Climate Change Science Institute at Oak Ridge National Laboratory

FY 2012 Annual Report

Climate Change Science Institute
AT OAK RIDGE NATIONAL LABORATORY

OAK RIDGE
National Laboratory

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MISSION STATEMENT

To advance understanding of the Earth system, describe the consequences of climate change, and evaluate and inform policy on the outcomes of climate change responses.

For more information, please go to the Climate Change Science Institute website at 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.

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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:

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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

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US Department of Agriculture
USDA Forest Service
USDA Land Management and Water Conservation Research
US Global Change Research Program
US Geological Survey

Other Partners

Barrow Arctic Science Consortium
DuraSpace

Letter from the Director

Climate Crossroads: 2012 Was a Year of Change and Opportunity

This annual report highlights select accomplishments of the Climate Change Science Institute at Oak Ridge National Laboratory for Fiscal Year 2012, which ended Sept. 30. Just a few weeks later, Superstorm Sandy crossed seven countries in nine days, killing more than 250 people in its path and causing US damages estimated in excess of $60 billion. In Sandy's aftermath, some political and business leaders identified climate change as a reason for a "new normal" in which once-in-a-century extreme events such as hurricanes, heat waves, droughts, and wildfires occur much more frequently. In November, participants at the United Nations climate conference in Qatar criticized failing efforts to curb greenhouse gases, a point emphasized in December in a paper in *Nature Climate Change*. Notably with Tom Boden of the CCSI as a co-author, the paper reported that the planet's temperature rise would likely exceed a previously set goal of 2 degrees Celsius (4 degrees Fahrenheit) above pre-industrial levels. When all was said and done, 2012 went down as the hottest year in recorded history for the continental United States.

These happenings underscore the importance and urgency of what we do here at CCSI—providing new knowledge about the Earth's climate system to inform policy and action. Our work, which includes developing advanced scientific tools and prototypes and executing environmental experiments with unprecedented complexity, is primarily funded by the Department of Energy's Office of Science, the largest supporter of basic research in the physical sciences in the United States. Policymakers might use CCSI research to decide, for example, as climate change in the Himalayas influences the availability of water affecting hundreds of millions of people, if infrastructure investments are needed to lessen risks to the populace or how to mitigate potential regional conflicts over food or water. Stakeholders might use CCSI insights to characterize sea-level uncertainties in support of engineering activities, such as building a new subway line to serve New Yorkers over the next century. Other examples of confronting the challenge of climate change include setting of insurance rates in regions prone to hurricanes, floods, or wildfires, which requires assessment of decadal risks, and making strategic utility-company investments to keep the supply chains filled based on assessments of fuel needs that may be reduced with warmer winters but increased with hotter summers. Moreover, Congress mandates that certain organizations have climate change factored into their strategic plans, and CCSI works with agencies, such as the Department of Defense, to meet those requirements.

James Hack, director, Climate Change Science Institute at Oak Ridge National Laboratory

We aim to understand the fate of carbon in the climate system—the central issue of greenhouse-gas-induced warming—so we can develop the predictive infrastructure to help answer questions about both low-probability, high-impact events such as Sandy as well as such equally impactful happenings as seasonal heat waves. We employ high-resolution modeling and simulation of Earth's climate system—its atmosphere, land, oceans, and ice—to generate mountains of data that scientists use to write the papers assessed in the Intergovernmental Panel on Climate Change reports detailing the state of the planet. The Office of Science, which deploys the world's fastest supercomputer here at ORNL, recognizes the challenges of dealing with "big data" and has invested in innovations to manage it.

As models and simulations are only as good as the data you put into them, CCSI is also conducting field studies on a scale never before attempted to make critical measurements and observations. In FY 2012 we ramped up major field programs to understand the carbon cycle in the Arctic and boreal ecosystems. One important question

Letter from the Director

Climate change research has the potential to improve our preparation for extreme weather events like Superstorm Sandy, which cost hundreds of lives and billions of dollars in damages.

we're addressing is what will happen to Earth's temperature as permafrost thaws and releases vast stores of carbon, a potential additional source of greenhouse gas that could accelerate warming. CCSI brings together all these approaches—field experiments, modeling and simulation, data management—and then weaves a picture of the future so people can assess regional vulnerabilities and impacts and explore adaptive strategies to offset stress on the system so it remains sustainable.

What's next for 2013? The major challenge for CCSI at its outset was to bring a more cohesive program in climate together under the ORNL umbrella. Inside ORNL we needed to explore how to partner activities that were working independently in ways that allowed the synergies available inside the laboratory to add value. I believe we've demonstrated the value of our strategy. The feedback from our primary sponsor in the Office of Science has been very positive. The cross-disciplinary nature of much of our ongoing work brings together unique areas of expertise to provide a much more comprehensive solution to problems. Building on its accomplishments, CCSI continues to grow its science and seek new research opportunities.

Since joining ORNL in 2008 I have played two roles, as both director of the National Center for Computational Sciences and as director of the CCSI at ORNL. Pressing challenges wrought by climate change are more important than ever, and CCSI needs and deserves single-minded, full-time attention at the director's level to focus on the next steps forward. To that end we are evolving the CCSI leadership paradigm, which involves a search for a full-time director with the vision, skills, and expertise to ensure the institute's continued success. Whereas I will step down from my CCSI role when a full-time successor is hired, I will remain engaged in the institute on the board overseeing its operation, which includes Computing and Computational Sciences Directorate head Jeff Nichols and Energy and Environmental Sciences Directorate leader Martin Keller.

Finally, it's important to thank Gary Jacobs, who was the critical partner in establishing the CCSI and giving it strong roots. He retired at the beginning of 2013 [see story, pages 23–24], but his contributions to CCSI were too great to delay acknowledgment to a subsequent annual report. He also wore two hats, as Environmental Sciences Division Director and as business development and operations manager for the CCSI. His experience and leadership will be sorely missed. Jay Gulledge has joined ORNL to assume Gary's ESD responsibilities and will play a role on the CCSI board, while John Sanseverino, who joined us in August as CCSI project manager, will manage the institute's operations.

Maybe a century from now, people will look back at 2012 as the year when crises spurred actions that took us in a new direction. But today, we're at a crossroads. World leaders have major decisions to make as greenhouse gas emissions slow in many developed nations, including the United States, but are more than offset by rises in developing nations. By providing knowledge to inform actions, CCSI may help turn jeopardy into opportunity to find solutions to one of the most pressing problems of our time.

James J. Hack
Director
Climate Change Science Institute
Oak Ridge National Laboratory

Four Integrated Themes

Playing with a Full Deck: Four Climate Change Institute Theme Areas Advance Research

The most recent Intergovernmental Panel on Climate Change assessment report, released in 2007, identifies key challenges for climate change research going forward. Specifically, climate models need to perform at higher resolutions to better capture regional, rather than continental or global, consequences of climate change. Observational data from field sites and instrumented stations is spotty in developing nations, and more information is needed about the carbon cycle to set emissions goals aimed at curbing climate change effects.

Since its creation in 2009, the Climate Change Science Institute at Oak Ridge National Laboratory has addressed these and other challenges through four theme areas—Earth System Modeling; Data Integration, Dissemination, and Informatics; Terrestrial Ecosystem and Carbon Cycle Science; and Impacts, Adaptation, and Vulnerability Science.

Image credit: Brett Hopwood

The Earth System Modeling group is using high-performance computing resources at ORNL, including the world-leading Titan supercomputer, to retool global Earth modeling techniques to operate at higher resolutions. The ongoing development of ultra-high-resolution models has led to models many times more detailed than standard models, which improves regional modeling in high demand by public and private decision makers. The group is in its second year of the Climate Science for a Sustainable Energy Future project, a collaborative effort to develop and test improvements to the existing Community Earth System Model so that the sixth-generation CESM can feature greater predictive accuracy on finer geographic scales.

Earth science datasets that inform the builders of complex climate models are the domain of the Data Integration, Dissemination, and Informatics group, which hosts a number of projects aimed at merging data from separate archives into single portals geared toward not only model developers but a broad range of scientists and stakeholders interested in climate change information. The group creates data management tools so that contributing researchers retain credit and users can easily adopt datasets to their own scientific needs. Already tasked with content management for several data centers, the group looks forward to making CCSI archives available through one portal over the next year.

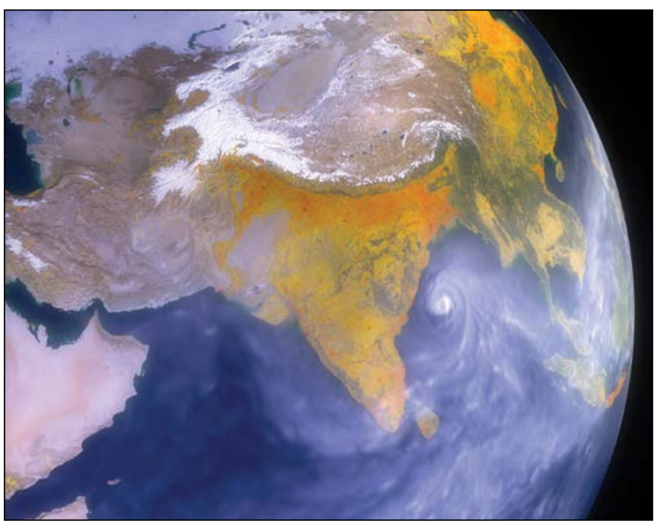
The Terrestrial Ecosystem and Carbon Cycle group primarily studies carbon cycle processes and feedbacks, or the influence of rising carbon dioxide concentrations on land ecosystems. Researchers estimate that 50 percent of the world's carbon is stored in soil and vegetation, which humans have a unique ability to manipulate through land use, such as agriculture and deforestation. In 2012, the group continued a hands-on approach by testing stressors, such as elevated carbon dioxide, on the fragile Arctic permafrost as part of the Next-Generation Ecosystems Experiments. The group is also pioneering the understanding of nutrient dynamics, such as nitrogen and phosphorous cycles, within the carbon-climate system.

To advise stakeholders who must prepare people and infrastructure for the risks associated with climate change, the Impacts, Adaptation, and Vulnerability Science group develops analysis tools and methods for assessing adaptation strategies. Many of these analysis methods span multiple scales, from local to global, and rely on advanced computer models and diverse datasets that include social, political, and economic, as well as environmental, assessments. Some major IAV research initiatives involve modeling the performance of energy infrastructure in response to climate change and the development of climate change information portals for the Department of Defense.—*Katie Elyce Freeman*

Earth System Modeling Improves Fidelity between Observed and Simulated Worlds

The climate models that supercomputers set into motion to produce simulations are "time machines" of sorts, allowing us to probe the past, picture the present, and project the future. The Computing and Computational Science Directorate's Earth System Modeling group at Oak Ridge National Laboratory strives to simulate the climate system in a way that faithfully depicts the observed world. The group tackles challenges from quantifying uncertainties and increasing model resolution to integrating models of ocean, atmosphere, land, and sea ice.

"We can use [Earth system models] as predictive tools," says Climate Change Science Institute Director James Hack, whose view is echoed by Daniel McKenna, who leads ESM activities at the lab. "But what are they missing in the way they're configured? How can they be improved? How can they make better use of the data that we're collecting about the climate system? We're trying to explore the whole modeling and simulation spaces as comprehensively as we can, and we try to do that using the unique ORNL computing resources."



Coupled population and climate simulations aid humanitarian relief efforts. Oak Ridge National Laboratory's Global Population Project helps thousands of experts coordinate disaster response, humanitarian relief, sustainable development, and environmental protection. To improve assessment of regional impacts of climate change, the Department of Energy is developing ultra-high-resolution Earth system models to run on supercomputers. The ESM climate output can be overlaid onto population data sets such as those created by CCSI's Budhendra Bhaduri, a principal member of the LandScan Global and LandScan USA population modeling programs at ORNL. Such simulations may reveal regions at risk for droughts and heat waves and guide stakeholders in taking action. Visualization credit: Jamison Daniel and Eddie Bright, ORNL

The Intergovernmental Panel on Climate Change's *Fourth Assessment Report: Climate Change 2007* concluded that global models were inadequate at projecting the effect of climate change on the hydrological cycle. Though models have improved since that assessment, it remains difficult to achieve accurate projections on subcontinental scales. Some of the 23 models cited in the report projected increases in regional rainfall while others predicted decreases in the same regions. How much confidence can we have in models that describe the same system yet arrive at different conclusions?

"It's particularly hard when you get down to regional space scales that matter to the people who are doing resource management for agriculture and so on," says Hack. "That's been one of the driving forces to try exercising our global modeling tools at very high resolution—the idea being that if we go to a higher resolution, we capture motion scales that we can't with standard models, which may give us a much better representation of processes that contribute to the hydrologic cycle."

CCSI researchers collaborate with the Earth system modeling community, whose activities are jointly funded by the Department of Energy Office of Science and the National Science Foundation, to assemble and experiment with a full, coupled climate system model that includes high-resolution ocean, atmosphere, land, and sea ice components. The models capture ocean motions down to about 50 kilometers and atmospheric motion scales down to about 120 kilometers—about eight times more detail than standard modeling frameworks, according to Hack. Moreover, CCSI experts are embedding regional models into the global models to look at phenomena on scales smaller than 10 kilometers.

Hack hopes high resolution will enable researchers to better capture the seasonal cycle of temperature and precipitation distributions, and longer-term modes of climate variability such as the El Niño–Southern Oscillation climate pattern, as well as extremes like hurricanes, intense storms, heat waves, and droughts.

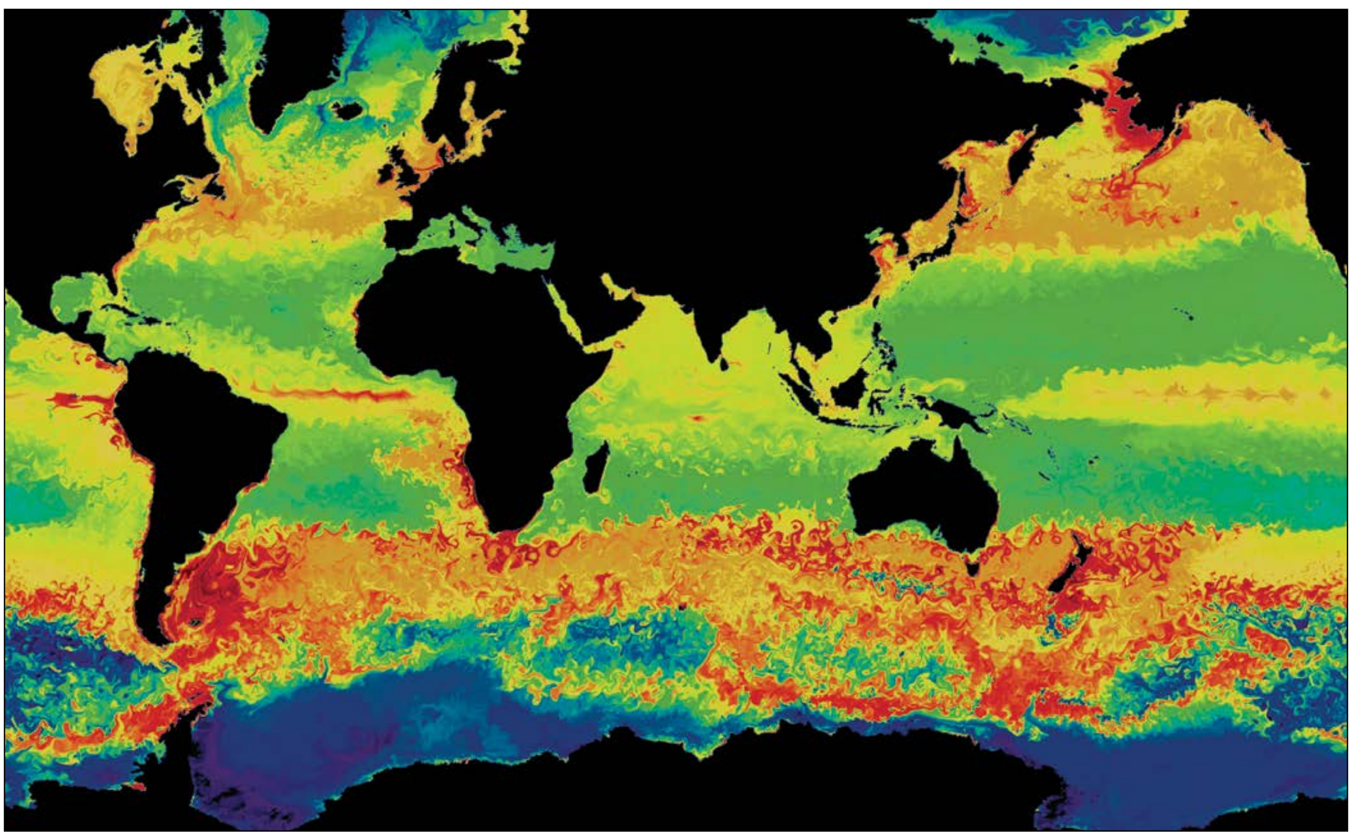
"By going higher resolution you capture many important phenomena a whole lot more accurately, and hopefully their statistics are realistically captured so you can make projections," Hack says. "We have to do a good job on [modeling] the past to be able to have any kind of confidence in the ability of the modeling framework to make reliable projections about the future."—*Dawn Levy*

Collaborators Endeavor to Accelerate Climate Answers with Model Improvements

Scientists of the Climate Change Science Institute at Oak Ridge National Laboratory are helping accelerate the development of the Community Earth System Model, which couples independent models describing atmosphere, oceans, land, and sea ice. The climate science community uses CESM to explore dynamic interactions that drive Earth's climate. Researchers at the Department of Energy's Oak Ridge, Argonne, Brookhaven, Lawrence Berkeley, Lawrence Livermore, Pacific Northwest, and Sandia national laboratories and the National Science Foundation's National Center for Atmospheric Research have teamed up for the Climate Science for a Sustainable Energy Future project. Its research endeavors aim to improve simulations at regional scales, better represent the hydrological cycle and quantify uncertainties in its simulation, and quantify and reduce uncertainties in carbon cycle and other biogeochemical feedbacks in the terrestrial ecosystem.

"The project aims to transform the climate model development and testing process and thereby accelerate the development of the Community Earth System Model's sixth-generation version, CESM3, scheduled to be released for predictive simulation in 5 to 10 years," says James Hack, who with Peter Thornton is the ORNL lead on the project.

CSSEF addresses the DOE Office of Biological and Environmental Research's goal to "deliver improved scientific data and models about the potential response of Earth's climate and terrestrial biosphere to increased greenhouse gas levels for policymakers to determine safe levels of greenhouse gases in the atmosphere." The project's maximum impact will be realized through its integration into the CESM project, a collaboration over more than 15 years between NCAR, several DOE labs, and academic institutions which every 5 or 6 years releases a new version of CESM.—*Dawn Levy*



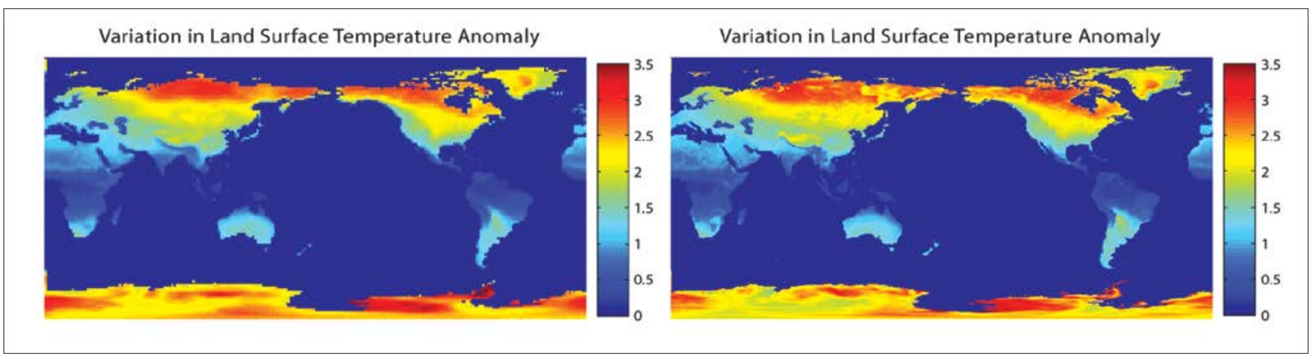
The Climate Science for a Sustainable Energy Future partners strive to improve models to enhance simulations' predictive capabilities. Simulations that include accurate ecosystem feedbacks may help determine how much carbon oceans can sequester in current and future climates. Shown in green is chlorophyll, a measure of biological activity that can be compared with observational data obtained with satellites. Image credit: Matthew Maltrud, Los Alamos National Laboratory

Ultra-high Resolution May Improve Regional Modeling of Climate Extremes

What is the probability of a drought developing in the Southwest this decade? Ultra-high-resolution climate models may improve our ability to provide informed projections. To quantify the skill of climate simulations to predict means and extremes, scientists are comparing high- and typical-resolution models. Using their highest-resolution model, with grid cells a mere one-quarter of a degree (about 37 kilometers) wide, researchers at the Climate Change Science Institute at Oak Ridge National Laboratory are analyzing whether simulated local and regional droughts influence climate extremes on larger scales.

"We're building a framework to run very-high-resolution global models to investigate computational climate models at scale accessible only with leadership computing resources," says ORNL mathematician Rick Archibald, one of nine researchers at ORNL teaming up with scientists at Lawrence Berkeley, Lawrence Livermore, and Los Alamos national laboratories on the Ultra-high-resolution Global Climate Simulation project, which is sponsored by the Department of Energy's Office of Science. James Hack is the principal investigator. Their high-resolution model couples independent models of atmosphere, oceans, sea ice, and land. It prescribes fixed conditions for sea ice and oceans but dynamic evolution of atmosphere and land.

"Understanding extreme events within a high-resolution coupled ocean-atmosphere model is a great challenge," says Kate Evans, whose expertise intersects mathematics and climate science, "because we need to assess how global and regional events are simulated at high resolution, as well as their influence with each other." If the project partners are successful in producing a high-resolution, coupled model with improved predictive skill, they will share it with the wider scientific community for investigations of natural climate variability and climate change caused by human activities.—*Dawn Levy*



Advantages of high-resolution modeling are apparent in these maps of land-surface-temperature swings, which are more extreme at the poles than at the equator. Deviations from the means are shown in degrees Celsius in the legends. CCSI researchers generated two sets of atmospheric simulations forced by sea surface temperature data covering 1979 to 1999. The lower-resolution model, T85, at left, is typical of models used in the IPCC's Fourth Assessment Report; its grid cells are about 100 kilometers (60 miles) wide at mid-latitudes. The higher-resolution T341 grid (about 37 kilometers wide), provides a more detailed map of variations and will help scientists explore local extremes. Image courtesy of Oak Ridge National Laboratory, with data production by Valentine Anantharaj, Marcia Branstetter, Kate Evans, and Benjamin Mayer; image generation by Rick Archibald, Kate Evans, and Daniel McKenna; and contributions from James Hack

Terrestrial Ecosystem and Carbon Cycle Science

Carbon Feedbacks of Land Ecosystems Inform and Improve Earth System Models

What happens to carbon emitted into the atmosphere? Some stays there and contributes to global warming, while oceans and lands take up the rest. Scientists at the Climate Change Science Institute at Oak Ridge National Laboratory track carbon's movement through permafrost, bogs, forests, and other terrestrial ecosystems to understand feedbacks to the climate. They employ information from large-scale field studies, global databases, and community models in simulations of, say, how droughts and wildfires affect carbon cycling or how much carbon dioxide deciduous trees can remove from the atmosphere and how much of that greenhouse gas soil microbes can release.

"Our primary objective is to improve our ability to make future climate projections with a coupled Earth system model like the Community Earth System Model," says Peter Thornton, leader of CCSI's Terrestrial Ecosystem and Carbon Cycle Science group, which receives support from the Department of Energy's Biological and Environmental Research Office, as well as National Aeronautics and Space Administration support for production and archiving of datasets. "We've identified a number of areas where there are feedbacks between land ecosystems—especially the carbon and nutrient biogeochemistry of those ecosystems—and the climate system as a whole."

Photosynthesis largely governs the uptake of atmospheric carbon dioxide on land. How much atmospheric carbon dioxide land can absorb depends on the availability of growth-limiting resources, such as phosphorus in rainforests or light in the Arctic during winter. How long the carbon stays out of the atmosphere depends on whether it has been assimilated into long-term reservoirs such as wood or short-term sinks such as leaves. Human activities, from farming and urban sprawl to burning fossil fuels and forests, are the biggest drivers of long-term changes in carbon storage in terrestrial ecosystems, Thornton says. Because models are the means for simulating climate a century from now, his CCSI collaborators strive to make sure modeled processes accurately represent the natural world.

"The biggest strength that we have on that global playing field is the ability to bring together [observers], experimentalists, modelers, and computational scientists to address these problems," Thornton says. "Without all those pieces working together, the picture is incomplete." Through the Terrestrial Ecosystem Sciences focus area and other projects, CCSI scientists leverage these strengths in carbon-cycle modeling.

Individual trees in a dogwood stand at the University of Tennessee Arboretum are enclosed while being exposed to air enriched in a heavy-carbon isotope of carbon dioxide, as part of the Partitioning in Trees and Soil experiment. Instrumentation monitors the concentration of isotopically labeled carbon dioxide within the enclosure, as well as a host of other environmental variables. Other nearby trees are also being measured as part of a controlled experiment to study the fate of carbon taken up during photosynthesis. Photo courtesy of Jeff Warren, Oak Ridge National Laboratory

Notably, the Climate Science for a Sustainable Energy Future project pioneers this integrated approach. Its partners at Oak Ridge, Argonne, Brookhaven, Lawrence Berkeley, Lawrence Livermore, Pacific Northwest, and Sandia national laboratories and the National Center for Atmospheric Research aim to accelerate the development of the Community Earth System Model's sixth version, scheduled to be released for predictive simulation in 5 to 10 years. Thornton's group quantifies uncertainties with interactions between carbon and nutrient cycles in land.

Another CCSI undertaking is the Integrated Earth System Modeling project, the first effort to couple an integrated assessment model (the Global Change Assessment Model, representing human activities affecting land use and greenhouse gas emissions, from Pacific Northwest National Laboratory), to a fully dynamic Earth system model, CESM, which links independent models of atmosphere, ocean, land, and ice. The CESM teams include groups at ORNL and at Lawrence Berkeley National Laboratory, working with the Community Land Model, the full CESM model, and new coupling software. Improved modeling of feedbacks of terrestrial ecosystems to climate will empower explorations of energy systems, hydrology, and climate adaptation and mitigation options.—*Dawn Levy*

Spruce and Peatland Responses Under Climatic and Environmental Change

Experiment Turns Northern Bogs and Forests into an Environmental-Change Lab

Vast boreal forests characterized by peat bogs and scrubby trees cover much of North America and Eurasia. Because this unique ecosystem may exert global effects with future warming, scientists are attempting to understand its dynamics through a first-of-a-kind experiment called SPRUCE, for Spruce and Peatland Responses Under Climatic and Environmental Change. The 10-year research project is a partnership between the US Department of Energy, the US Forest Service, and university scientists to assess the response of boreal lands to further warming and elevation of greenhouse gases.

“This whole-ecosystem experiment will be warming trees, shrubs, and microbes down to a depth of 2 or 3 meters,” says Principal Investigator Paul Hanson of the Climate Change Science Institute at Oak Ridge National Laboratory. “The boreal ecosystem is under-studied and especially vulnerable to climate change. We want to gain a better understanding of its carbon dioxide and methane feedbacks to the atmosphere as well as provide quantitative data to improve ecosystem models.”

To analyze how changing climate affects diverse organisms from bacteria to spruce trees, researchers are designing a dozen high-tech, open-topped chambers to be built in northern Minnesota in 2013. Each encasing 25 trees, the chambers will allow for micro-climate control of air and belowground temperatures and carbon dioxide concentrations. In August 2012, scientists initiated the collection of peat cores to assess baseline conditions. Experimental treatments are scheduled to be turned on early in 2014 and are expected to run for a decade.—*Dawn Levy*

SPRUCE participant Joanne Childs of Oak Ridge National Laboratory measures roots below the ground to characterize the subsurface carbon cycle. Image credit: ORNL

The SPRUCE site, shown in this aerial photograph, will feature microclimate-controlled chambers 40 feet in diameter and 25 feet tall. Prototypes, shown in the inset, are now under construction in Tennessee. Similar chambers will be built at the Minnesota site in 2013 for experimental treatments that will be turned on in 2014 and run for a decade. Image credit: ORNL

Next-Generation Ecosystem Experiments–Arctic

Ecosystem Megaproject Studies Climate Change in the Vast and Vulnerable Arctic

From left, Next-Generation Ecosystem Experiments–Arctic collaborators Larry Hinzman (University of Alaska–Fairbanks) and David Graham and Ken Lowe (both of Oak Ridge National Laboratory) extract an ice core (shown in inset), which will be subjected to warming experiments back at the lab to quantify release of greenhouse gases. Such observations and experiments improve models so they can better predict the fate of the Arctic as climate changes. Image credit: Stan Wullschleger

The Arctic is warming twice as fast as the rest of the planet. While scientists understand the rudimentary reasons—natural responses to human-caused global warming are amplified at high latitudes—much remains unknown. A pioneering project under way since June 2012 in Alaska joins researchers from universities and national laboratories to model, from bedrock to vegetative canopy, an ecosystem containing vast stores of trapped carbon that may spur further warming as permafrost thaws. The Next-Generation Ecosystem Experiments project aims to reduce uncertainty in climate prediction by improving the representation of Arctic dynamics.

"It is a great concept for the Department of Energy, and especially the Office of Biological and Environmental Research, to bring together communities doing field and laboratory studies as well as modeling," says Project Director Stan Wullschleger of the Climate Change Science Institute at Oak Ridge National Laboratory. "These globally important and poorly understood ecosystems remain inadequately represented in the Earth system models, and taking steps to improve climate models by encouraging interactions among these diverse disciplines is exciting."

To increase confidence in climate projections for high-latitude regions, the collaborators will make observations and conduct experiments in drained thaw lake basins and ice-rich tundra. Initially focusing on carbon dioxide and methane, the researchers will quantify the behavior of these ecosystems and enter the knowledge gained into a high-resolution (30 × 30 kilometer, or 19 × 19 mile, grid cell) Earth system model. During the first three years of the study, they will complete a full cycle of this integrated model-experiment approach. In the ensuing decade, they hope to extend the approach with a trans-Alaskan transect that will help them predict the effects of global warming throughout the Arctic over the next century.—*Dawn Levy*

Data Integration, Dissemination, and Informatics

Data Group Helps Researchers Translate Raw Numbers into Scientific Understanding

Oftentimes, data from field studies and models require post-processing to enhance scientific understanding. The mission of the Climate Change Science Institute's Data Integration, Dissemination, and Informatics group is ensuring that researchers addressing climate change and its effects can readily discover and use the data in CCSI archives.

The group curates more than 10,000 diverse environmental and climate data sets and many tools for their management, navigation, and analysis. Along with data for Oak Ridge National Laboratory projects, CCSI manages federated data sets used worldwide, including the Department of Energy's Atmospheric Radiation Measurement remote sensing information about cloud formation and its influence on heat transfer; DOE's Carbon Dioxide Information Analysis Center, which includes the World Data Center for Atmospheric Trace Gases, for climate-change studies; the ORNL Distributed Active Archive Center of biogeochemical data from the National Aeronautics and Space Administration's Earth science missions; and the Earth System Grid, a portal led by DOE and co-funded by NASA, the National Oceanic and Atmospheric Administration, the National Science Foundation, and international laboratories, to distribute modeling data used in publications that will be cited in the Intergovernmental Panel on Climate Change's Fifth Assessment Report, expected in 2013. Historically, all the archives and tools have worked independently. But to accommodate the growing urgency of understanding climate change—and the oceans of data generated by modern measurement platforms—they must communicate and work together.

"We optimize strategies for coping with the '3 Vs'—variety, velocity, and volume—of the big data that climate science generates," says Group Leader Giri Palanisamy. "Never has there been a greater need for preparing observational and simulation data in an easy-to-consume format to inform stakeholders and policymakers about the state of the Earth system.

"First, how do I use 100 terabytes of data quickly?" Palanisamy explains. "Second, how do I combine 3,000 data sets that are totally different and figure out how to use different types of data in a common analytics platform?"

Until now, researchers typically started from scratch with data management for every new project. But when the Next-Generation Ecosystems Experiment project (an environmental observation effort under way in the Arctic) was established in 2010, the data group proposed a data management architecture capitalizing on tools and archival capabilities in place within CCSI. The plan is to store NGEE data in existing centers for observation and modeling data, for example, ARM and ESG. The distributed NGEE data archives could be accessed from a single NGEE portal. Users will be able to browse and request data sets, which the portal will bundle and deliver, rather than having to navigate separate archives. This approach allows any new CCSI project to leverage existing data-management capabilities.

Researchers with the Atmospheric Radiation Measurement Climate Research Facility launch a balloon-borne radiosonde to collect meteorological data. Photo courtesy of Giriprakash Palanisamy, Oak Ridge National Laboratory

Palanisamy's vision for 2013 is to establish a portal as a clearinghouse for all CCSI data. A user will be able to browse all CCSI archives, see where desired data are stored, and quickly download them. The system will use Mercury, a tool for metadata searching and harvesting developed at ORNL.

Analyzing and visualizing diverse data types are even more complex tasks. CCSI has many excellent standards-based tools to help, including EDEN, UV-CDAT, NCVWeb, and ORNL's spatial analysis software. The data group is identifying existing data management tools that can be modified to handle large, diverse data ensembles. The researchers are also participating in community-based data management initiatives such as DataOne, which heightens visibility of CCSI data tools.—*Deborah Counce*

Climate Data Center Initiatives

Calling on Data Centers to Cultivate Climate Change Research

Climate Change Science Institute Data Integration, Dissemination, and Informatics projects contribute to the sprawling science of climate change—which relies on disciplines as varied as ecology, geology, and the chemical sciences, among others—by centralizing diverse archives (data integration), releasing data quickly to researchers and policymakers (dissemination), and packaging data to better inform about climate change (informatics).

With carbon dioxide data available for emissions since the Industrial Revolution, Oak Ridge National Laboratory's Carbon Dioxide Information Analysis Center is the main point of reference for the Intergovernmental Panel on Climate Change's Fifth Assessment Report's analysis of fossil-fuel carbon dioxide emissions—a strong indicator of global warming's progression. The Earth Systems Grid, funded by the Department of Energy and the National Aeronautics and Space Administration and managed by CCSI researchers, is a federated data system important to IPCC activities because hundreds of climate researchers access its more than 800 terabytes of climate model data.

Essential to global climate change research, which requires diverse measurements to understand Earth's atmosphere, the Atmospheric Radiation Measurement Data Archive collects at least 3,000 types of climate data from more than 100 instruments. Additionally, ORNL's Data Active Archive Center, funded by NASA, uses a slew of observational data to corroborate climate simulation data. DAAC queries in excess of 1,000 field sites and data-collection towers for current satellite, sensor, and ground-based readings on local ecology. Also, the US Geological Survey Core Metadata Clearinghouse, which is hosted by ORNL, met a milestone this year of 100,000 biological data records from more than 90 providers.—*Katie Elyce Freeman*

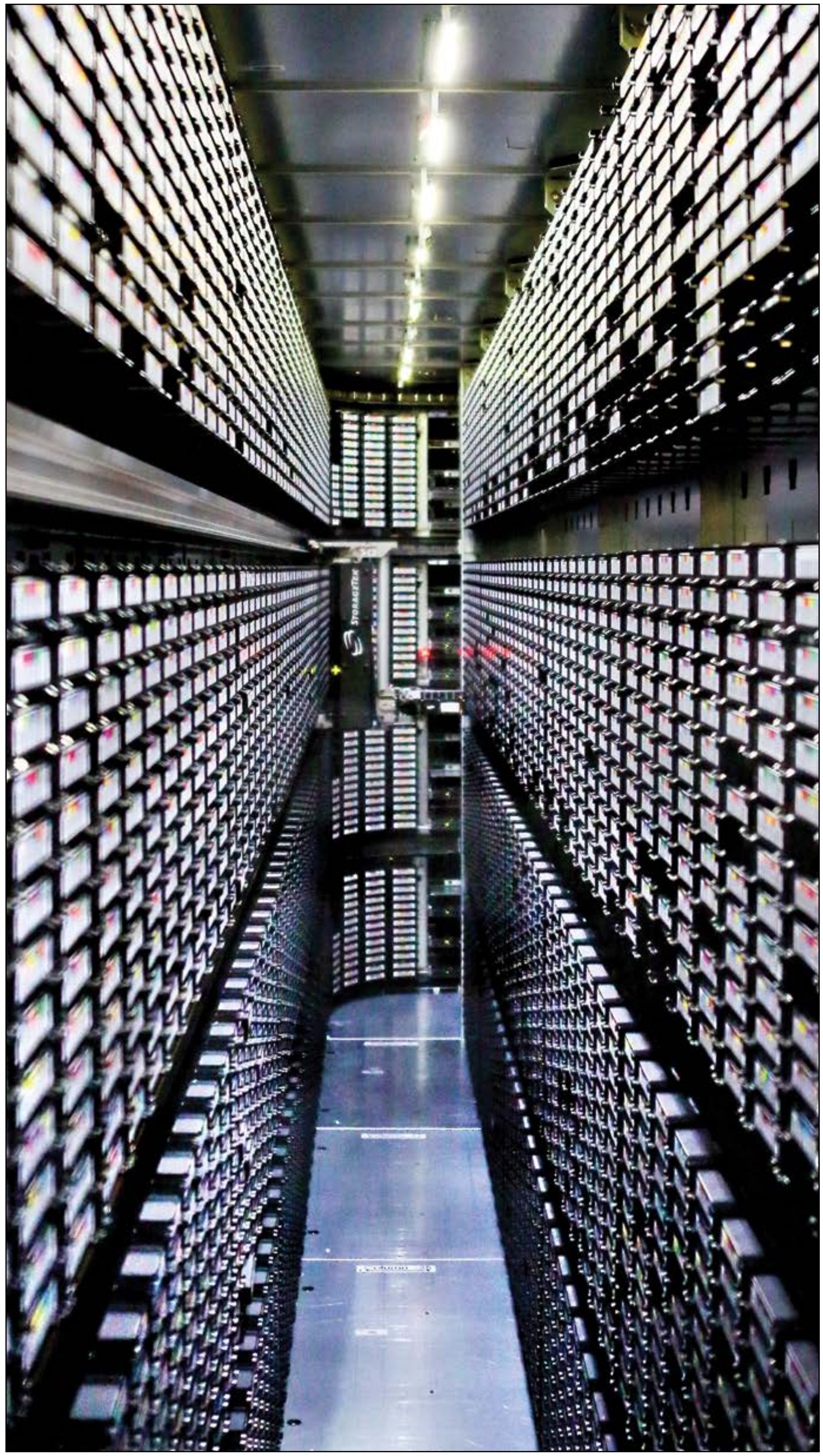
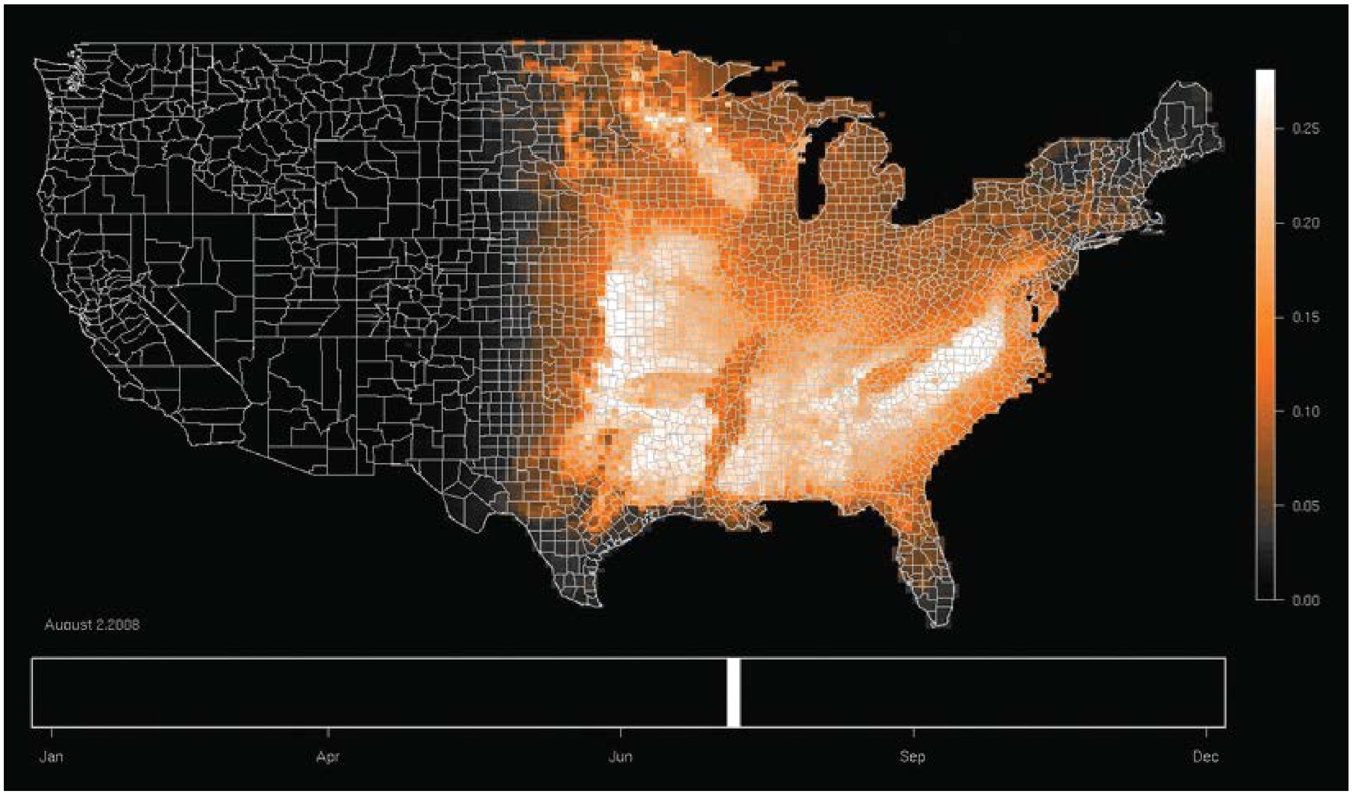


Image credit: Jason Richards

Data Observation Network for Earth

DataONE Streamlines Daunting Earth Science Data Searches



A projection of bird migration patterns rendered by the data-intensive eBird project maps the expected occurrence of the eastern bluebird for August 2008. Such predictions require multiple sources of data collected from different research disciplines. DataONE simplifies such searches through its comprehensive search software and formatting tools. Image courtesy of Cornell Lab of Ornithology

With the aid of new and improving technologies, such as satellites and complex computer models, studying planet Earth has never generated more data—an avalanche of numbers, text, and images that offers insight into the dynamics of our environment. To mine growing online datasets and archives residing in far-flung locations, a ten-institution collaboration including researchers with the Climate Change Science Institute at Oak Ridge National Laboratory has created a single search engine to explore multiple data stores. Called the Data Observation Network for Earth, or DataONE, the tool connects scientists and the public to existing Earth and life sciences data through one interface.

"This search system enables researchers to discover and access data that exist at many different repositories around the Internet," says Robert Cook, co-principal investigator for DataONE, which is led by the University of New Mexico and supported by the National Science Foundation. "By providing easy access to Earth science data, we want to help scientists, educators, and policymakers better understand life on Earth and the environment that sustains it."

Launched in July 2012, DataONE's search system accesses diverse datasets including those of ORNL's Distributed Active Archive Center. Such datasets would otherwise be available only on their respective websites and in inconsistent formats. To avoid wasting time and money collecting data that already exists, DataONE encourages data sharing and reuse. The site's DataUp tool prompts contributors to provide data in a format that is consistent, readable, and properly credited. Data sharing benefits large-scale efforts, including collaborations in climate modeling and strategy assessments for adapting to or mitigating the effects of climate change.—*Katie Elyce Freeman*

Impacts, Adaptation, and Vulnerability Science

Research Group Advances Impacts Science so Stakeholders Can Cope with Climate Change

Businesses and communities vulnerable to temperature shifts, seasonal anomalies, and other effects of climate change increasingly seek information to guide risk management. The Impacts, Adaptation, and Vulnerability Science group within the Climate Change Science Institute at Oak Ridge National Laboratory explores how the consequences of climate change will affect societal systems, including infrastructures for transportation and housing, industries such as agriculture and energy production, and ecological systems in which humans interact.

"In short, the Impacts, Adaptation, and Vulnerability group focuses on the consequences of climate change to things humans care about," says Benjamin Preston, CCSI deputy director. "This means we often address questions of interest to those who aren't in the science community, such as decision makers in the public and private sectors."

Preston's group models relationships between climate change scenarios and aspects of human livelihood of interest to particular stakeholders. This strategy often requires the integration of multiple models. Climate models, for example, provide information about the fate of volatile weather events, such as extreme rainfall or drought. Meanwhile, demographic models represent concentrations of people and how they change over time, which can inform patterns of economic development. By integrating insights from different models, the group projects how human assets may be threatened by climate and how to manage such risks.

"How do we protect our people and property from climate change impacts? First, we have to know where we have the most to lose, which requires information on the distribution of people, assets, and industries; then how and when we could lose those resources, which requires information on climate change," says Preston. "By improving understanding of potential vulnerabilities to climate variability, we can provide insights relevant to decision-making about policies and investments that can increase society's resilience."

Volatile storms, expected to increase in strength and scope as Earth warms, destroy property and put lives at risk.

As seasonal norms change, some regions may experience unprecedented drought, which can affect water availability and crop yields.

The coarse resolution of current climate models makes predicting impacts for individual coastlines, cities, and infrastructure networks difficult. Data are typically generated in 100-kilometer (60-mile) blocks, which poorly reflect nuances in topography, population density, and other factors that could indicate vulnerability to climate change. To address regional or local scales, there is a large demand among IAV researchers for enhancing the resolution of climate models. Within CCSI, the IAV group works closely with the Earth System Modeling group to benefit from its capabilities for high-resolution climate modeling.

Ultimately, IAV scientists aim to apply methods of evaluating climate change impacts, such as high-resolution models to inform decision makers responsible for developing adaptation strategies. Such strategies could range from building flood barriers to installing irrigation systems that reach crops increasingly plagued by drought. Preston's group participates on a number of projects, including collaborations supported by the Department of Energy to develop regional integrated assessment modeling capabilities that explore the implications of climate change for critical infrastructure networks. During 2012, the IAV group also developed climate change decision support tools for the US Department of Defense and coastal communities in Australia. IAV staff also played prominent roles in the Congress-mandated US National Climate Assessment, which will be released in 2013, and the Intergovernmental Panel on Climate Change's Fifth Assessment Report, to be released in 2014.—*Katie Elyce Freeman*

Multi-criteria Analysis for Coastal Adaptation

Analysis Tool Prescribes Plans for Australian Coasts Threatened by Rising Sea Levels

Australian coasts are subject to constant erosion and storm damage, and scientists anticipate future sea-level rise could encroach on populated coastlines to add insult to injury. To combat coastal hazards, the Sydney Coastal Councils Group, with funding from Australia's Department of Climate Change and Energy Efficiency, called on Benjamin Preston, Climate Change Science Institute deputy director, and Megan Maloney, CCSI research associate, to evaluate three coastal regions, including the Sunshine Coast, the metropolis of Sydney, and the rural community of Bega Valley Shire. In collaboration with the University of the Sunshine Coast, Preston and Maloney evaluated adaptation options to assess the best practices for each region based on a range of economic, social, and environmental criteria.

"Local governments want to be flexible and avoid long-term financial commitments, but they still have to protect infrastructure, public health and safety, and the environment," says Maloney. "Seawalls, for example, provide a level of protection against coastal hazards, but they are expensive. Also, some communities don't want seawalls blighting the scenic coastline, so different options will be required in different locations."

To assess risk to properties, the evaluation tool integrates information on coastal hazards, assets, and judgments of local experts. Twelve adaptation options were assessed for each property, representing three basic types of adaptation: retreating by moving businesses and homes further back from the coast; accommodating coastal hazards by enhancing the resilience of buildings and infrastructure; or protecting properties with fortifications like seawalls. According to Preston, this project represents the kind of capabilities researchers need to develop to support practical decision making about climate-risk management.—*Katie Elyce Freeman*

Rising sea levels leave coastal communities vulnerable to flood and erosion. Climate Change Science Institute researchers provide stakeholders with information to prepare for these threats.

Regional Integrated Assessment Modeling

Models Evaluate Climate Change Stress on Regional Energy Facilities

The Department of Energy's Regional Integrated Assessment Model project estimates threats to power plants in the Southeast based on regional climate change scenarios, including rising average temperatures and extreme weather events.

Scientists have spent more than a generation examining what conditions cause climate change, but today, researchers at the Climate Change Science Institute at Oak Ridge National Laboratory are looking beyond the question of "how" to "what now?" As the entire globe heats up, communities, sectors, and systems will experience climate change in different ways depending on geographic, environmental, and socioeconomic factors. To explore the impact of climate change on an individual region—knowledge that would benefit government and corporate infrastructure planning for the future—the Department of Energy's Regional Integrated Assessment Model project, in collaboration with Pacific Northwest National Laboratory and others, uses climate model predictions to investigate stressors on electric power production in the Gulf Coast region and broader Southeast.

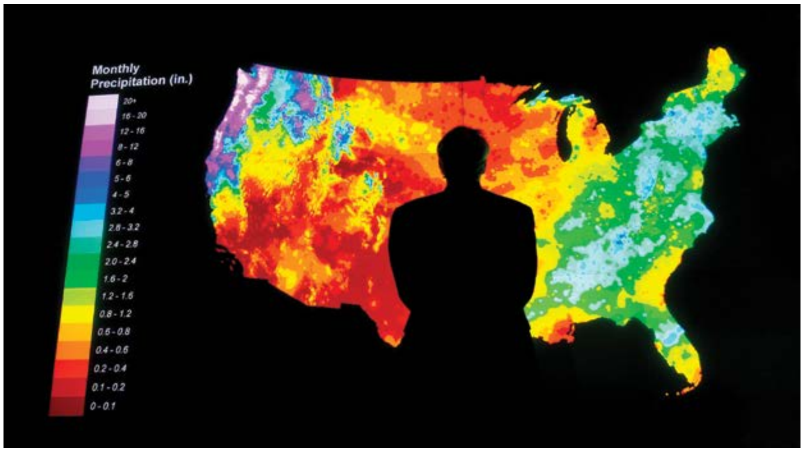
"The integrated models allow us to estimate to what degree the region's electricity production may be threatened by climate change, especially during periods of seasonal heat waves and seasonal drought, when at the same time demand for cooling is expected to rise," says Tom Wilbanks, an investigator leading this analysis.

Principal Investigator Benjamin Preston and his team are using simulations of sea-level rise and storm-surge events on the Gulf Coast, not unlike those experienced during Hurricane Katrina in 2005 and Superstorm Sandy in 2012, as well as the effect of average temperature rises on turbine efficiency in the Southeast, to assess how energy facilities may be threatened, with implications for national energy economies. Through these studies, the team also hopes to better understand how the results generated by regional integrated assessment models vary depending on the scale of resolution of models, which often lose detail and accuracy when applied to smaller regions.—*Katie Elyce Freeman*

High-Profile Assignments

Director and National Committee Recommend Climate Model Improvements

James Hack, director of the Climate Change Science Institute at Oak Ridge National Laboratory, participated in a National Academy of Sciences and National Research Council committee commissioned to evaluate how current US climate models are utilized and to develop a strategy for advancing the field of climate modeling over the next two decades. Hack was selected for his expertise in climate model development and experience as director of CCSI, as well as his role as director of the National Center for Computational Sciences at ORNL, which runs one of the world's most comprehensive climate models on the Titan supercomputer.



James Hack surveys a climate modeling visualization on the EVEREST Powerwall at Oak Ridge National Laboratory. Image credit: Jason Richards

The committee report contains a dozen key findings, including the need for greater detail and higher resolution in global climate models that currently inadequately treat regional responses to climate forcing, which would be useful for the stakeholder community to know. Collaborative climate change assessments, such as the anticipated 2014 Fifth Assessment Report from the Intergovernmental Panel on Climate Change, also point to the need for increasing realism in models and simulations, as mitigation and adaptation plans depend on these analyses.

Four Scientists Make Key Contributions to World's Foremost Climate Change Report

ipcc
INTERGOVERNMENTAL PANEL ON
climate change

In light of their significant contributions to climate change science, four Climate Change Science Institute researchers are writing, coordinating, and reviewing chapters of the Intergovernmental Panel on Climate Change's Fifth Assessment Report, AR5, expected in 2013 and 2014. The report aims to update scientists, policymakers, and the public on the scientific, technical, and socioeconomic aspects of climate change.

Working Group I: The Science of Climate Change

Paul Hanson served on the Working Group I AR5 Second Draft Review Committee. Hanson also represented a group of US-government-nominated scientists who reviewed Chapter 6, "Carbon and Other Biogeochemical Cycles."

Peter Thornton is a lead author of Chapter 6.

Working Group II: Climate Change Impacts, Adaptation, and Vulnerability

Benjamin Preston is a coordinating lead author of Chapter 16, "Adaptation Opportunities, Constraints, and Limits." Preston is also a member of the core writing team for the AR5 Synthesis Report.

Thomas Wilbanks is a coordinating lead author of Chapter 20, "Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development," and a lead author of the Working Group II Technical Summary and Summary for Policymakers.

High-Profile Assignments

Scientists Advise Tennessee Business, Civic Leaders on Preparing for Climate Change

Tennessee's average temperature is expected to rise 2 degrees Celsius (approximately 4 degrees Fahrenheit) or more by the end of the twenty-first century, impacting agriculture, human health, and tourism, among other important areas. Sustainable Tennessee is a grassroots effort to inform business owners, civic leaders, and others invested in adapting the state's resources to meet long-term challenges of climate change. Volunteering their expertise in climate change impacts and adaptation, three CCSI researchers—Esther Parish, Benjamin Preston, and Virginia Dale—coordinated, contributed to, and edited a comprehensive report, *Sustaining Tennessee in the Face of Climate Change: Grand Challenges and Great Opportunities*, that explains how climate change will affect Tennessee's landscape, people, economy, energy supply, and natural resources.

"The report and the initiative of Sustainable Tennessee provided a first point of reference for individuals whose businesses or communities may be impacted by climate change to help facilitate discussion and learning among different stakeholders about climate change in the state," says Preston, CCSI deputy director.

Parish, Preston, and Dale presented the report at Vanderbilt University in September alongside researchers from the University of Tennessee–Knoxville, Vanderbilt, and the University of Memphis who co-authored the report.—*Katie Elyce Freeman*

Statistics and Milestones

FY 2012 Metrics for the Climate Change Science Institute at Oak Ridge National Laboratory

130	Scientific publications
203	Scientific presentations/seminars
79	Conferences or workshops organized or attended
19	Public outreach/media interactions
38	Leadership activities in national/international planning activities

Retirement

Jacobs Reflects on Three Decades of Adaptation to a Changing Research Climate

Gary Jacobs, director of the Environmental Sciences Division and operations and business manager for the Climate Change Science Institute at Oak Ridge National Laboratory, retired on Jan. 1, 2013. When he arrived at ORNL in 1983, his focus was studying legacy radionuclide contamination from the 1950s and 1960s. In his 30 years at the lab, he has had the opportunity to broaden his focus into several areas of environmental science. Most recently, that scope has expanded to include the urgent effort to understand global climate change and its consequences.

During that span, Jacobs says, he's seen the lab's role broaden from merely accomplishing the near-term needs of the Department of Energy to working as a partner with DOE and other national labs in helping to set research directions. "People in the research areas are taking more of a leadership role and creative role," he says. "You need to not only deliver the science but also be a trusted partner in thinking about where research is needed."

While climate change research has gained visibility over the years, ESD under Jacobs' direction has developed a high profile in a number of other fields as well. Jacobs points out the mercury Science Focus Area at ORNL, developed by Liyuan Liang and her team, as a significant step in helping DOE identify and plan needed research. In this concentration scientists study the behavior of mercury in the environment, particularly its conversion into highly toxic methyl mercury. "The mercury project is astounding," Jacobs says. "It's been fun to watch that team, because they've advanced to the point where many in the world of mercury research want to work with them. That's a great example of how the lab can take on a new mission, learn the science, and deliver outstanding results. This fundamental science project complements our long-term monitoring of mercury [emitted by processes at DOE's Y-12 weapons plant at Oak Ridge] in the fish of East Fork Poplar Creek, which has supported the needs of DOE for over 25 years."

Other ESD staff members are conducting forefront research in sustainable bioenergy and the economics of renewable fuels. "They're making great strides in defining what sustainability is and how you actually measure it. We have three internationally known data centers related to climate change that have thrived for many years serving both the research and stakeholder communities [the Atmospheric Radiation Measurement Archive, the National Aeronautics and Space Administration Distributed Active Archive Center, and Carbon Dioxide Information Analysis Center]." Environmental impact statements were a big part of ESD's work in the early years, and federal agencies still turn to the division for large, complex EISs that demand exceptional expertise. Says Jacobs, "We truly span from fundamental science to applications."

Gary Jacobs, right, and Bill Hagarty of the Tennessee Department of Economic and Community Development examine a climate visualization on the EVEREST Powerwall at the National Center for Computation Sciences. Image credit: Dobie Gillispie

From subsoil contaminants to climate science

A geochemist by training, Jacobs came to ORNL to support Nuclear Regulatory Commission research on disposal of high-level nuclear waste. Then he began research and development in stabilizing low-level radioactive waste buried in pits and trenches at ORNL, part of DOE's environmental restoration program.

One memorable project he worked on during that era, Jacobs recalls, was in situ vitrification, in which giant electrodes were used to pass intense currents though contaminated soils and waste deposits to melt them. The molten wastes would then cool into glass, immobilizing the contaminants.

"That project was so promising in everyone's eyes, and then it was abandoned for use because a few steam explosions

Retirement

occurred from soil moisture interacting with the molten soil during testing," he says. "What was so interesting about it to me, as a geochemist, was that we were able to study the fundamental process of how rocks melt, the physics and the chemistry, and create a unique data set that the geological community wouldn't have had otherwise."

When DOE began to hand off environmental restoration to a cleanup contractor in the 1990s, much of ESD's funding in that area evaporated. "The division went from approximately 230 staff to about 130 in just a few years," Jacobs says. "It was a very trying time. We basically were out of the cleanup R&D business."

But the end of the cleanup era steered ESD in a new and ultimately more promising direction. "We came to focus on BER [the Office of Biological and Environmental Research] and the Office of Science as a primary sponsor. That was a good move for the division—it brought financial stability and greater scientific productivity," he says.

By then a section head in ESD, Jacobs began to lean toward research administration rather than field work. "I learned that working with BER to plan future work is the way you grow programs," he says. ESD and other national labs helped DOE managers design the Natural and Accelerated Bioremediation Research program—a 10-year basic research effort in using microorganisms to clean up contamination. Under that program, ESD won its first big proposal to establish a field research center for remediation R&D at the Y-12 National Security Complex. "It was very successful, with lots of good, strong scientific contributions. It was one of the first projects I helped get off the ground."

In 1999, Jacobs was drawn into two ventures that introduced him to the emerging issues of the carbon cycle and climate change. Dave Reichle, then associate laboratory director of biological and environmental research at ORNL, enlisted him to work on a DOE "roadmap" document for carbon sequestration. Through that experience, Jacobs was part of the ORNL team for Carbon Sequestration in the Terrestrial Environment, or CSiTE, a successful multi-lab proposal to establish a DOE consortium for research on increasing carbon storage in plants and soils. Jacobs co-directed CSiTE before returning to program development as deputy director of ESD.

Meanwhile, ORNL colleagues Stan Wullschleger, Paul Hanson, Mac Post, and others were working hard to develop ideas for projects in carbon cycling and experimentation. Projects like Next-Generation Ecosystem Experiments, a characterization of Arctic ecosystems to provide data for climate modeling, and Spruce and Peatland Responses Under Climatic and Environmental Change, a study of how northern peatlands respond to warming and higher carbon dioxide concentrations, grew out of planning in which ESD helped DOE, Jacobs says.

"Research on how ecosystems respond to environmental stress and change has been ESD's strength for decades. But, with climate change, we had to re-think where we should be doing research and how our observations and experiments could better support improvements to Earth system models. This was a major paradigm shift, and the staff did a great job," he says.

"A workshop report that Paul [Hanson] co-organized with national and international participants suggested key ecosystems to study," he recalls. "Number 1 was high-latitude northern areas, then boreal forests, and tropics next, and this is the order DOE is using. So, we've had good people who could be involved indirectly in planning new programs."

ORNL's emergence as a leadership computing facility in the early 2000s prompted a renewed focus on carbon cycle and climate change, Jacobs says. Then ORNL established a climate change initiative, which led to CCSI, and brought Jim Hack in to lead what went from a small effort in Earth system modeling to a world-class institute.

"It was challenging, forming the institute, because of directorate stovepipes," Jacobs says. Martin Keller (who heads ORNL's Energy and Environmental Sciences Directorate) and Jeff Nichols (who leads the Computing and Computational Sciences Directorate) "made a personal commitment to get rid of the stovepipes, and Jim and I made a commitment not to honor the stovepipes but to seek ways to bring computing, advanced data, and the carbon cycle and modeling together, and we're seeing the results from that now.

"Martin and Jeff and Jim began a significant change in how we viewed climate research at the lab. Before it was just a collection of separate programs; then it evolved into CCSI, which now has strong threads that run through it and connect the various research themes. I think we're poised to push that further."—*Deborah Counce*

Exceptional Computing Resources

World-Class Supercomputing Elevates Possibilities for Climate Change Research

Located at Oak Ridge National Laboratory, the Climate Change Science Institute shares a zip code with three of the world's most powerful supercomputers, including Titan, the Department of Energy's Cray XK7 system ranked No.1 on the Top500 list in November 2012 and managed by the Oak Ridge Leadership Computing Facility.

Exploiting unmatched computer power for climate research, scientists used supercomputers at ORNL and Lawrence Berkeley National Laboratory to generate a large fraction of the simulation data contributed by DOE and the National Science Foundation to the Intergovernmental Panel on Climate Change's Fourth Assessment Report in 2007, which earned an international team of scientists and Al Gore the Nobel Peace Prize.

From left, Climate Change Science Institute researchers Danielle Touma, Moet Ashfaq, Kate Evans, Salil Mahajan, Daniel McKenna, Marcia Branstetter, and Patrick Worley run high-resolution climate models on the world's most powerful supercomputer, Titan, located at Oak Ridge National Laboratory. Image credit: Jason Richards

In 2010, the National Atmospheric and Oceanic Administration selected ORNL to house its 1.1-quadrillion floating point operations per second (petaflop/s) system, Gaea (No. 40), for use by NOAA researchers and their partners. Kraken (No. 25) is the NSF's 1.17-petaflop/s system managed by OLCF for projects conducted by scientists from the University of Tennessee and NSF.

For open science research, potential users can access Titan through one of three programs. Allocating the majority of Titan's computing time at 60 percent, the Innovative and Novel Computational Impact on Theory and Experiment program supports large-scale projects that cannot be accomplished on widely available computing systems. Reserving 30 percent of Titan's time, the Office of Advanced Scientific Computing Research Leadership Computing Challenge considers high-risk, high-rewards projects supporting DOE's Office of Science mission, and the Director's Discretion program uses 10 percent of computing time for projects of strategic importance.

OLCF's user support team of computational scientists, many of whom are experts in engineering, Earth science, and other scientific fields being advanced on Titan, assists users with developing and scaling scientific application codes and creating visualizations. The facility also offers cybersecurity and training so users can make the most of high-performance computing capabilities.

Those capabilities have increased now that Titan has 10 times the speed of its predecessor, Jaguar, a Cray XT5 system that ranked No. 1 from November 2009 to November 2010. Titan combines advanced but conventional central processing units similar to those in Jaguar with new graphics processing units, composed of streaming multiprocessor cores designed to efficiently handle specific types of floating point arithmetic work. This deployment of a CPU/GPU hybrid architecture is the world's largest and is expected to more seamlessly execute many types of numerical simulation models, including climate models.

To simulate global climate, researchers must couple several components of the Earth system—atmosphere, land, ocean, and sea ice—each with its own repertoire of complex equations and types of data. Titan's architecture has a peak calculating capability of 27 quadrillion calculations per second and 710 terabytes of memory to allow processors to handle titan-sized data portions.

"Many computational fluid problems lend themselves to representations of the data that map well onto a GPU architecture," says James Hack, CCSI director. "So the GPUs can scream through many parts of these problems faster than a standard CPU."

The ability to scream through problems is what scientists need to quickly and more accurately project climate change consequences, such as water availability, agriculture, and potential health challenges, occurring as soon as a few decades into the future.—*Katie Elyce Freeman*

Awards and Achievements

Staff Honored with Research, Career, and Service Awards

UT-Battelle Corporate Fellow

Paul Hanson

Paul Hanson was named a UT-Battelle Corporate Fellow for his significant contributions in the last 25 years to the field of environmental effects research, notably on the impacts of climate change on North American forest ecosystems. He is currently a group leader in Oak Ridge National Laboratory's Environmental Sciences Division.

Early DOE Career Award

Daniel Hayes received an Early Department of Energy Career Award for his proposal "Model-Data Fusion Approaches for Retrospective and Predictive Assessment of the Pan-Arctic Scale Permafrost Carbon Feedback to Global Climate." With funding from the Office of Biological and Environmental Research, Hayes plans to integrate disparate data on carbon stored in Arctic soil and peatlands, then model and analyze the data to study the transfer of carbon from frozen organic material to the atmosphere as permafrost thaws.

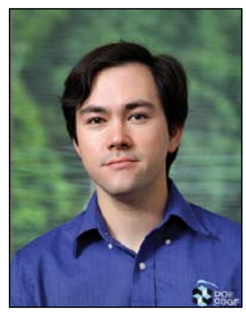
Daniel Hayes

Excellence in Science Delivery Recipients

The Climate Change Science Institute's Forrest Hoffman, Jitendra Kumar, and Richard Mills received the 2012 Southern Research Station Director's Award for Excellence in Science Delivery, as well as the Federal Laboratory Consortium Interagency Partnership Award, for the ForWarn satellite-based forest disturbance monitoring system, which tracks abnormal changes concerning storms and other weather, insects, animals, diseases, wildfires, and land use. Colleagues from the US Department of Agriculture Forest Service, the National Aeronautics and Space Administration–Stennis, and the US Geological Survey Eros were co-recipients of the awards.

Forrest Hoffman

Jitendra Kumar



Richard Mills

ESD Administrative Assistant of the Year

Tara Hall

Tara Hall has been named Environmental Sciences Division Administrative Assistant of the Year for her exemplary support, enthusiasm in assisting wherever needed, and anticipating needs before they arise.

ESD Postdoctoral Research Scientist of the Year

Xiaojuan Yang

Postdoctoral research associate Xiaojuan Yang has been named Environmental Sciences Directorate postdoctoral research scientist of the year for her creative research in ecosystem simulation science to further our understanding of the global biogeochemistry of phosphorus in soil.

In Memoriam

Patrick Mulholland

Patrick Mulholland, a researcher in the Environmental Sciences Division and Climate Change Science Institute at Oak Ridge National Laboratory, died on Earth Day, April 22, 2012, after a long struggle with amyotrophic lateral sclerosis (Lou Gehrig's disease). Named ORNL's Distinguished Scientist of the Year in 2011, Mulholland worked at the lab as an environmental biologist for his entire 31-year career, specializing in stream ecology, watershed hydrology and ecology, and the impacts of climate change on freshwater ecosystems. He conducted much of his work at the Walker Branch watershed on the Department of Energy's Oak Ridge reservation.

"Pat was one of those truly unique people," says Gary Jacobs, ESD director from 2004 to 2012. "He not only made huge contributions to our science by studying complex scientific questions and producing high-impact results that provided foundational information for important policy developments, but he was simply a nice person who valued people and mentored many students and post-grads. His efforts have been critical to ORNL's success as an internationally recognized ecosystem science institution."

Mulholland was an author on more than 140 journal articles and co-author of a book on groundwater and stream interactions. He was named a Fellow both of the American Geophysical Union and the American Association for the Advancement of Science and contributed to the Intergovernmental Panel on Climate Change's Fourth Assessment Report, for which he and many others won the 2007 Nobel Peace Prize.

Born in Syracuse, N.Y. in 1952, Mulholland spent most of his adolescence in Elyria, Ohio, where he graduated from Elyria Catholic High School. He went on to graduate from Cornell University with a bachelor's degree in civil and environmental engineering in 1973 and a master's degree in environmental engineering in 1975. Mulholland received his doctorate in environmental biology from the University of North Carolina at Chapel Hill in 1979, the year he joined the ESD at ORNL.

While at Chapel Hill, Mulholland met his wife, Cathey Daniels. The couple was married in 1978. They raised one daughter, Anna, and two sons, Rick and Joe, in Oak Ridge. Later, Mulholland would become a grandfather to Anna's son, Charles Robert Taubenheim.

In his spare time, Mulholland coached youth sports in the Oak Ridge/Knoxville area and played basketball, soccer, and tennis. He was politically active, marching on Washington in 1971 to oppose continued US involvement in the Vietnam War, fighting to preserve natural land and water resources through Tennessee Citizens for Wilderness Planning, and participating in Barack Obama's 2008 grassroots campaign in North Carolina.

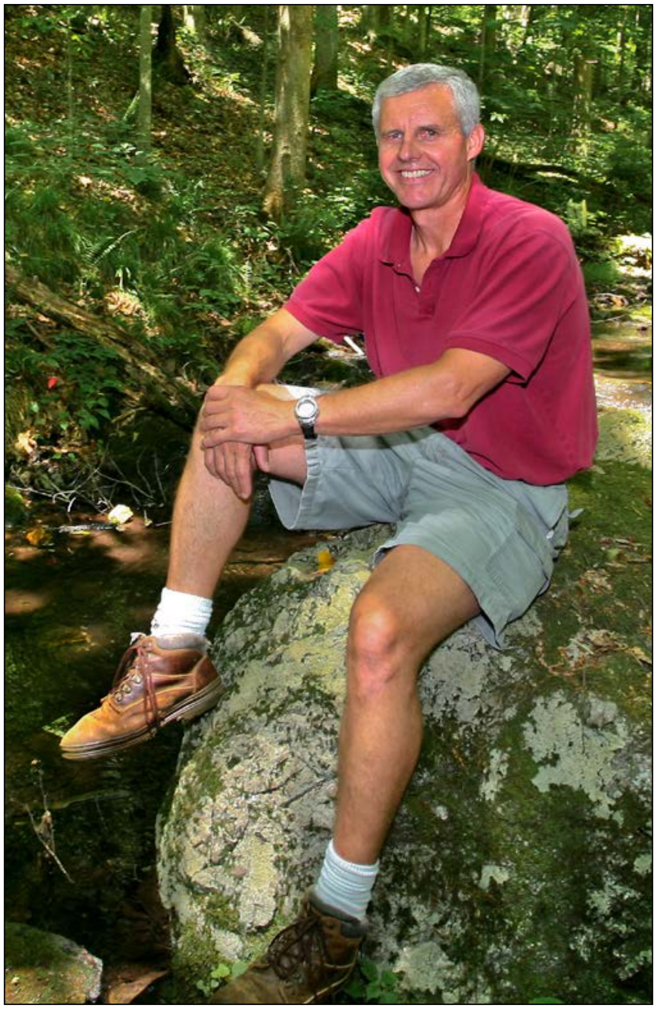


Image credit: Jason Richards

Although Mulholland increasingly struggled with speech and mobility as symptoms of ALS toward the end of his career, he continued his life's work to better understand and protect the environment. He led development of the National Ecological Observatory Network's aquatic experiment, which will be conducted at 10 US sites over the next decade to study how streams respond to a loss of animal life and a resulting buildup of nutrients. In 2011 he received the Award of Excellence from the North American Benthological Society, an international scientific organization to promote better understanding of the biotic communities of lake and stream bottoms and their role in aquatic ecosystems.—*Katie Elyce Freeman*

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