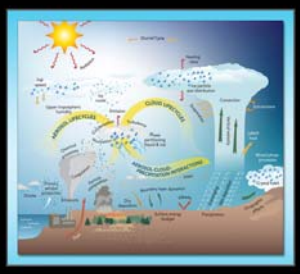
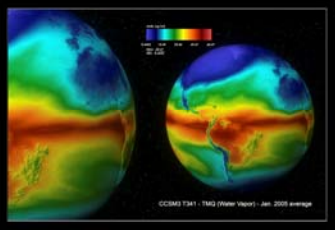
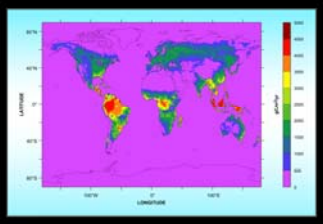
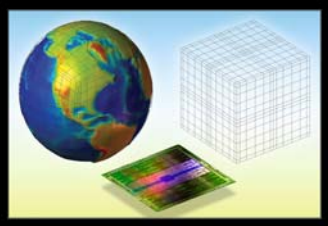
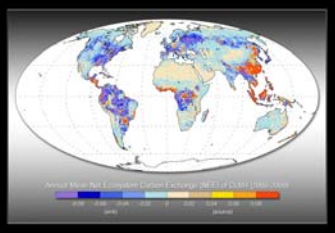
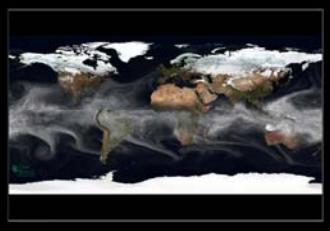
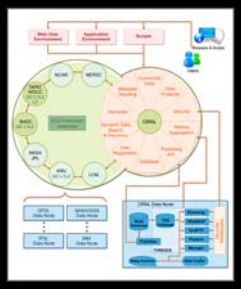
Climate Change Science Institute

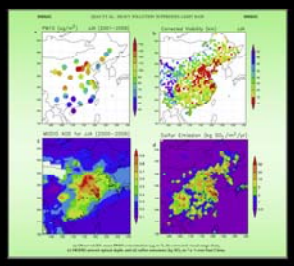
Oak Ridge National Laboratory

December 2011





OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Climate Change SCIENCE INSTITUTE

Annual Report
Fiscal Year 2011

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.

From Our Leadership

It is with great enthusiasm that we are releasing our first annual report for the Oak Ridge Climate Change Science Institute. In it, we briefly describe the Institute, our goals, our sponsors, and our partners. However, the annual report primarily provides us with an opportunity to celebrate our staff and their research accomplishments. The research activities that are highlighted were selected from CCSI publications and represent results from across our four Research Themes. As you will see in our Fiscal Year 2011 metrics, the CCSI staff had a highly productive year, and, as summarized in the last section, our researchers were honored in many ways, from awards conferred by scientific societies to selections for prominent positions on the IPCC's Fifth Assessment Report. Fiscal Year 2011 was our first year of co-location of our ~100 staff and guests, and it has been rewarding to see the resulting exchange of ideas across many disciplines. Ecologists have learned about dynamical cores, modelers now know about roots and mycorrhiza, and our data experts are working to create advanced tools for dealing with observations as well as simulation data. We have a great many challenges in front of us, but we are excited about our research that will lead to new insights into the Earth system and its response to changes in climate across a wide variety of scales. The Leadership Team encourages you to visit the CCSI website, ccsi.ornl.gov, for additional details about our vision, our projects, and our scientific staff.

About Us

CCSI continues to integrate scientific capabilities between world-class experimental systems, carbon and water cycle observation systems, and Earth system modeling. We have defined four overarching themes that enable leadership to identify where resources, proposal writing, and other efforts should be directed to maintain focus and achieve a critical mass of effort. Our projects are grouped by the primary research theme that they support. However, many of our projects are truly multi-theme, as they draw upon the expertise from more than one research theme, thereby creating the integration which is essential to our success.

The four themes and their respective leads are

Earth System Modeling (James Hack)
Data Integration, Dissemination, and Informatics (Giri Palanisamy)
Terrestrial Ecosystem and Carbon Cycle Science (Peter Thornton)
Impacts, Adaptation, and Vulnerability Science (Ben Preston)

A complete listing and description of CCSI projects can be found on our website: ccsi.ornl.gov. The funding for our projects has been approximately $100 million annually for both Fiscal Year 2010 and Fiscal Year 2011. While the majority of CCSI's funding comes from the US Department of Energy Office of Biological and Environmental Sciences, several projects are funded by a variety of other sponsors, including

US DOE Office of Advanced Scientific Computing Research
National Aeronautics and Space Administration
National Oceanic and Atmospheric Administration
US Geological Survey

Our partnerships are a critical component in achieving our strategic vision. Through partnerships, we are able to conduct more comprehensive climate change research, seamlessly. Our current partners include

DOE 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 State University
Johns Hopkins University
Lund University (Sweden)
New York University
Massachusetts Institute of Technology
Purdue University
Rutgers University
Texas A&M University
UC-Berkeley
UC-Davis
UC-Irvine
University of Alberta (Canada)
University of Illinois – Chicago
University of Michigan
University of Oregon
University of Prince Edward Island (Canada)
University of Puerto Rico
University of Sydney (Australia)
University of Tennessee
University of Utah
University of Victoria (Canada)
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
US Army Cold Regions Research and Engineering Lab
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

Fiscal Year 2011 CCSI Metrics

129 Publications

197 Presentations and Posters

93 Workshops, Conferences, and Major Meetings—Hosted & Attended

63 Press and Community Interactions

129 Committee Service

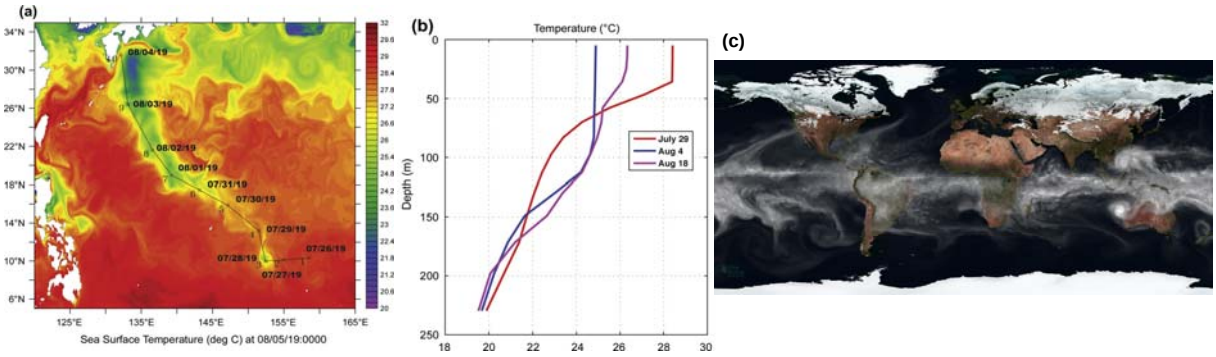
Research Highlights

A Prototype Two-Decade Fully Coupled Fine-Resolution CCSM Simulation

A fully coupled global simulation using the Community Climate System Model (CCSM) was configured using grid resolutions of 0.1° for the ocean and sea ice, and 0.25° for the atmosphere and land, and was run under present-day greenhouse gas conditions for 20 years. It represents one of the first efforts to simulate the Earth system at such high horizontal resolution and will serve as a baseline reference for even more ambitious investigations into the scientific benefits of higher resolution global simulation configurations. The climatology of the circulation of the atmosphere and the upper ocean were compared with observational data and reanalysis products to identify persistent mean climate biases. Intensified and contracted polar vortices, and too cold sea surface temperatures (SSTs) in the subpolar and mid-latitude Northern Hemisphere were the dominant biases produced by the model. Intense category 4 cyclones formed spontaneously in the tropical North Pacific. A case study of the ocean response to one such event shows the realistic formation of a cold SST wake, mixed layer deepening, and warming below the mixed layer as shown in figures (a) and (b). Too many tropical cyclones formed in the North Pacific however, due to too high SSTs in the tropical eastern Pacific. In the North Atlantic anomalously low SSTs lead to a dearth of hurricanes. Agulhas eddy pathways are more realistic than in equivalent stand-alone ocean simulations forced with atmospheric reanalysis.

A new multi-institutional effort to build on this work is under way, employing the latest version of the Community Earth System Model. Great care has been taken to minimize systematic circulation errors by using the isotropic spectral dynamical core and through attention to achieving the best possible global energy budget. Preindustrial simulations are under way (figure c), exploiting new workflow and data-sharing infrastructure designed to facilitate execution and analysis of these ultra-high-resolution explorations of Earth system variability.

McClean, J., **D. C. Bader**, F. O. Bryan, P. W. Jones, J. Dennis, A. Mirin, M. Vertenstein, D. P. Ivanova, M. E. Maltrud, Y.-Y. Kim, J. Boyle, N. Norton, A. Craig, R. Jacob, and **P. Worley**. 2011. A prototype two-decade fully-coupled fine-resolution CCSM simulation. *Ocean Modelling*, 39: 10-30. doi: 10.1016/j.ocemod.2011.02.011.

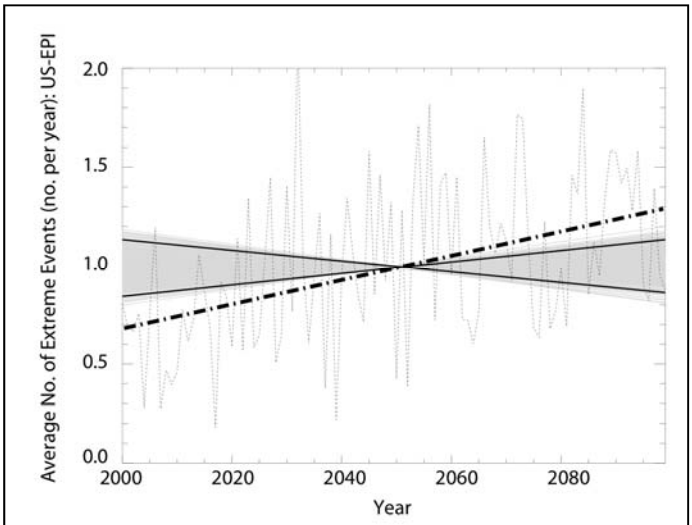


(a) Track of a Category 4 tropical cyclone event in July–August of model year 19 superimposed on the SST (°C) cold water ''wake'' under and to the right of the track of the center of the storm in the tropical northwest Pacific. (b) Vertical profiles of temperature (°C) at station 9 (133°E, 26°N) that correspond to pre-storm conditions (07/29/19), a day after the passage of the storm's center (08/04/19), and the water column once the near-inertial oscillations have largely abated (08/18/19). (c) Snapshot of column-integrated water vapor from a fully coupled T341 atmosphere and 0.1° ocean configuration of the CESM4 using pre-industrial forcing.

Research Highlights

Statistical Significance of Trends in Monthly Heavy Precipitation over the US

Extreme events of precipitation have a potential for impacting our social and economic activities. It is therefore essential to determine if there has been a systematic change in the extremes over the past years and what awaits us in the future owing to global warming. Precipitation has a very incoherent structure. The probability density function of precipitation is skewed and is clearly non-Gaussian. In this study, we investigate non-parametric as well as parametric bootstrapping as an alternative approach for the analysis of linear trends in heavy precipitation over the US. Trends in monthly heavy precipitation, defined by a return period of one year, are assessed for statistical significance in observations and Intergovernmental Panel on Climate Change (IPCC) 4th Annual Report (AR4) Global Climate Model (GCM) simulations over the contiguous United States using Monte Carlo bootstrapping techniques. Two different observational datasets are employed to test for trends in monthly heavy precipitation and are found to exhibit consistent upward trends in the 20th century, one of which is found to be statistically significant at the 95% confidence level. Upward trends similar to observations are observed in some climate model simulations of the 20th century, but their statistical significance is marginal. For projections of the 21st century, a statistically significant upward trend is observed in 11 of the 14 climate model runs forced with the Special Report on Emissions Scenarios (SRES) A2 greenhouse gas emissions estimate. However, we find that the role of natural variability of the climate-system cannot be ruled out when analyzing trends in monthly heavy precipitation, as some GCM simulations show a downward trend even in the 21st century projections, when the greenhouse gas forcings are strong.



Trends in monthly heavy precipitation over the US in one CCSM3 SRES A2 scenario climate projection of the 21st century. Shown above are the US EPI (Extreme Precipitation Index) time-series (dotted, thin), trend in the US EPI time-series (dash-dot, thick), trends in the US EPI of 500 realizations of the data obtained by reshuffling (envelope of gray thin lines), and the 95% confidence limit simulation envelope (black, solid). Note that the dash-dot line lies outside the 95% simulation envelope, indicating that the trend is statistically significant. The EPI is defined here for monthly heavy precipitation events with return period of one year.

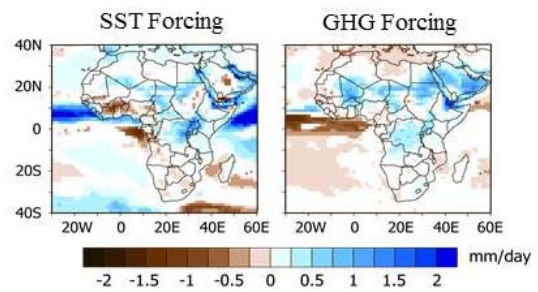
Mahajan, S., G. R. North, R. Saravanan, and M. G. Genton. 2011. "Statistical Significance of Trends in Monthly Heavy Precipitation over the US." *Climate Dynamics.*

Quantifying the Relative Roles of Future SST and GHG Forcing on the West African Monsoon

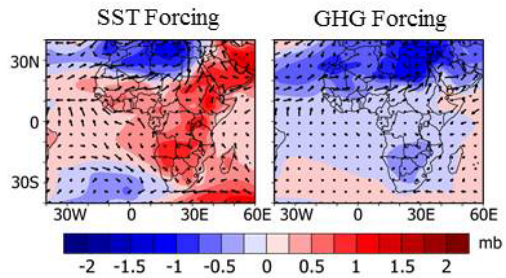
We use an ensemble of global climate model experiments to examine the relative roles of future direct atmospheric radiative forcing and sea surface temperature (SST) forcing in shaping potential future changes in boreal summer precipitation over West Africa. We find that projected increases in precipitation throughout the Western Sahel result primarily from direct atmospheric radiative forcing. The changes in atmospheric forcing generate a slight northward displacement and weakening of the African easterly jet (AEJ), a strengthening of westward monsoon flow onto West Africa and an intensification of the tropical easterly jet (TEJ). Alternatively, we find that the projected decreases in precipitation over much of the Guinea Coast region are caused by SST changes that are induced by the atmospheric radiative forcing. The changes in SSTs generate a weakening of the monsoon westerlies and the TEJ as well as a decrease in low-level convergence and resultant rising air throughout the

Research Highlights

mid-levels of the troposphere. Our experiments suggest a potential shift in the regional moisture balance of West Africa should global radiative forcing continue to increase, highlighting the importance of climate system feedbacks in shaping the response of regional-scale climate to global-scale changes in radiative forcing.



Change in Precipitation



Skinner, C. B., **M. Ashfaq**, and N. S. Diffenbaugh. "Influence of 21st Century Atmospheric and Sea Surface Temperature Forcing on West African Climate." *Journal of Climate.* doi: 10.1175/2011JCLI4183.1. (in press).

Ocean Surface Water Partial Pressure of CO_2 Database

Approximately 5.2 million measurements of surface water partial pressure of CO_2 (pCO_2) obtained over the global oceans during 1957–2010 are listed in the Lamont-Doherty Earth Observatory (LDEO) database, which includes open ocean and coastal water measurements. The data assembled include only those measured by equilibrator-CO_2 analyzer systems and have been quality-controlled based on the stability of the system performance, the reliability of calibrations for CO_2 analysis, and the internal consistency of data. To allow reexamination of the data in the future, a number of measured parameters relevant to pCO_2 measurements are listed. The overall uncertainty for the pCO_2 values listed is estimated to be ± 2.5 µatm on the average.

For simplicity and for ease of reference, this version is referred to as V2010, meaning that data collected through December 31, 2010, have been included. It is intended to update this database annually. In this update, 21 new cruise/ship files are added to the previous version (V2009). The data presented in this database include the analyses of pCO_2, sea surface temperature (SST), sea surface salinity (SSS), pressure and temperature of the equilibration, and barometric pressure in the outside air from the ship's observation system. A minor equilibration temperature problem has been corrected in the R/V *Laurence M. Gould* data for 2010. The global pCO_2 data set is available free of charge as a numeric data package (NDP) from the Carbon Dioxide Information Analysis Center (CDIAC). The NDP consists of the oceanographic data files and documentation that describes the procedures and methods used to obtain the data.

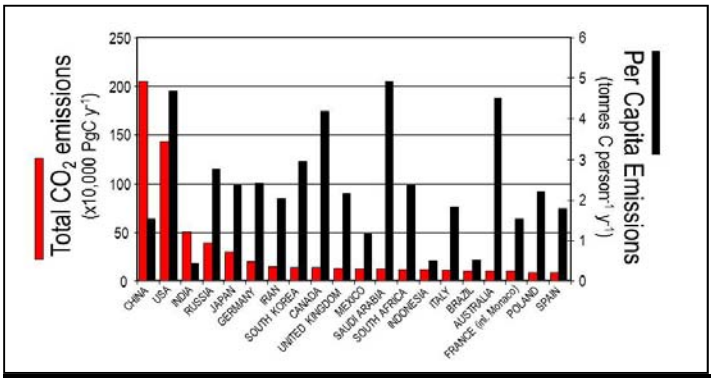
Takahashi, T., S. C. Sutherland, and **A. Kozyr**. 2011. *Global Ocean Surface Water Partial Pressure of CO_2 Database: Measurements Performed During 1957-2010* (Version 2010). ORNL/CDIAC-159, NDP-088 (V2010).

DOE BER Fossil-Fuel and Cement-Production CO_2 Emission Estimates

Each year the CDIAC at ORNL quantifies the release of carbon from fossil-fuel use and cement production at global, regional, and national spatial scales. The CDIAC emission time series estimates are based largely on annual energy statistics published at the national level by the United Nations (UN). The latest updates based on UN data (http://cdiac.ornl.gov/trends/emis/overview_2007.html) estimate the global release to be 8.37 billion

Research Highlights

tons of carbon for 2007. CDIAC also projects fossil-fuel CO_2 emission estimates for two additional years based on data published annually by British Petroleum for select countries. As stated in a correspondence to the editor of *Nature Geosciences* (Friedlingstein et al. 2010) (http://www.nature.com/naturegeoscience), the growth in CO_2 emissions closely follows the growth in Gross Domestic Product (GDP) corrected for improvements in energy efficiency. The contraction of GDP due to the global financial crisis that began in 2008 resulted in a 1.3% decrease in global fossil-fuel CO_2 emissions from 2008 to 2009. Despite this drop, the 2009 global fossil-fuel and cement emissions were the second highest in human history at 8.4 $\pm$ 0.5 Pg C, just below the 2008 emissions. The global decrease from 2008 to 2009 hides large regional differences. The largest decreases occurred in Europe, Japan, and North America (for example, USA -6.9%, UK – 8.6%, Germany -7%, Japan -11.8%, Russia -8.4%), whereas some emerging economies recorded substantial increases in their total emissions (for example, China +8%, India + 6.2%, South Korea (+1.4%).



Top 20 CO_2 Emitters & Per Capita Emissions 2009 (Global Carbon Project 2010; Population World Bank; CDIAC 2010)

Friedlingstein P., R. A. Houghton, **G. Marland**, J. Hackler, **T. A. Boden**, T. J. Conway, J. G. Canadell, M. R. Raupach, P. Ciais, and C. Le Quere. 2010. "Update on CO_2 Emissions." *Nature Geosciences* (advanced online publication, 21 November 2010).

Semantics and Provenance in a Service-Oriented Distributed Computing Environment

An approach was presented to add semantics into current geospatial catalogue services (e.g., Open Geospatial Consortium [OGC] Catalog Service for Web [CSW]) by extending the underlying information model. Semantics for geospatial data, services, and service chains, represented using OWL/OWL-S, are organized and registered in the CSW by extending OGC CSW ebXML Registry Information Model (ebRIM) elements. The approach demonstrates that semantics can be used to improve the data/services/service chains discovery capability of geospatial catalogue services. The process models, working as a kind of geospatial knowledge, can address the analysis issues in the cyber-infrastructure and support on-demand delivery of geospatial information and knowledge.

Geospatial data provenance is crucial in determining the reliability of data products and can be regarded as part of metadata for data quality. A provenance service for geospatial data products was proposed in our work. This proposed geospatial provenance service uses the ebRIM communication protocol. This approach fits well with the current service stack of the GIS domain and facilitates the management of geospatial data provenance in an open and distributed environment.

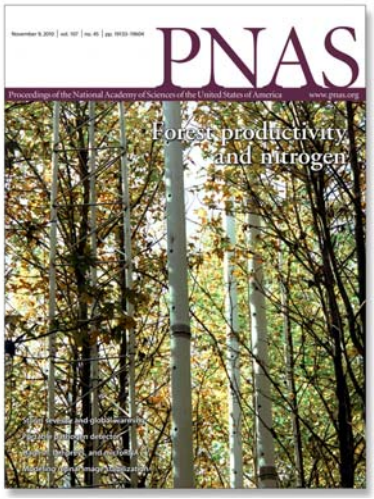
Yue P., J. Y. Gong, L. P. Di, L. L. He, and **Y. X. Wei**. 2011. "Integrating Semantic Web Technologies and Geospatial Catalog Services for Geospatial Information Discovery and Processing in Cyberinfrastructure." *Geoinformatica* 15:273-303.

Yue P., **Y. Wei**, L. Di, L. He, J. Gong, and L. Zhang. 2011. "Sharing Geospatial Provenance in a Service-Oriented Environment." *Computers, Environment, and Urban Systems* (in press).

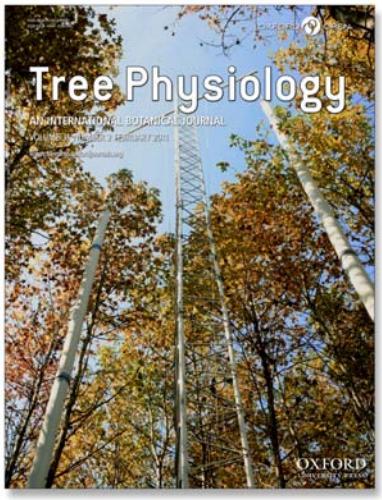
Free Air CO_2 Enrichment Experiment

The ORNL free-air CO_2 enrichment (FACE) experiment ended in 2009 with a flurry of research activity made possible by the experiment's termination after 12 years of operation. Results of that research came to fruition in papers published in Fiscal Year 2011. Warren et al. (2011a) reported that elevated CO_2 substantially reduced

Research Highlights



stand-level water use by sweetgum trees during an acute drought and heat event. Foliar stress under elevated CO_2 resulted in enhanced premature leaf senescence and abscission, reducing the overall productive capacity of the forest. Water-use data from the ORNL FACE experiment were used in a model evaluation of higher-order responses (Warren et al. 2011b). The Biome-BGC model simulated the observed reduction in sweetgum transpiration and predicted an annual increase in potential water yield in response to eCO_2. ***The direct effect of elevated CO_2 on forest water balance through reductions in transpiration could be considerable, especially following canopy closure and development of maximal leaf area index.*** Belowground analysis focused on nitrogen. Greater rates of potential net N mineralization in deeper soils coincided with the stimulation of root production at deeper soil depths under elevated CO_2 (Iversen et al. 2011). That analysis is particularly important in light of the evidence from stable isotope analysis of leaf litter that indicated N availability declined during the 12 year experiment, and it declined faster in elevated CO_2 (Garten et al. 2011). These and other results were used in a comprehensive analysis that reevaluated earlier conclusions about the response of net primary productivity (NPP) in the ORNL FACE experiment (Norby et al. 2010). NPP was significantly enhanced by elevated CO_2 during the first 6 years of the experiment, but as NPP subsequently declined, so did the enhancement of NPP in elevated CO_2. The decline in responsiveness to CO_2 was attributed to a constraint imposed by limited and declining N availability. These results provide a strong rationale and process understanding for incorporating N limitation and N feedback effects in ecosystem and Earth System models used in coupled carbon cycle–climate change assessments.



Garten, C. T., **C. M. Iversen**, and **R. J. Norby**. 2011. "Litterfall ^{15}N Abundance Indicates Declining Soil Nitrogen Availability in a Free-Air CO_2-Enrichment Experiment." *Ecology* 92:133-139.

Iversen, C. M., T. D. Hooker, A. T. Classen, and **R. J. Norby**. 2011. "Net Mineralization of N at Deeper Soil Depths as a Potential Mechanism for Sustained Forest Production under Elevated [CO_2]." *Global Change Biology* 17:1130–1139.

Norby, R. J., J. M. Warren, **C. M. Iversen**, B. E. Medlyn, and R. E. McMurtrie. 2010. "CO_2 Enhancement of Forest Productivity Constrained by Limited Nitrogen Availability." *Proceedings of the National Academy of Sciences* 107:19368–19373.

Warren, J. M., R. J. Norby, and **S. D. Wullschleger**. 2011a. "Elevated CO_2 Enhances Leaf Senescence During Extreme Drought in a Temperate Forest." *Tree Physiology* 31:117–130.

Warren J. M., E. Pötzelsberger, **S. D. Wullschleger**, H. Hasenauer, **P. E. Thornton**, **R. J. Norby.** 2011b. Ecohydrological impact of reduced stomatal conductance in forests exposed to elevated CO_2. *Ecohydrology* 4: 196-210.

Data Sharing and Retrieval Using OAI-PMH

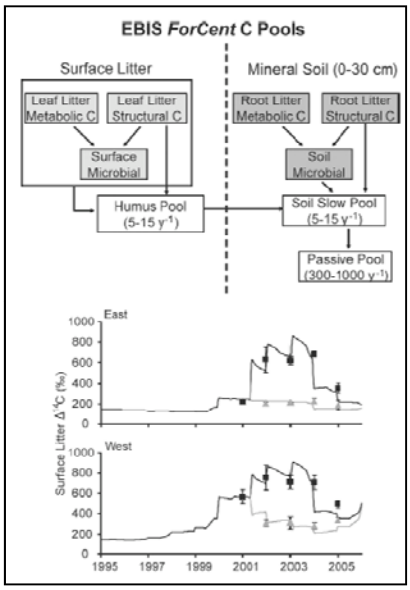
Given that data are often of use to multiple communities of practice, which may have differing norms for data and metadata structure and semantics, effective standards for data and metadata exchange are important factors for users to be able to find and retrieve data. Toolsets that provide a coherent presentation of information across multiple standards are important for data search and access. One such toolset, Mercury, is an open-source metadata harvesting, data discovery, and access system, built for researchers to search for, share, and obtain spatiotemporal-biogeochemical data used across a range of climate and ecological sciences. Mercury is used across multiple projects to provide a coherent search interface for spatiotemporal data described in any of several metadata formats. Mercury has recently enabled harvesting and distribution of metadata using the Open Archive Initiative Protocol for

Research Highlights

Metadata Handling (OAI-PMH). By using OAI-PMH, Mercury harvests metadata from several servers around the world in an incremental fashion rather than a complete dump every time, thus reducing the network traffic load and increasing system efficiency. We have developed tools to consume and redistribute metadata using OAI-PMH services in many XML metadata standards. By implementing these tools, we seek to significantly lower the technical barriers for users to find and use relevant data, regardless of any one particular data provider's repository.

Devarakonda R., G. Palanisamy, **J. M. Green**, and **B. E. Wilson**. 2011. "Data Sharing and Retrieval using OAI-PMH." *Earth Science Informatics* 4:1-5.

EBIS Data Improved a Classic Ecosystem Carbon Cycling Model and Created Others for Application to Projections of Forest Soil Carbon Processes and Stocks



Data from the DOE Enriched Background Isotope Study (EBIS) were used to improve the classic carbon cycling model, DayCent, and to create a new root production model. EBIS field studies quantified the fate and transport of uniquely enriched carbon isotopes in experimentally manipulated leaf litterfall for soils of an upland oak forest of eastern Tennessee. The experiment revealed important processes not currently included in forest carbon cycle models, including (1) isolated cycling of carbon within the surface organic pool, (2) a multicomponent root growth model, and (3) the necessary inclusion of plant phenological growth patterns. EBIS research tracked the fate of ^{14}C-labeled carbon from native temperate forest vegetation in multiple-year manipulations to isolate the dominant form of carbon supporting mineral soil microbial communities (Kramer et al. 2010). Recent leaf-litter carbon was determined to have no measurable effect on microbial respiration or biomarkers in the underlying mineral soil and showed that root-derived carbon is the major (>60%) source of carbon for microbes in temperate deciduous forest soils.

The next-generation model (ForCent) was developed and tested using EBIS data (Parton et al. 2010). Similarly, researchers developed Radix 1.0, a model of fine-root dynamics. Radix simulates two live-root pools, two dead-root pools, non-normally distributed root mortality turnover times, a stored carbon pool, and seasonal growth and respiration patterns (Riley et al. 2009). Predicted live-root turnover times were < 1 year and ~ 10 years for short- and long-lived carbon pools, respectively. Root populations with decadal turnover times implies a lower amount of belowground net primary production used to grow fine-root tissue than is currently predicted by models with a single annual turnover pool. Application of improved soil carbon cycle and root productivity models for forests will provide better global carbon cycle projections when fully implemented within their land-surface components.

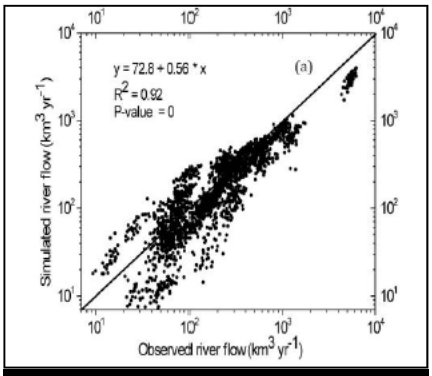
Kramer, C., S. Trumbore, M. Froberg, L. M. Cisneros-Dozal, D. Zhang, X. Xu, G. Santos, and **P. J. Hanson**. 2010. "Recent (<4 Year Old) Leaf Litter Is Not a Major Source of Microbial Carbon in a Temperate Forest Mineral Soil." *Soil Biology and Biochemistry* 42:1028–1037.

Parton, W. J., **P. J. Hanson**, C. Swanston, M. Torn, S. E. Trumbore, W. Riley, and R. Kelly. 2010. "ForCent Model Development and Testing using the Enriched Background Isotope Study (EBIS) Experiment." *JGR-Biogeosciences* 115: G04001. doi:10.1029/2009JG001193.

Riley, W. J., J. B. Gaudinski, M. S. Torn, J. D. Joslin, and **P. J. Hanson**. 2009. "Fine-Root Mortality Rates in a Temperate Forest: Estimates using Radiocarbon Data and Numerical Modeling." *New Phytologist* 184:387–398.

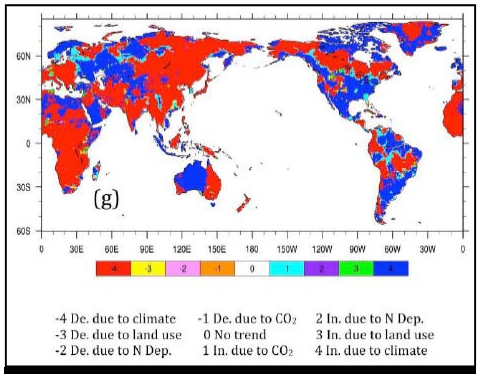
Research Highlights

The Impact of Climate, CO_2, Nitrogen Deposition, and Land Use Change on Simulated Contemporary Global River Flow



CLM4 predicted river flow and recent trends are in reasonable agreement with observations.

We investigated how climate, rising atmospheric CO_2 concentration, increasing anthropogenic nitrogen deposition, and land use change influenced continental river flow over the period 1948–2004 using the Community Land Model version 4 (CLM4) with coupled river transfer model (RTM), a global river routing scheme. The model results indicate that the global mean river flow shows a significant decreasing trend and that climate forcing likely functions as the dominant controller of the downward trend during the study period. Nitrogen deposition and land use change account for about 5% and 2.5% of the decrease in simulated global scale river flow, respectively, while atmospheric CO_2 accounts for an upward trend. However, the relative role of each driving factor is heterogeneous across regions in our simulations. The trend in river flow for the Amazon River basin is primarily explained by CO_2, while land use change accounts for 27.4% of the downward trend in river flow for the Yangtze River basin. Our simulations suggest that to better understand the trends of river flow, it is not only necessary to take into account the climate, but also to consider atmospheric composition, carbon-nitrogen interaction, and land use change, particularly for regional scales.



Interannual variability and long-term trends in global total river flow are dominated by climate, but direction and magnitude of trend as well as dominant controlling factor varies by region.

Shi, X., **J. Mao**, **P. E. Thornton**, **F. M. Hoffman**, and **W. M. Post**. 2011. "The Impact of Climate, CO_2, Nitrogen Deposition and Land Use Change on Simulated Contemporary Global River Flow." *Geophysical Research Letters* 38: L08704.

Climate Change Experiments in High-Latitude Ecosystems

Boreal and tundra ecosystems are critical to understanding our changing Earth system. These high-latitude systems contain large amounts of carbon stored in soils that could be released upon warming. This represents a significant source of uncertainty in models. Increasing confidence in climate projections requires an approach that ultimately improves representation of important ecosystem-climate feedbacks across complex and highly connected landscapes.

Scientists in the ORNL CCSI have long used models, observations, and experiments to improve climate predictions. Given the need to quantify ecosystem-climate interactions in high-latitude ecosystems, a lab-university team has put forth an agenda that calls for a new generation of experiments to address major uncertainties in water, energy, and carbon cycle processes. The goal is to quantify climate feedbacks in boreal forests and permafrost-dominated tundra landscapes. A network of field observations and experiments could provide high-resolution, long-term, and continuous measurements to quantify processes and reveal insights into the behavior of the larger system. The infrastructure and logistical challenges required to conduct experiments in high-latitude ecosystems will exceed those of previous experiences in temperate regions. One approach might be to modify techniques used in other large-scale experiments and design them for the realities of high-latitude research.

Research Highlights

Scientists working under the umbrella of the CCSI believe that the full value of climate change research and model-data integration in boreal forests and the Arctic can only be realized through the incorporation of process knowledge into Earth system models.

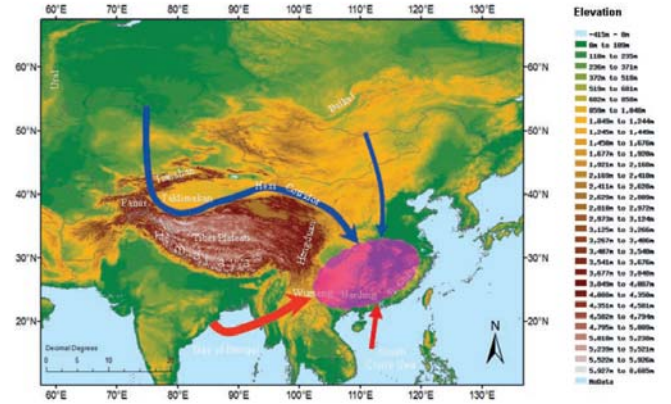
Wullschleger, S. D., L. D. Hinzman, and C. J. Wilson. 2011. "Climate Change Experiments in High-Latitude Ecosystems." *EOS* 90:145.

Assessing Net Ecosystem Carbon Exchange of US Terrestrial Ecosystems by Integrating Eddy Covariance Flux Measurements and Satellite Observations

More accurate projections of future carbon dioxide concentrations in the atmosphere and associated climate change depend on improved scientific understanding of the terrestrial carbon cycle. Despite the consensus that US terrestrial ecosystems provide a carbon sink, the size, distribution, and interannual variability of this sink remain uncertain. Here we report a terrestrial carbon sink in the conterminous US at 0.63 Pg C per year with the majority of the sink in regions dominated by evergreen and deciduous forests and savannas. This estimate is based on our continuous estimates of net ecosystem carbon exchange (NEE) with high spatial (1-km) and temporal (8-day) resolutions derived from NEE measurements from eddy covariance flux towers and wall-to-wall satellite observations from Moderate Resolution Imaging Spectroradiometer (MODIS). We find that the US terrestrial ecosystems could offset a maximum of 40% of the fossil-fuel carbon emissions. Our results show that the US terrestrial carbon sink varied between 0.51 and 0.70 Pg C per year over the period 2001–2006. The dominant sources of interannual variation of the carbon sink included extreme climate events and disturbances. Droughts in 2002 and 2006 reduced the U.S. carbon sink by ~20% relative to a normal year. Disturbances, including wildfires and hurricanes, reduced carbon uptake or resulted in carbon release at regional scales. Our results provide an alternative, independent, and novel constraint to the US terrestrial carbon sink.

Xiao, J. F., Q. L. Zhuang, B. E. Law, D. D. Baldocchi, J. Q. Chen, A. D. Richardson, J. M. Melillo, K. J. Davis, D. Y. Hollinger, S. Wharton, R. Oren, A. Noormets, M. L. Fischer, S. B. Verma, D. R. Cook, G. Sun, S. McNulty, S. C. Wofsy, P. V. Bolstad, S. P. Burns, P. S. Curtis, B. G. Drake, M. Falk, D. R. Foster, **L. H. Gu**, J. L. Hadley, G. G. Katulk, M. Litvak, S. Y. Ma, T. A. Martinz, R. Matamala, T. P. Meyers, R. K. Monson, J. W. Munger, W. C. Oechel, U. K. T. Paw, H. P. Schmid, R. L. Scott, G. Starr, A. E. Suyker, and M. S. Torn. 2011. Assessing Net Ecosystem Carbon Exchange of U.S. Terrestrial Ecosystems by Integrating Eddy Covariance Flux Measurements and Satellite Observations." *Agricultural and Forest Meteorology* 151:60–69.

The Great 2008 Chinese Ice Storm, Its Socioeconomic-Ecological Impact, and Sustainability Lessons Learned



The encounter of continental polar (cP; blue arrows) with tropical maritime (mT; red arrows) air masses to the east of the Tibetan Plateau. The pink oval marks the ice storm region. The thicker arrows indicate the dominant directions in airmass movement.

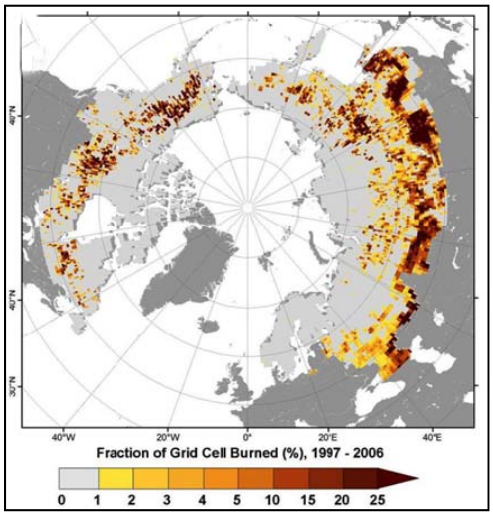
Extreme events often expose vulnerabilities of socioeconomic infrastructures and point to directions of much-needed policy change. Integrated impact assessment of such events can lead to finding of sustainability principles. Southern and central China has for decades been undergoing a breakneck pace of socioeconomic development. In early 2008, a massive ice storm struck this region, immobilizing millions of people. The storm was a consequence of sustained convergence between tropical maritime and continental polar air masses, caused by an anomalously stable atmospheric general circulation pattern in both low and high latitudes. Successive waves of freezing rain occurred during a month period, coating southern and central China

Research Highlights

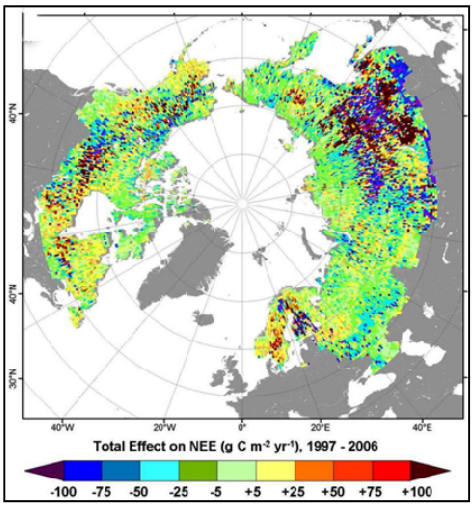
with a layer of ice 50–160 mm in thickness. We conducted an integrated impact assessment of this event to determine whether and how the context of socioeconomic and human-disturbed natural systems may affect the transition of natural events into human disasters. We found that (1) without contingency plans, advanced technologies dependent on interrelated energy supplies can create worse problems during extreme events; (2) the weakest link in disaster response lies between science and decision making; (3) biodiversity is a form of long-term insurance for sustainable forestry against extreme events; (4) sustainable extraction of nontimber goods and services is essential to risk planning for extreme events in forest resources use; (5) extreme events can cause food shortage directly by destroying crops and indirectly by disrupting food distribution channels; (6) concentrated economic development increases societal vulnerability to extreme events; and (7) formalized institutional mechanisms are needed to ensure that unexpected opportunities to learn lessons from weather disasters are not lost in distracting circumstances.

Zhou, B., **L. Gu**, Y. Ding, L. Shao, Z. Wu, X. Yang, C. Li, Z. Li, X. Wang, Y. Cao, B. Zeng, M. Yu, M. Wang, S. Wang, H. Sun, A. Duan, Y. An, X. Wang, and W. Kong. 2010. "The Great 2008 Chinese Ice Storm, Its Socioeconomic-Ecological Impact, and Sustainability Lessons Learned." *Bulletin of the American Meteorological Society* 92:47–60. doi: 10.1175/2010BAMS2857.1.

Model-Data Fusion Analysis Suggests Weakening Sinks and Strengthening Sources in High-Latitude Ecosystems are Creating a Positive Feedback to Climate Warming Through the Carbon Cycle



Studies indicate that, historically, terrestrial ecosystems of the northern high-latitude region may have been responsible for up to 60% of the global net land-based sink for atmospheric CO_2. However, these regions have recently experienced remarkable modification of the major driving forces of the carbon cycle, including surface air temperature warming that is significantly greater than the global average and associated increases in the frequency and severity of disturbances. Whether Arctic tundra and boreal forest ecosystems will continue to sequester atmospheric CO_2 in the face of these dramatic changes is unknown. Here we show the results of model simulations that estimate a 41 Tg C per year sink in the boreal land regions from 1997 to 2006, which represents a 73% reduction in the strength of the sink estimated for previous decades in the late 20th century. Our results suggest that CO_2 uptake by the region in previous decades may not be as strong as previously estimated. The recent decline in sink strength is the combined result of (1) weakening sinks due to warming-induced increases in soil organic matter decomposition and (2) strengthening sources from pyrogenic CO_2 emissions as a result of the substantial area of boreal forest burned in wildfires across the region in recent years. Such changes create positive feedbacks to the climate system that accelerate global warming, putting further pressure on emission reductions to achieve atmospheric stabilization targets.



Hayes, D. J., A. D. McGuire, D. W. Kicklighter, K. R. Gurney, and J. M. Melillo. 2011. "Is the Northern High Latitude Land-based CO_2 Sink Weakening?" *Global Biogeochemical Cycles* 25(3), GB3018, doi: 10.1029/2010gb003813.

Research Highlights

A Method for Experimental Heating of Intact Soil Profile for Application to Climate Change Experiments

Photograph of the prototype system and its control (upper photo) and the tops of the 3m-long heaters and a schematic diagram of a single heater installed in the ground (lower photo).

A multidisciplinary group of ORNL scientists developed, conceived, simulated, constructed, and tested a new experimental system for simulating future belowground temperature increases in a temperate deciduous forest in Oak Ridge, Tennessee. The new system uses low-wattage, 3m-long deep heaters installed around the circumference of a defined soil volume. The heaters add the necessary energy to achieve a set soil temperature differential within the treatment area and soil volume and add energy inputs equal to energy that might be lost from lateral heat conduction away from the treatment area. The new method, which was designed to work in conjunction with aboveground heated chambers, requires only two control sensor positions, one for aboveground air temperatures at 1m and another for belowground temperatures at a defined soil depth beneath the biologically active layers of the soil. The method was demonstrated to be capable of achieving target temperature differentials throughout an annual cycle while maintaining both diurnal and seasonal cycles at all soil depths.

Consensus Global Circulation Model (GCM) projections of the climatic and atmospheric changes suggest a mean warming of 3.8 and 3.3°C during the winter and summer, respectively, by the end of this century. Levels of future warming at these or even higher projections exceed the observed variation in mean annual temperatures (± 2°C) and atmospheric conditions under today's climate, and therefore represent a range of conditions that necessitate experimental manipulation. Temperatures observed in biologically active surface soils (0 to 1 m or greater depths relevant to deep rooting and carbon storage) represent a dynamic balance between heat flows from surface air masses and stable deep soil temperatures.

Often overlooked in previous warming studies is the reality that deep soil temperatures will also become elevated as they equilibrate with new mean annual temperatures. Such deep warming has not been achieved using previous warming technologies. Instead, preferential heating of surface soils has occurred as soils deeper in the profile remained unaffected. Although often characterized as a zone of lower carbon concentrations, deep soils contain significant carbon stocks and support quantifiable populations of roots and soil microbes that are unfortunately ignored in current warming studies. During the operation of our new warming method, observations of soil CO_2 efflux from the surface of the target soil volumes showed unexpectedly high CO_2 losses for the temperature differentials tested. Stimulation of biological activity within previously undisturbed deep-soil carbon stocks was the hypothesized source.

Hanson, P. J., K. W. Childs, **S. D. Wullschleger**, J. S. Riggs, W. K. Thomas, **D. E. Todd**, and **J. M. Warren**. 2011. A Method for Experimental Heating of Intact Soil Profiles for Application to Climate Change Experiments. *Global Change Biology* 17:1083–1096, doi: 10.1111/j.1365-2486.2010.02221.x.

Research Highlights

Utility of Formal Planning for Climate Change Adaptation

Formal planning for climate change adaptation is emerging rapidly at a range of geopolitical scales, yet little critical attention has been dedicated to evaluating the utility of such planning or even how to undertake its evaluation. Research led by CCSI scientists has attempted to tackle both of these challenges. Preston et al. (2011) interrogated a range of existing adaptation guidance instruments to identify planning processes critical for adaptation. They then used these processes as evaluation criteria and searched for evidence of their presence within 57 adaptation plans from the US, the United Kingdom, and Australia. Their results suggest that adaptation plans often suffer from critical weaknesses including limited consideration for socioeconomic drivers or entitlements to the various forms of capital needed for effective adaptation. In addition, in examining the specific actions identified within adaptation plans, the study revealed a preferential bias among organizations for capacity-building activities over the implementation of more substantive actions to reduce climate vulnerability. CCSI's researchers have also contributed to focused case studies that suggest the underlying causes for this lack of progress on adaptation can be attributed to a perceived lack of credible and relevant information about climate change and its risks as well as the inherent complexities of policy development to address emerging challenges (Measham et al. 2011). To the extent these findings are representative of adaptation planning in general, there appear to be significant deficiencies in current efforts toward climate change preparedness. This reinforces the need to enhance delivery of information to decision makers regarding both climate change and the costs and benefits of different adaptive responses.

Preston, B. L., R. M. Westaway, and E. J. Yuen. 2011. Climate Adaptation Planning in Practice: An Evaluation of Adaptation Plans from Three Developed Nations. *Mitigation and Adaptation Strategies for Global Change* 16(4):407-438.

Measham, T. G., **B. L. Preston**, and T. F. Smith et al. 2011. Adapting to Climate Change Through Local Municipal Planning: Barriers and Challenges. *Mitigation and Adaptation Strategies for Global Change*, doi: 10.1007/s11027-011-9301-2.

Climate Change Response

One of the nation's top priorities in advancing knowledge about climate change responses is to work toward a capacity to treat climate change mitigation and adaptation as parts of an integrated national response to concerns about climate change. ORNL is one of the very few institutions in the world with strong leadership positions in *both* mitigation R&D and adaptation analysis and assessment. Two published papers are intended to approach this issue from two very different directions: in one case starting with climate change adaptation and the other case with climate change mitigation. The first paper (Wilbanks and Kates 2010) begins with the clear fact that climate change impacts are real, and adaptation to such impacts is an unavoidable part of a national response. But literatures on sustainability science, hazards response, and community and regional resilience show that embedding climate change adaptation in responses to multiple threats and stresses helps us to understand climate change impacts, themselves often products of multiple stresses, and to achieve community acceptance of needed adaptations as co-benefits of addressing multiple threats, as well as mainstreaming processes of climate change adaptation through a larger envelope of social relationships, institutional roles, and policy contexts associated with risk management, including contexts related to mitigation as well.

The second paper (Wilbanks 2011) begins with the clear fact that adaptation can only cope with many kinds of impact costs if mitigation is able to keep climate change at a moderate level. In a world where current trends in greenhouse gas emissions point toward relatively severe climate change by the latter part of this century, it can be argued that reducing such risks cannot be achieved through incremental improvements in known energy technologies. It will require the discovery and rapid mobilization of transformational new energy technologies.

Research Highlights

If so, the challenge is to accelerate invention as well as innovation. This paper reviews current knowledge about both demand and supply aspects of accelerating transformational scientific discovery.

Wilbanks, T. J., and R. Kates. 2010. "Beyond Adapting to Climate Change: Embedding Adaptation in Responses to Multiple Threats and Stresses," *Annals of the Association of American Geographers*. 100/4 (October 2010): 719–728.

Wilbanks, T. J. 2011. "Inducing Transformational Energy Technological Change," in W. Nordhaus and N. Nakicenovic, eds., *Technological Change and Global Warming*, special issue of *Energy Economics*, 33.4:699–708 (July 2011).

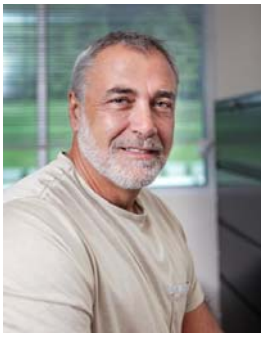
Awards and Recognition

Budhendra Bhaduri – received the Homeland Security Award in the field of Emergency Response to Natural and Man-made Disasters from the Christopher Columbus Fellowship Foundation and Agusta-Westland North America. Bhaduri was also named a 2011 Corporate Fellow for his role in conceiving, designing, and implementing novel geocomputational methods to solve a wide variety of global problems in energy, the environment, and national security.

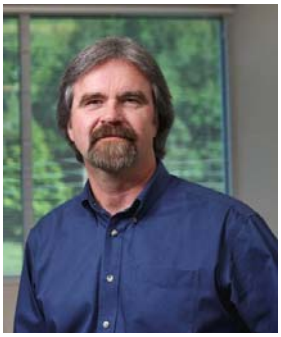
Patrick Mulholland—received the North American Benthological Society (NABS) 2011 NABS Award of Excellence. Mulholland also received the 2011 UT - Battelle Distinguished Scientist Award for his distinguished career in environmental science that has made critical contributions to our understanding of forested watersheds and their response to environmental stressors, including acid precipitation, nitrogen deposition and climatic variability and change.

Melanie Mayes—received the Stanley I. Auerbach Award for Excellence in Environmental Science.

Benjamin Preston—was selected as a Board Member of the American Meteorological Society Board on Societal Impacts.



Alexander Kozyr—received the Technical Communications Award from the East Tennessee Chapter of the Society for Technical Communications.



Dale Kaiser—President of the Smoky Mountain Chapter of the American Meteorological Society.

Awards and Recognition

Intergovernmental Panel on Climate Change—Authors and Co-Authors

Gregg Marland
Contributing Author, AR5 Working Group II, Chapter 6—Carbon and Other Biogeochemical Cycles
Lead Author, Special Report on Carbon Dioxide Capture and Storage, Chapter 9—Implications of Carbon Dioxide Capture and Storage for Greenhouse Gas Inventories and Accounting

Benjamin Preston
Coordinating Lead Author, AR5 Working Group II, Chapter 16—Adaptation Planning and Implementation

Peter Thornton
Lead Author, AR5 Working Group I, Chapter 6—Carbon and Other Biogeochemical Cycles

Thomas Wilbanks
Coordinating Lead Author, AR5 Working Group II, Chapter 20—Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development

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