessment Report, or AR5, to provide the scientific community's consensus about the state of the planet. Researchers in the Climate Change Science Institute at Oak Ridge National Laboratory contributed instrumentally to three of the four reports.

Peter Thornton

Paul Hanson

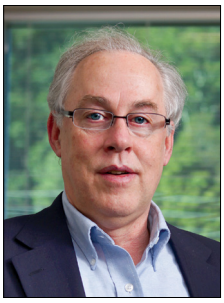
On Sept. 27 in Stockholm, Working Group I issued its Summary for Policymakers. An unedited version of the full science report was released online on Sept. 30. The edited report was published online in January 2014 and will be published in book form a few months later. ORNL's Peter Thornton was a lead author for Chapter 6, "Carbon and Other Biogeochemical Cycles." This chapter focuses on biogeochemical processes and feedbacks and the influence of rising greenhouse gas concentrations on the Earth system including its land ecosystems.

The Department of Energy asked ORNL's Paul Hanson to serve as a member of the U.S. government review panel of the Second Order Draft of the Working Group I and the Summary for Policy Makers. In that capacity he was the lead reviewer responsible for coordinating, presenting, and summarizing the input of a team of reviewers focusing on Chapter 6.

"It's reporting a critical uncertainty in our projections of future climate by examining carbon cycle–climate system feedback," Thornton said of his chapter. "It goes beyond what's been done in previous reports by adding other biogeochemical cycles for our consideration of these climate-system feedbacks. There's been an ongoing focus on the carbon cycle. "

Benjamin Preston

Tom Wilbanks



James Hack

David Greene

Other ORNL scientists are important contributors to upcoming IPCC reports. ORNL is the only organization in the country with two coordinating lead authors in the Working Group II report. Benjamin Preston is coordinating lead author for Chapter 16, "Adaptation Opportunities, Constraints, and Limits," and Thomas Wilbanks is coordinating lead author for Chapter 20, "Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development." Wilbanks is also a lead author of two summary sections. Working Group II will publish its report online in August 2014.

Preston is a member of the core writing team for the AR5 synthesis report, due in November 2014.

The previous IPCC assessment report, AR4, was published in 2007. It described human activities releasing greenhouse gases into the atmosphere since the Industrial Revolution—mainly carbon dioxide from fossil fuels and nitrous oxide and methane from farming. The expected consequences include melting glaciers, rising sea levels, and intensified heat waves, floods, and droughts. AR4 projected this century Earth's average temperature may rise by 1–6 degrees Celsius (2–12 degrees Fahrenheit) as a result of rising atmospheric greenhouse gases.

The IPCC shared a 2007 Nobel Prize with former vice president Al Gore for "efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change." ORNL's Wilbanks, James Hack, and David Greene, who recently retired, were among about 200 scientists recognized as co-laureates for their contributions to AR4.—*by Dawn Levy*

Research and Career Awards

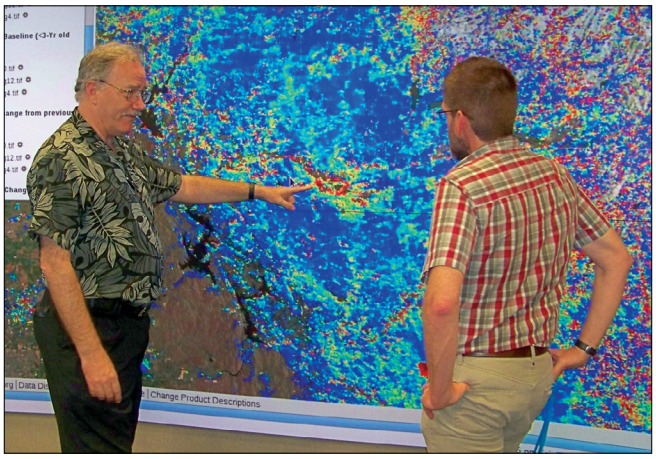
Team Developing Forest-Threat Early Warning System Sweeps Five Awards

From left, CCSI's Jitendra Kumar, Forrest Hoffman, and Richard Mills have won five awards for collaborative development of the first near-real-time forest threat early warning system in the contiguous United States. Photo credit: Jason Richards, ORNL

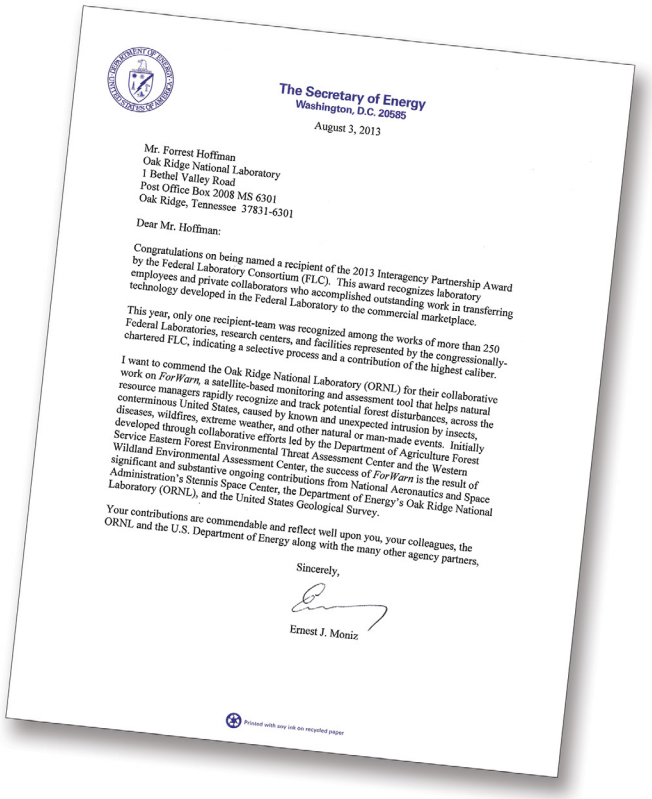
ForWarn is the first near-real-time early warning system for detecting forest threats in the contiguous United States. For their contributions to its development, Forrest Hoffman, Jitendra Kumar, and Richard Mills of the Climate Change Science Institute at Oak Ridge National Laboratory have won an impressive five national, regional, and local awards with research collaborators at the U.S. Department of Agriculture Forest Service's Eastern Forest Environmental Threat Assessment Center, the National Aeronautics and Space Administration's John C. Stennis Space Center, and the U.S. Geological Survey's Center for Earth Resources Observation and Science Data Center.

A satellite-based system, ForWarn delivers maps providing information about forest greenness from coast to coast every eight days. The maps compare current vegetation greenness levels to those from a year ago, three years ago, and the past decade to highlight potential disturbances and post-disturbance recovery. ForWarn's tools help attribute disturbances to insects, disease, wildfire, extreme weather, and human development.

The ForWarn team's awards include a NASA Group Achievement Award from NASA's Stennis Space Center; the 2013 Interagency Partnership Award from the Federal Laboratory Consortium (FLC) for Technology Transfer; a 2012 Partnership Award from the FLC Southeastern Region; the Most Distinguished Scientific or Technical Contribution Award from ORNL's Computer Science and Mathematics Division; and the 2012 Director's Science Delivery Award of the USDA Forest Service Southern Research Station.—*by Dawn Levy*



When Forest Service researchers came to ORNL on Aug. 23, 2013, to analyze "big data" regarding a number of forest disturbances, they were at the right place at the right time to view effects of past wildfires in the West and give the massive Rim Fire burning in California near Yosemite National Park a closer look. The ForWarn "Early Detect" map showing the Yosemite wildfire had just been processed and made available that day. Forest Service research ecologist Bill Hargrove, left, and ORNL research scientist Forrest Hoffman use a ForWarn map to examine growing impacts. ForWarn's capability to provide information about the fitness of forests over time may improve predictions about the number of years required for vegetation to recover to its prefire level of greenness. Through close examination of vegetation impacts, the collaborators may be able to help resource managers track recovery from increasingly frequent and intense blazes. Photo credit: Jitendra Kumar, ORNL



The Secretary of Energy
Washington, D.C. 20585

August 3, 2013

Mr. Forrest Hoffman
Oak Ridge National Laboratory
1 Bethel Valley Road
Post Office Box 2008 MS 6301
Oak Ridge, Tennessee 37831-6301

Dear Mr. Hoffman:

Congratulations on being named a recipient of the 2013 Interagency Partnership Award by the Federal Laboratory Consortium (FLC). This award recognizes laboratory employees and private collaborators who accomplished outstanding work in transferring technology developed in the Federal Laboratory to the commercial marketplace.

This year, only one recipient-team was recognized among the works of more than 250 Federal Laboratories, research centers, and facilities represented by the congressionally-chartered FLC, indicating a selective process and a contribution of the highest caliber.

I want to commend the Oak Ridge National Laboratory (ORNL) for their collaborative work on *ForWarn*, a satellite-based monitoring and assessment tool that helps natural resource managers rapidly recognize and track potential forest disturbances, across the conterminous United States, caused by known and unexpected intrusion by insects, diseases, wildfires, extreme weather, and other natural or man-made events. Initially developed through collaborative efforts led by the Department of Agriculture Forest Service Eastern Forest Environmental Threat Assessment Center and the Western Wildland Environmental Assessment Center, the success of *ForWarn* is the result of significant and substantive ongoing contributions from National Aeronautics and Space Administration's Stennis Space Center, the Department of Energy's Oak Ridge National Laboratory (ORNL), and the United States Geological Survey.

Your contributions are commendable and reflect well upon you, your colleagues, the ORNL and the U.S. Department of Energy along with the many other agency partners,

Sincerely,

Ernest J. Moniz

Printed with soy ink on recycled paper

The ForWarn team's awards have received recognition from Secretary of Energy Ernest Moniz (congratulatory letter shown here), Secretary of Agriculture Thomas Vilsack, and NASA Administrator Charles Bolden. Image courtesy: Forrest Hoffman, ORNL

UT-Battelle Honors Hack and Wullschleger for Distinguished Contributions

James Hack

James Hack and Stan Wullschleger of the Climate Change Science Institute at were honored Nov. 15 at UT-Battelle's annual Awards Night celebration. Each year the company, which manages ORNL for the U.S. Department of Energy's Office of Science, lauds the distinguished contributions of approximately 1 percent of the lab's employees.

Hack, an atmospheric scientist, came to ORNL in 2008 to direct the National Center for Computational Sciences, a leadership computing facility supporting transformational science. In 2009 he became the founding director of CCSI. He won UT-Battelle's "R&D Leadership, Director Level" award under the "Science & Technology" category for his exemplary leadership of both organizations as well as for advancing high-performance computing and climate research.

Wullschleger, an Arctic researcher, directs the Next-Generation Ecosystem Experiments project, which joins researchers from universities and national laboratories to model an ecosystem containing vast stores of trapped carbon that may spur further global warming as permafrost thaws. He received UT-Battelle's "Science Communicator" award in the "Community Engagement" category. He was lauded for sustained communications efforts to educate the public—as well as the broader scientific community—about climate change research, thereby sharing the excitement and value to society of ORNL's and DOE's scientific research programs.

Wullschleger Named UT-Battelle Corporate Fellow

Stan Wullschleger

Stan Wullschleger has been selected as a 2013 UT-Battelle Corporate Fellow. The rank recognizes a researcher's significant accomplishments and continuing leadership in scientific, engineering, and technological fields. Wullschleger, who conducts research in ORNL's Environmental Sciences Division and its Climate Change Science Institute, was recognized for superlative leadership in climate and environmental sciences that has advanced knowledge in fields critical to ORNL's mission. He was honored for individual achievements as well as contributions as a mentor and collaborator. Since joining ORNL in 1990, Wullschleger has performed pioneering research in climate change, the genetic basis for bioenergy crops, carbon-water cycles, and molecular ecology.

He is the national project director for DOE's Next Generation Ecosystem Experiments–Arctic, a research initiative to address the coupled physical, chemical, and biological behavior of permafrost-rich terrestrial ecosystems. He has published 144 peer-reviewed articles with 8,500 citations, organized six international conferences, and delivered more than 200 invited talks.

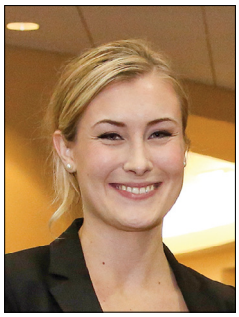
Wilbanks Receives Trinity University's Highest Alumni Honor

Tom Wilbanks

Trinity University in San Antonio awarded Tom Wilbanks, a Corporate Research Fellow at Oak Ridge National Laboratory, its 2013–14 Distinguished Alumni Award. Wilbanks, who works in the lab's Climate Change Science Institute and Environmental Sciences Division, received the award during a January 31, 2014, ceremony in Texas. He earned a bachelor's degree in interdisciplinary social sciences from Trinity in 1960 and a doctorate in geography from Syracuse University in 1969.

Trinity's award, the highest alumni honor the university bestows, recognizes graduates who "have distinguished themselves through personal or professional achievement." Wilbanks is recognized for his contributions to knowledge in science, particularly in the areas of sustainability and climate change. With other lead authors of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, he was a co-laureate for the 2007 Nobel Prize for Peace, which the panel shared with former Vice President Al Gore.

Intern Roisin Langan Wins Best Abstract Award at Student Poster Session



Roisin Langan

Roisin Langan, an intern at Oak Ridge National Laboratory, spent last summer improving the ability of climate models to predict the variability and extremes of precipitation. With guidance from her mentors, Richard Archibald and Kate Evans of ORNL's Climate Change Science Institute, Langan analyzed data generated on the Oak Ridge Leadership Computing Facility's Titan supercomputer. Her project, titled "Stochastic Representation of Unresolved Processes in Climate Models," garnered attention labwide, winning the best abstract award at ORNL's Research Alliance in Math and Science (RAMS) banquet, a student poster session held August 8. Research in this field could result in more accurate warning systems for extreme events, such as flooding, droughts, and heat waves, and help stakeholders plan economic and humanitarian relief efforts.

"This experience helped me gain invaluable networking channels, experience, and instruction in effective scientific communication," said Langan, a recent graduate of the University of California, Santa Barbara. Now an intern through ORNL's Nuclear Engineering Science Laboratory Synthesis program, she hopes to enter a graduate program in computational science in fall 2014.

Association for Computing Machinery Honors Worley as Distinguished Engineer

Patrick Worley

Patrick Worley of Oak Ridge National Laboratory has been named a Distinguished Member of the Association for Computing Machinery (ACM), the world's largest educational and scientific computing society. He is one of 40 ACM members so recognized in 2013. Worley is affiliated with ORNL's Climate Change Science Institute and with its Computer Science and Mathematics Division.

The ACM Distinguished Member program recognizes members with at least 15 years of professional experience who have made significant accomplishments or achieved a significant impact on the computing field. The program can recognize the top 10 percent of ACM's worldwide membership, which currently exceeds 100,000.

ACM President Vinton G. Cerf lauded the distinguished members as "the problem solvers, prophets, and producers who are powering the future of the digital age." He noted that these ACM members "are the driving force for enabling the computing community to change how we live and work."

Worley holds a doctorate in computer science from Stanford University. In 1987 he joined ORNL, where he designs, implements, and optimizes parallel algorithms that run on some of America's most powerful supercomputers, including the Titan system at the Oak Ridge Leadership Computing Facility, and conducts research into techniques and technologies for improving the productivity of the performance optimization process.

Within CCSI, Worley focuses on the performance evaluation and optimization of the Community Earth System Model (CESM), which couples independent models describing atmosphere, oceans, land, sea ice, and land ice, as well as on the development of numerical algorithms and component models for inclusion in the CESM. He also uses CESM components and kernels to evaluate computing systems with an eye to determining suitability for computational climate science and informing the computing industry about the needs of computational climate scientists.

Worley is an associate editor for the journal Parallel Computing. From 2006 to 2012 he was both a co-chair of the CESM Software Engineering Working Group and the principal investigator for the Performance Engineering and Analysis Consortium (PEAC) End Station, an Innovative and Novel Computational Impact on Theory and Experiment (INCITE) project to advance the U.S. Department of Energy's leadership-class supercomputing platforms. Worley remains a co-principal investigator of PEAC and is also a co-principal investigator of a fusion energy INCITE project.

Four Integrated Research Themes

Research at the Climate Change Science Institute at Oak Ridge National Laboratory provides science-based understanding of the climate system to help decision makers assess climate-change risks to infrastructures, environments, and health as well as weigh consequences of policies and practices.

Earth System Modeling

Using state-of-the-art algorithms and powerful supercomputers, researchers advance Earth system modeling techniques and explore the benefits of high-resolution models in investigations of global to regional climate, focusing on connections to water and biogeochemical cycles. These modeling frameworks capture and quantify interactions and feedbacks between large- and smaller-scale phenomena and more accurately simulate climate behavior on local to regional scales.

Data Integration, Dissemination, and Informatics

Earth system datasets are used to guide development of models that generate insight about climate change. ORNL manages diverse model and observational data collections and participates in federated data distribution systems. These systems merge separate data archives to make them accessible through remote portals. Data-management tools allow contributors to archive data with uniquely identifiable histories and users to access and adopt datasets for their own scientific needs.

Image credit: Brett Hopwood

Terrestrial Ecosystem and Carbon Cycle Science

Research on terrestrial ecosystems and carbon focuses on improving the projection of future CO_2 concentrations; strengthening understanding of ecosystem response to climate change; enhancing integration of land-use and land-cover change into climate models; expanding integration of observations, experimentation, and modeling; and developing more complete process models that can be incorporated into Earth system models.

Impacts, Adaptation, and Vulnerability Science

Understanding societal and ecological consequences of climate change informs policies and actions about adaptation and mitigation. Researchers characterize climate extremes, assess impacts of climate change on settlements and support systems (e.g., energy, transportation, and water), provide insights about human and national security, and analyze ecosystem services and sustainability.

Data Integration, Dissemination, and Informatics

Oak Ridge Center's Data Important for Accurately Assessing Global Carbon Emissions

The Earth's atmosphere requires a balance of greenhouse gases (e.g., carbon dioxide): an excess will make the planet too hot, whereas a dearth will make it too cold. Recent studies have shown that daily background concentrations of carbon dioxide in the lower atmosphere have risen above 400 parts per million for the first time in nearly one million years. Accurate assessment of carbon dioxide emissions is important to better understand the global carbon cycle, inform climate policies and project future climate change, according to a May 8, 2013, report titled "The Global Carbon Budget 1959–2011" in the journal *Earth Systems Science Data*. The authors, who represent institutions in Australia, France, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and the United States, include Robert Andres and Tom Boden of the Climate Change Science Institute at Oak Ridge National Laboratory.

The report presents the latest estimates of carbon dioxide sources and sinks. ORNL's Carbon Dioxide Information Analysis Center provided all the estimates in the report on the annual release of carbon dioxide into the atmosphere from fossil fuel consumption, the most significant of the human-influenced sources of carbon dioxide. "Fossil fuel consumption is the reason carbon dioxide is increasing in the atmosphere," Boden said. "It's the smoking gun of climate change."

Robert Andres

Tom Boden

The center's estimates include emissions from transportation, industry, electricity generation, home heating/cooling, and cement production. Other organizations provided estimates on emissions from land-use changes, fluxes of carbon to the atmosphere, and uptake by the terrestrial biosphere and Earth's oceans.—*by Wendy Hames*

'Biodiversity Information Serving Our Nation' Puts Finding Species at Your Fingertips

The Climate Change Science Institute worked with the U.S. Geological Survey to develop BISON—Biodiversity Information Serving Our Nation. BISON is a web-based federal resource for finding species in the U.S. and its territories. BISON offers more than 100 million mapped records of nearly every living species nationwide, and the vast majority of the records pertain to specific locations, not just county or state. The Core Science Analytics and Synthesis (CSAS) program of the USGS developed BISON as an integrated and permanent resource for biological-occurrence data from the United States. BISON will leverage the accumulated human and infrastructural resources of the long-term USGS investment in research and information management and delivery.

"Scientists at Oak Ridge National Laboratory provided unparalleled expertise in processing and managing data and provided cyber infrastructure that enabled a project of this ambitious scope to succeed," said Giri Palanisamy, head of the Data Integration, Dissemination and Informatics group at ORNL's CCSI. With ORNL colleagues Biva Shrestha and Ranjeet Devarakonda, he provided the data processing architecture for the BISON portal.

Giri Palanisamy

CSAS is also the U.S. node of the Global Biodiversity Information Facility (GBIF), an international, government-initiated and funded effort focused on making biodiversity data freely available for scientific research, conservation, and sustainable development. CSAS, with its partners at the Department of Energy's ORNL, hosts a full mirror of the hundreds of millions of global records to which GBIF provides access. BISON has been initiated with the 110 million records GBIF makes available from the U.S. and is integrating millions more records from other sources each year.

Elsevier and Oak Ridge National Laboratory Implement Reciprocal Linking

Elsevier articles published on ScienceDirect and datasets in ORNL DAAC repository now joined

Elsevier, a world-leading publisher of scientific, technical, and medical information products and services, announced its implementation of reciprocal linking between Earth science content on ScienceDirect and related data sets of the Department of Energy's Oak Ridge National Laboratory (ORNL). Elsevier publishes more than 2,000 journals, including The Lancet and Cell, and close to 20,000 book titles. ScienceDirect is a premier full-text scientific database offering journal articles and book chapters to its more than 10 million users. The platform offers search and retrieval functionalities that enable users to work effectively in the knowledge discovery process.

The ORNL Distributed Active Archive Center (ORNL DAAC), which is funded by the National Aeronautics and Space Administration, provides facilities for archiving, discovery, and accessibility of biogeochemical dynamics data. In operation since 1994, the ORNL DAAC assembles, distributes, and provides data services for a comprehensive archive of terrestrial biogeochemistry and ecological dynamics observations and models to facilitate research in support of NASA's Earth science. Research datasets deposited at the ORNL DAAC are now automatically linked to relevant articles in Elsevier journals available on ScienceDirect using digital object identifiers, and vice versa.

This fruitful cooperation between Elsevier and the ORNL DAAC promotes the flow of data into trusted archives and supports long-term storage, wide availability, and preservation of research data. Interconnecting journal articles and relevant data serves the needs of researchers and funding agencies by diminishing the loss of data and helps researchers find data that is necessary to reproduce results from the literature.

Robert Cook

ORNL DAAC Chief Scientist Robert Cook, a member of ORNL's Climate Change Science Institute, said, "The way researchers work has dramatically changed with the developments of the Internet and new computer technology. Linking data to the research article is an important matching advancement in digital publications. Now readers will be able to discover and access the complete data products that are used in the article they are reading. Previously, readers only had access to the data presented in tables and figures in the article."

Bethan Keall, publishing director for energy and Earth sciences at Elsevier, said, "We are delighted to be able to offer authors and readers the opportunity to seamlessly link their published article to the underlying data with one easy click and are proud to work together with the ORNL DAAC on this initiative. It is through collaborations such as this one that we recognize the value of research data for science and help make it easier for researchers to find relevant data sets and present them in the right context ."

HIPPO Global-Scale Air Chemistry Datasets Now Available

Data from the High-performance Instrumented Airborne Platform for Environmental Research Pole-to-Pole Observations (HIPPO) study of greenhouse gases and aerosols are now available to the atmospheric research community and the public. These comprehensive datasets include the first high-resolution vertically resolved measurements of over 90 unique atmospheric species from nearly pole-to-pole over the Pacific Ocean, measured during a two-year series of five month-long missions spread throughout the annual cycle. The datasets will provide opportunities for research across a broad spectrum of Earth sciences, including those analyzing the evolution in time and space of the greenhouse gases that affect global climate.

The HIPPO data are available at two portals. One, maintained by the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC), located at the Climate Change Science Institute at Oak Ridge National Laboratory, is the CDIAC HIPPO Data Archive. The other portal, maintained by the Earth Observing Laboratory (EOL) of the National Science Foundation's National Center for Atmospheric Research, is the EOL HIPPO Data Archive.

Atmospheric Radiation Measurement Scientists Help Validate Climate Change Models

Earth system models—computer simulations that run models of specific climate scenarios—require an immense body of knowledge against which to "check the answers." The sheer volume of data requires sophisticated methods for archiving and distribution, a need which the Department of Energy's Atmospheric Radiation Measurement Data Archive program excels at meeting.

"Climate change is a very complex science, and to successfully conduct research, we need a long time series of observational data, which we can use to improve climate change models," said Giri Palanisamy, senior information analyst for ARM and head of the Data Distribution, Dissemination, and Informatics group at the Climate Change Science Institute at Oak Ridge National Laboratory.

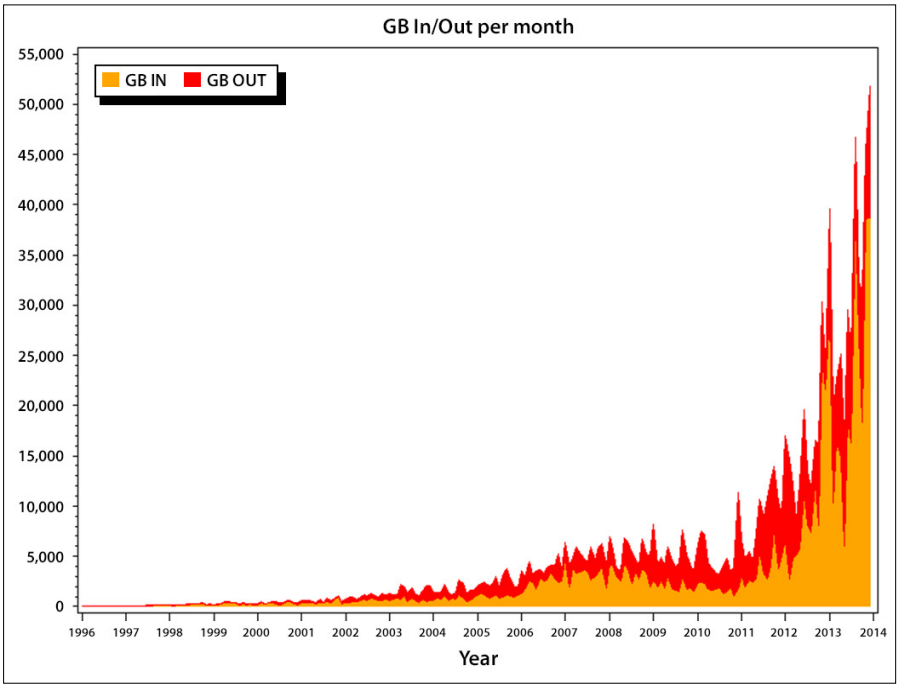
Despite its intimidating name, ARM doesn't measure nuclear radiation from bombs but rather studies cloud formation processes and their influence on radiative transfer. ARM is one of the biggest climate change observational projects funded by DOE's Biological and Environmental Research program. With its ground-based and mobile research infrastructures, ARM primarily "looks up" at the atmosphere, observing how atmospheric radiation affects cloud properties with an eye to determining what that means for heating, cooling, and precipitation, which affect important activities like crop production.

Climate scientists can validate data from their simulations against observational data from ARM. If the data doesn't corroborate, scientists can correct the errors and improve the accuracy of their models. But a huge needle-in-a-haystack problem threatens progress: in excess of 560 terabytes of data are waiting to be searched.

According to Palanisamy, "The data is growing exponentially, with multiple terabytes coming in [each] day. We had to tackle this big data challenge, not only for archiving but also for distributing." ARM is host to more than 4,000 data products. Many are continuous sensor-based measurements, while others are "value-added products," or data calculated from existing physical data that would otherwise be impractical to measure. This ocean of data could potentially make it very difficult for scientists to get the information they need.

Giri Palanisamy

ARM's answer to this is its new Data Discovery User Interface, an open-access tool. It allows users to easily search ARM's data with a sophisticated search engine and filtering options, enabling them to quickly drill down to the information they need. Moreover, it provides snapshots of the data, data availability, and quality reports. ARM has also deployed a new computing cluster technology that allows users to transfer and process the data they need on ARM's cyber infrastructure and take summarized data back to their computer for further analysis. "That will help them use ARM data in a seamless manner in their research, which will eventually help us understand climate change," Palanisamy said.—*by Justin Kaffka*

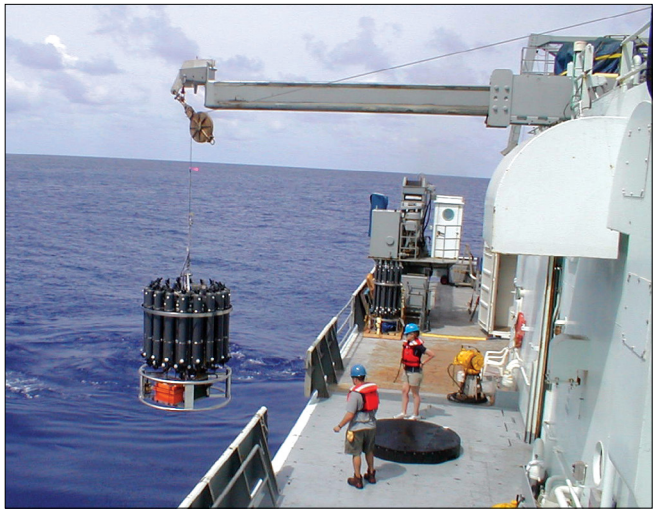


From 1992 to 2011 the ARM database archived about 220 terabytes of data, and since 2011 the database has more than doubled that to 560 terabytes. Each month the organization receives almost 40,000 gigabytes of data (shown in orange) and disseminates more than 50,000 gigabytes (shown in red). Image credit: Giri Palanisamy

Ocean Carbon Data Products Wash Up New Information on Climate Change

As long as there is more carbon dioxide in the atmosphere than in the surface waters of the ocean, the ocean "sucks" carbon dioxide out of the atmosphere, acting as a carbon sink. Unfortunately, the opposite is also true—if there's more carbon dioxide in the water than the air, then the ocean releases carbon dioxide into the atmosphere. That's why scientists at the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory are interested in studying the distribution and origin of carbon dioxide in the ocean.

"It's very important to know how much carbon dioxide influences atmospheric temperature," said Alexander Kozyr, ocean data analyst for CDIAC, a project of the Data Integration, Dissemination, and Informatics group at ORNL's Climate Change Science Institute. "The more carbon dioxide in the atmosphere, the more heat the Earth holds. It's very important to know how much carbon dioxide the ocean can take, especially man-made carbon dioxide. If we know the balance between the ocean and the atmosphere, we can find out the ocean's capacity to serve as a sink for storing atmospheric carbon dioxide."



The PACIFICA database compiles its data from more than 306 scientific cruises on specialized research vessels. Measurements are generally taken from depths as low as 6,000 meters, or 3.7 miles below sea level. Sampling equipment (shown being lowered into the ocean) includes detectors of conductivity, sea-water temperature, and depth. Ocean samples are brought back to the surface for measurements of dissolved inorganic carbon, total alkalinity, pH, partial pressure of carbon dioxide, salinity, oxygen, and nutrients Photo credit: Alex Kozyr

CDIAC recently released three new data products in search of answers. The Pacific Ocean Interior Carbon database—dubbed PACIFICA—archives measurements from formal scientific voyages to aggregate consistent, quality-controlled data from the depths of the ocean. The Lamont-Doherty Earth Observatory database and Surface Ocean Carbon Dioxide Atlas database store millions of measurements of surface partial pressures of carbon dioxide obtained by attaching scientific equipment to vessels informally engaged in research; these Volunteer Observing Ships include luxury cruise ships, cargo ships, and other vessels willing to participate. The data is used worldwide in climate change research and in papers cited by the Intergovernmental Panel on Climate Change.

The Australian research icebreaker Aurora Australis braves Antarctic waters in search of carbon and other oceanographic measurements. PACIFICA merges data from locations all over the Pacific, including the Pacific sector of Antarctic waters. Photo credit: Alex Kozyr

In 2013, carbon dioxide levels in the atmosphere reached over 400 parts per million, a number unprecedented since measurement of atmospheric carbon dioxide levels began in the 1950s. As the ocean takes in more of this carbon dioxide, there has been an unforeseen side effect—the increased acidification of oceanic waters. Subsequently, ecological disasters like "coral bleaching," where the organic material in a reef is destroyed, have also increased.—*by Justin Kaffka*

Terrestrial Ecosystem and Carbon Cycle Science

Climate Project Accelerates Warming on Plots in Sensitive Ecosystem to Study Impact

An ORNL-led climate change project known as SPRUCE, for the Spruce and Peatland Responses Under Climatic and Environmental Change, has begun construction on specially designed warming technologies that will mimic global warming in one of the Earth's most sensitive ecosystems. The boreal peatland forest of northern Minnesota is only one stretch of an ecosystem that extends through Canada, northern Europe, and Russia.

A cold, damp earth rich in carbon from the mash of slowly decomposing vegetation covering its floor, boreal peatland forests are called "carbon sinks" because much of the carbon that would be released as carbon dioxide in warmer, dryer forests is trapped in shrubs and bogs because of the wet and cold climate. Warming temperatures threaten to unleash these carbon stores, releasing the greenhouse gas carbon dioxide in the atmosphere at an unstable rate.

These sensitive conditions make Minnesota an ideal setting for SPRUCE, which will use the warming technologies now under construction on-site in conjunction with a dozen, open-topped chambers to support the experimental climate being imposed on the raw environment. Experimental treatments, including the elevation of carbon dioxide levels along with warming, will begin in the 2014 fiscal year. In the past year, ORNL supported construction of local access roads and installation of more than three miles of electrical supply lines and extensive "dock" boardwalks to service experimental plots. The project, which began development and prototype design in 2010, is set to run for 10 years.
—by Katie Elyce Jones

Boreal forests, which are characterized by the presence of bogs (or peatlands) containing high levels of stored carbon, blanket much of North America and Eurasia. Peatlands may generate important greenhouse gas feedbacks to the atmosphere as the world warms. Paul Hanson of the Climate Change Science Institute leads an experiment to assess the response of boreal peatlands to increases in temperature and carbon-dioxide concentrations. Environmental Monitoring Station - S1 Bog. Photo credit: SPRUCE science staff

The treatments for the Spruce and Peatland Responses Under Climatic and Environmental Change experiment, or SPRUCE, will be activated in 2014. Real-time and full-scale manipulations like SPRUCE allow researchers to quantify the response of organisms and ecosystems to future conditions that can't be measured in the field or inferred from recorded ecological records. Photo courtesy Paul Hanson, SPRUCE

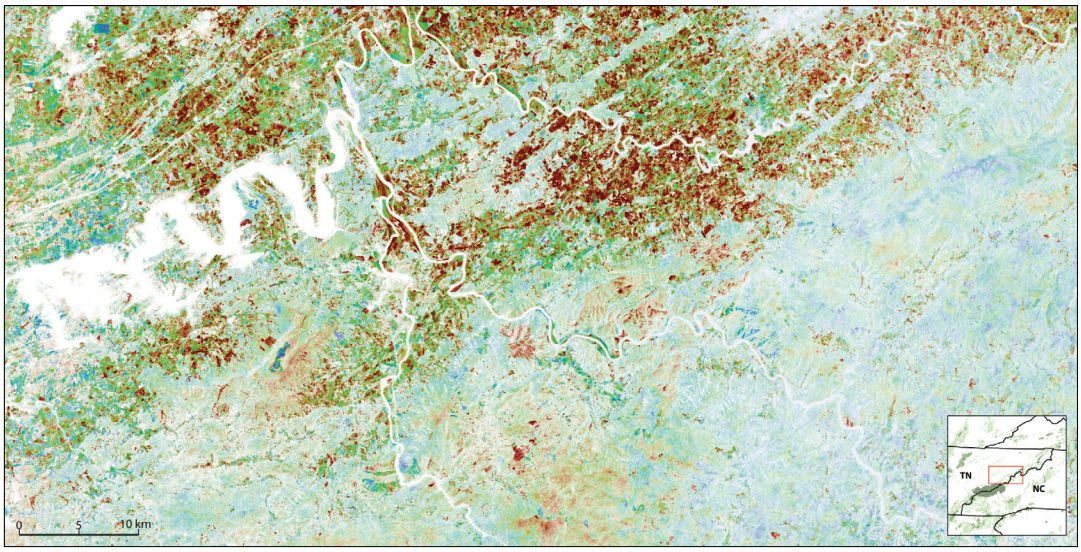
Scientists Classify Forest Disturbances to Grow Understanding of Climate Change

Fire, logging, insects, and extreme weather can wreak havoc on forests. With support from the Department of Energy and the National Science Foundation, Oak Ridge National Laboratory climate modeler Daniel Hayes and University of Tennessee–Knoxville ecologist Joseph Hughes map eastern U.S. forests to characterize changes. They use satellite imagery collected by the National Aeronautics and Space Administration as well as ground data from the U.S. Department of Agriculture Forest Service and the U.S. Geological Survey to calibrate and validate the satellite data. The maps help improve the models that are set in motion in simulations to explore the effect of landscape alterations on the carbon cycle. Hughes presented the research Aug. 7 in Minnesota during a talk at the annual meeting of the Ecological Society of America.

feedbacks from such disturbances as forest fires to the carbon cycle, energy balance, and hydrology.

The researchers rely on remote sensing data from Landsat, a program jointly managed by NASA and USGS. Since 1972, the program's satellites have collected high-resolution imagery of Earth. "Every 16 days we get a new picture of the same spot," said Hughes, who maps data collected between 1984 and 2011 at a typical resolution of 30-meter-wide pixels. "That's an amazing time series and really great data density. You can't see a car, but you can see roads and streams and forests."

The researchers use Thematic Mapper sensors of Landsats 4, 5, and 7 to measure signatures of land, ice, clouds, and more. Plants reflect mostly in the green bandwidth of visible light and the near-infrared bandwidth.



A map of total forest changes near Newport, Tennessee, from 2000 to 2011 shows red regions that experienced vegetation removal (due to fire or logging), blue areas of regrowth, and green zones that are a mixture of both. Darker areas experienced more aggregate change than lighter areas, such as the Cherokee National Forest to the southeast and Douglas Lake to the west. Image credit: Joe Hughes

"We want the models to capture all the important processes that impact the carbon cycle," said Hayes, a research scientist in ORNL's Climate Change Science Institute and Energy and Environmental Sciences Directorate. He holds a joint appointment as an assistant professor in UTK's Department of Ecology and Evolutionary Biology, where Hughes is his graduate student. "Landscape changes—from turning a forest into a Walmart parking lot to insect outbreaks and fires—have implications for climate."

Current Earth system models do not represent land disturbances in much detail, if they represent them at all, according to Hayes. He is interested in exploring

Two mid-infrared bandwidths, which transmit through the sky with less scattering than do longer wavelengths, help the researchers screen out atmospheric noise. A long-wave infrared bandwidth measures temperature.

The images capture change that is often difficult to witness, such as insect infestations that damage forests over several years. "We need lots of data and pretty sensitive methods to find these slow, creeping changes," said Hughes, whose project, sponsored by NSF's Coupled Human/Natural Systems program, generates disturbance maps that have helped scientists evaluate the effectiveness of protecting areas such as those managed by the Nature Conservancy.

Hayes uses the temporally and spatially explicit dataset captured in Hughes's forest maps to quantify disturbances in models and discern their dynamics with the climate. His models track carbon as it cycles through land, oceans, ice, and atmosphere. Among land disturbances, fire has the biggest effect on the global climate budget. Combustion quickly sends carbon to the atmosphere as carbon dioxide or methane. Its lasting effects reset forest patterns for regrowth, carbon uptake, energy balance, and water movement.

"We know fire is extremely important because models that don't incorporate fire don't match the reality of the global carbon cycle very well," Hayes said. "You not only need to be able to have the fire in the model when it happens, you need to have fires included in your model somehow in the past because everything that happens in the past has a legacy."

Hayes is figuring out how to best represent past events to capture legacy effects. As global warming has made some areas warmer and drier, fires in those regions have become more frequent and severe. "It's certainly happening in the boreal regions," Hayes said. "A huge area of unmanaged forests has big implications for climate."

Hayes will next expand the geographic scope of techniques he and Hughes developed for eastern forests.

Daniel Hayes, shown here outside of Nome, Alaska, traveled to the Arctic in June to study climate change. Photo credit: Santonu Goswami

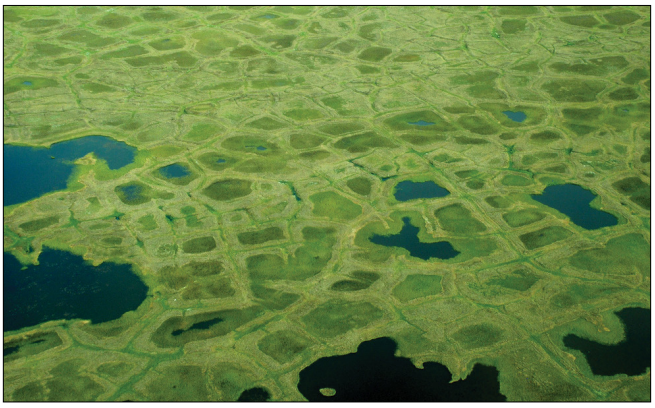
For DOE's Next Generation Ecosystem Experiments project in the Arctic, on which Hayes collaborates, his models may shed light on major climate feedback processes and reduce uncertainty in climate prediction. Such efforts are urgently needed because, as a result of amplification of natural responses to human-caused global warming at high latitudes, the Arctic is warming twice as fast as the rest of the planet.—*by Dawn Levy*

Climate Institute Researchers of Plants, Roots, and Soil Shed Light on Arctic Ecosystem

The Arctic is a vast, complex ecosystem that covers a large portion of the Earth's surface and plays a critical role in global climate processes. Yet we know remarkably little about it, particularly its plants.

To gain a better understanding of the importance of Arctic vegetation in climate models, a team of researchers from the Climate Change Science Institute is taking a closer look at the intricacies of the Arctic's plant communities, research that has huge implications for global climate models. Because plants are instrumental in the terrestrial carbon, water, and energy exchange, the team's work will not only reveal much about the Earth's northern latitudes but also help climate modelers in their quest to better understand the complex relationships that, woven together, create Earth's climate. They shared their work Aug. 5 in Minnesota during talks at the annual meeting of the Ecological Society of America.

Using the environs of Barrow, Alaska, as their laboratory, ORNL researchers Stan Wullschleger, Richard Norby, Colleen Iversen, Joanne Childs, and Victoria Sloan study different



Polygon formations in Alaska provide researchers with a unique natural laboratory with which to study the Arctic and, by extension, the Earth's climate. Image credit: NGEE-Arctic

portions of the Arctic plant ecosystem that, while seemingly separate, are all intricately connected. They are participants in the Next-Generation Ecosystem Experiments (NGEE-Arctic) project of the U.S. Department of Energy's Office of Science. NGEE-Arctic seeks to increase confidence in climate

projections by quantifying the physical, chemical, and biological behavior of terrestrial ecosystems in Alaska. The results will likely inform research in the greater Arctic, which is warming twice as fast as the rest of the planet.

If climate models are to continue to evolve, a better understanding of the Arctic is necessary. The NGEE-Arctic project will entail three years of integrated modeling and experiment at the Barrow Experimental Observatory followed by a decade of extending the approach across Alaska. Data will be used to reduce uncertainty in climate models and help predict the effects of global warming over the next century.

Plants of a feather

Even with the most powerful computers in the world, climate scientists are forced to make numerous approximations and classifications to simplify their models. For example, plant functional types, or PFTs, are categories researchers use to classify plants according to certain characteristics, i.e., deciduous versus evergreen trees, or trees versus grasses. Scientists need a database of where the various categories are located on the globe. Enter Stan Wullschleger, who is attempting to better classify Arctic plants by type and function, giving climate modelers one more level of precision in their quest to better predict the years ahead.

Despite this need, the Community Land Model, a portion of the popular Community Earth System Model used to model global climate change, treats all of the Arctic's diverse plant types as a "grass." A better, more precise classification system is needed to further our understanding of the larger Arctic ecosystem and its effects on the Earth's climate.

"The challenge likely to be encountered in moving forward with modeling vegetation dynamics lies in evaluating the trade-offs between simplicity in our classification of PFTs, while capturing sufficient complexity in describing differences among PFTs for major ecosystem properties and processes," said Wullschleger.

If climate models are to continue to increase in accuracy, a more nuanced and thorough classification of PFTs is critical.

After the thaw

Wullschleger's teammate, Richard Norby, is digging a little deeper, literally. By exploring the effects of soil nitrogen on the Arctic's vegetation, Norby is gaining a better understanding of the role of climate change in reorganizing plant communities. It's expected among researchers that as climate change escalates, the Arctic's thawing permafrost will release nitrogen stored in the soil for eons.

The released nitrogen will almost certainly escalate plant growth, but different plant types will respond differently. "Essentially, we're linking plant community structure and

ORNL's Colleen Iversen separates live and dead plant material during a recent field harvest near Barrow, Alaska. Photo credit: NGEE-Arctic

function to soil moisture and nutrient availability," said Norby. By studying the relationship between leaf area and nitrogen availability in polygonal land structures around Barrow, Norby hopes to make accurate estimates of the effects of nitrogen on Arctic plant life.

Specifically, Norby's project tracks nitrogen availability with depth as the active permafrost layer thaws during the growing season; seasonal variation in plant nitrogen; the spectral signatures of plant communities that will correlate with nitrogen content; and the linkage between plant and soil characteristics, with root characteristics controlling nitrogen uptake.

Norby soon hopes to expand his research to other sites in Alaska that are undergoing rapid change.

"A reorganization of Arctic plant communities may be a significant result of climate change that drives important feedbacks to the atmosphere and to permafrost stability," he said.

The root of it all

More may be happening just under that permafrost than we know. The final piece in the team's research involves the classification of root systems. Just as Wullschleger is attempting a finer categorization of plant types and function, his colleague Colleen Iversen hopes to accomplish the same with the Arctic's root systems.

Surprisingly, belowground plant characteristics are not represented in most large-scale climate models. And in environments such as the tundra that are typified by extreme conditions, surveys indicate that roots and belowground stems can contain as much as six times the mass of aboveground plant parts. The plant species that call the tundra home have a variety of unique adaptations

that enable them to survive in harsh Arctic conditions. These unique, integral systems are begging to be classified and, ultimately, associated with PFTs for a more complete representation in models of the processes that govern the Arctic ecosystem.

The symbiotic nature of the team's various research interests all serve one purpose: to give climate modelers a better picture of the Arctic, a heretofore mysterious region that is not accurately represented in modern models yet plays critical roles in the global climate system. Therefore, scale is at the heart of the research.

"When I measure roots in the soil, I'm measuring in centimeters," said Iversen. "Ultimately, I want to be able to scale that to 100 meters."

Despite being tucked away in a little corner of Northern Alaska, the team's research has truly global implications. Simply put, a more accurate model of the Arctic equals a more accurate model of the world.—*by Gregory Scott Jones*

Researchers Map Where Tree Species Survive and Thrive under Climate Change

Trees have existed on Earth for nearly 400 million years, and today about 100,000 species populate the planet. Increasingly, trees are placed at risk by climate change, which spurs heat waves, droughts, fires, and infestations. Plants cannot easily adapt to quickly changing conditions or migrate as habitable lands shrink owing to expansion of cities and croplands. Projecting the future of forests requires knowing what tree species exist where, and under what environmental conditions they can survive and even thrive.

"We are working to understand conditions and quantify the suitability of known habitats for particular tree species and identify regions that have similar conditions in the present as well as in the future under various climate change scenarios," said Jitendra Kumar, a researcher with the Climate Change Science Institute. Along with collaborators, Kumar presented a paper on mapping tree species Aug. 6 in Minnesota at the Ecological Society of America's annual meeting. "This has implications for forest resource management today and a greater implication for the future, given variations in environmental conditions due to climate change."

Kumar and Forrest Hoffman, both experts in data analytics algorithms at CCSI, have teamed with Kevin Potter of North Carolina State University and William Hargrove of the U.S. Department of Agriculture Forest Service on a Forest Service–sponsored project to map trees in the contiguous United States. The results will aid in management of the nation's forest resources, particularly tree species that are rare or economically important.

Kumar and his colleagues created a statistical delineation of the world into 30,000 uniquely defined ecoregions based on fairly high-resolution climatic and soil-related variables. Although the initial analysis of the large, complex Earth science data set was performed on small in-house computers, the project will require use of some of ORNL's supercomputing resources for planned future analysis.

"ORNL plays a key role in developing the data analytics approaches and computational tools crucial for this project," Kumar said. "The Multivariate Spatio-Temporal Clustering methodology employed in this work was developed at ORNL, and the lab is one of the few places in the country that possesses the resources for this data- and computing-intensive work."

Jitendra Kumar

Through the mapping process, researchers are identifying the range of conditions in which various tree species can survive and how those environmental characteristics influence tree productivity. "We can paint a future scenario for these trees and plan ahead for forest resources management in a changing climate," Kumar said. "Trees in areas of changing conditions are potentially at risk. Based on our 'presence and absence' mapping of about 200 tree species during the most recent phase of our efforts, most are expected to see reduction in their suitable habitat under warming climates, and a handful will gain more suitable habitat area."

Trees have the ability to adapt and migrate, but the processes require adequate time. Researchers must understand the connectivity of the landscape to determine if it supports species migration or if human intervention will be required to place trees in suitable habitats. "We know there's not enough time for the trees to actually migrate on their own through natural process, and they may need human-assisted migration to places where we think they will be able to grow," he said.

The mapping process currently includes tree species in the contiguous United States in grid cells about four square kilometers (2.48 square miles) in area. Kumar said ground data comes from the Forest Service's Forest

Inventory Analysis, an archive that provides long-term observations for the health and productivity of forests through a large number of research plots across the nation. "Available data are very limited since FIA plots are expensive to monitor," Kumar said.

To use the data collected on the ground by the Forest Service as well as data collected from remote sensing satellites managed by the National Aeronautics and Space Administration, researchers employ a clustering technique to delineate ecoregions using a large set of variables. Next, they constrain the species range projections across these ecoregions using observations from FIA plots and locations monitored by the Global Biodiversity Information Facility, an international organization that collects and shares worldwide data on biodiversity.

The project focuses on a key point, according to Kumar: "We have the data for tree health and productivity at sparse observation locations across the country, and we also know the environmental conditions at those places. What is the relationship between those two kinds of information, and how can we upscale the information to the entire country in an objective and quantitative way?"

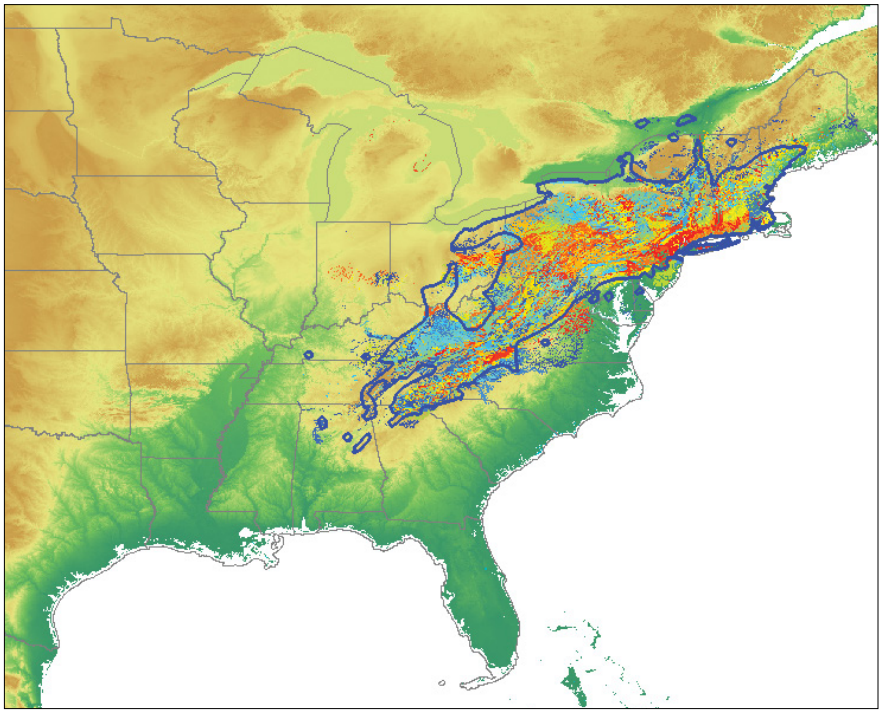
Upscaling refers to an analysis method for projecting point measurements (in this case, observations from FIA and GBIF) to develop continuous maps of tree species productivity.

To determine the relationship between tree health and environmental conditions, researchers are developing techniques to compute the suitability of different conditions in a quantitative manner and to develop statistical models of habitat suitability that can be applied to areas not directly studied and observed. They have completed mapping for the current climate in the contiguous United States and are now in the early stages of mapping species extent and estimating productivity under future climate scenarios in the same region.

For future climate scenario projections, researchers are using results from the Met Office Hadley Centre, a climate change research center in Great Britain, and the National Center for Atmospheric Research in Boulder, Colo. The data are from two global, parallel climate simulations performed for the third phase of the Climate Model Intercomparison Project, which was performed for the Intergovernmental Panel on Climate Change Fourth Assessment Report.

The project is also being expanded to other countries: ORNL-led researchers have already created presence/absence maps for a variety of species around the globe. "We are now developing more quantitative methods and using FIA and GBIF observations to predict productivity for woody tree species under present and projected future environmental conditions," Kumar said. "We expect to complete the first version of these maps employing our new analytics method by the end of the year."

The U.S. Department of Agriculture Forest Service provided funding for this project.—*by Wendy Hames*



A topology map shows the range of tree productivity from low to high biomass production (blue to red, respectively) for Betula lenta *(sweet birch). Image courtesy of Jitendra Kumar, Oak Ridge National Laboratory*

Climate Scientist Conducts Ecological Model Workshop, Field Campaign in Alaska

During two weeks in June, Daniel Hayes of the Climate Change Science Institute and the Environmental Sciences Division at Oak Ridge National Laboratory communed with fellow scientists and with nature—including an abundance of mosquitoes—while studying climate-change repercussions in Alaska. Work led by Hayes makes valuable contributions to greater understanding of the vulnerable Arctic, which is warming twice as fast as the rest of the planet due to amplified effects at high latitudes. The scientific community is engaged in intensive, integrated efforts to understand this vast ecosystem, with observers and experimentalists providing data that feed models and simulations.

Hayes spent his first week at the University of Alaska–Fairbanks conducting a focused workshop he organized for 20 invited scientists who have been working independently on an ecological model developed in the 1980s. The Terrestrial Ecosystem Model—or TEM—is one of the oldest ecological models in existence and has become something of a generic term for many land models, along the lines of brand names like Kleenex or Xerox.

Unlike newer, more formal ecosystem models, TEM has been studied over several decades by various climate modeling groups working on individual projects. Hayes said researchers at a number of organizations learned to use the model as students, then moved to other institutions, where they started their own lines of development and trained new students in its use.

"There are branches of research going on all over the place, so the point of this workshop was to bring everybody together into one place for the first time," said Hayes, who spoke throughout the week about modeling Arctic ecosystems. Participants spent the first day of the workshop updating each other about their TEM studies. A field trip to a research site near Fairbanks on the second day gave the modelers an opportunity to see an example of where and how the data used in TEM are collected. The third day featured a discussion to coordinate research efforts for improving efficiency and avoiding duplication. The final two days were spent creating and assigning tasks to researchers participating in several small, self-organized workgroups.

Participants left the workshop with a list of action items. "We're setting up a website and data-sharing system that will be for everybody involved in the model to be able to share code and data sets," Hayes explained. "It's our way of having some more formal communication between the different groups." Researchers at six institutions—ORNL, UAF, the Marine Biological Laboratory, Purdue University, Lehigh University, and Argonne National Laboratory—are currently working on TEM's different branches. Participants hope to repeat the gathering of TEM researchers in 2015 to discuss the progress of the subgroups in advancing development of the model as well as next steps.

During a field campaign Daniel Hayes organized on Alaska's Seward Peninsula, Jenny Liebig, left, a graduate student at the University of Tennessee, takes research notes while Santonu Goswami of Oak Ridge National Laboratory uses a spectrometer to measure vegetation conditions. Photo credit: Daniel Hayes

A job that bites

Hayes' second week in Alaska, this time in Nome on the Seward Peninsula, involved a field campaign to support modeling projects. He was joined by postdoctoral research associate Santonu Goswami of the ORNL Environmental Sciences Division and CCSI as well as a collaborator from UAF and four researchers working on an Arctic project in Barrow, Alaska, for the U.S. Department of Energy's Next-Generation Ecosystem Experiments.

Before the field study, the group had mapped specific areas of the Seward Peninsula to look for changes that occur from thawing of permafrost, fire, and human land use including development. These changes have important consequences for the ecological environment on land, wildlife, climate, resource management, and human subsistence. Said Hayes, "There are various ways that thawing manifests itself on the landscape, so we were looking at different features," including temperatures of soil and permafrost, depth of the seasonally unfrozen soil layer, and characteristics of vegetation.

Goswami's special interest was ground-based spectral measurements of vegetation, which required what Hayes

termed "an extremely fancy camera." "We take detailed surveys of vegetation at the ground level and analyze those in comparison with ground-based spectral measurements from the same spots, recording the reflectance of the vegetation in various wavelengths," Hayes said. "Of course, we cannot realistically make these measurements on the ground over the whole landscape. So we have created a 'spectral library' where we have a set of measured reflectances for each vegetation type from the ground."

Daniel Hayes' field campaign near Nome supported climate modeling projects but subjected him to mosquitoes galore. Photo credit: Guido Grosse

After acquiring data from other sources and mapping patterns, researchers use the spectral library to look up vegetation types associated with these landscape-scale reflectance patterns and create a map of vegetation for the whole region. "What we are ultimately interested in is making a map of vegetation over the landscape for each year that the satellite has collected data—since 1984—so we can see how the landscape has changed over time," Hayes added.

The time spent outdoors near Nome generated a great deal of data but also exposed the researchers to a great number of mosquitoes, which are most prevalent in Alaska during June and July. "It's extremely buggy there," Hayes said. "You would have hundreds on you at any time." The researchers had to wear mosquito nets to protect their faces, and at times their arms were covered with swarms of the biting insects.

Hayes and the other researchers are now working to analyze the copious data they collected from the trip. The preliminary information will serve as a starting point for future work and new proposals. Hayes said the group has some mapping and satellite images in hand but needs closer images. "It's quite a stretch to go from images collected by satellites in space all the way down to this point on the ground," Hayes said. "We're going to deliver these preliminary results to NASA program managers and see if we can convince them to fly some data-collecting aircraft over our sites."

Hayes said NGEE-Arctic Project Director Stan Wullschleger of ORNL's Environmental Sciences Division and CCSI will publicize the second week's work in presentations to scientists, government officials, and educators.

Funding was provided by UAF, NGEE, and a DOE Early Career Award to Hayes. The five-year Early Career Awards bolster the nation's scientific workforce by providing support to exceptional researchers during a time when many scientists do their most formative work.—*by Wendy Hames*

Earth System Modeling

Researchers Prepare for Future Climate with Help of America's Fastest Scientific Supercomputer

By understanding changes in the Earth's past and present climate to improve projections about the future, researchers at the Climate Change Science Institute are helping local stakeholders better prepare for a future likely rife with unexpected, and unpleasant, climate surprises.

Specifically, Moetasim Ashfaq, an atmospheric physicist and computational climate scientist with the institute, is using a suite of regional and global climate models to determine how future temperatures and precipitation will change as a result of climate change and how those changes will impact society.

"Once we know how the temperature and precipitation change, then we can try to answer how this affects our everyday lives," Ashfaq said.

Ashfaq is pairing the model suite with Oak Ridge National Laboratory's Titan supercomputer, America's fastest for open science. Titan's hybrid architecture, which employs state-of-the-art central processing units as well as energy-efficient graphics processing units, enables achievement of a head-turning 27 petaflops of peak computational power, the type of muscle necessary to tackle one of mankind's greatest challenges.

Recently Ashfaq has focused primarily on the mainland U.S. and Southern Asia (India, Pakistan, Bangladesh, and Nepal), for which he refined global climate model projections by dynamically downscaling them through regional- and hydrological-scale models. For instance, his research recently focused on snowmelt in the Western U.S., a region greatly challenged by declining water supplies.

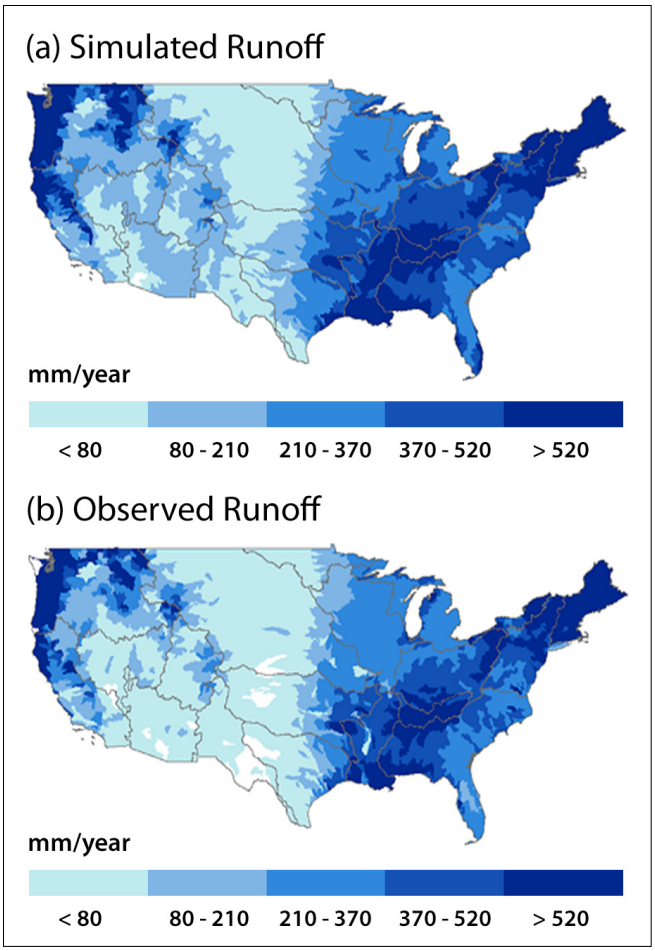
After modeling the hydrology of the continental U.S. at a resolution of 12 kilometers (7.5 miles), Ashfaq focused on the Western winter snow, as any potential temperature increases would probably lead to reductions in snowmelt, the main source of water for much of the region.

Reliable prediction of future climate changes and their accompanying effects requires refining climate models to ever smaller spatial scales. Because climate change will affect people and governments down to the local level, zeroing in on specific regions is paramount to understanding its impact. To address this need Ashfaq and his team have now expanded their high-resolution climate modeling capacity by adding more global and regional climate models in their modeling framework and going to even finer resolutions.

For example, Ashfaq's regional modeling framework involves refinement of 12 global climate models that are part of the fifth phase of the Coupled Model Intercomparison Project through two regional climate models (RegCM4 and WRF) at 18-kilometer (11.2-mile) horizontal grid spacing. Similarly, Ashfaq has used the Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model, used widely for continental-scale hydrology for more than five years, and his team is the only research group in the U.S. that has calibrated the model down to 4 kilometers (2.5 miles) over the contiguous U.S.

Other research areas include determining how future changes in precipitation will influence our country's hydropower, such as how runoff will affect dams, and how an increase in floods or stream flows will impact infrastructure such as roads and buildings.

For example, if certain areas are more likely to be inundated with water following heavy rainfall, should building codes in those areas be altered to increase safety? Ashfaq and collaborators will use the Distributed Hydrology Soils and Vegetation Model, which Ashfaq calls "the younger brother of



The Variable Infiltration Capacity hydrological model, run here at the highest resolution yet achieved (i.e., grid cells 4 kilometers, or 2.5 miles, in width), reveals the movement and distribution of water in the contiguous United States in unprecedented detail. Image credit: Moetasim Ashfaq, CCSI

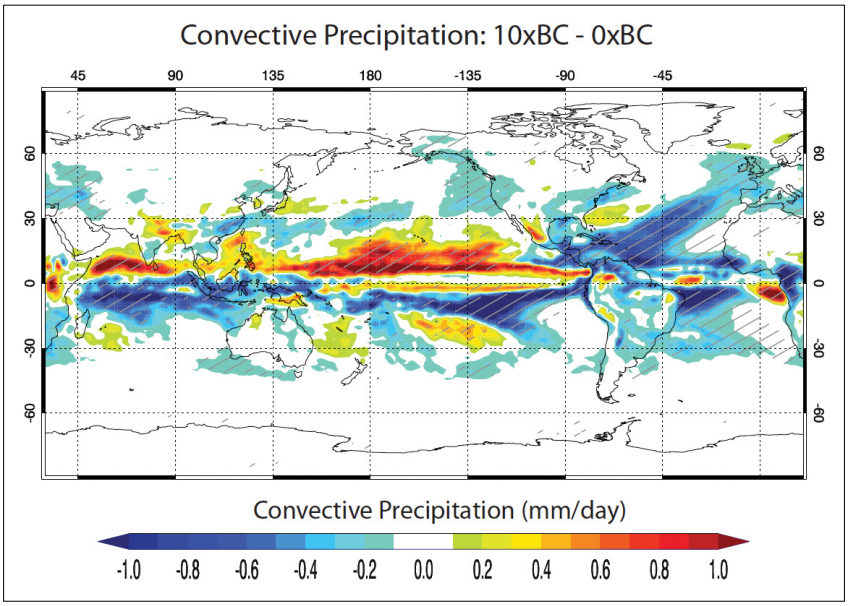
VIC," down to a grid spacing of 90 meters (295 feet) to arrive at an unprecedented understanding of what areas are most vulnerable in varying precipitation scenarios.

"Our efforts are geared toward building a foundation for the long-term goal of developing a multidisciplinary Earth system modeling framework that will enable more comprehensive, rigorous investigation of the challenges posed by climate variability and anthropogenic climate change," said Ashfaq.—*by Gregory Scott Jones*

Researchers Harness Titan to Quantify Effects of Black Carbon

Carbon dioxide is all the rage these days. When it comes to climate change, it's the culprit du jour and the chemical compound most Americans associate with a warming planet. Despite its immense notoriety, however, it isn't the only actor on the climate stage. A supporting cast of varied chemical compounds including nitrous oxide and methane likewise play important roles in the Earth's changing climate.

One character in particular has thus far been largely overlooked. Black carbon (BC) aerosol, the byproduct of the unresolved combustion of fossil fuels, biomass, and biofuels, is perhaps the second strongest anthropogenic climate change agent behind carbon dioxide. BC absorbs more solar radiation than it reflects, consequently heating up the atmosphere.



In a simulation that increases tropospheric black carbon aerosols to 10 times their current model-estimated levels, the inter-tropical convergence zone shifts northward. Image credit: Salil Mahajan, CCSI

Despite its importance, BC's climate impacts are not well understood. In fact, current global climate models may underestimate BC's radiative forcing, or the difference in solar radiant energy received by the Earth compared to the amount BC sends back to space, by as much as a factor of five.

To better model BC's effects, researchers need an improved understanding of its role in the climate system. By harnessing the power of the lab's Titan supercomputer, America's most powerful for open science, researchers at the Climate Change Science Institute are using evolved models to determine how increases in BC will alter Earth's climate in the future.

Specifically, the team started with present-day Community Earth System Model (CESM)–simulated estimates of BC currently in the atmosphere and increased that amount by two, five, and 10 times in different global CESM simulations, said team member Salil Mahajan.

The findings, were detailed in the October 2013 issue of *Journal of Climate*. Besides increasing temperatures, additional quantities of BC also greatly affected global precipitation.

Because most of the world's BC resides in the Northern Hemisphere (home to the majority of the human population), much of the BC-induced atmospheric heating occurs north of the equator. This heat imbalance between the Northern and Southern hemispheres results in a southward atmospheric energy transport across the equator via the mean Hadley circulation, which carries heat and moisture away from the deep tropics and toward mid-latitudes. The Hadley circulation is strongly tied to the inter-tropical convergence zone, or an elongated band dominated by tropical rains.

"Increases in BC could have a significant impact on the global climate with an increase in global temperatures, decrease in global precipitation, and northward shift in the tropical rain band," said Mahajan. "All of these things are affected by increases in black carbon in our simulations."

Now that researchers have a more accurate picture of BC's effects, they can better help society prepare for them. And together with our evolving understanding of the effects of carbon dioxide and other greenhouse gases, policymakers will have unprecedented knowledge with which to tackle the climate conundrum.—*by Gregory Scott Jones*

Meshing the Math Behind Global Climate Models Requires Big Resources and Teamwork

Climate simulations make for memorable images of shrinking ice sheets and tapering coastlines, but behind these visual representations of predicted climate change is a lot—*a lot*—of math.

Kate Evans, leader for the Oak Ridge National Laboratory Computational Earth Sciences Group and member of the Climate Change Science Institute, where she focuses on Earth systems modeling, prioritizes informing the research community and public about the challenges of developing global climate models. So when the opportunity arose in July 2013, Evans accepted an invitation to talk about strategies for developing more sophisticated models at the international Mathematics of Planet Earth Conference in Melbourne, Australia.

Kate Evans, leader for the Oak Ridge National Laboratory Computational Earth Sciences Group, shared strategies and challenges of developing a global climate model at the Mathematics of Planet Earth Conference in Melbourne, Australia, this past summer. Photo credit: Jason Richards

Evans and other ORNL modelers use one of the most powerful supercomputers in the world, Titan, located at the lab, to develop new numerical methods and fine-scale models for the complex, open-source Community Earth System Model (CESM). A prominent global climate model that has evolved with advances in computational power and ballooning amounts of climate data, CESM simulates global and regional climate in high resolution by connecting land, atmosphere, ocean, and ice models.

"We develop [models with] high-resolution data points around the globe," Evans told Mathematics of Planet Earth in an online interview prior to the conference. "It involves large-scale computers, the largest in the world, [and] developing numerical methods so that they run efficiently and accurately."

Because the most accurate climate models consider more variables over more points on the globe across more points in time, these multiscale models (from global to ever smaller regional scales) are run on exceptionally powerful computers that can handle the mathematical workload. Computers like Titan, which is capable of a peak performance of 27 quadrillion calculations per second, require developers to continually upgrade models to take advantage of hardware and software advancements.

"It's a tough thing to run these models at high resolution," Evans told Mathematics of Planet Earth. "We're always wanting to add more subgrid-scale physics—that's things like clouds or being able to resolve interactions between the ocean and the atmosphere so we can predict hurricanes."

Evans said they not only need a large computer but also diverse teams of computational and field scientists to consolidate all the mathematical components, from the equations that solve scientific problems to the algorithms that manage computational operations.

"One of the biggest challenges is gathering a big team together," Evans said. "You need someone who understands the hardware, someone who knows how to write good code that will run on this one-of-a-kind computer, someone who understands the algorithms that scale well, and someone who understands climate and what's important to solve with these models."

In her Australia talk Evans also discussed the accountability that comes with such resources, as modelers constantly verify and validate new methods so the results are accurate and reproducible.

"Not all scientists have access to one of the largest computers in the world, so I discussed issues of how we reproduce our runs so they can be vetted by the scientific community," Evans said. "So while developing these models is a challenge, it's also exciting because within several years, the models we develop here will be widely used and evaluated. We want to set the bar high for capability."—*by Katie Elyce Jones*

Oak Ridge National Laboratory Researchers Improve Fidelity of Earth System Models

Oak Ridge National Laboratory (ORNL) researchers are partnering with other Department of Energy (DOE) laboratories to improve the supercomputing applications that deliver breakthroughs in climate science.

Forrest Hoffman, Kate Evans, James Hack, and other scientists at ORNL's Climate Change Science Institute participate in three projects funded through the Scientific Discovery through Advanced Computing, or SciDAC, Program. These projects aim to improve the Community Earth System Model, a megamodel that couples interactive component models of the atmosphere, ocean, land, and sea and land ice. ORNL scientists are integrating multiscale algorithms to better simulate atmospheric and oceanic phenomena, verifying the accuracy of ice sheet simulations, and improving the representation of biogeochemical cycles on land and in the ocean and atmosphere. These researchers and dozens of others run Earth system models on the Oak Ridge Leadership Computing Facility's Titan supercomputer.

Forrest Hoffman

"These projects are designed to advance the simulation and predictive capabilities of the models," said Hoffman, one of the SciDAC principal investigators. "These projects partner climate scientists, mathematicians, and computer scientists to improve the accuracy and scientific fidelity of these complex models and to deliver a new generation of Earth system models with unsurpassed performance on the leadership class computing facilities that DOE operates."

Hoffman attended the SciDAC-3 Program meeting in Rockville, Maryland, July 24–26. The annual meeting assembles lead investigators and collaborators in math, computer science, and a variety of scientific fields to coordinate computational research that fosters new discoveries.—*by Jennifer Brouner*

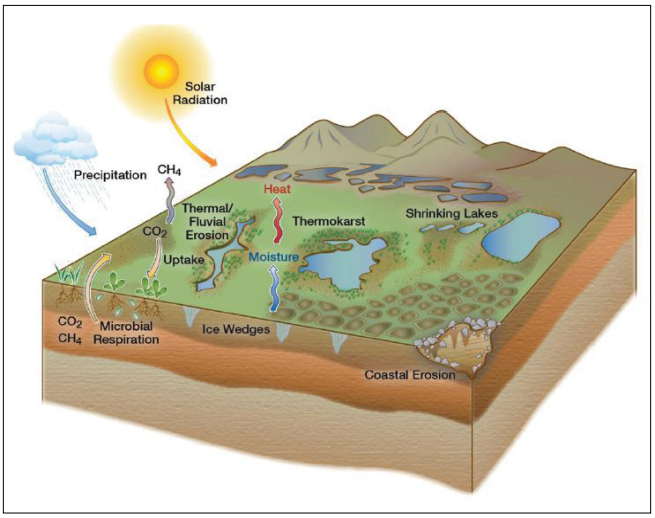
New Algorithm Enables Unprecedented Sampling, Modeling of Arctic

The Arctic is a big, cold, and desolate place. Not to mention that much of it is fairly inaccessible.

For these reasons, conducting meaningful on-the-ground research there is a tricky business. To characterize the environment, researchers need tools to extend their limited observations to the larger landscape. For example, how different are conditions on one piece of land from those hundreds of miles away? How will those conditions shift in 10, 20, or 30 years?

To answer questions like these, a team of researchers from the U.S. Department of Energy's Oak Ridge National Laboratory and the U.S. Department of Agriculture's Forest Service used a unique algorithm to divide the state of Alaska into "bioclimatic" regions based on the results of climate and permafrost models. The team produced decadal maps of representative regions at multiple levels of division. Data from 2000 to 2009 and an ensemble of model results from 2090 to 2099 revealed how current ecosystems may shift under a changing climate.

"You want to be sure that you take samples that are representative of the larger ecosystem," said team member Forrest Hoffman of ORNL's Climate Change Science Institute, who presented results from the project



NGEE-Arctic research activities are designed to identify and quantify mechanisms underlying processes that control carbon and energy transfer in the Arctic biosphere, as well as how those processes play out in a changing Arctic landscape. Image credit: NGEE-Arctic

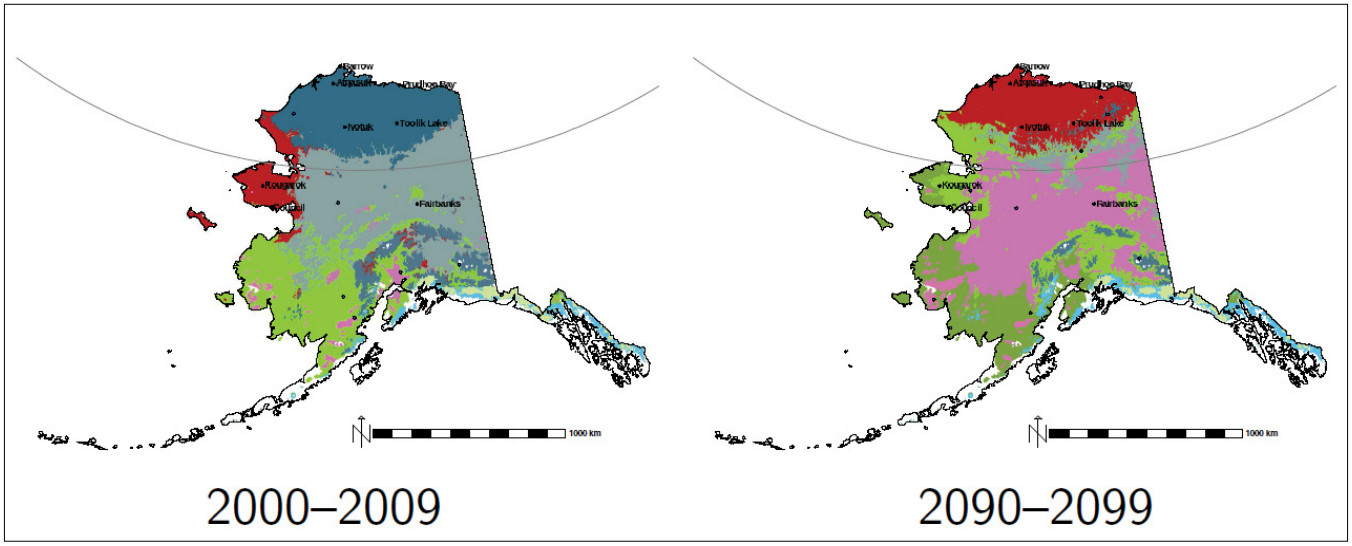
Aug. 5 in Minnesota at the annual meeting of the Ecological Society of America. The findings were also published online in June in *Landscape Ecology*. "Resource and logistical constraints limit the frequency and extent of environmental observations, particularly in the Arctic, necessitating the development of a systematic sampling strategy to maximize coverage and objectively represent environmental variability at desired scales."

Team members include Jitendra Kumar and Richard Mills of ORNL and William Hargrove of the Forest Service. Their effort employed a quantitative methodology for delineating sampling domains and showed how the representativeness of eight possible sampling sites may change in the future. The research is useful for informing site selection for DOE's Next-Generation Ecosystem Experiments project, or NGEE–Arctic, and determining if measurement sites and networks accurately represent vast and potentially vulnerable high-latitude ecosystems in which natural responses to human-caused global warming are amplified.

Team members developed software that enables a unique algorithm, based on a cluster algorithm, to work on parallel computing systems, thus allowing the analysis of larger datasets.

Ultimately, the team hopes to demonstrate that these techniques can be applied at different temporal and spatial scales to meet the needs of individual research groups and climate modelers.

Soon the team will apply the same methodology at a smaller spatial scale to define domains within the Barrow Environmental Observatory in Alaska, where the NGEE–Arctic project is under way. The researchers will use remote sensing to categorize the region's unique polygonal ground features and create input for models to simulate the behavior of Arctic tundra.—*by Gregory Scott Jones*



Shown in arbitrary colors are the 10 most different ecoregions in Alaska as determined by a data mining algorithm. Because the arbitrary colors are the same in both maps, a change in color represents an environmental change between the present (2000–2009) and the future projection (2090–2099). In this progression, conditions on the Seward Peninsula "migrate" to the North Slope. Image courtesy Forrest Hoffman

Impacts, Adaptation, and Vulnerability Science

US–Brazil Partnership Seeks to Reduce Barriers to Bioenergy Development

Global challenges require global solutions. That's why the world's two largest producers of biofuels—the United States and Brazil—are supporting research and scientific cooperation to address the challenges of climate change and meet energy demands with sources such as biomass that are more sustainable than fossil fuels.

A bioenergy workshop June 11–13 at Oak Ridge National Laboratory brought together nearly two dozen researchers to tackle these grand challenges. Lee Lynd of Dartmouth College and Maggie Davis and Keith Kline, both of ORNL's Environmental Sciences Division and Climate Change Science Institute, organized the event, called the Global Sustainable Bioenergy Project Workshop on Future Research. Lynd and Kline, along with ORNL's Martin Keller, are members of the Global Sustainable Bioenergy project.

"Bringing researchers together is important to build effective collaborations. The Global Sustainable Bioenergy project is creating a vision of what is desirable in terms of bioenergy and other services as well as how to achieve that vision," said Kline, also of the Center for Bioenergy Sustainability. "Specifically, the workshop addressed the key barriers to bioenergy today by linking researchers from four continents specializing in geospatial analysis, food security, and bioenergy sustainability."

Financial support for the workshop came from the São Paulo Research Foundation, known as FAPESP, and ORNL. Activities included informal discussions on the first day, formal planning and brainstorming sessions at ORNL on the second day, and a videoconference on the third day for on-site attendees from the United States, Brazil, and Great Britain as well as an additional 10 remote participants in Brazil, South Africa, and The Netherlands.

Bioenergy is energy derived from biomass, which is biological material such as wood and wood residues; agricultural waste; crops; and urban waste such as grass and tree trimmings, paper, and woody construction materials. Many technologies can convert biomass into biofuels to replace conventional fossil fuels such as petroleum, coal, propane, and natural gas. To be considered renewable, biomass should come from sustainably managed resources. Renewable biofuels are better for the environment because plants absorb carbon dioxide, generate oxygen, and provide other ecosystem services as they grow, Kline said. Biofuels also emit less sulfur and other toxic pollutants than fossil fuels.

"Use of fossil fuels transfers into today's atmosphere billions of tons of heat-trapping greenhouse gases that would remain secured in the Earth if not for human intervention,"

Brazilian sugarcane is one of the world's primary sources of biomass used in the production of liquid biofuels.

Kline said. This is in sharp contrast to bioenergy because there is a natural cycle of sequestration and release of carbon and nutrients as plants grow, die, and decay. If biofuels were to displace fossil fuels, net emissions of greenhouse gases would decrease. In fact, according to ORNL's Bioenergy Science Center, "By 2050 biofuels could reduce our greenhouse gas emissions by 1.7 billion tons per year—equivalent to more than 80 percent of current transportation-related emissions."

Most current liquid biofuels are produced using feedstock supplied by existing commercial agricultural operations for sugarcane in Brazil and corn in the United States. Fuel blends containing ethanol from corn and sugarcane provide energy for transportation (think ethanol/gasoline blends at your local fuel station), but use of crop commodities as feedstock or biofuels has led to substantial concern over land-use change and food security. Most bioenergy use worldwide is based on wood and grass burned inefficiently for heating and cooking in developing nations.

ORNL is at the forefront of research and development of liquid biofuels from crop residues, such as the stalks that remain after the harvest of corn and sugarcane, and from perennials such as switchgrass, a native, warm-season grass. But challenges remain.

Food versus fuel

Lynd said the GSB researchers are helping test two hypotheses related to key barriers to bioenergy growth. The first hypothesis is that it is physically possible to make room for bioenergy while honoring other land-use priorities. The

second hypothesis states that a systemic approach to food and bioenergy production could positively affect many urgent human needs.

"Conventional thinking is that we have a situation of 'food versus biofuel' and that these two necessarily compete for resources," Lynd said. "This need not be the case. We can manage landscapes to improve net production of both food and biofuel."

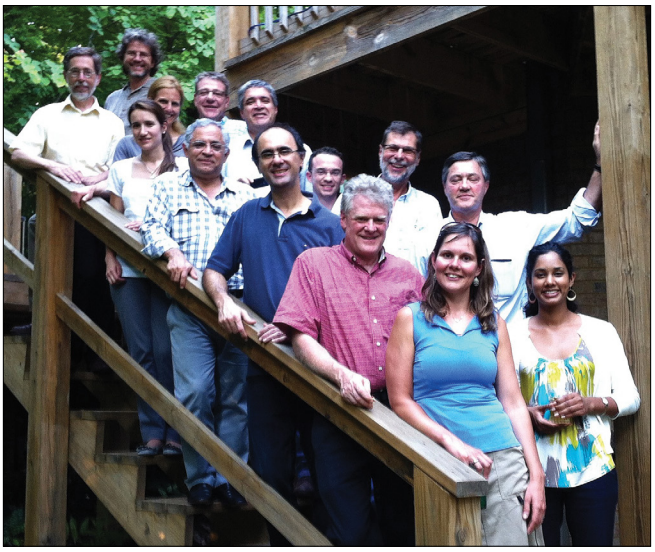
Among the concerns with biofuel development is the potential for a reduction in land available for the world's food supply or higher food prices and hunger. However, GSB project researchers are working on ways to integrate bioenergy production with existing land management and markets so that food security is maintained or improved. One approach is to increase yields and the efficiency of land management to provide more services with equal or reduced inputs. Another approach considers how to increase incentives for investment in equipment and infrastructure to support production systems that integrate both food and fuel. Other approaches consider long-term investments needed to improve capabilities to grow and use resources with less vulnerability to fluctuations in external markets.

Symbiotic science

Davis, a post-master's researcher at CCSI, noted the importance of participants from around the world working together on critical and controversial issues. "Collaborative research can build understanding and consensus around research results," she said. "Developing a stronger understanding of sustainable bioenergy production opportunities will be essential to expanding deployment of clean, renewable alternatives to fossil fuels."

Researchers who attended the workshop are now better equipped to finalize proposals and call upon appropriate colleagues for effective collaborations in GSB and related projects. These include the Biotechnology-based Ecologically Balanced Sustainable Industrial Consortium, known as BE-Basic, an international public–private partnership funded by the Dutch government to develop sustainable, industrial bio-based solutions; the Latin America, Caribbean and Africa project, known as LACAF, that is investigating the potential for sustainable bioenergy development in the Americas and Africa; bioenergy research programs at Penn State University, Dartmouth College, the Porter Institute of the Imperial College London, and the Institute on the Environment of the University of Minnesota; and the New Partnership for Africa's Development, an African Union project to address poverty and development on that continent.

Davis added that researchers who attended the workshop shared recent results and learned about the work of GSB colleagues from other nations. Science-based exchanges such as these can accelerate technology transfer and build research protocols that make it easier to share and compare results, increasing the value of individual projects.—*by Wendy Hames*



Some of the participants at the Global Sustainable Bioenergy Project Workshop on Future Research continued discussions during a social event in Oak Ridge following the first day of the workshop at Oak Ridge National Laboratory. From left front (along the handrail) are John Sheehan, Erica Smithwicks, Luiz Horta, Andre Santanche, Lee Lynd, and Maggie Davis. From left back are Keith Kline, Nicole Kalas, Jeremy Woods, Jansle Rocha, Helio Joris, Edgar Beauclair, Heitor Cantarella, and Amanda Ramcharan. Photo credit: Virginia Dale

Mitigating Climate Change Will Require Aggressive Measures

Unless world leaders initiate a large, concerted effort soon, keeping the planet's rise in temperature below 2 degrees Celsius above pre-industrial levels will soon become an unachievable goal, say authors of a Dec. 2, 2012, article in *Nature Climate Change*. The findings were published as part of the Global Carbon Project, which provides regular analyses of major global carbon sources and sinks. The authors, who represent institutions in Australia, France, Norway, the United Kingdom, and the United States, include Tom Boden of the Climate Change Science Institute at Oak Ridge National Laboratory. Current emission estimates produced by ORNL's Carbon Dioxide Information Analysis Center are tracking radiative forcing scenarios closer to a 4 to 6 degree Celsius global-temperature increase, so achieving a rise of only 2 degrees Celsius would require high-level technological, social, and political innovations, say the authors.—*by Dawn Levy*

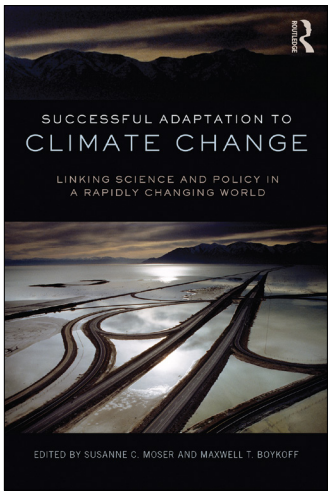
Preston Co-Authors Chapter on Successfully Adapting to Climate Change

Decision-makers need scientific information, human context to guide meaningful action

Benjamin Preston, deputy director of the Climate Change Science Institute, has co-authored a chapter in the book *Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World*. In the chapter, titled "Water, seas, and wine: Science for successful climate adaptation," Lauren Rickards of Melbourne University, Suraje Dessai of the University of Leeds, Ryan Meyer of the California Ocean Science Trust, and Preston argue it is no longer sufficient for researchers to carry out studies and then merely hand off the results to decision-makers who use them to improve their decisions.

"Our chapter focuses on the role of scientific research in facilitating successful adaptation to climate change," Preston said. "In looking at a range of case studies, we observe that the nature of science and how it engages with decision-making is changing as society places increasing emphasis on not just the generation of knowledge, but also its effective communication and application."

As climate change progresses, in England, for example, where water sources have been privatized since 1989, should prices rise in drier areas? In Australia, where 85 percent of the population lives within 31 miles of the coast, should shoreline development be restricted as sea levels rise? Moreover, should grape growers move when droughts threaten their *terroir*, the environmental conditions that affect wine quality?



These cases of water, coastal, and agricultural management demonstrate new challenges for researchers, research institutions, and funding agencies. As decision-makers and stakeholders increasingly demand scientific insights to inform their actions, scientists are asked to do more than simply carry out research. "Increasingly, they are expected to provide decision-support, engage directly with stakeholders, and communicate effectively," Preston said. These changing practices have yet to be fully reflected in science policy, he added. Case in point: As climate change afflicts increasing numbers of people worldwide, research funding for social sciences still dramatically lags that for biophysical sciences.—*by Dawn Levy*

ORNL Analysis Predicts Losses from Extreme Weather Damage Could Double by 2050

Researcher tackles unprecedented county-by-county economic loss forecast

U.S. economic losses from extreme weather could at least double by 2050, according to an Oak Ridge National Laboratory analysis published this month in the online edition of the journal Global Environmental Change.

"A side effect of America's growth has been the tendency to put more people, infrastructure, and assets in harm's way, and when a storm comes through, that increased exposure drives up economic losses," said author Benjamin Preston, deputy director of ORNL's Climate Change Science Institute, who studied historical data from more than 3,000 U.S. counties and used predictive modeling in the assessment. Preston works in impacts, adaptation, and vulnerability science, a field devoted to analyzing the effects of climate change on people, governments and industries.

So far in the 21 century, Americans have seen hefty price tags for extreme weather damage. The bulk of disaster losses are associated with extreme events in highly populated, wealthy areas. In 2011 alone the U.S. witnessed a record 14 weather disasters causing $1 billion or more in damages each. Climate change will likely cause such disasters to occur with greater frequency and severity, as projected in a 2012 Special Report from the Intergovernmental Panel on Climate Change.

Preston sought to quantify what population growth and continued development might mean for future losses,

independent of any changes in the frequency or intensity of severe weather events associated with climate change. He used county data about population and wealth from 1960 to 2009 to plot each county's socioeconomic exposure through time. Then he used the historical data to generate predictions of exposure until 2054.

Counties in the Southeast and Southwest could experience the most rapid growth in wealth and exposure, he found, while those in the already densely populated Northeast and West Coast will become exposed to risk more slowly.

Preston projected that current annual U.S. disaster losses of $10 billion to $13 billion could increase by a factor of 1.8 to 3.9 by 2050. Whether losses double or quadruple depends on two different assumptions researchers make when projecting losses based on socioeconomic exposure.

Research in impacts, adaptation, and vulnerability science has the potential to improve preparation for extreme weather events like Superstorm Sandy, which cost dozens of lives and billions of dollars in damages.

"A commonly used assumption is that losses increase in direct proportion with exposure," Preston said. "So, if a community grows to be twice as wealthy, it will lose twice as much when disaster strikes."

Based on this traditional assumption Preston calculated that future losses would grow slightly faster than the economy as a whole, quadrupling by the year 2050. In a second approach, Preston based his calculations on losses reported in recent Federal Emergency Management Agency disaster assistance applications. This empirical approach suggested losses will grow more slowly than the economy, only doubling by 2050—a difference of billions of dollars compared to loss projections under the traditional assumption. According to Preston, this result suggests that communities may become more resilient to extreme weather as they develop.

Regardless of differences between the two approaches, Preston underscores that losses from extreme events are increasing across the U.S., even without accounting for the potential effects of climate change.

"Despite uncertainties in projecting economic losses of extreme weather events, this study reflects how the U.S. continues to grow more vulnerable to extreme events," Preston said.

Improving projections for population growth and development, as well as changes in climate, could inform social and political debate over whether individual communities should invest in changes now to protect their people and property in the future.

The study was funded by ORNL's Laboratory Directed Research and Development program, which supports strategic investments in promising research areas.—*by Katie Elyce Jones*

Outreach and Education

Doubts Melt as Scientists and Filmmaker Discuss Climate Change at *Chasing Ice* Screening

Oak Ridge National Laboratory researchers and director deliberate on disappearing glaciers

Glaciers thrice as tall as the Empire State building calve, crumble, and careen into the sea during *Chasing Ice*, a film in which National Geographic photographer James Balog chronicles the rapid disappearance of Arctic ice as Earth's average temperature rises. In 2007 Balog launched his Extreme Ice Survey by placing time-lapse cameras in Alaska, Montana, Iceland, and Greenland to compress years into seconds and capture the death throes of ancient glaciers. Because atmospheric carbon dioxide cannot be seen with the naked eye, Balog chose to photograph ice, the first place the effects of greenhouse-gas increases could be witnessed, "to make the invisible visible and tangible," said *Chasing Ice* director/producer Jeff Orlowski. After the February 1, 2013, screening of the movie at a Knoxville theater, Orlowski was on hand with four scientists from the Climate Change Science Institute at Oak Ridge National Laboratory to answer a range of audience questions from how a gas that makes up less than 1 percent of the atmosphere can exert such a powerful effect to whether glaciers are goners.

The Extreme Ice Survey placed time-lapse cameras in Alaska, Montana, Iceland, and Greenland to capture evidence of climate change. Image courtesy of chasingice.com

When asked about the consequences of Greenland, well, greening with the disappearance of ice sheets, CCSI Deputy Director Benjamin Preston, who moderated the discussion, replied that the complete melting of the Greenland ice sheet would unlock about 7 meters (22 feet) of global sea-level rise. "That's basically a level of oceans that none of us has ever seen," Preston said.

Last year CCSI's Kate Evans, who develops high-resolution models of continental-scale ice dynamics, simulated the behavior of all of Greenland's glaciers on ORNL's Jaguar supercomputer. She told the audience that massive meltwater from Greenland can affect the salt density and temperature gradients that drive global ocean circulation patterns. "If you have a lot of ice-sheet melt into the North Atlantic, you can shut down the warm-water conveyor belt and thus shut down warm-air transport up to northern Europe," she said. "So you can actually see cooling in that region even though the global warming itself is happening."

Chasing Ice heightens awareness of climate change. Image courtesy of chasingice.com

Orlowski said the consequences of climate change encompass more than just ice. If a sequel to *Chasing Ice* ensues, time-lapse photography may also reveal evidence of climate change in declining forests, advancing deserts, raging wildfires, shifting croplands, and migrating species. Meanwhile, Balog plans to expand his ice survey by adding cameras in Antarctica, Argentina, and Mount Everest as well as additional sites in the Arctic.

The higher sea levels produced by melting glaciers increase the devastation of storm surges. "Events like [Hurricane] Sandy are going to really start waking people up," said Orlowski, pointing out once-in-100-years megastorms may happen every few years. Preston, who explores potential impacts of climate change on society, noted, however, that such events may prompt local rather than global action: "The lessons we're going

to learn from Sandy are going to be lessons learned by New York and New Jersey, and they're going to be built around questions like how do we build a more resilient community so that when these events happen, we don't see tens of billions of dollars in losses?"

An audience member asked how carbon dioxide, which makes up less than half of 1 percent of the atmosphere, can exert such a dramatic effect. "[Greenhouse] gases are transparent to incoming ultraviolet radiation, and they trap outgoing infrared radiation, and they're very good at that," responded CCSI's Tom Boden, who leads ORNL's Carbon Dioxide Information Analysis Center, which collects, archives, and analyzes data about greenhouse-gas sources and concentrations on behalf of the international community. "Even though they're only present in the atmosphere in small amounts, relatively speaking, to more common, abundant elements, they're incredibly powerful heat trappers."

Another theatergoer asked what fields students interested in climate change should pursue. "There's this whole diversity of folks who are working on this particular issue, from the science—whether it's biology or chemistry or physics—to economics and social science and moral philosophy," said Preston. "Climate change is truly a multidisciplinary and interdisciplinary endeavor," Boden agreed. "Oceanography, climatology, chemistry, biology, political sciences, social sciences, computer sciences—we need talent in all of those areas to continue to tackle not only climate change, but also the next generation of environmental problems that are associated, like the acidification of the oceans."

When director Jeff Orlowski agreed to chronicle the Extreme Ice Survey, he thought he'd be producing a YouTube video. Five years later his movie was lauded at Sundance and two dozen other film festivals and will be televised this spring. Image credit: James Balog

It's never too early to learn about climate, climate variability, and climate change. Third-grade classes in Knoxville and Barrow, Alaska, are among the followers

From left, Benjamin Preston, Tom Boden, Jeff Orlowski, Kate Evans, and Stan Wullschleger field questions from the audience after the Knoxville debut of Chasing Ice. *Image credit: Dawn Levy*

of a blog by climate scientists conducting large-scale field studies in Alaska. CCSI's Stan Wullschleger leads the Next-Generation Ecosystem Experiment to model, from bedrock to vegetative canopy, an ecosystem containing vast stores of trapped carbon. As permafrost thaws, organic matter decomposes and releases carbon dioxide and methane, which is approximately 25 times more powerful than carbon dioxide as a warming agent.

"Ice is a prevalent form of all Arctic systems, even terrestrial systems that we see in the boreal forests and the Arctic tundra," Wullschleger told the audience. "We have high amounts of ground ice and permafrost and ice-wedge polygons that dominate the tundra on the north slope of Alaska. These too are systems that are vulnerable to increases in temperature." He described the fate of ponds that form in low-lying areas when ice melts. "These thaw lakes over the last 50 years are shrinking and disappearing," he said.

"Are we at the point of no return?" asked an audience member. Boden noted background tropospheric carbon dioxide levels have risen to more than 390 parts per million, mainly due to burning of fossil fuels, and global emissions of carbon are now about 10 billion tons annually. Keeping global warming below 2 degrees Celsius (approximately 4 degrees Fahrenheit) over the next century is unlikely, he said. "We're on an emissions trajectory where 3, 4, possibly 5 degrees Celsius [about 6, 8, or 10 degrees Fahrenheit] is probably more likely," Boden said. "Are we at the point of no return? Don't know. But it would be very, very difficult right now to get ourselves off our current trajectory, especially as we're seeing very large growth in fossil fuel emissions from countries that are sitting on vast reserves of coal right now with very large populations and very daunting future energy requirements."—*by Dawn Levy*

Oak Ridge National Laboratory Climate Scientists Address Environmental Reporters

Society of Environmental Journalists hear about supercomputing, tundra, and peat bogs

Oak Ridge National Laboratory climate scientists are doing their part to make sure environmental journalists have the latest knowledge to relay to readers. When nearly 300 members of the Society of Environmental Journalists convened in Chattanooga in October, ORNL researchers addressed them both at the annual meeting and in Oak Ridge, about an hour's drive away, during tours of the lab.

Moetasim Ashfaq, an atmospheric physicist and computational climate scientist in ORNL's Climate Change Science Institute and Computing and Computational Sciences Directorate, literally went the extra mile to brief the journalists Oct. 5 in Chattanooga. Ashfaq spoke on the panel "Climate & Weather: Is Juiced Up Severe Weather Already the New Normal?" Reporter Nancy Gaarder of the *Omaha World-Herald* moderated the panel, which included scientists from the National Climatic Data Center and the University of Georgia. The panelists discussed changes likely over the next 30 years, given warmth locked in by past greenhouse-gas emissions; impacts at the backyard level so reporters could craft stories relevant to readers; and research that may have uncovered the specific mechanics behind North America's changing weather.

Moetasim Ashfaq. Photo credit: Jason Richards

"Though scientists can be reluctant to reach out to the press, it's an effective channel for informing the wider public that there are extremes we're more confident about forecasting, as well as less confident about forecasting, and sharing the reasons for distinguishing between the two," Ashfaq said.

Earlier that week 25 SEJ attendees were bused to ORNL for an Oct. 3 tour that especially showcased climate research. James Hack, director of the National Center for Computational Sciences and a member of the CCSI board of directors, gave a presentation about climate modeling in the Exploratory Visualization Environment for Research in Science and Technology (EVEREST). The EVEREST facility creates depth in detailed images for a 3D effect. Hack spoke of using America's fastest supercomputer, Titan, housed at the NCCS, for models and simulations that provide a window into our climate's past, present, and future. The simulations provide science-based answers to inform policy, guide strategy, and accelerate action.

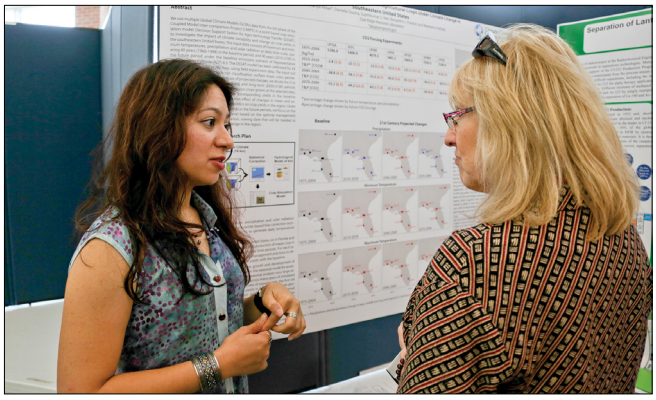
ORNL climate scientist Richard Norby, right, leads environmental journalists on a tour of a prototype site for the Spruce and Peatland Responses Under Climatic and Environmental Change experiment, which is now under way in Minnesota. Photo credit: Genevieve Martin, ORNL

At lunch Stan Wullschleger, principal investigator for the Next Generation Ecosystem Experiment–Arctic, spoke of a pioneering project under way since June 2012 in Alaska. NGEE-Arctic brings together a large team of researchers from universities and national laboratories to model an ecosystem containing vast stores of trapped carbon that may spur further warming as permafrost thaws. Rounding out the day, Colleen Iversen, Anna Jensen, and Richard Norby gave a tour of the ORNL prototype site for another large-scale field study, the Spruce and Peatland Responses Under Climatic and Environmental Change experiment, known as SPRUCE. Now being deployed in Minnesota, SPRUCE aims to assess the response of northern peatland ecosystems to increases in temperature and exposures to elevated atmospheric carbon dioxide concentrations. As field studies provide data to improve models, both SPRUCE and NGEE are likely to build a better understanding of the behavior of terrestrial ecosystems and increase confidence in climate projections.—*by Dawn Levy*

Climate Researchers Expand Knowledge, Skills at Postdoctoral Symposium

Oak Ridge National Laboratory's Postdoctoral Association, in conjunction with ORNL Fellows, hosted its first ORNL Postdoc Research Symposium on July 18. About 350 postdoctoral and post-master's researchers from across the lab had the opportunity to highlight their research and accomplishments, learn about the lab's broad areas of research, and network within the ORNL community.

Mariya Absar was among about 15 postdoctoral and post-master's researchers from the Climate Change Science Institute who presented at the symposium, which included a keynote lecture from Ramamoorthy Ramesh, the lab's new deputy for science and technology; oral presentations and poster sessions from about 100 individuals; and awards for outstanding presentations and posters.



Post-master's researcher Mariya Absar (left) explains the research in her poster presentation to V.J. Ewing of Creative Media. Photo credit: Jason Richards

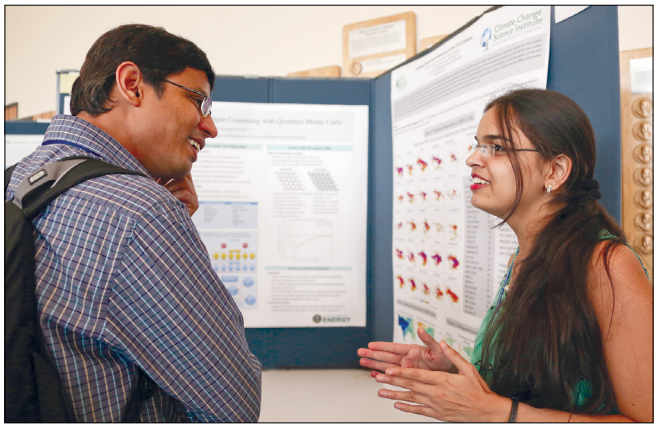
"I attended the symposium to share my current research with other postdocs and post-master's and to get feedback from other scientists attending the event," said Absar, a CCSI post-master's researcher who presented a poster assessing production and adaptation of agricultural crops with respect to climate change. "I also wanted to learn what kind of research other postdocs and post-master's are involved with and to network with others attending the event."

CCSI postdoctoral fellow Rui Mei, who presented a poster on South Asian monsoon precipitation, agreed: "It is good to know what other research topics are going on around the lab. I received very useful feedback and suggestions for my poster both at the symposium and after it."

Absar also found the critique valuable. "The detailed feedback will help me improve my future poster presentations," she said. "I have two conferences coming up by the end of this year, and the feedback I received was very helpful."

CCSI postdoctoral researcher Anna Jenson (left) and Raja Payyavula of Energy and Environmental Sciences look at a key point on a poster presentation at this summer's ORNL Postdoc Research Symposium. Photo credit: Jason Richards

CCSI postdoctoral researcher Santonu Goswami, who presented a poster about a proposed system to characterize permafrost changes in the Arctic, said, "Working in one corner of the lab does not really allow me to get acquainted with other early career scientists. The symposium really helped me to get to know other postdocs and post-master's and see what different areas everyone is busy doing research in. This also helps me realize how great ORNL is and the potential it offers to help build a research career for an early career scientist like me. Additionally, it helps me to identify potential research collaborations with other early career scientists within the lab."



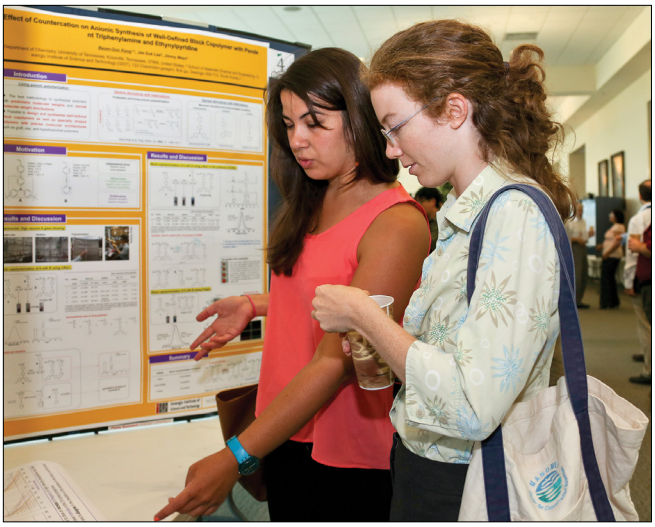
Venu Gopal Vandavasi of Neutron Sciences (left) listens to CCSI post-master's researcher Deeksha Rastogi during the poster presentations component of the ORNL Postdoc Research Symposium. Photo credit: Jason Richards

Leadership potential

Perhaps the most significant benefit for Goswami was the opportunity to enhance leadership skills. "The activities of the postdoc association help build leadership skills through professional development and working with peers," he said. "Being able to contribute meaningfully in my field within the next few years is what I am aiming for. This means publishing research findings in high-impact journals as well as building leadership in the field."

Former CCSI post-master's researcher Danielle Touma, who is now enrolled in a Ph.D. program at Stanford University, presented a poster on 21st century precipitation changes. "I attended the symposium because I believe that one of the most important aspects of research is sharing the knowledge you gain with others," she said. "Also, I was interested in participating in something within my own community and understanding what other people in my career level work on at ORNL."

Added Touma: "ORNL has a much wider range of research than I thought. Seeing the variety of posters and oral presentations and speaking about them with other post-master's and postdocs was pretty inspiring."—*by Wendy Hames*

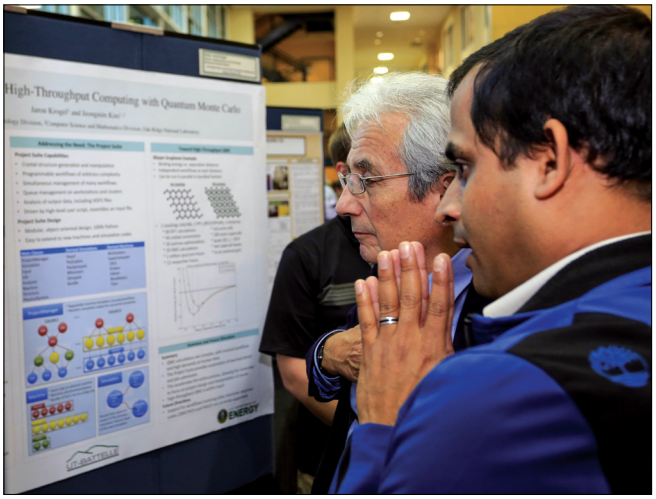


CCSI post-master's researchers Danielle Touma (left) and Megan Maloney discuss Touma's poster presentation at the ORNL Postdoc Research Symposium. Photo credit: Jason Richards

Global Change Workshop Focuses on Collaboration, Public Communication

A team of researchers from Oak Ridge National Laboratory's Climate Change Science Institute led a nationally attended workshop to discuss priorities for the next generation of ecologists who investigate threats of global change and work across scientific fields to develop mitigation methods. The workshop was organized as part of the 98th Annual Meeting of the Ecological Society of America, held in Minneapolis in August.

The U.S. Global Change Research Program, which comprises 13 agencies including the Department of Energy, defines global change as "changes in the global environment that may alter the capacity of the Earth to sustain life." Global change research addresses issues such as land productivity, climate change, water availability, and the health of ecological systems. The five-hour workshop titled "Next Generation Ecologists in Global Change Research: Current Status and Future Directions" focused on past lessons, present views, and future visions for global change ecologists.



Santonu Goswami, right, speaks with Nobel laureate Albert Fert at an early-career and postdoctoral fellows poster session in November. Goswami and colleagues previously organized a global change workshop for early-career scientists led by Climate Change Science Institute researchers in August. Photo credit: Jason Richards

"Global change is one of the most serious threats to human society and, as such, is a core research agenda around the world," said CCSI postdoctoral researcher Santonu Goswami, who led the workshop along with CCSI colleagues Xiaofeng Xu, a postdoctoral research associate, and Daniel Hayes, a modeler in ORNL's Ecosystem Science Group.

Four CCSI scientists presented at the workshop, including Hayes; Richard Norby, a UT-Battelle corporate fellow and scientist in Ecosystem Science; Stan Wullschleger, a UT-Battelle corporate fellow and national project director of DOE's Next-Generation Ecosystem Experiments; and Natalie Griffiths, a researcher in Ecosystem Science.

Norby stressed the importance of interdisciplinary work through developing communication skills, establishing partnerships with modelers and field scientists, and consistently sharing data with other researchers.

Xu agreed: "Networking for collaboration among early-career scientists was a highlight of the workshop."

Hayes and Wullschleger emphasized the need to understand where one's work fits into the big picture and to effectively communicate research findings to the general public.

"Early-to-mid-career scientists were able to think about how they might engage in community outreach," Goswami said.

Following the workshop was a one-hour discussion that encouraged early-career researchers to learn more about educating policy makers and the public on climate change and other global change issues.—*by Katie Elyce Jones*

CCSI in the News: Notable Media Coverage

Ashfaq Quoted on Modeling Mountains in *Science* Magazine

Moetasim Ashfaq

In a recent *Science* magazine news article debating the drivers of the South Asian summer monsoon, researcher Moetasim Ashfaq of the Climate Change Science Institute at Oak Ridge National Laboratory weighed in about the role of the Tibetan Plateau. He explained the complex topography of mountainous regions makes it difficult to model climate in the Himalayas. To better understand the importance of the plateau for the summer monsoon over South Asia, he has used a high-resolution (10-km) regional climate model requiring massive computing power. Results from his high-resolution experiments suggest that the plateau is critical for the progress of the monsoon over South Asia. "What the topography does is bring moisture from the equator further inland," Ashfaq said.

In *New Scientist*, Iversen and Norby Get to the Boreal Roots of Climate Change

Colleen Iversen

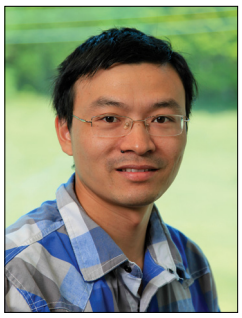
Rich Norby

Peat bogs sequester carbon that would otherwise end up in the atmosphere. They cover a mere 3 percent of Earth's surface, yet they store a third of its carbon. As Earth warms, some fear peat bogs could release stored carbon, triggering further warming. A *New Scientist* article showcased work by Colleen Iversen and Rich Norby of the Climate Change Science Institute to heat a boggy ecosystem for a decade and simultaneously expose it to elevated carbon dioxide. Similar studies with trees surprised scientists by showing additional carbon was used not to make leaves, but to form new roots. For the Spruce and Peatland Responses Under Climatic and Environmental Change experiment, or SPRUCE, Iversen has planted automated cameras in Minnesota peatlands to observe their roots from her computer in Tennessee. "These are the things that are still sort of magical to people, the things that we don't understand very well," she said.

Postdoctoral Researcher Wang Invited to Climate Change Symposium

Gangsheng Wang, a postdoctoral research associate in the Climate Change Science Institute and Environmental Sciences Division at Oak Ridge National Laboratory, was invited to attend the Dissertations Initiative for the Advancement of Climate Change Research VIII symposium. Sponsored by the National Science Foundation and the National Aeronautics and Space Administration, the symposium was held October 12–19 in Colorado Springs, Colo.

"The symposium provided a good opportunity for me to interact with other scholars and experienced climate change experts from the natural and social sciences," said Wang, one of just 42 postdoctoral researchers invited to attend out of 249 applicants. The symposium fostered interdisciplinary research in climate change by connecting young researchers across a variety of disciplines.



Gangsheng Wang

Wang conducts research at ORNL on microbially driven soil ecological processes and their interactions with environmental factors such as temperature, soil water content, and pH. He worked with ORNL mentors Melanie Mayes and Mac Post to develop a model that accounts for how different forms of carbon and nutrients in soil react with enzymes excreted into the soil by microbial communities. ORNL's Laboratory Directed Research and Development program and the U.S. Department of Energy Office of Science's Biological and Environmental Research program funded Wang's project.—*by Wendy Hames*

Author on Famous Climate Report Looks Back on Strides in Research, Public Awareness

On April 22 the Climate Change Science Institute hosted leading atmospheric scientist Ben Santer, one of the authors on the groundbreaking 1995 Intergovernmental Panel on Climate Change report that concluded humans exert a discernible influence on global warming. Santer delivered a presentation to ORNL researchers and staff on his career in climate science and his pursuit to communicate the causes of climate change and scientists' research methods to the public.

"The clear portrayal of science in the public sphere is worth fighting for," Santer said. "Over my lifetime, I've seen signals showing public awareness and understanding of these issues."

At Lawrence Livermore National Laboratory where he has worked since 1992, Santer analyzes complex computer models that use data on a range of climate indicators, such as temperature and water vapor levels, measured via weather balloons, satellites, and ice cores. Using this observational data, models simulate how climate has changed in the past and what it is likely to do in the future. Across the board, Santer said, climate models that account for natural changes in climate, such as fluctuating solar activity, as well as human activities, like the burning of fossil fuels, corroborate a pronounced warming trend recorded since the mid-twentieth century. Models that only consider natural influences cannot explain this warming.

Ben Santer

Santer argued the greatest transformation in climate science during his career is the move from single climate model studies to multi-model studies—aided by technological innovations and increased research interest. Integrating data in several models at once can utilize the best features of each model to generate more accurate simulations.—*by Katie Elyce Jones*

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Diffenbaugh N, Scherer M, Ashfaq M, "Response of snow-dependent hydrologic extremes to continued global warming," *Nature Climate Change*, **3**(4), 379–384 (2012).

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Evans K, Lauritzen P, Mishr AS, Neale R, Taylor M, Tribbia J, "AMIP Simulation with the CAM4 Spectral Element Dynamical Core," *J. Climate*, **26**, 689–709 (2013).

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