NIGEC

National Institute for Global Environmental Change

Final Technical Report

1990-2007


Contents

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Preface

This Final Technical Report of the National Institute for Global Environmental Change (NIGEC) has been prepared in accordance with the terms of the Cooperative Agreement between the Office of the President of the University of California and the U.S. Department of Energy. While this report emphasizes the research conducted by the NIGEC Regional Centers during recent years, an overview of the NIGEC program from its beginnings provides a description and evaluation of the program's vision, strategy and major accomplishments that I hope will be of value to those interested in the ecological aspects of environmental research. By including appendices with complete listings of NIGEC publications, principal investigators and participating institutions, this report may also serve as a useful comprehensive documentation of NIGEC.

In addition to the Directors of the NIGEC Regional Centers who have provided the technical content of this report, I would like to thank the former National Director Ruth Reck for her insightful contributions and the DOE Program Manager Jeff Amthor for his support. I would also like to acknowledge the assistance of the National Office Staff in the report's compilation and production.

— W. Lawrence Gates
National Director

Map of states covered by NIGEC regional centers.

Program Overview

Formation

The National Institute for Global Environmental Change (NIGEC) was authorized by the U.S. Congress in the Energy and Water Development Appropriations Act of 1989. (In the original congressional bill of Representative Bevill of Alabama, NIGEC was defined as the National Institute *on* Global Environmental Change; the name change to the National Institute for Global Environmental Change evidently occurred later and has not been documented.) Other Congressional members who were leaders in supporting NIGEC's formation in 1990 included Representative Vic Fazio.

The funding of NIGEC came in the form of a Congressional earmark to the budget of the U.S. Department of Energy, and was part of an effort to support academic research on environmental change in regions of the country that had historically received relatively little federal funding. The final identification of the universities that were to host the NIGEC regional centers, also took into consideration their ability to develop a high-quality research program in collaboration with other institutions in their geographical region. Dr. Marvin Goldman, a Professor at UC Davis, was instrumental in having the national office eventually hosted in Davis at an off-campus site.

Vision, Goals and Strategy

The overall vision of NIGEC may be stated as the performance of (academic) research on the (regional) interactions between ecosystems and climate in support of the climate change program of the Office of Biological and Environmental Research of the U.S. Department of Energy. This vision has led to the development of a series of priority research goals that have guided the areas to which NIGEC support has been directed, the most enduring of which is the measurement of the exchanges of carbon and energy between the atmosphere and terrestrial ecosystems and the use of those observations to evaluate climate and carbon cycle models. Other goals that have been identified as relevant over the years include atmospheric radiation and aerosols, modeling of the response of regional ecosystems to climate change, and integrated assessment of the impacts of environmental and ecological changes.

The strategy to meet these goals has been conditioned on the one hand by the priorities of the DOE and on the other hand by the ability of the Regional Centers to assemble appropriate research programs. As described in this report, each Regional Center has developed a research portfolio focused on selected regional ecological issues and projects. The changing priorities of the DOE, however, have made the support of longer-term research programs more difficult, and have impeded the development of a coherent national (as opposed to regional) program.

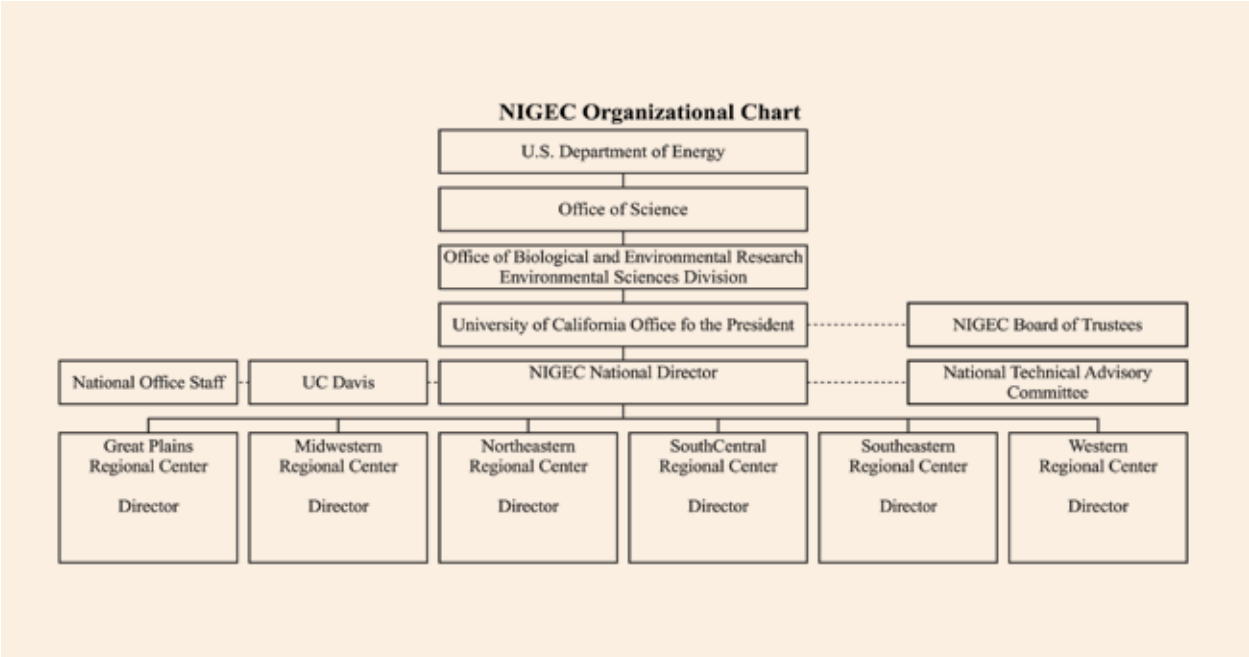
In the sixteen years during which NIGEC existed there have been significant advances in our understanding of both sides of climate-ecosystem interactions. NIGEC did not actively participate in development and improvements in global climate models during this period. Rather, NIGEC has focused on the measurement, analysis and interpretation of ecosystem impacts of climate change and climate variability and in recent years, the measurement of carbon fluxes from selected regional ecosystems and incorporation of this data into ecosystem models.

Organization and Operation

Consistent with its vision and strategy, and in recognition of the nation's geographical and ecological diversity, NIGEC was organized around a number of Regional Centers, each of which had a unique awareness of regional resources and environmental concerns. The original regional centers were in the Midwest, Northeast, Southcentral and Western parts of the country in 1990, and were supplemented by a fifth center in the Southeast in 1992 and by a sixth center in the Great Plains region in 1993. Further information on the history and organization of each regional center is given in this report.

The six NIGEC Regional Centers and their host institutions were:

- **The Great Plains Regional Center** at the University of Nebraska in Lincoln, Nebraska
- **The Midwestern Regional Center** at Indiana University in Bloomington, Indiana
- **The Northeast Regional Center** at Harvard University in Cambridge, Massachusetts
- **The Southcentral Regional Center** at Tulane University in New Orleans, Louisiana
- **The Southeast Regional Center** at the University of Alabama in Tuscaloosa, Alabama
- **The Western Regional Center** at the University of California Davis in Davis, California

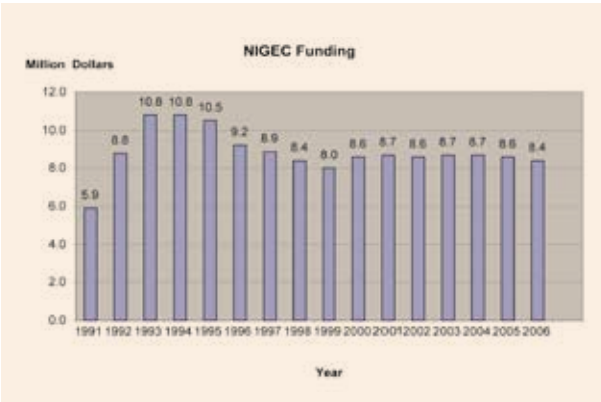


The organization of NIGEC is shown in the following figure.

The function and responsibilities of the NIGEC Board of Trustees, the National Office, the National Technical Advisory Committee and the Regional Centers are spelled out in the NIGEC management plan. In summary, the Board of Trustees was appointed by the Office of the President of the University of California (UCOP) with the concurrence of the Department of Energy (DOE), and consisted of fourteen members, two of which were nominated by each of the six regional centers' host institutions and two nominated by the DOE. The Board of Trustees reviewed the overall performance of NIGEC and made specific recommendations for its improvement to UCOP. The last formal meeting of the NIGEC Board of Trustees was held in November 2004 in Davis, California.

The National Director of NIGEC maintained administrative oversight of the activities and operation of NIGEC as a whole, and, in coordination with DOE, represented NIGEC in relations with other relevant national and international programs. With the assistance of an office manager, the National Director maintained fiscal oversight of the operations of the National Office and Regional Centers, and proposed appropriate research initiatives in cooperation with the Regional Center Directors and the DOE Program Manager. The National Director was appointed by UCOP upon nomination by the Board of Trustees, and in turn appointed the members of a National Technical Advisory Committee whose function was to provide independent advice and recommendations on NIGEC activities. The Directors of the Regional Centers, nominated by their respective host institutions, were appointed by the Board of Trustees with DOE concurrence, and had primary responsibility for the development, management and review of the regional programs, which was the core of NIGEC's research efforts.

The relatively complex structure of NIGEC (as compared say, with a program in which the principal investigators are supported directly from the office of a governmental funding agency) has presented a number of challenges to the management of the program. Among these were the administrative costs involved in maintenance of the six regional centers in addition to a national office, the difficulty in formulating a coherent national effort from the separate programs created by the regional centers, and the approximate 18 months time lag between the call for proposals from potential principal investigators and the award of research support. These issues have been noted by the National Technical Advisory Committee in its periodic



The total annual funds provided by the DOE for NIGEC operations and research.

evaluations of NIGEC operations, and were the subject of recommendations in the external NIGEC reviews (i.e., the so-called Mac Donald and Waggoner reports of 1991 and 1997, respectively). These characteristics notwithstanding, NIGEC has successfully delivered an impressive volume of research (see publications generated by regional centers within their reports) in broad support of the priorities laid down by the DOE. The total annual funding provided by the DOE for NIGEC is shown in the figure below.

Major Accomplishments

The major research accomplishments of NIGEC are highlighted in the reports of the Regional Centers. These reports describe a rich mosaic of research generally focused on the response of representative elements of regional ecosystems to environmental change. Taken as a whole, NIGEC's research presents important evidence on the impacts of climate variability and change, and in some cases adaptability, for a broad range of both managed and unmanaged ecosystems, and has thereby documented significant regional issues on the environmental responses to climate change. NIGEC's research has demonstrated large regional differences in the atmospheric carbon exchange budgets of croplands and forests, that there are significant variations of this exchange on diurnal, synoptic, seasonal and interannual time scales due to atmospheric variability (including temperature, precipitation and cloudiness), and that management practices and past history have predominant effects in grasslands and croplands.

It is the mid-latitude forests, however, that have received more attention in NIGEC than any other specific ecosystem, and NIGEC's initiation of and participation in the AmeriFlux program is generally considered to be its most significant single accomplishment. This network of carbon flux measurement sites in North American old-growth forests was initiated by NIGEC scientists in 1996 and modeled after the eddy covariance measurements at the Harvard Forest in central Massachusetts, the first site to make continuous multi-year measurements. AmeriFlux is now supported by several funding agencies, and consists of some 35 sites in 18 states (plus six in Canada) and an even large international flux network. Although the AmeriFlux goal of developing reliable estimates of net ecosystem CO_2 exchange, for future estimate of a national CO_2 budget by integrating or upscaling the regional scale results has proven difficult to achieve, the body of AmeriFlux data is a uniquely valuable documentation of the factors influencing the exchanges of heat and greenhouse gases between the terrestrial (forest) ecosystem and the atmosphere. Instead, these measurements have shown a significant extent of interannual variability in the annual net carbon exchange, with several sites switching between positive and negative net CO_2 exchanges at the annual scale, revealing the sensitivity of ecosystems to short term weather patterns, particularly interactions with the water budget. Additionally, the importance of past disturbance and land use history on CO_2 exchange was not previously appreciated.

Closure and Legacy

In order to better integrate its environmental research programs with the priorities of the national Climate Change Science Program, the DOE decided in 2004 to terminate the NIGEC project in 2006 and to replace it with a successor program known as the National Institute for Climatic Change Research (NICCR). The NICCR program is managed from DOE Headquarters and involves a smaller number of regional centers, five instead of six, thus reducing administrative costs. Consequently, the NIGEC Regional Centers and the National Office ceased operations in 2007, with the dissolution the NIGEC Board of Trustees and National Technical Advisory Committee.

While NIGEC's efforts may be characterized as concerned with the interaction between ecosystems and climate, the bulk of its research has been focused on the effects of atmospheric change on the terrestrial biosphere, rather than on the effect of biospheric or ecological changes on the atmosphere. This emphasis on "one-way" interaction has allowed NIGEC to concentrate its resources on the impacts of increased atmospheric CO_2 on vegetation in the context of the surface carbon and water budgets. An important legacy of NIGEC has been to draw attention to the potential vulnerabilities of our terrestrial ecosystems and the critical role of terrestrial ecology in determining future climate. In addition to its published research and accumulated data bases, a further significant legacy of NIGEC are the hundreds of students and post-doctoral research assistants that have been trained in NIGEC projects over the years. NIGEC has made a lasting contribution to the education and training of the next generation of multidisciplinary earth scientists who are essential for continuing to address environmental research at policy relevant scales.

NIGEC Regional Center Reports

NIGEC Regional Centers

Great Plains Regional Center: University of Nebraska

Midwestern Regional Center: Indiana University

Northeastern Regional Center: Harvard University

South Central Regional Center: Tulane University

Southeastern Regional Center: University of Alabama

Western Regional Center: University of California, Davis

Great Plains Regional Center

Great Plains Regional Center Report
University of Nebraska—Lincoln

Great Plains Regional Center

I. BACKGROUND INFORMATION:

The Great Plains Regional Center (GPRC) was established in 1992 with Dr. William Easterling as Director and Dr. Blaine Blad as Associate Director. In 1997, Dr. Shashi Verma became the GPRC Director, after Dr. Easterling left the University of Nebraska. In July 2001, Dr. Blad retired.

The GPRC focuses on the region encompassed by Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wyoming. The Great Plains region encompasses the nation's largest grassland biome. The region produces nearly a quarter of the nation's agricultural crops and livestock. Its interior continental position produces large interseasonal extremes of temperature and precipitation, and the frequency of extreme events, especially droughts, is higher in the Great Plains than in regions near large water bodies. Small changes in already marginal climatic conditions produce disproportionately large impacts on agriculture and other ecosystems in the region. The deep loess soils, typical of the Great Plains, store large amounts of carbon in the form of soil organic matter. Moreover, observed changes in the composition and location of ecotones, changes in the extent and intensity of land use, coupled with periodic climate variations strongly influence the cycling of nutrients and the exchange of carbon in the Great Plains. Finally, several climate models predict severe climate changes in midlatitude continental interiors relative to global average changes. These factors point out the need for a program of research in global environmental change focused in the Great Plains region.

II. CENTER'S STRATEGIC VISION:

The Great Plains region is typified by strong climatic gradients, fertile carbon-storing soils, and important agricultural and grassland systems. The GPRC is devoted to supporting research that develops quantitative information on the role of key ecosystems as sources or sinks of carbon dioxide. Through understanding gained by the research it supports, the GPRC provides scientific information required to assess the consequences of climate change on social, physical, and biological resources within the region.

III. RESEARCH FOCI:

The primary purpose is to support a research program that increases basic understanding of how agricultural and grassland ecosystems exchange carbon with the atmosphere and how environmental change is likely to impact key ecosystems in the region. Specific research foci are described below:

- **Research Focus 1: To Increase Understanding of the Net Carbon Exchange and the Processes Involved (AmeriFlux and Related Studies).** The GPRC supports research on the measurement and analysis of net exchange of CO_2 and other energy-relevant trace gases (e.g., N_2O and CH_4) between the atmosphere and terrestrial ecosystems (e.g., agricultural and grassland ecosystems). This research addresses the following questions. What are the net annual exchanges of CO_2, N_2O, and CH_4 and the interannual variability in those exchanges in key ecosystems in the region? What biophysical and physiological factors control the surface exchange rates of CO_2 and water vapor? What is the role of below-ground processes in regulating carbon exchange?
- **Research Focus 2: To Increase Understanding of the Effects of Environmental Change on Ecosystems.** The GPRC supports studies to determine the effects of (future) environmental change associated with energy production on ecosystems. These include experimental manipulations of temperature, precipitation, CO_2, and/or ozone in ecosystems important to the region. Also included are studies focusing on quantitative effects of environmental changes on interactions between plants and insects.
- **Research Focus 3: To Evaluate Tools Needed to Determine Impacts of Environmental Change on Social, Biological, and Physical Systems.** The GPRC supports the development and testing of the tools needed for integrated assessments of impacts of environmental change in the Great Plains region. For example, the GPRC is interested in determining how accurate and realistic existing models (e.g., crops, grasslands/pastures, livestock output) are when applied to the Great Plains. It will be important to determine where, when, and why different models work and why they fail. Having determined weaknesses (if any) of particular models, it will then be important to determine how those weaknesses can be overcome or corrected.
- **Research Focus 4: To Evaluate Effects of Sulfur-Based and/or Carbon-Based Aerosols on Earth's Radiation Balance.** This focus was implemented in 2005-06. The

GPRC collaborated with the other regional centers to fund projects in the new NIGEC aerosol-climate interaction research initiative.

IV. ACCOMPLISHMENTS (GPRC FUNDED PROJECTS):

Arkebauer and Dobermann of the University of Nebraska are focusing on the determination of annual ecosystem respiration and global warming potential for major agroecosystems in the Great Plains region through the acquisition of unique datasets on continuous, year-round measurements of soil surface CO_2, N_2O, and CH_4 fluxes. The maize site (site 1) had fertilizer applied early in the season and was also fertigated (fertilizer applied through a center pivot irrigation system) several times thereafter. After each fertilizer application, the N_2O flux exhibited a dramatic sharp peak, particularly when soil water content was high. The rainfed soybean site (site 2), by contrast, received no fertilizer and the N_2O fluxes were small throughout the season. The soil surface CO_2 fluxes from the two sites were fairly close to each other later in the season; however, site 1 exhibited larger fluxes early in the season. Since site 1 is continuous maize (compared to a maize/soybean rotation) this may be related to greater crop residue decomposition early in the season. The CH_4 fluxes also differed between the two sites; these differences are likely related to differences in soil moisture content in the irrigated vs. non-irrigated sites.

Blair et al. of Kansas State University used multiple experimental approaches to study the effects of climate change on plant and soil processes in grassland ecosystems. One approach is based on the use of field-scale Rainfall Manipulation Plots (RaMPs) to manipulate (1) amounts and timing of growing season rainfall events and (2) temperature in intact tallgrass prairie plots. This study is documenting interannual variability in plant and soil responses to altered rainfall patterns and elevated temperatures, as well as long-term changes in plant community composition and ecosystem-level C and N pools and fluxes. Results to date suggest that altered precipitation patterns will be accompanied by changes in plant community composition, productivity, and ecosystem-level C and N cycling.

Boote et al. of the University of Florida and Iowa State University are conducting a detailed evaluation of key crop models for predicting growth and yield responses to climate change. They tested and improved the CERES-Maize model by incorporating leaf and canopy assimilation, growth and maintenance respiration, and leaf area growth. The new model performed well predicting leaf photosynthesis, canopy assimilation, and biomass accumulation over diverse locations differing in temperature and solar radiation, and gave good closure in crop carbon balance. Also, the CROPGRO-Soybean model was tested by comparison to phytotron temperature and CO_2 studies and optimized against 1400 values from 20 years of soybean variety trials across the U.S. The model showed the correct responses to temperature and CO_2, except for the need to decrease base temperature for leaf photosynthesis by 2°C.

Hanan et al. of Colorado State University are investigating how land use decisions in the Great Plains region of eastern Colorado impact carbon, water, and energy dynamics through implementation of a new AmeriFlux "cluster site," consisting of three eddy covariance instrument systems in contrasting land use. Initial results show a huge release of carbon dioxide associated with conversion of CRP (Conservation Reserve Program) land back to dryland agricultural systems. Subsequent crop production temporarily recaptures some of the carbon but most of the release is long term because it corresponds to the change from perennial to annual vegetation cover. Should economic conditions change, or the CRP be terminated, it is probable that much of the 800,000 hectares of CRP in eastern Colorado would be converted back to dryland crops. The initial impact of such a large change in land use in the region could inject as much as 1.1 Tg carbon (4.0 Tg CO_2) into the atmosphere.

Joern and Logan of Kansas State University and the University of Nebraska found that multiple temperature-dependent processes underlie the highly variable population dynamics of grasshoppers in Great Plains grasslands. Seasonal appearance of species was directly controlled by soil temperature which determines hatching date. Variable environmental temperatures along with food intake determined developmental, growth and survivorship rates, increasing with temperature. Direct effect of solar heating on body temperature and the accompanying control of body temperature through thermoregulation were combined with indirect effects of body temperature on digestion rate to affect population growth. Grasshopper-predator (spider) interactions greatly limit grasshopper populations and can be disrupted by small increases in ambient temperatures. Food plant quality also affected population growth responses and interactions with thermal effects described above. This project provided critical information needed to predict responses of key insect herbivores in Great Plains grassland habitats to anticipated climate change.

Mader et al. of the University of Nebraska, Kansas State University, and U.S. Meat Animal Research Center have been evaluating ecosystem models for beef cattle production. Their ongoing modeling effort includes incorporating physiological responses by the animal to climatic conditions. Because dark-hided cattle have been found to have as much as 0.7 °C greater body temperatures than light-hided cattle, dark-hided cattle are more susceptible to summer heat stress but may be less susceptible to winter cold stress. Pregnancy rate decreases 3.5% for each °C ambient temperature above normal. Model analysis suggests that if only 20% of the cow herds in the U.S. were affected by above-normal temperatures, a rise in average ambient temperature of just 0.5 °C would cost the cattle industry over 5 billion dollars, annually.

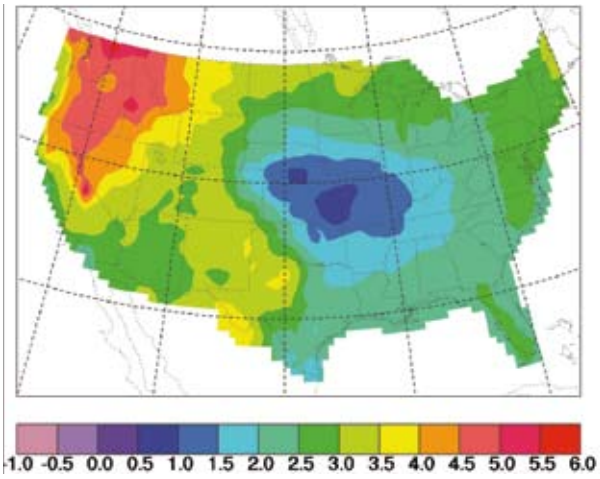
Rainfall Manipulation Plots (RaMPs).

Mearns and Easterling of the National Center for Atmospheric Research and the Pennsylvania State University determined that the spatial resolution of general circulation models (grid point spacing of three degrees or greater) is too coarse to provide reliable climate change information to agricultural and ecological models for impact estimation. Results show that grid point spacing of one degree in the Great Plains provides climate information to crop models that greatly reduces statistical error between observed and modeled crop yields, thus improving the reliability of impact estimates. Comparison of yield simulated with controlled down-scaled climate change model experiments versus GCM experiments showed significant differences that varied by soil type. Overall, adaptation was more effective in reducing climate change impacts with down-scaled climate changes than with coarse resolution GCM climate changes for the same locations.

Ojima et al. of Colorado State University investigated the role of land use changes, driven by climate change and social and economic forces, in regulating net exchanges of terrestrial carbon and other greenhouse gases, such as N_2O and CH_4. The daily version of the CENTURY model (DAYCENT) was used to compare net greenhouse gas fluxes for various agricultural systems under current and improved management. This analysis of alternative cropland management practices in dryland systems of the Great Plains indicates that soil carbon gains are often offset by emissions of other GHG. The use of more continuous cropping rotations and the more efficient use of nitrogen fertilizers result in more sustainable net greenhouse gas reductions. Grassland soils used for wheat/fallow rotations are depleted in soil carbon and have the potential to sequester significant amounts of carbon upon conversion to intensive irrigated agriculture, judicious nitrogen additions, and appropriate residue management or to rangeland with small nitrogen inputs. Analysis of climate change impacts on water resources, crop and livestock operations, and soil organic matter levels, as well as coping strategies to deal with these impacts have been completed for the Great Plains and has been published in the Great Plains Assessment report, "Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change–Central Great Plains."

Pan et al. of St. Louis University and Iowa State University have coupled two crop models interactively with a regional climate model and simulated CO_2 and water fluxes over the U.S. Midwest. This newly coupled model incorporates individual crop variety, dynamic crop phenology, subgrid-scale land use heterogeneity, and two-way interactive feedback between crop development and atmospheric conditions. The interactive coupling and explicit crop representation improve noticeably CO_2 and water fluxes over the intensively cultivated U.S. Midwest compared to the uncoupled model with only single generic crop. Their modeling effort has also discovered a "warming hole" (in an analogy to the ozone hole) in summer daytime maximum surface air temperature over central U.S. under a future scenario climate. Observed temperatures also show that the central U.S. experienced a summer cooling trend during 1975 to 2000, consistent with the projected warming hole. The changes in low-level circulation patterns coupled with surface hydrology may be responsible for the warming hole.

Owensby et al. at Kansas State University have been measuring carbon exchange in grazed and ungrazed tallgrass prairie in Kansas. They have determined yearly carbon balances for each year from burn-to-burn and found that the net carbon uptake/release was essentially zero. In an extreme drought year, the prairie was a source of carbon. On grazed areas the carbon losses were reduced during the drought. They have confirmed a compensatory mechanism for carbon capture on the grazed area which shows new leaves that regrow following grazing have a greater photosynthetic capacity in late season than those on ungrazed prairie. Even though the ungrazed area had 2-3 times as much green leaf area in the late season, the grazed area had as much as twice the carbon acquisition. The investigators have



Pan et al.

shown that grazing reduces evapotranspiration which leads to a generally greater soil water content in the late growing season. They have also shown that the greatest carbon losses from the system come from soil respiratory processes and that grazing reduces those losses.

Paustian and Elliott of Colorado State University and the University of Nebraska and ***Antle et al.*** of Montana State University developed an integrated ecosystem-economic modeling approach to analyze climate change impacts on agriculture and the effects of adaptation and mitigation strategies on land use, productivity, and terrestrial carbon cycling in the Great Plains. Models were applied at a variety of scales, from field to state to regional (central U.S.) levels for GCM-derived climate scenarios. Among the key findings were that detrimental impacts of climate change on productivity and soil carbon (C) balance were partially offset by positive effects due to economically driven changes in land use and management. The linked ecosystem-economic models were subsequently applied to investigate mitigation opportunities through soil carbon sequestration by adoption of alternative cropping practices, at subregional (Montana) and regional (central U.S.) scales. Databases and database tools developed for the regional analyses were used to provide estimates of C emissions and sinks from agricultural soils for the U.S. national greenhouse gas inventory. Model analyses were provided to the Agricultural Sector Assessment of the U.S. National Assessment of Climate Change Impacts, with simulations of ecosystem productivity and soil C changes under two climate change scenarios.

Pendall et al. of the University of Colorado used stable isotopes as tracers of CO_2 fluxes on shortgrass steppe under CO_2 enrichment. They found that carbon cycling and decomposition rates were stimulated under elevated CO_2 in grasslands, especially if water was limiting. Net ecosystem production was not altered by elevated CO_2 during years of above-average moisture, but was enhanced during water limited conditions. Soil carbon (C) sequestration appears to depend on soil moisture feedbacks to elevated CO_2 in grasslands.

Rice et al. of Kansas State University examined the relatively long-term impact of elevated CO_2 on grassland ecosystems. One unknown consequence of increased carbon (C) input into the soil is the change in nutrient availability and the grassland ecosystem response to limited nitrogen (N) resources. Under elevated CO_2, the soil to a depth of 30 cm accrued 470 +/- 150 g C m^{-2} which equates to a rate of 0.58 Mg C ha^{-1} yr^{-1}. Greater C sequestration under elevated CO_2 suggests that tallgrass prairies can sequester C in response to rising atmospheric CO_2. By measuring the different fractions of the soil organic matter, they estimated that the intermediate pool represented 48% of the total C in the elevated CO_2 treatment and 37% in the ambient condition. This increase in the intermediate C pool suggests a rapid buildup of soil C under elevated CO_2. The amount of N in the soil organic matter was significantly greater with elevated CO_2. The source of the increased N appears to be from increased N fixation, and greater recycling of soil N. The C:N ratio of the organic matter was generally higher with elevated CO_2. When N was added to the soil, greater amounts of N were immobilized by the soil and less recovered in the plant under elevated CO_2 relative to ambient CO_2. However higher microbial activity and greater plant N use efficiency under elevated CO_2 translate to no additional N constraints on tallgrass prairie productivity under elevated CO_2.

Tieszen et al. of Augastana College merged remotely-sensed data with stable isotopic tracers of carbon to study land cover dynamics and the climate controls over carbon fluxes. They showed the significance of photosynthetic systems (biodiversity) for land cover performance in the Great Plains. Most notably, the presence of C_3 dominance in the northern Great Plains produces a land cover class that initiates photosynthetic activity nearly at the same time as C_4 dominated systems do in the south. This pattern of C flux differs from that which characterizes the seasonal green wave shown by agricultural systems or deciduous forests. They established the importance of temperature and precipitation in the distributions of C_3 and C_4 species. They developed an isotope equation which shows that the C_4 composition is largely controlled by growing season temperature and late season precipitation. This relationship allowed them to redistribute photosynthetic systems based on climate fields predicted by simulations using a doubled concentration of CO_2. These redistributions are both dramatic and different depending on the specific model, suggesting the need for a more refined regional simulation of climate fields.

Verma and Berry of the University of Nebraska and the Carnegie Institution of Washington made year-round eddy covariance flux measurements in a native tallgrass prairie in north-central Oklahoma to quantify carbon exchange and its interannual variability. This prairie is dominated by warm season C_4 grasses. The soil is a relatively shallow silty clay loam underlined with a heavy clay layer and a limestone bedrock. During the study period, the prairie was burned in the spring of each year and was not grazed. When carbon loss during the burn (estimated from pre- and post-burn biomass samples) was incorporated

with the annual net ecosystem CO_2 exchange (NEE), the prairie was found to be approximately carbon neutral (i.e., net carbon uptake/release was near zero) in years with no moisture stress or with some stress late in the season. During a year with severe moisture stress early in the season, the prairie was a net source of carbon. The greatest source of interannual and intraannual variability of the net carbon exchange in this ecosystem was moisture stress (severity as well as the timing of occurrence).

V. WORKSHOP SPONSORED:

- **The annual GPRC PI Workshop.** The aim of the workshop was to facilitate interactions among investigators and to stimulate exchanges of data and information. About 60% of the time was spent primarily on the general discussion of ongoing research projects. The remaining time was devoted to focused discussions in breakout groups.
- **Workshop on Influences of Atmospheric Pressure Fluctuations on Fluxes of Trace Gases from Soils, Lincoln, NE, April 20-21, 1999.** The workshop's goal was to determine whether a project consisting of a field experiment, with supporting theoretical work, is justified to measure the range of spatial and temporal variability of soil fluxes of trace gases introduced by atmospheric pressure fluctuations. The group concluded that such a project was justified since existing evidence strongly suggests that pressure effects are influencing measurements. As a result of this workshop, a proposal entitled "A Pilot Study of Influences of Atmospheric Pressure Fluctuations on Fluxes of Trace Gases from Soils" was submitted to the GPRC. This proposal was externally reviewed and funded from the Director's discretionary fund.
- **Workshop on Flux Data Analysis and Procedures, Boulder, CO, May 2000** (co-sponsored by the Great Plains, Midwestern, Northeast, Southeast, and Western Regional Centers). The aim of this workshop was to discuss procedures for a uniform and consistent analyses of the tower flux measurements being made at various AmeriFlux sites.
- **Workshop on Measurement and Analysis of Soil Respiration, Boulder, CO, October 2003**. This workshop had 80 participants and was co-chaired by Dr. Bev Law of Oregon State University, Dr. Gene Takle of Iowa State University, and Dr. Mike Ryan of USDA-Forest Service, Fort Collins, CO. The participants identified some of the major needs for advancing our understanding of the long-term changes in the contribution of soil processes to atmospheric carbon dioxide. The products (13 refereed journal articles) of the workshop are published in a special issue of Biogeochemistry (2005, Vol. 73, No. 1).

GREAT PLAINS REGIONAL CENTER
List of PIs' & Co-PIs' Institutions

Augustana College, Sioux Falls, SD

Battelle Pacific Northwest National Laboratory, Richland, WA

Carnegie Institution of Washington, Stanford, CA

Colorado State University, Fort Collins, CO

Columbia University, New York, NY

Duke University, Durham, NC

Harvard University, Cambridge, MA

Iowa State University, Ames, IA

Kansas State University, Manhattan, KS

Montana State University, Bozeman, MT

National Center for Atmospheric Research, Boulder, CO

Oregon State University, Corvallis, OR

Pennsylvania State University, University Park, PA

Rutgers University, New Brunswick, NJ

San Diego State University, San Diego, CA

South Dakota School of Mines & Technology, Rapid City, SD

Texas A&M, College Station, TX

University of Arizona, Tucson, AZ

University of California-Riverside, Riverside, CA

University of Colorado, Boulder, CO

University of Delaware, Newark, DE

University of Florida, Gainesville, FL

University of Iowa, Iowa City, IA

University of Maryland, College Park, MD

University of Minnesota, Minneapolis, MN

University of Missouri-Columbia, Columbia, MO

University of Montana, Missoula, MT

University of Nebraska-Lincoln, Lincoln, NE

University of North Dakota, Grand Forks, ND

University of Virginia, Charlottesville, VA

University of Wisconsin-Madison, Madison, WI

Yale University, New Haven, CT

GREAT PLAINS REGIONAL CENTER
Research Projects

PI, CO-I	Institution	Project	Years
ANTLE, John M. Susan Capalbo Julie Hewitt Linda Young	Montana State University	Heterogeneity and Scale in Modeling the Economic Impacts of Climate Change in Great Plains Agriculture	1996-1998
ANTLE, John M. Susan Capalbo Julie Hewitt	Montana State University	Testing Hypotheses in Integrated Impact Assessments: Climate Variability and Economic Adaptation in Great Plains Agriculture	1998-2001
ARKEBAUER, Tim Achim Dobermann	University of Nebraska-Lincoln	Continuous Measurements of Soil Surface CO_2, N_2O and CH_4 Fluxes to Estimate Ecosystem Respiration and Global Warming Potentials in Great Plains Agricultural Systems	2002-2005
ARKEBAUER, Timothy	University of Nebraska-Lincoln	Controls on Soil Surface CO_2, N_2O and CH_4 Fluxes, Ecosystem Respiration and Global Warming Potentials in Great Plains Agricultural Systems	2005
BIRKS, John Ben Balsley G.H. Wagner J.R. Brown	University of Colorado at Boulder	Profiling CO_2 and Water Vapor Through the Atmospheric Boundary Layer and Lower Troposphere in Support of the AmeriFlux Program	1999-2002
BLAIR, John Timothy Todd Charles Rice Alan Knapp	Kansas State University	Effects of Altered Soil Moisture and Temperature on Soil Communities, Primary Producers and Ecological Processes in Grassland Ecosystems	1993-1996
BLAIR, John Alan Knapp Phillip Fay	Kansas State University Colorado State University University of Minnesota - Duluth	Belowground Responses to Manipulation of Precipitation Timing and Amounts in a Grassland Ecosystem	1999-2002
BLAIR, John Alan Knapp Philip Fay	Kansas State University Colorado State University University of Minnesota - Duluth	Belowground Responses to Multiple Climate Change Factors: Interactive Effects of Warming and More Extreme Precipitation Patterns on Grassland Ecosystems	2002-2005
BLAIR, John Philip Fay Alan Knapp	Kansas State University Kansas State University Colorado State University	Effects of Altered Rainfall Timing and Warming on Soil Processes and Plant Responses in a Grassland Ecosystem	2005
BOGARDI, Istvan I. Matyasovszky Lucien Duckstein	University of Nebraska - Lincoln University of Nebraska - Lincoln The University of Arizona	Space-Time Local Hydrology Influenced by Changing Climatology: Disaggregation, Prediction and Comparison	1993-1996
BOOTE, Kenneth James Jones William Batchelor	University of Florida, University of Florida, Iowa State University	Evaluating and Improving CROPGRO-Soybean and CERES-Maize Models for Predicting Growth and Yield Response to Climate Change Factors	2001-2004
BRANDLE, James William Easterling Gene Takle	University of Nebraska The Pennsylvania State University Iowa State University	Assessment of Climate Change on Mixed Agricultural and Forest Landscape on the North American Great Plains	1993-1996
BUYANOVSKY, G.A. Steve Hu G.H. Wagner J.R. Brown	University of Missouri University of Nebraska - Lincoln	Assessment of Climate Impact on Carbon Exchange Between an Agroecosystem and the Atmosphere	1998-2000
CHEN, Tsing-Chang Joseph Tribbia	Iowa State University National Center for Atmospheric Research	Observational and Numerical Study for Interannual and Interdecadal Variabilities of the Atmospheric Circulation	1993-1995
CLARK, William C.	Harvard University	Empirical Evaluation of Effectiveness of Possible Strategies for Assessment of Global Environmental Change: Part II	1996-1998
DEMOTT, Paul Anthony Prenni, Sonia Kreidenweis	Colorado State University	Investigation of Hygroscopicity and Cloud- and Ice-Nucleating Activities of Combustion Aerosols	2005

DYKE, Paul T. William Easterling, Norm Rosenberg	Texas A&M University University of Nebraska-Lincoln Battelle Pacific Northwest National Laboratory	Comparative Economics and Environmental Impact of Biomass for Energy Production Under New Digester Technologies and Increased CO_2 Levels	1994-1997
EASTERLING, Willaim Linda Mearns	The Pennsylvania State University National Center for Atmosheric Research	Climate Impact Modeling and Analysis Project (CIMAP)	2004-2006
ELLIOTT, Edward C. Vernon Cole	Colorado State University	Regional Projections of C Dynamics with Global Change in the Central United States	1993-1996
ELLIOTT, Edward C. Vernon Cole	Colorado State University	Spatially Explicit Projections of C Dynamics with Global Change in the Central United States	1996-1998
ELLIOTT, Edward PAUSTIAN, Keith LeRoy Hahn	University of Nebraska - Lincoln Colorado State University USDA-ARS	Agroecosystem Boundaries and C Dynamics with Global Change in the Central United States	1998-2001
ELLIOTT, Edward	Colorado State University	Coordination of the Central US National Institute for Global Environmental Change Integrated Assessment	1998-2001
GOSNOLD, William Paul Todhunter	University of North Dakota	Climate Change in the Midcontinent of North America	1993-1995
GOSSELIN, David Steven Meyer,	University of Nebraska - Lincoln	Process-Oriented Environmental Change Education: A Model for Connecting Research to the Classroom	1996-1999
GOSSELIN, David Steven Meyer	University of Nebraska - Lincoln	Creating Connections Between Regional Climate Change Information and the Public: A Multi-Faceted Approach	1999-2002
HAM, Jay Alan Knapp Clenton Owensby	Kansas State University	Carbon, Water and Energy Fluxes from a Tallgrass Prairie: Effect of Land Management and Environmental Factors on Surface-Atmosphere Exchange	1997-1999
HAM, Jay M. Alan K. Knapp	Kansas State University	Carbon, Water and Energy Fluxes From a Tallgrass Prairie: Long-Term Investigation of Biological, Environmental and Land Use Factors	1994-1997
HAM, Jay Clenton Owensby Pay Coyne	Kansas State University Kansas State University Agricultural Research Center, Hayes, KS	Net Ecosystem Carbon and Water Vapor Exchange of Tallgrass Prairie: Component Fluxes and Spatial Heterogeneity	2005
HAN, Qingyuan Ronald Welch	South Dakota School of Mines & Technology	Effect of Ecosystems on Cloud Microphysics and Aerosol Distribution	1993-1996
HANAN, Niall Ingrid Burke, Keith Paustian T. Peterson	Colorado State University	Carbon, Water and Land Use in Conservation Reserve Program Lands of the Shortgrass Prairie	2005
HANAN, Niall Jack Morgan Keith Paustian Ingrid Burke	Colorado State University USDA-ARS, Fort Collins, CO Colorado State University Colorado State University	Carbon, Water and Land-Use in Conservation Reserve Program Lands of the Shortgrass Prairie	2002-2005
HOAGLAND, Kyle Stephen G. Ernst	University of Nebraska-Lincoln	Impacts of Global Climate Change on Phytoplankton Productivity in Lakes Along a Thermal Gradient	1993-1995
HOTCHKISS, Rollin Thomas Fontaine John Antle Ranjan Muttiah Scott Kenner Jeff Arnold	University of Nebraska - Lincoln South Dakota School of Mines and Technology Montana State University Texas A & M University	Water Resources and Global Climate Change: Integrated Assessment of Consequences	1995-1998
JOERN, Anthony Simon Mole	University of Nebraska-Lincoln Kansas State University University of Nebraska-Lincoln	Impact of Global Climate Change on Grassland Insect Pest Populations	1995-1998
JOERN, Anthony David Logan	University of Nebraska-Lincoln Kansas State University University of Nebraska-Lincoln	Effect of Global Climate Change on Grassland Pests: Impacts on Interactions Between Rangeland, Grasshoppers and Spider Predators	2003-2006

LEE, Xuhui	Yale University	Response of Soil Respiration to Rain	2004-2006
LILLESAND, Thomas John Magnuson	University of Wisconsin-Madison	Satellite Observation of Lake Ice as a Robust Indicator of Regional Climate Change	1993-1995
MADER, Terry LeRoy Hahn John Harrington, Jr.	University of Nebraska USDA-ARS Meat Naimal Research Center Kansas State University	Predicted Global Change Effects on Livestock Performance Based on Empirical Algorithms	1999-2001
MADER, Terry Steve Hu John Harrington	University of Nebraska-Lincoln University of Nebraska-Lincoln Kansas State University	Evaluating Models Predicting Livestock Output Due to Climate Change	2001-2004
MADER, Terry Steve Q. Hu John Harrington	University of Nebraska-Lincoln Kansas State University University of Nebraska-Lincoln	Evaluation of Ecosystem Models for Beef Cattle Production	2004-2006
MALANSON, George	University of Iowa	Local and Regional Scaling with a Spatially Explicit Ecological Model	1994-1997
MEARNS, Linda F. Giorgio William Easterling Albert Weiss	National Center for Atmospheric Research National Center for Atmospheric Research The Pennsylvania State University University of Nebraska - Lincoln	Formation of Annotated Climate Change Scenarios from a Regional Climate Model, Application to Crop Models and Analysis of Spatial Scaling Characteristics of Climate and Crop Yields	1996
MEARNS, Linda F. Giorgio William Easterling, Albert Weiss	National Center for Atmospheric Research National Center for Atmospheric Research The Pennsylvania State University University of Nebraska - Lincoln	Development of a Nested Regional Model for the Conterminous US and Formation of High Resolution Climate Change Scenarios with Application to Crop Climate Models	1993-1996
NIELSON, Ronald James Lenihan Dennis Ojima	Oregon State University Colorado State University Colorado State University	Potential Global Warming Impacts on Vegetation Distribution, Productivity and Hydrology at Landscape to Regional Scales in the Great Plains Region	1994-1997
OECHEL, Walter Steven Running	San Diego State University Montana State University	Understanding and Determining Patterns of and Controls on Regional Net Ecosystem Production in Great Plains and Midwest Regions: A Proof of Concept	2002-2004
OJIMA, Dennis William Easterling, Mac Callaway	University of Colorado at Boulder University of Nebraska-Lincoln	Land Use and Climate Change Impacts on Carbon Fluxes (LUCCI)	1996-1998
OJIMA, Dennis William Parton Kathleen Gavin William Easterling	Colorado State University Colorado State University Colorado State University The Pennsylvania State University	Ecological, Climatic, Economic and Socio-Cultural Drivers of Land-Use Change in the Great Plains	1998-2001
OWENSBY, Clenton Jay Ham, Alan Knapp	Kansas State University	Landscape-Level Trace Gas Fluxes on Grazed and Ungrazed Tallgrass Prairie	1999-2002
OWENSBY, Clenton Jay Ham Alan Knapp	Kansas State University	Landscape Trace-Level Gas Fluxes on Grazed and Ungrazed Tallgrass Prairie	2002-2005
PALECKI, Michael Kenneth Dewey Daniel Leathers David Robinson	University of Nebraska University of Nebraska Rutgers University University of Deleware	Detection of Climate Change Using Long-Term Daily Climate Records Over Grassland Regions of the Northern Hemisphere	1993-1996
PALECKI, Michael David Robinson	University of Nebraska-Lincoln Rutgers University	Prototype Information System for Disseminating Annotated Climate Change Scenarios for Impact Assessments	1996
PAN, Zaitao Eugene Takle, William Batchelor	Iowa State University Iowa State University Mississippi State University	Test and Evaluation of Coupled Climate-Ecosystem Models	2002-2005
PENDALL, Elise Arvin Mosier P. Tans James White	University of Colorado USDA-ARS, National Oceanic and Atmospheric Administration University of Coloado	Stable Isotope Tracers of CO_2 Fluxes on Shortgrass Steppe Under CO_2 Enrichment	1999-2002
PORPORATO, A. P. D'Odorico	Duke University University of Virginia	Transferring Alterations in Climate Extremes to Plant Productivity and Soil Biogeochemistry in Grasslands: The Soil Water Balance as a Mediator of Dynamics	2004-2006

RICE, Charles Clenton Owensby	Kansas State University	Sequestration of Carbon Dioxide into Soil Organic Carbon Pools Under Elevated Carbon Dioxide Environment	1995-1998
RICE, Charles	Kansas State University	Belowground Carbon Allocation and Cycling in Wheat and Tallgrass Prairie Ecosystems	1998-2001
ROSENZWEIG, Cynthia R. Goldberg	Columbia University	The Effects of Climate Variability on Corn and Soybean in the US Midwest	1997
RUNDQUIST, Donald David Gosselin	University of Nebraska-Lincoln University of Nebraska-Lincoln	Natural Responses of Shallow Lakes and Wetlands for Detecting Climatic/Environmental Change	1993-1996
SCHULTZ, Peter CRANE, Robert E.J. Barron	The Pennsylvania State University	A Reduced-Form Climate Model and Downscaling Methodology for Integrated Assessment of Climate Change	1997-1999
STENCHIKOV, Georgiy A. Robock	University of Maryland	The Diurnal Cycle Over the Great Plains in the Future: Mechanisms and Spatial Distribution	1997-1999
SUAREZ, Donald Peter Vaughan	University of California, Riverside USDA- ARS	Modeling CO_2 Flux at an AmeriFlux Site Using Unsatchem, A Coupled Approach to Water Flow, CO_2, Heat and Solute Transport	1998
TIESZEN, Larry	Augustana College	Assessment of Climate and Management Induced Directional Changes in Great Plains Vegetation with NDVI and Stable Carbon Isotopes	1993-1996
VERMA, Shashi B. Tim Arkebauer, Joon Kim, David Valentine, D.S. Schimel, E.A. Holland W.M. Pulliam	Univsity of Nebraska- Lincoln University of Nebraska-Lincoln University of Nebraska-Lincoln Colorado State University Natinal Center for Atmospheric Research Natinal Center for Atmospheric Research Colorado State University	An Integrated Investigation of Methane and Carbon Dioxide Fluxes in Mid-Latitude Prairie Wetlands: Micrometeorological Measurements, Process-Level Studies and Modeling	1993-1996
VERMA, Shashi Joseph Berry	University of Nebraska - Lincoln Carnigie Institution of Washington	Net Exchange of Carbon Dioxide in Grassland and Agricultural Ecosystems in the ARM-CART Region	1996-1999
VERMA, Shashi Joseph Berry	University of Nebraska - Lincoln Carnigie Institution of Washington	Measurement and Modeling of Net Exchange of Carbon Dioxide in Grassland and Agricultural Ecosystems in the ARM-CART Region	1999-2002
WALTERS, Daniel M. Soundararajan, H. Yant	University of Nebraska-Lincoln	Quantitative Assessment of Cropping System Effects on Soil Carbon Sequestration by C Analysis of Humic Acid and Soil Respiration: Proof of Concept	2003
WALTERS, Daniel M. Soundararajan, H. Yang	University of Nebraska-Lincoln	Quantitative Assessment of Cropping System Effects on Soil Carbon Sequestration by C Analysis of Humic Acid and Soil Respiration	2005
WEISS, Albert Tim Arkebauer	University of Nebraska-Lincoln	Winter Wheat Ecosystems for the Future: Addressing Climate Change	1997
WELKER, Jeff Rod Chimner, Jack Morgan, G. Schuman Jace Fahnestock	Colorado State University USDA-ARS Crop Sience Laboratory USDA-ARS Crop Sience Laboratory USDA-ARS High Plains Grasslands Research Laboratory	C, N and H_2O Dynamics in Mixed-Grass Prairie Following Coupled Changes in Winter Snow and Summer Precipitation	2002-2005
WHITE, Steven Doug Goodin John Harrington David Kromm H. Seyler	Kansas State University	Global Change in Local Places	1996-1999

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Abler, R. (editor) (2003), *Global Change and Local Places: Estimating, Understanding, and Reducing Greenhouse Gases*. Cambridge University Press, Global Change in Local Places was partially funded by Great Plains NIGEC (through Kansas State University). Five chapters in the text have Kansas State authors:

3. Global change and Southwestern Kansas: local emissions and non-local determinants John A. Harrington Jr, David E. Kromm, Lisa M. B. Harrington, Douglas G. Goodin and Stephen E. White, pp. 57-78.

7. Changing places and changing emissions: comparing local, state and United States emissions William E. Easterling, Colin Polsky, Douglas G. Goodin, Michael Mayfield, William A. Muraco and Brenton Yarnal, pp. 143-157.

8. Explaining Greenhouse Gas emissions from localities David P. Angel, Samuel A. Aryeetey-Attoh, Jennifer DeHart, David E. Kromm and Stephen E. White, pp. 158-170.

9. Attitudes toward reducing Greenhouse Gas emissions from local places Susan L. Cutter, Jerry T. Mitchell, Arleen A. Hill, Lisa M. B. Harrington, Sylvia-Linda Kaktins, William A. Muraco, Jennifer DeHart, Audrey Reynolds and Robin Shudak, pp. 171-191.

10. Reducing Greenhouse Gas emissions: learning from local analogs C. Gregory Knight, Susan L. Cutter, Jennifer DeHart, Andrea Denny, David G. Howard, Sylvia-Linda Kaktins, David E. Kromm, Stephen E. White and Brenton Yarnal, pp. 192-213.

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Midwestern Regional Center

Midwestern Regional Center Report
Indiana University – Bloomington

Midwestern Regional Center

I. BACKGROUND INFORMATION

The Midwestern Regional Center was established in 1990 as one of the four original regional centers of the National Institute for Global Environmental Change.

The Midwestern Region includes the states of Ohio, Indiana, Illinois, Michigan, and Wisconsin. In 2002, these five states had a population of 45,673,000 or 16% of the total population of the United States. This region has 32 Metropolitan Statistical Areas (MSA) of greater than 100,000 residents. The largest cities (Chicago, Detroit, Cleveland) are located on the Great Lakes.

In these midwestern Great Lakes states, agriculture is the single largest land use, with 38% in row crops and 18% in pasture. The second largest category is forests with 30%. About 7% is in wetlands and 4% of the land use is urban, transportation and other built structures.

The region's economy is based primarily on (1) manufacturing, (2) wholesale and retail trade, (3) banking, finance and insurance, and (4) agriculture. Major manufacturing sectors include metal products, machinery, printing, food products, furniture and wood products, transportation, and electronics. The agricultural sector includes row crops, such as soybeans and corn, hog and cattle feedlots, and dairies. Some of the country's largest agricultural producers are located in the Midwest, leading to a substantial international trading market. About 15% of the total farm income in the United States is from this region. Forest products and resources are important in two of these states.

The Great Lakes are the most significant natural resource in the region and in general, water resources are very important, both in terms of the value of freshwater ecosystems as natural resources and the multiple demands of human populations for agricultural, municipal and industrial uses. There are issues of both quality and quantity, depending on the use and part of the region affected.

II. CENTER'S STRATEGIC VISION

The Midwestern Regional Center (MWRC) supports high quality research that contributes to a better understanding of how agricultural and forested ecosystems may affect the atmosphere and climate and how future climate and atmospheric change might affect these ecosystems. A primary focus is to conduct research that allows a comparative analysis of the carbon dynamics of forests, particularly in the midwestern region. A second focus is to assess the possible consequences of climate change and variability upon the agricultural and forested ecosystems of the region, including physical, biological, and socio-economic aspects.

III. RESEARCH FOCI

Goal 1: To investigate carbon exchange dynamics and atmospheric effects on Midwestern forest and agricultural ecosystems.

Analyses will continue using both eddy covariance methods and ecological inventory methods to quantify the productivity and carbon dynamics of forest ecosystems in the region. The goal is to define, analyze, and model the specific processes and mechanisms that contribute to the spatial and temporal variation in CO_2 sources and sinks as a result of differences in weather, species, and previous management practices. Studies of ecological processes particularly important to carbon dynamics (e.g., bole growth, phenology, fine root turnover, photosynthesis, soil respiration) are encouraged. The MWRC will emphasize comparative analyses which examine (1) inter-annual variation in net carbon exchange and associated weather variability, (2) carbon dynamics across several forest sites with contrasting climatic, edaphic, and biological factors and processes, and/or (3) differences in carbon flux measurement and modeling methodologies.

Goal 2: To examine possible effects of environmental change associated with energy production on terrestrial ecosystems.

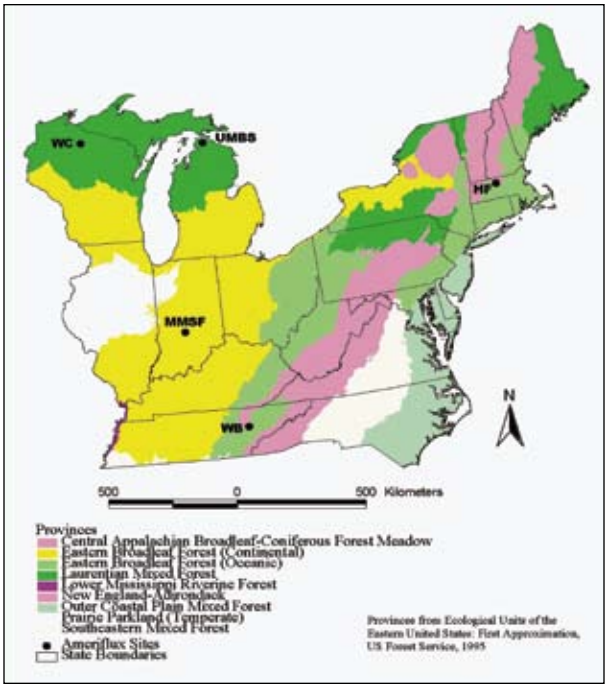
The MWRC will support research that examines possible effects of (multiple) environmental changes associated with energy production on forested and agricultural ecosystems. Interactions between environmental changes associated with energy production and human manipulations of ecosystems are also of interest. For example, studies that examine ecosystem-level interactions with pests, pathogens, or invasive species, or that consider human manipulation of land cover in the context of energy production and associated environmental changes are encouraged. Projects may be experimental (laboratory and/or field) combined with modeling. When appropriate, use of existing DOE research facilities and field sites for ecosystem research is encouraged.

Goal 3: To evaluate effects of sulfur-based and/or carbon-based aerosols on earth's radiation balance.

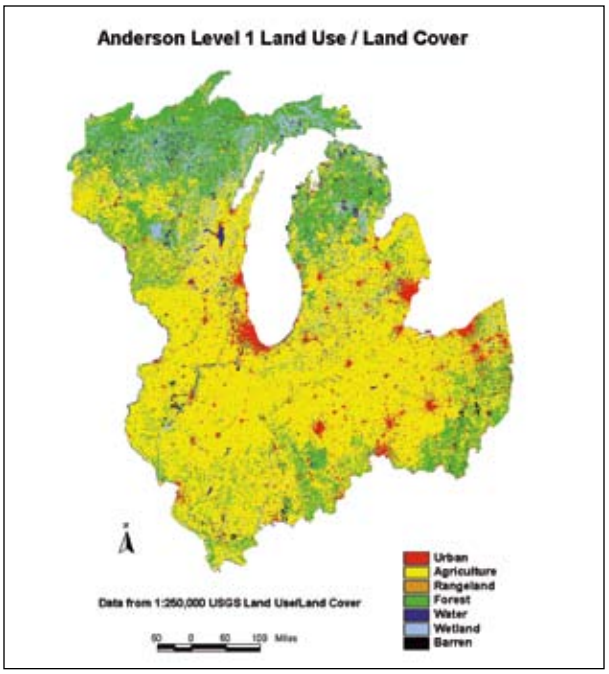
The MWRC will collaborate with the other regional centers to fund projects in the new NIGEC aerosol-climate interaction research.

A Bit of History: The Midwestern Regional Center has had two phases in the development and implementation of research themes. Initially the research themes reflected then current DOE programmatic areas such as aerosols, atmospheric trace gases, and climate models. The geographic area for the Midwestern Regional Center included the Great Plains until th e Great Plains Regional Center was established in 1994. Other research themes were based upon important natural resources of the region and included climate change impacts on grasslands, agriculture, and forests, as well as water resources. Yet other research themes included carbon dynamics, human dimensions of global change, and integrated assessment. This diversity of themes was interesting but resulted in an unfocused program. Some of these research areas (aerosols, climate models, water resources) were either scaled back or dropped by DOE. The DOE Program Manager also recommended more focus in the MWRC research program. Accordingly, in 1995, considerable efforts were made to focus the Midwestern Regional Center program on the current research themes.

Beginning in 1996 most projects have been and currently are in carbon dynamics. The Midwestern Regional Center has established and supported three AmeriFlux sites in the Midwest to contribute to the AmeriFlux network. These three sites (Tall Tower / Willow Creek, WI; Morgan-Monroe State Forest, IN; University of Michigan Biological Station, MI) plus two other sites (Harvard Forest, MA; Walker Branch, TN) provide reasonable latitudinal and longitudinal coverage across much of the eastern deciduous forest biome of North America. The synergy of the investigators in these AmeriFlux sites has been excellent, resulting in several publications.



AmeriFlux sites in the eastern deciduous forest biome: Willow Creek (WC), University of Michigan Biological Station (UMBS), Morgan-Monroe State Forest (MMSF), Harvard Forest (HF), Walker Branch (WB).



Land use / land cover in the Midwestern United States.

IV.RECENT RESEARCH ACCOMPLISHMENTS

A. Carbon Dynamics of Forests and Agriculture

TALL TOWER/WILLOW CREEK SITES

Terrestrial-atmosphere carbon exchange measurements were initiated in 1995 at the 447 m tall WLEF television transmitter tower near Park Falls in northern Wisconsin. Instruments at this tower sample a three-level eddy covariance CO_2, water vapor, temperature, and momentum flux profile (30, 122, and 396 m above the ground) and a six-level CO_2 mixing ratio profile (11 through 396 m). This system, referred to as the "Tall Tower site," provides a unique opportunity to investigate and quantify local and regional ecosystem atmosphere CO_2 flux. The "flux footprint" of the Tall Tower is roughly 100 times the area of a typical above-canopy tower and extends several kilometers upwind during unstable meteorological conditions. A 30-m above-canopy tower was constructed at Willow Creek research area in early 1998 and another 10-m above-canopy tower was constructed at Lost Creek in 2000. This project has measured regional flux at the Tall Tower, net ecosystem flux at the canopy tower at Willow Creek, and a subset of components of flux measurements at 15 sites in the region of the Tall Tower.

Above: Willow Creek tower. **Far top left:** View from MMSF tower in winter. **Far bottom left:** UMBS tower.

Dominant vegetation of this region includes: (1) mixed conifer (Jack Pine, Red Pine, Eastern White Psine), (2) northern hardwoods (Sugar Maple, Red Maple, Quaking Aspen, White Birch), and (3) bogs and fens (Black Spruce).

MORGAN-MONROE STATE FOREST SITE

Morgan-Monroe State Forest (MMSF) is Indiana's largest state forest with approximately 9733 hectares located in Morgan and Monroe counties, just north of Bloomington. MMSF is adjacent to other large areas of public lands such as Yellowwood State Forest, Brown County State Park, and the Hoosier National Forest. MMSF is predominately secondary successional broadleaf forest with a wide variety of deciduous tree species present in this region, as it is located within the transition zone between the beech-maple and oak-hickory associations of the Eastern Deciduous Forest. A 47-m above-canopy tower and related instrumentation were constructed near Orcutt Road in MMSF and became fully operational in March 1998. In addition to the measurements being made on the tower, a wide variety of ecological inventory and nitrogen dynamics measurements are being made at this site.

UNIVERSITY OF MICHIGAN BIOLOGICAL STATION SITE

The most recent AmeriFlux site established in the Midwestern region is at the University of Michigan Biological Station (UMBS) near Pellston, Michigan. A 47-m above-canopy tower and related instrumentation were installed and became fully operational in September 1998. This tower design and instrumentation follows closely those used at the MMSF site in Indiana. Also the suite of ecological variables being measured at the UMBS site are essentially the same as for the MMSF site. Vegetation at the UMBS site is mixed northern hardwoods (Sugar Maple, Red Oak, Bigtooth Aspen) mixed with Red Pine and Eastern White Pine.

B. Most Significant Long-term Accomplishments

1. Contributed to the development of the AmeriFlux network of CO_2-flux tower sites. CO_2-flux towers are operational at six AmeriFlux sites in the Midwestern region: northern lower Michigan, south central Indiana, and three in northern Wisconsin.

2. Increased interactions with the CO_2-flux investigators within the Midwestern Region and with investigators at other AmeriFlux sites.

3. Developed complementary programs focused upon forest production dynamics, carbon sequestration, litter decomposition, and below-ground processes. All three AmeriFlux sites in the Midwestern Region have ecological and process modeling projects which address mechanisms and processes of carbon fluxes at local to regional scales, including factors such as heterotrophic respiration which greatly influences the net carbon dynamics of forests.

4. Encouraged and facilitated collaborative, comparative research on the carbon dynamics of forest ecosystems as affected by and affecting global environmental change at several temporal and spatial scales across NIGEC regions and in several locations.

Project Summary by Research Topic or Theme

Topics 1990 - 1993	Projects	Publications	Pub /Project
Atmospheric trace gases	5	8	1.6
Climate models	4	13	3.3
Carbon dynamics	3	11	3.7
Impacts: water resources	7	11	1.6
Impacts: forests	3	14	4.7
Impacts: agriculture	1	3	3.0
Energy policy	4	3	0.8
Themes 1993 - 1995	**Projects**	**Publications**	**Pub /Project**
Aerosols	3	9	3.0
Atmospheric trace gases	2	7	3.3
Carbon dynamics	1	7	7.0
Impacts: agriculture	3	11	2.3
Impacts: forests	3	14	4.7
Human dimn / Integrated assess	4	5	1.3
Themes 1996 - 2005	**Projects**	**Publications**	**Pub /Project**
Carbon dynamics	18	79	4.4
Impacts: agriculture	3	11	2.3
Impacts: forests	3	14	4.7
All Themes 1990 - 2005	**Projects**	**Publications**	**Pub /Project**
Aerosols	3	9	30.
Atmospheric trace gases	7	15	2.1
Climate models	4	13	3.3
Carbon dynamics	22	97	4.4
Impacts: water resources	7	11	1.6
Impacts: forests	9	42	4.7
Impacts: agriculture	7	25	3.8
Human dimn/Integrated assess	8	8	1.0
TOTALS	**67**	**220**	**3.3**

MIDWEST REGIONAL CENTER
Research Programs

Project Director	Institution	Project	FY
BAILEY, Mary Timney	University of Cincinnati	A study of energy policy in the Midwestern States	1991
BAKWIN, Peter S.	University of Colorado	Regional atmosphere/forest exchange and concentrations of carbon dioxide	1997-2002
BALSER, Teresa	University of Wisconsin	Evaluating changes in soil carbon cycling in reed canary grass invaded soils subject to elevated atmospheric CO2 and increased soil nitrogen	2005
BIRKS, John W.	University of Colorado	Effects of environmental factors on phytoplankton emissions of dimethyl sulfide: Implications for climate change	1991
BOLSTAD, Paul V.	University of Minnesota	Are northern temperate wetlands a net source of atmospheric CO2?	
BOLSTAD, Paul V.	University of Minnesota	Measuring and modeling component and whole-system CO2 flux at local to regional scales	1997-2002
BOLSTAD, Paul V.	University of Minnesota		2004-2005
CAMERON, Guy N.	University of Houston	Effects of climate change on species in grassland-forest habitats: A regional perspective	1994-1995
CARELTON, Andrew M.	Indiana University	Climatic influences of land surface conditions in the Midwest United States	1990
COLLETT, Jr., Jeffrey L.	University of Illinois	The drop size-dependent nature of cloud chemistry and its relationship to the processing of atmospheric aerosols and trace gases	1992-1993
CRILL, Patrick	University of New Hampshire	High frequency measurements of CO2 efflux from forest soil	2004-2005
CURTIS, Peter	Ohio State University	Mass and energy exchange in northern mixed hardwoods	2003-2005
DOERING, III, Otto C.	Purdue University	Climate change effects on Midwestern agriculture: evaluation of firmland impacts and potential adaption strategies	1995-1998
ELLSWORTH, David	University of Michigan	Canopy conductance and CO2 uptake in response to CO2 and O3	2003-2005
EMANUEL William R.	University of Virginia	Carbon sources and sinks in Eastern U.S. Forests	1997-1999
FITZHUGH, Ross	University of Illinois	C & N dynamics in agricultural ecosystems Under elevated CO2 and O3	2004-2005
GORHAM Eville	University of Minnesota	Establishment by paleostratigraphic techniques of the sensitivity of Minnesota's wetlands to climate change	1992

GRIMMOND, Susan B.	Indiana University	Measurements of fluxes and concentrations of CO2 in and over a deciduous forest in the Midwest	1996-1998
HAITJEMA, Hendrik M.	Indiana University	Supra-regional modeling of groundwater response to climate change	1990-1992
HAYES, John M.	Indiana University	Isotopic studies of the biogeochemical CO2 and the abundance of 13C in sedimentary organic matter	1990-1992
HITES, Ronald A.	Indiana University	Atmospheric concentrations of trace level organics: Do organochlorines contribute to ozone depletion?	1990-1991
HOAGLAND, Kyle D.	University of Nebraska-Lincoln	Genetic basis for variation in freshwater phytoplankton productivity related to water temperature	1991
HOLLANDER, David J.	Northwestern University	Isotopic studies of the biogeochemical cycle of carbon: Relationships between pCO2 and the abundance of 13C in sedimentary organic matter	1992
ISLAM, Shafiqul	University of Cincinnati	Atmosphere-soil moisture interactions and climatic feedbacks in the Midwestern United States	1992
JELINSKI, Dennis E.	University of Nebraska-Lincoln	Climate and North American plant formations: Associations between the water balance and satellite-derived vegetation patterns	1991
KOLSTAD, Charles	University of California, Santa Barbara	Incorporating learning into an integrated assessment model of climate change	1994
KRUTILLA, Kerry M.	Indiana University	The economic consequences and CO2 emissions impact of energy taxation	1990
KRUTILLA, Kerry M.	Indiana University	Modeling the impact of economic transition in Eastern-Block countries on CO2 emissions profiles: A dynamic environmental-economic simulation	1993
LARSON, Susan M.	University of Illinois	The effect of atmospheric aerosols on optical and radiative properties of the atmosphere	1993-1994
LeBLANC, David C.	Ball State University	Radial growth responses of White Oak (Quercus alba L.) and Northern Red Oak (Quercus rubra L.) to variation in temperature and precipitation along latitudinal and longitudinal climate gradients	1997-1998
LEE, Jae K.	Argone National Laboratory	Climate change effects on agriculture in the Great Lakes Region	1993-1994
MAGNUSON, John J.	University of Wisconsin-Madison	Potential effects of global climate change of Midwestern lakes: Physics, fishes and plankton	1991-1992
MAUSEL, Paul	Indiana State University	Amazonian deforestation, succession and carbon cycling III A GIS/spectral multitemporal analytical approach	1993
MITTER, Eric L.	Indiana University	The impact of the corporate average fuel economy standards on the life span and lifetime energy consumption of automobiles: A population dynamics approach	1990
MORAN, Emilio F.	Indiana University	Amazonian deforestation and carbon cycling management	1991-1992
MORAN, Emilio F.	Indiana University	Contrasting successional rates and carbon cycling in eutrophic and oligotrophic ecosystems of Amazonia	1993-1995
MORGAN, M. Granger	Carnegie Mellon University	Development and demonstration of the uses of multivariate outputs in integrated climate assessment models	1994
OECHEL Walter	San Diego State University	Understanding and determining the patterns of and controls on regional net ecosystem production in the Great Plains and Midwestern regions: a proof concept	2002-2003
PARK, Richard	Indiana University	Predicting the basinwide responses of interior wetlands to global climate change	1992-1993
PRYOR, Sara C.	Indiana University	Nitrogen dynamics in mid-latitude forest	1999-2001
RANDOLF, J.C.	Indiana University	Fuel switching impacts on carbon dioxide emissions from Midwestern Great Lakes States electric utilities	1990
RANDOLF, J.C.	Indiana University	Adaptation, migration, or extinction? A Study of the Influence of climate change of on the biodiversity and biotic productivity selected biomes of North America	1991-1992
RANDOLF, J.C.	Indiana University	Comparative analysis of carbon budgets	1995-1998
RANDOLF, J.C.	Indiana University	Acquisition, analysis, and integration of ecological variables at the Morgan-Monroe in temperate deciduous forests State Forest AmeriFlux site	1999-2002
ROBERSTON, G. Philip	W.K. Kellogg Biological Station Michigan State University	Trace gas fluxes in the U.S. Midwest: feedbacks in agricultural ecosystems	1991-1994
ROOD, Mark J.	University of Illinois	Climate forcing by aerosol particles in the Midwestern United States	1993-1995
RUBIN, Barry M.	Indiana University	Analysis of regional economic and energy demand impacts arising from global temporal dynamics and biospheric environmental change	1992-1995
SEASTEDT, Timothy R. OJIMA, D.S.	University of Colorado	Biological hysteresis in climate change models for Great Plains: Implications for productivity and hydrologic cycles	1991-1992
SCHMID, Hans Peter	Indiana University	Fluxes and concentrations of CO2 in successional forest in the Midwest	1999-2001
SCHMID, Hans Peter	Indiana University	Forest-atmosphere exchange of CO2 over a mixed hardwood ecosystem in the Midwest	2002
SUN, Wen-yih	Purdue University	Numerical study of the drought in the Midwestern region	1992
TEERI, James A.	The University of Michigan	Above and belowground ecosystem responses to elevated atmospheric CO2	1992-1996
TEERI, James A.	The University of Michigan	Mass and energy exchange in a Northern mixed hardwood ecosystem	1997-2002
VERMA, Shashi B.	University of Nebraska	A field study of methane and carbon dioxide fluxes in a boreal wetland ecosystem: Measurement and analysis	1991
WHITE, Jeffrey R.	Indiana University	Temporal and spatial variability of methane cycling in wetland ecosystems of the Northern Temperate Zone	1990-1993
WHITEHEAD, Donald R.	Indiana University	The effect of variability in microclimateand regional climate on the productivity of neotropical migrant landbirds in Midwestern forests	1994-1996
WHITEHEAD, Donald R.	Indiana University	The influence of climatic change on the long-term hydrological and biogeochemical trajectories of North American Watershed-Lake ecosystems	1990-1992
WILLARD, Daniel E.	Indiana University	The effect of global climate change on wetland function and distribution, and consequent land use and economic change	1990-1991
WINKLER, Julie A.	Michigan State University	Maximum and minimum temperature variations in a perturbed climate and implications for specialized agriculture in the Great Lakes Region	1994-1995

MIDWEST REGIONAL CENTER
Generated Publications

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Northeast Regional Center

Northeast Regional Center Report
Harvard University

Northeast Regional Center

I. REGIONAL DESCRIPTION: NORTHEAST REGIONAL CENTER

The Northeast Region of NIGEC included the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont. The southern part of the area is the most densely populated in the United States. Nevertheless forests of young to middle age cover greater than 80% of the land area, representing significant economic and environmental resources. The Northeast and Mid-Atlantic urban-industrial complex is the source of vast quantities of greenhouse gases and pollutants. The proximity of densely and sparsely populated regions, intense emission sources and vegetation-dominated forests, provided a unique setting to study the effects of climatic variation on growing forests, effects of forest on atmospheric temperature, humidity, and composition, to observe the processes of atmospheric cleansing as they occur, and to measure the ecological and atmospheric effects of pollutants, gaseous and particulate, along a steep concentration gradient.

II. CENTER'S STRATEGIC VISION

The strategic vision of the NERC emphasized integrated research on ecological responses of forests to management, climatic change, and environmental stressors (air pollution, inputs of nutrients, heavy metals, and acids, invasive species such as the hemlock woolly adelgid). The main focus of NERC was to quantify the structure, development, and productivity of forests in a region thought to be important of US and global uptake of anthropogenic CO_2 by forests. Was such uptake actually occurring, and if so, why? Was climate change or pollution having an effect? What was the influence of past and current land management?

An important secondary focus of NERC was on quantifying and understanding emissions, deposition, and effects of pollutants, aerosols, greenhouse gases, and ozone-destroying chemicals in the region. NERC supported studies of human-induced changes in atmospheric chemistry and radiative processes by leveraging its geographical location, which places its principal study sites where they consistently sample both very clean and highly polluted air.

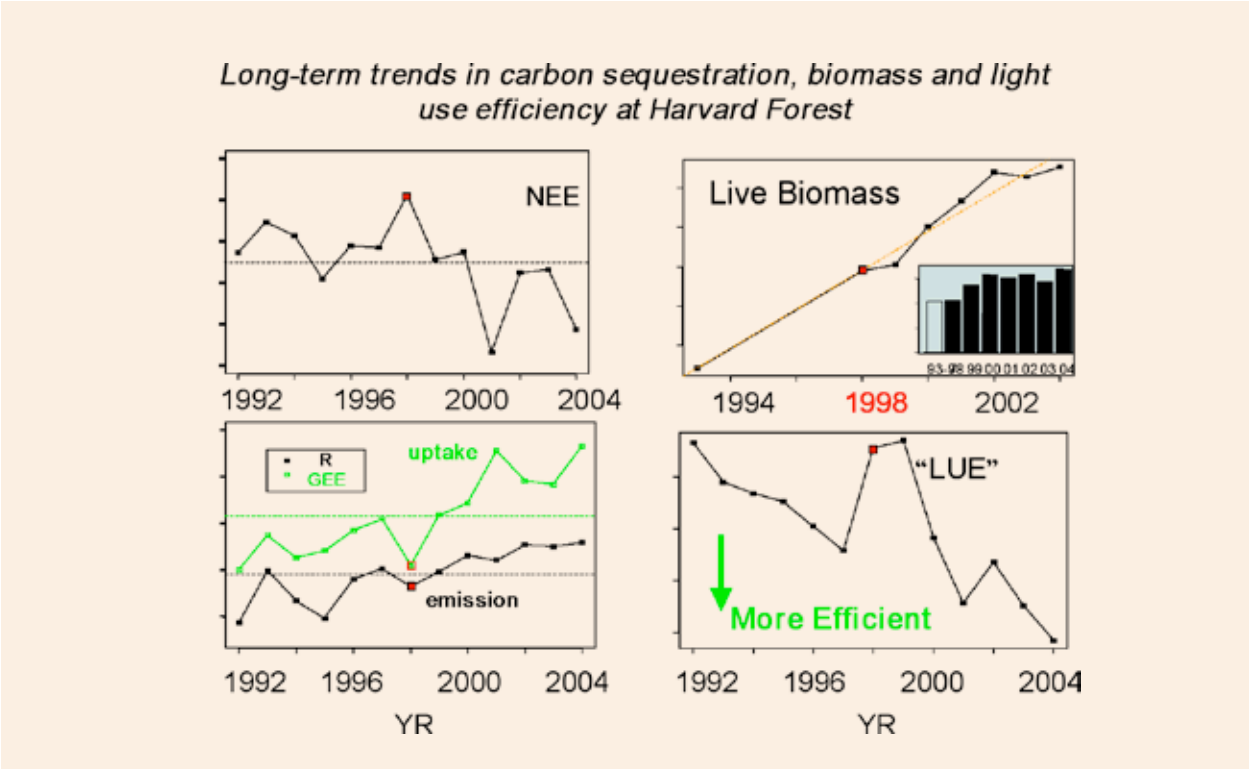
NERC endeavored to create a strongly interdisciplinary research program in which process and laboratory studies and modeling were integrated into a framework built around long-term quantitative observations and manipulations. Two sites, Harvard Forest (Petersham, MA) and Howland Forest (Howland, ME), provided the anchors for the observational elements of the program. These sites were the first and second in the world to make long-term eddy flux observations. They are the longest running of the continuous eddy flux measurements in the AmriFlux network, and served as incubators to develop the methodology for the AmeriFlux network. They were the settings for successive efforts to validate the eddy flux measurements against conventional ecological data. These locations provided infrastructure and a knowledge base for many other types of investigation. Fore example, they were the focus for a diverse set of manipulations (e.g., open-top chambers, logging, soil warming, and nutrient additions), ecological studies of forest development and invasive species, stable isotope measurements, analysis of meteorological and environmental observations, measurements of concentration an deposition of air pollutants, modeling and historical and palynological studies, Long-term trends in ecosystem structure and function under climate change continue to bet the subject of vigorous ongoing research in the NICCR program, within the Department of Energy science program, and in the US Climate Change Science Program.

NERC operated as a Science Team to bring diverse disciplines together. Scientists supported by NERC communicated often and met annually to review results and plan coordinated work. All data from NERC-supported investigations was required to be shared with NERC researchers soon after collection, at eh annual meeting, and, as promptly as possible, with the public through NIGEC-NERC and AmeriFlux data archives (http://www.as.harvard.edu/daa.data.html, and http://cdiac.esd.ornl.gov/programs/ameiflus/data2.htm). The policy of maximum data sharing was viewed as essential to success of the NEERC strategic vision, and was reinforced by the Director through the RFP process.

III. ACCOMPLISHMENTS

Overview

NERC synthesized long-and-short-term observations, manipulation, ecological and historical studies, and modeling to address, directly and quantitatively the main factors that regulate forest processes. The studies spanned time scales from transient changes in environmental conditions (hours) to climatic forcing and legacies of prior disturbance (years, decades). The specific program goals



Long-term trend in Net Ecosystem Exchange (NEE, upper left), Gross Ecosystem Exchange (GEE) and Respiration (R) (lower left), above-ground biomass (upper right) and woody biomass increment (inset), and light use efficiency (GEE at highest levels, 1200-1500 mEm m-2s-1) (lower right). The forest has grown larger and more efficient, with accelerating growth rates, for the past 15 years. Coincident stresses in 1998 damaged the canopy, interrupting ecosystem performance for ~3 years [Urbansk et al., 2007].

were to (1) investigate carbon exchange of forest ecosystems, (2) study the effects of climate change, disturbance by pests, logging and severe weather, and air pollution on forest resources, atmospheric chemistry, and atmospheric radiation, (3) study the effects of forests on regional air quality and climate, and (4) quantify emission sources of greenhouse gases and ozone-destroying chemicals from the industrialized Northeast.

A. Long-Term Accomplishments of NERC

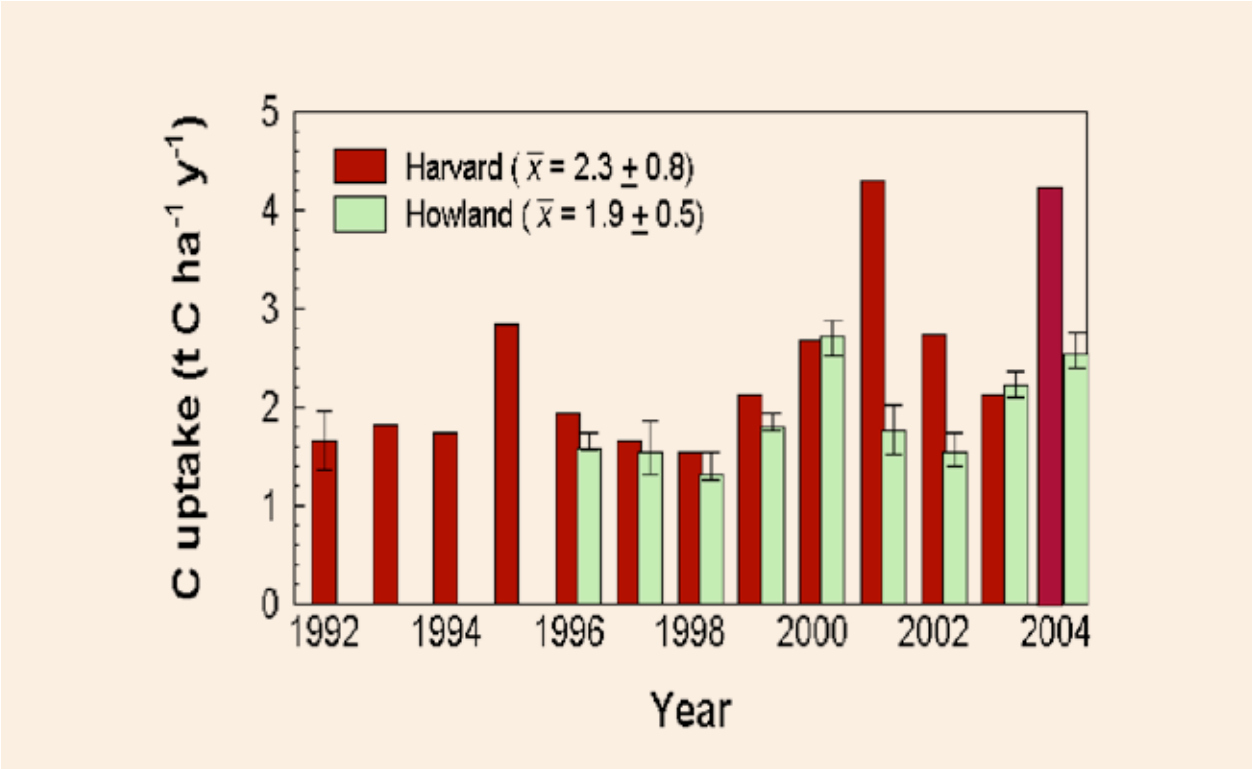
NERC supported a very wide range of studies over a period of 15 years. The following summary of major results from this work touches upon some high points, but doesn't attempt to provide a comprehensive catalog.

Long-term studies of the carbon cycle on ecosystem-scale

- The carbon budget at Howland (evergreen) and Harvard (northern deciduous) forests were satisfacor closed by both ecological measurements and eddy flux observations, lending strong support to the validity of the eddy flux measurements.
- The forests area taking up increasing amounts of CO_2 annually, currently ~ four tons *C*/ha/yr at Harvard Forest. The acceleration of uptake in an 80-year-old, typical Northeastern forest, was a big surprise, that opens important new questions about the durability and magnitude of CO_2 uptake in the future. The trend appears to be due to changes in stand age, successional changes in stand composition (mid-succession Red Oak displacing pioneer Red Maple), longer growing seasons, and disequilibrium of pools of coarse woody debris (Fig. 10). The result supports the view that management of the forest resource both for market income from wood products and for carbon sequestration could pay major societal benefits.

Seasonal and interannual variations tin carbon uptake are regulated by both respiration processes and canopy photosynthesis, and in many years are strongly correlated despite separation by ~ 400 km and differences in vegetation type (Fig.11) Major events, such as severe damage to the developing canopy in the spring of 1998, have legacies that persist for ~ 3 years (Fig.1). Hence any effort to assess trends in forest carbon sequestration must cover periods of ~ 10 years, at least in the NERC region.

The results provided strong support for the important role of forests in Eastern North America in recent sequestration of fossil fuel CO_2 form the atmosphere, and point towards the age distribution of these forests, and to a lesser extent recent



Annual uptake of CO2 at Harvard and Howland forests, showing strong covariance of inter-annual variations [Richardson et al., 2006]. The Harvard trend towards greater uptake is not seen at Howland.

climate warming, as the major factors causing this uptake of CO_2. We do not know how large these forests can grow or how long uptake will proceed, and there are many unanswered questions as to how the forest resource could be managed to optimize short-term market income simultaneously with long-term carbon sequestration.

Regional and national emissions of greenhouse gases.

- Harvard Forest turned out to be an excellent site to measure output of greenhouse gases and ozone-destroying chemicals, due to the alternation of pollution events with influx of clean background air. Measurements of time series of concentrations of CFCs, CO and other pollutants at Harvard Forest shoed that emissions of CFCs (greenhouse and ozone-destroying gases regulated by the Montreal Protocol) declined much more slowly than expected. The results help explain why the expected decline in the stratospheric burden of chlorine has not been observed, and the persistence of sources raises important regulatory issues. Concerns over slippage in controls on these gases can directly be addressed by observing their concentrations, and assessing the ratios to primary pollutants such ac CO, CO_2, and CH_4 [Barnes et al.,].

Effects of changing forest cover on regional climate

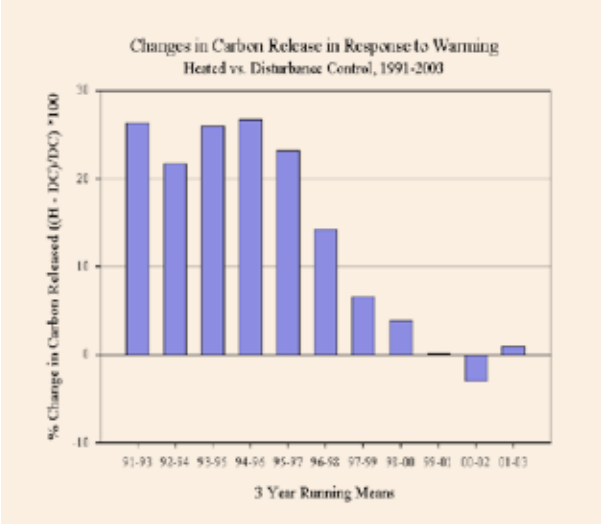
- Using flux data from Harvard Forest and ceilometer data from nearby Orange Airport, the strong influence of forest evapo-transpiration on regional boundary layer humidity and clouds was quantified. The result showed that changes in land cover have had significant regional climatic effects by changing Bowen ratios at landscape scales, especially in spring. This effect could have significantly masked climatic warming trends in the first half of the 20th Century [Fitzjarrald].

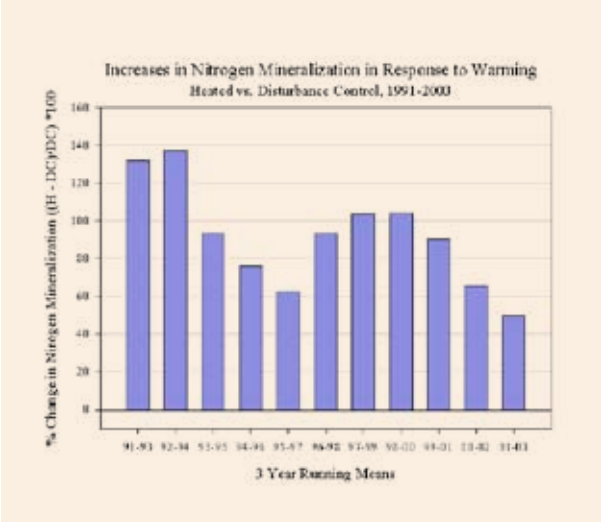
Manipulations and experiments

- Long-term additions of nitrogen tot the forest ecosystem indicated 85-100% retention of added nitrogen. Harwood stands increased wood production somewhat but conifers were degraded. The results indicate that susceptible species can be damaged by nutrient inputs even with “nitrogen saturation”, and casts doubt upon the stimulation of carbon sequestration hypothesized in response to deposition of atmospheric nitrogen to forests [Nadelhofer].
- Long-term elevation of soil temperature led to increased soil respiration, but excess respiration basically ceased after a few (three to five) years when labile pools of

organic matter were depleted. However, enhanced release of nutrients continued, indicating that on decadal time scales, warming adds fertilizer to forest ecosystems. This result turns conventional thinking about warming effects upside down, at least for the cool midaltitude forests of New England [Melillo].

- Commercial harvesting at the Howland site had a very modest effect on release of CO_2 (for the practice of the paper-products industry in Maine). Fertilization also had a notably small effect, simulating CO_2 uptake [Richardson]. A similar study at Harvard Forest showed the ecosystem recovering to become a sink for CO_2 in less than five years. [O'Donell].





Long-term trends (three-year running means) in CO2 excess efflux from heated (+ 5 C) soil *(left panel)* and in the excess rate of mineralization of fixed nitrogen *(right panel)*, showing the re-estaablishment of steady-state respiration over time, but persistence of excess N-mineralization [Melillo].

Deposition of pollutants

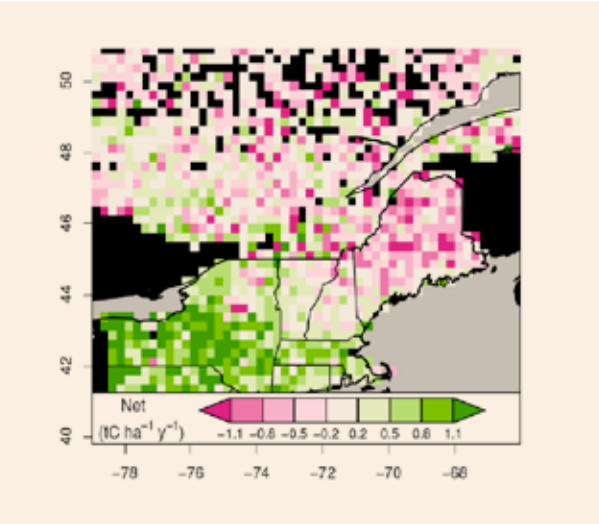
- Using direct flux measurements for the first time, it was shown that nitrogen oxide radicals (NO, NO_2) deposit on the forest at very low rates. Removal of atmospheric nitrogen oxides thus requires oxidation to nitric acid and wet or dry deposition. This result settles a long-standing controversy based on divergent studies in the laboratory, and it indicates that oxidation processes and not deposition represents the critical step in removing nitrogen oxide pollutants from the atmosphere.
- Observations of deposition of mercury (Hg) quantified emissions from the northeast industrial region, and, during a major smoke event, from forest fires in the sub-boreal zone. The magnitude of the deposition flux indicated significant inputs of this highly toxic pollutant from distant sources.

Modeling and analysis

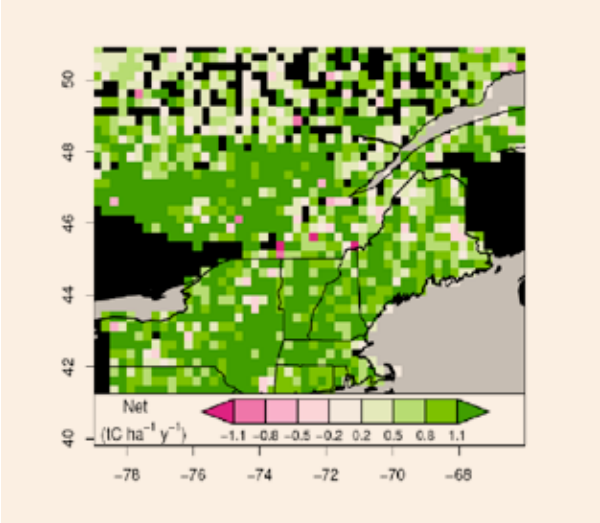
Model studies (using PneT) showed that flux data have the strongest purchase on model parameters at daily to seasonal time scales, but limited capability to likely constrain parameters for unmeasured pool sizes and slow turnover rates. This limitation was due partly to likely deficiencies in the model structure and partly to the basic information content of the data [Ollinger]. The result provides impetus of efforts to add to tower flux data direct measures of relevant pool sizes and associated functional rates for large areas, using remote sensing, adaptations of FIA data, etc.

An extremely promising approach to a truly predictive model of ecosystem development and response to climate change was developed by Moorcroft and colleagues using age- and height-structured ecosystem model that determines the emergent properties of ecosystems directly from the properties of individual plants, using aggregation techniques borrowed from statistical physics. The resulting model ("ED-2") was calibrated and applied at Harvard Forest, and elegantly shown to work without adjustment at Howland, despite the dramatically different vegetation assemblage and history [Medvigy], and across the region (by comparison with FIA data; Albani). This model was applied to estimate the uptake and release of CO_2 on regional scale, as shown in Figure 1.

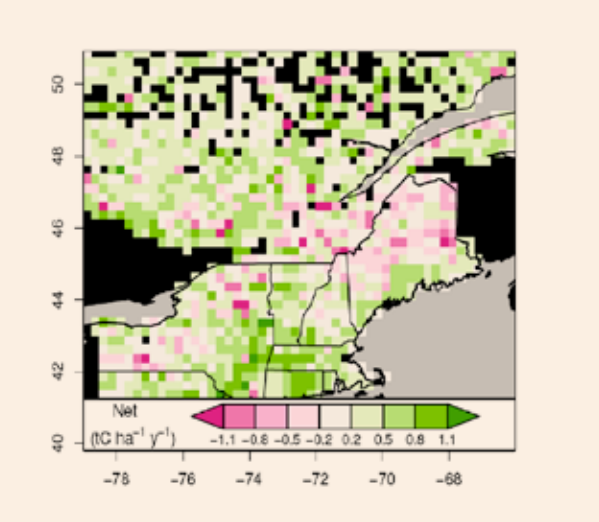
Figure 1. Net above-ground carbon accumulation (growth minus mortality minus harvesting).



Panel 14(a) shows the observed patterns of above-ground carbon accumulation calculated from the forest inventory measurements. The observed uptake is large, especially in New York, while Maine and parts of Southern Quebec had negative rates of uptake.



Panel 14(b) shows the net carbon accumulation rates obtained in the default model simulations which greatly overestimate the observations rate of net carbon uptake.



Panel 14(c) shows the predictions of optimized model, which matches the observations much better than the default model. The optimized model is at its best in New England, but under-predicts in New York and over-predicts in Quebec.

NORTHEAST REGIONAL CENTER
Research Programs

P.I., Co-.I.	Institution	Title	Funding
ABER, John	University of New Hampshire	Soil chemistry and throughfall at Harvard Forest	1990-1992
BALDWIN, Peter	University of Colorado	Vegetation spectral reflectance signature	1991-1992
BAZZAZ, Fakhri	Harvard University	Decline of Growth Enhancements by Elevated CO2 After Long-Term Exposure	1992-1994
BAZZAZ, Fakhri	Harvard University	Predicting Responses of Temperate Forest Ecosystems to Elevated Atmospheric CO2 Concentrations and Air Temperatures	1994-1996
BAZZAZ, Fakhri	Harvard University	Competitive Balance Between Coniferous and Deciduous Species: Consequences to Carbon Flux in New England Forests	1996-1999
BAZZAZ, Fakhri	Harvard University	Impact of Elevated CO2 and N Deposition on Net Ecosystem Exchange of CO2 in Regenerating Temperate Forests	2000-2003
BENDER, Michael	Princeton University	The composition of air in the firn layer of ice sheets and the reconstruction of anthropogenic changes in greenhouse gas concentrations.	1992-1996
BENDER, Michael	Princeton University	The Composition of Air in the Firn of Ice Sheets and the Reconstruction of Anthropogenic Changes in Atmospheric Chemistry	1996-2002
BERNTSON, Glen	University of New Hampshire	Impacts of elevated CO2 and N deposition on net ecosystem exchange: Fluxes of CO2and H2O in regenerating temperate forests	1999-2000
BOONE, Richard NADELHOFFER, Knute	Harvard University Marine Biology Laboratory	Biological and physical controls on soil organic matter	1991-1995
BOWDEN, Richard	Allegheny College	Effects of soil moisture and temperature on fluxes of CO2 and CH4 in a temperate forest soil	1992-1993
BOYLE, Edward	Massachusetts Institute of Technology	Modern calibration of deep ocean climate records: multiple-tracer studies of living benthic foraminifera	1992-1995
BRADLEY, Raymond	University of Massachusetts	Recent climatic change from Lake sediments	1992-1993
BROEKER, W. BENDER, M. WAHLEN, Martin	Lamont-Doherty Earth Observatory University of Rhode Island Scripps Institute of Oceanography	Forest Sources and Sinks of CH4, CO2, and N2O: A Biogeochemical Tracer Study Using the Enclosed Ecosystem Apparatus of "Biosphere 2"	1993-1995
BRASWELL, Robert Scott Ollinger	University of New Hampshire, (Complex Systems Research Center)	Synthesis of multi-scale satellite observations with Ameriflux data for understanding and predicting forest ecosystem dynamics	2003-2005
BROADHUS, James SOLOW, Andrew	Woods Hole Oceanographic Institute	Detecting adaptation to environmental risk: a study of US east coast storm climate	1991-1993
CLARK, William	Harvard University	International Research Archive on Science Policy Dimensions of Global Environmental Change	1990-1991
CLARK, William	Harvard University	An empirical evaluation of the effectiveness of possible strategies for the assessment of global environmental change	1995-1996
CONTE, Maureen	Woods Hole Oceanographic Institute	Development of a Novel Biomarker-Aerosol Method to Quantify Carbon Isotopic Discrimination of Terrestrial Photosynthesis	2002-2004
CRILL, Patrick HARRISS, Robert	University of New Hampshire	Sources of Atmospheric Methane in the Eastern United States	1991-1992
CRILL, Patrick HARRISS, Robert	University of New Hampshire	Sources of Atmospheric Methane in the Eastern United States	1993-1996
CRILL, Patrick	University of New Hampshire	Elements of CO2 Exchange in a Tropical Forest: Soil and Bole Respiration	1997-1999
CRILL, Patrick	University of New Hampshire	Pilot Study of Automated CO2 Flux Measurements Across a Wetland/Upland Transition in Harvard Forest	2002-2003
CRILL, Patrick VARNER, Ruth	University of New Hampshire	High Frequency Measurements of CO2 Efflux from Forest Soil	2004-2006
DAVIDSON, Eric AMTHOR, Jeff	Woods Hole Research Center Lawrence Livermore National Laboratory	Generalizing the core experiment work at Harvard Forest to address global change issues through modeling of forest metabolism and analysis of satellite imagery.	1992-1995
DAVIDSON, Eric GOLTZ,Stewart	Woods Hole Research Center University of Maine	Regionalizing the Harvard Forest long-term flux measurements: Complementary studies from Howland, Maine	1995-1998
DAVIDSON, Eric Neal Scott DAIL, Bryan David Hollinger	Woods Hole Research Center Woods Hole Research Center University of Maine USDA Forest Service	Forest-Atmosphere CO2 Exchange in a Spruce-Hemlock Stand Near Howland, Maine	1998-2001

DAVIDSON, Eric Neal Scott DAIL, Bryan David Hollinger	Woods Hole Research Center Woods Hole Research Center University of Maine USDA Forest Service	Leveraging long-term NEE measurements: Investigations of ecosystem processes through partitioning of fluxes and through experimental manipulations at Howland, Maine	2001-2004
DAVIDSON, Eric Neal Scott DAIL, Bryan David Hollinger	Woods Hole Research Center Woods Hole Research Center University of Maine USDA Forest Service	Long-term CO2 exchange and biomass measurements in a spruce-hemlock stand near Howland, Maine, supporting regional-scale studies and ecosystem manipulation experiments	2004-2006
DAVIDSON, Eric TRUMBORE, Susan	Woods Hole Research Center University of California, Irvine	Controls on Soil Carbon Storage and Soil CO2 Fluxes at the Harvard Forest Core Experiment	1995-1997
DAVIDSON, Eric TRUMBORE, Susan	Woods Hole Research Center University of California, Irvine	Controls on Soil Carbon Turnover in Forests Along a Latitudinal Transect	1997-2000
DAVIDSON, Eric TRUMBORE, Susan	Woods Hole Research Center University of California, Irvine	Sources of Interannual Variation of Soil Respiration in Two New England Forests	2000-2003
DAVIDSON, Eric TRUMBORE, Susan	Woods Hole Research Center University of California, Irvine	Responses of Autotrophic and Heterotrophic Respiration in Soils to Seasonal and Interannual Variation of Temperature and Precipitation in a Temperate Forest	2003-2006
DICKERSON, Russell Michael Zachariah Jeffrey Stehr	University of Maryland	Sulfate-Coated Soot and its Impact on Global Climate	2005-2006
DOWLATABADI, Hadi A. Patwardhan	Carnegie-Mellon University	Decision-making in coastal areas undergoing uncertain environmental change	1991-1993
FARRELL, Brian	Harvard University	The role of baroclinic wave amplitude and transport variation in climatic change/ Assessing the Sensitivity of Transient Wave Variance and Fluxes to Perturbations Associated with Climate Change Using Non-Normal Stochastic Methods	1990-1997
FIERING, Myron ROGERS, Peter	Harvard University	How close is close enough? / Climate impact on hydrology of the Northeast with emphasis on extreme events	1991-1993
FITZJARRALD, David Kathleen Moore	SUNY, Albany	Factors that Influence the Surface Energy Budget/ Turbulence and Turbulent Exchange At Harvard Forest/ Observation, analysis, and parameterization of forest-atmosphere exchange mechanisms	1990-1996
FITZJARRALD, David Kathleen Moore	SUNY, Albany	Observation, analysis, and parameterization of forest-atmosphere exchange mechanisms	1996-1999
FITZJARRALD, David Kathleen Moore	SUNY, Albany	Observations, analysis and parameterization of forest-atmosphere exchange mechanisms	1999-2002
FITZJARRALD, David	SUNY, Albany	Forest-Atmosphere Exchange Processes Related to Regional Carbon Budgets	2002-2005
FITZJARRALD, David	SUNY, Albany	Forest-Atmosphere Exchange Processes Related to Regional Carbon Budgets	2005-2006
FOSTER, David Julian Hadley	Harvard Forest	CO2 Exchange by Hemlock Forests in Central New England	1996-1998
FOSTER, David Julian Hadley	Harvard Forest	A Physiological Model of CO2 Exchange by Hemlock Forests in Central New England	1998-2000
FOSTER, David Julian Hadley	Harvard Forest	Evaluating the Effects of Diverse Vegetation Types and Soil Drainage Classes on Net Carbon Exchange of a Landscape Mosaic with Mobile and Fixed Eddy Covariance Systems	2000-2003
FOSTER, David Julian Hadley	Harvard Forest	Effects of forest age, soil drainage and interannual climate variation on deciduous forest carbon exchange	2003-2004
FOSTER, David Julian Hadley	Harvard Forest	Effects of forest age, soil drainage and interannual climate variation on deciduous forest carbon exchange: A comparison to long-term Harvard Forest measurements, in a contrasting forest type	2004-2006
FROLKING, Steve	University of New Hampshire	Modeling the Ecosystem Carbon Balance of Northeastern Forests With a Focus on Soils	1998-2000
GOODY, Richard	Harvard University	Physical Basis for Climate Change Models	1990-1991
HOBBIE, John JACOBY, Henry	Marine Biological Laboratory Massachusetts Institute of Technology	Integrating an Ecosystem Model into a Global Change Impact Assessment	1996-1997
JACOBSEN, Stein	Harvard University	Precise Determination of Climate Changes Over the Past 1000 Years	1990-1991
JACOBY, Henry	Massachusetts Institute of Technology	Coupling an impacts model to a framework for integrated assessment	1993-1996

KASPERSON, Jeanne KASPERSON, Roger	Clark University	Uncertainty, signals, and public perceptions of climate change/ Assessing vulnerability to severe storms and sea-level rise	1991-1993
KEITH, Henry	Columbia University	Atmospheric Energy Fluxes: A Model-Data Comparison	1992-1993
LANGFORD, John	Aurora Flight Sciences Corp.	The Perseus unmanned scientific Research Aircraft: A new tool for global climate change research	1990-1991
LEE, Xuhui	Yale University	Forest Ecosystem Respiration with the Eddy Covariance	1999-2000
LEE, Xuhui Tom Siccama	Yale University	Forest Ecosystem Respiration with the Eddy Covariance II	2001-2004
LEE, Xuhui	Yale University	Response of soil respiration to rain	2004-2006
LERDAU, Manuel	SUNY, Stonybrook	Pilot studies of the role of water stress in affecting isoprene emission from plants of the Harvard Forest in Petersham, MA	1994-1995
LINDZEN, Richard	Massachusetts Institute of Technology	Dynamic Heat and Moisture Transport and Baroclinic Adjustment	1992-1997
McCEIGHT, Richard WARING, Richard	Oregon State University	Spectral and image analysis of Harvard forest data	1991-1993
McELROY, Michael	Harvard University	The Environmental Applications of Chinese Energy Use	1993-1994
McELROY, Michael James Elkins	Harvard University NOAA	Past climates and factors regulating past climate change	1990-1995
McELROY, Michael James Elkins	Harvard University NOAA	Isotopic Composition of Atmospheric CO2 Inferred from Carbon in C4 Plant Cellulose: Studies of the Global Carbon Cycle	1995-1998
McELROY, Michael James Elkins	Harvard University NOAA	Evaluation of Sources and Sinks for Greenhouse and Ozone-Depleting Gases in Rural New England: a Prelude for Mitigation II	1998-2001
McELROY, Michael James Elkins	Harvard University NOAA	Influence of Biotic Exchange and other Sources on Atmospheric CO2 Concentrations in a New England Deciduous Forest (Ameriflux site) utilizing Other Trace Gases Measurements	2001-2004
McELROY, Michael DUTTON, Geoffrey	Harvard University University of Colorado	Influence of Biotic Exchange and other Sources on Atmospheric CO2 Concentrations in a New England Deciduous Forest (Ameriflux site) utilizing Other Trace Gases Measurements	2004-2006
MELILLO, Jerry Paul Steudler Knute Nadelhoffer	Marine Biological Laboratory	Human Influences on Forest Nitrogen Budgets and their Implications for Forest Carbon Storage	1998-2001
MELILLO, Jerry Paul Steudler Knute Nadelhoffer	Marine Biological Laboratory	Global Warming and Carbon Storage in Mid-Latitude Forest Ecosystems	2001-2004
MELILLO, Jerry Paul Steudler	Marine Biological Laboratory	Soil Warming and Carbon-Cycle Feedbacks to the Climate System	2004-2006
MIN, Qilong	SUNY, Albany	A Regional Climatology of Cloud and Aerosol for Forest-Atmosphere Energy Exchange	1999-2002
MIN, Qilong	SUNY, Albany	A regional climatology of cloud and aerosol for forest-atmosphere exchange: Impacts of clouds and aerosols on CO2 uptake	2003-2006
MOODY, Jennie JACOB, Daniel	University of Virginia Harvard University	The Influence of Regional-scale Transport on the Concentrations of Climatically Important Trace Gases at Harvard Forest, Massachusetts	1992-1995
MOOMAW, William	Tufts University	Course Case Studies for National Correlations between Greenhouse Gas Emissions and Economic Activity	1992-1993
MOORCROFT, Paul	Harvard University	Past, present & future rates of terrestrial CO2 flux in North-Eastern Forests: the role of eco-physiological responses, land-use history & disturbance legacies	2004-2006
MUNGER, J. William (formerly Wofsy) Steven C. Wofsy	Harvard University	Climatic and Biological Control of Carbon, Nitrogen and Trace-Gas Fluxes between Atmosphere and Mid-Latitude Deciduous Forests	1998-2001
MUNGER, J. William (formerly Wofsy) Steven C. Wofsy	Harvard University	Long-term measurements of ecological and environmental factors and of net exchange fluses and concentrations of CO2, nitrogen oxides, and ozone at Harvard Forest	2001-2004
MUNGER, J. William (formerly Wofsy) Steven C. Wofsy	Harvard University	Long-term response by the carbon budget of a mid-latitude deciduous forest to ecological processes, climate variations, and air pollutants.	2004-2006
OLINGER, Scott John Aber	University of New Hampshire	Resolving the Effects of Multiple Environmental Changes on Net Carbon Balances Through Time-Series Application of a Forest Ecosystem Model	2002-2005
PETEET, Dorothy	Columbia University	Paleoclimate from boreal ecosystems.	1992-1993
ROSEN, Richard	AER, Inc.	Variability in observed large-scale atmospheric moisture fluxes	1995-1998

SCHLOSSER, Peter M. Stute W.S.Broecker	Columbia University	Paleotemperatures for the North American Continent Derived from Noble Gases in Groundwater	1991-1993
SIEVERING, Herman	University of Colorado	Preliminary Assessment of Coarse Particle Nitrate at the Harvard Forest and its Contribution to Atmospheric Forest Canopy Fluxes	1994-1995
SHOLNIKOFF, Eugene	Massachusetts Institute of Technology	Bellagio II: managing the transition to a global climate change regime	1990-1991
SMITH, Ronald	Yale University	The Source and Radiative Effect of Upper Level Water Vapor	1991-1994
STONE, Peter	Massachusetts Institute of Technology	Coupled Atmosphere-Ocean Models.	1991-1997
TALBOT, Robert	University of New Hampshire	Nitric acid over midlatitude forests/ The atmosphere-biosphere exchange of nitric acid in a forest setting/ Dry Deposition of Atmospheric Nitric Acid and Particulate Nitrogen in a Forest Setting	1991-1996
TUREKIAN, Karl N. Tanaka W. C. Graustein	Yale University	The fate of atmospheric SO2 using cosmogenic 35S	1990-1992
WILLIAMS, Earle	Massachusetts Institute of Technology	Schumann Resonance Measurements as a Sensitive Diagnostic for Global Change	1992-1995
WILSON, Richard Daniel Kammen	Harvard University Princeton University	A Conceptual Framework for Risk Analysis of global Environmental Change/ The Layout of Risk Assessments and Understanding of Uncertainties by Analogy/ De Minimus Risk in Climate Change Decision Making/ Reducing Emissions of Greenhouse Gases by Alternative Energy Sources	1990-1995
WILSON, Richard	Harvard University	Removing Constraints that Limit Nuclear Energy Use in China and Improving Energy Efficiency	1994-1995
WOFSY, Steven C. J. William Munger Carol C. Barfor Cassandra Volpe Horii	Harvard University	Chemical Climate in Eastern North America/ Direct Measurements of Carbon Dioxide and Nitrogen Oxide Fluxes in Central New England/ Net exchange of CO2 and nitrogen oxides in northern forests and related biomes	1990-1995
WOFSY, Steven C. J. William Munger Carol C. Barfor Cassandra Volpe Horii	Harvard University	Long-term, whole ecosystem observations of atmosphere-biosphere exchange in a mid-latitude forest: Rates of carbon storage and inputs of nitrogen oxides/ Climatic and Biological Control of Carbon, Nitrogen and Trace-Gas Fluxes between Atmosphere and Mid-Latitude Deciduous Forests	1995-1998

NORTHEAST REGIONAL CENTER
Students Supported

YEAR	Ph.d.	Masters	Undergrad
1993	3	9	12
1994	5	7	12
1995	4	6	3
1996	4		
1997	14	3	7
1998	15		6
1999	14	3	7
2000	14		6
2001	6	5	7
2002	10	4	14
2003	4	1	13
2004	8	4	14
2005	7	5	25
Totals:	108	47	126

NORTHEAST REGIONAL CENTER
Generated Publications

Aber, J., S. Ollinger, B. Currie, M. Martin, M. Castro, E. Boose, D. Foster, A. Magill, D. Kicklighter, S. McNulty (2004), Synthesis and Extrapolation: Models, Remote Sensing and Regional Analyses, in *Forest Landscape Dynamics in New England: Ecosystem Structure and Function as a Consequence of 1000 Years of Change*. Foster, D.F. and J.D. Aber (Editors), Yale University Press, New Haven, CT.

Aber, J., A. Magill, K. Nadelhoffer, R. Boone, J. Melillo, P. Steudler, J. Hendricks, R. Bowden, W. Currie and W. McDowell, The chronic nitrogen amendment experiment, in *Forests in Time, The Environmental Consequences of 1000 Years of Change in New England*, Synthesis Volume of the Harvard Forest LTER Program, D. Foster and J. Aber (eds.), Oxford University Press (in press).

Aber, J., A. Magill, K. Nadelhoffer, J. Melillo, P. Steudler, P. Micks, J. Hendricks, R. Bowden, W. Currie, W. McDowell and G. Berntson (2004), Exploring the process of nitrogen saturation, in, *Forests in Time, The Environmental Consequences of 1000 Years of Change in New England,* D. Foster and J. Aber (eds.), Chapter 12, pp. 259-279, Yale University Press, New Haven, CT.

Aber, J.D., P.B. Reich, and M.L. Goulden (1996), Extrapolating leaf CO_2 exchange to the canopy: a generalized model of forest canopy photosynthesis compared with measurements by eddy correlation, *Oecologia, 106*: 257-265.

Aber, J.D., S.V. Ollinger, and C.T. Driscoll (1997), Modeling nitrogen saturation in forest ecosystems in response to land use and atmospheric deposition, *Ecological modeling., 101:* 61-78.

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Amthor, J. S., Goulden, M. L., Munger, J. W., and Wofsy, S. C. (1994) Testing a mechanistic model of forest-canopy mass and energy exchange using eddy correlation: carbon dioxide and ozone uptake by a mixed oak-maple stand, *Aust. J. Plant Physiol., 21*, 623-621.

M. Albani, D. Medvigy G. C. Hurtt and P.R. Moorcroft (2006), The contributions of land-use change, CO_2 fertilization and climate variability to the carbon sink in the Eastern United States, *Global Change Biology* (in press).

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Barnes, D. H., S. C. Wofsy, B. P. Fehlau, E. W. Gottlieb, J. W. Elkins, G. S. Dutton, and S. A. Montzka (2003), Urban/industrial pollution for the New York City–Washington, D. C., corridor, 1996– 1998: 1. Providing independent verification of CO and PCE emissions inventories, *J. Geophys. Res.*, *108*(D6), 4185, doi:10.1029/2001JD001116.

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Barnes, D. H., S. C. Wofsy, B. P. Fehlau, E. W. Gottlieb, J. W. Elkins, G. S. Dutton, and P. C. Novelli (2003), Hydrogen in the atmosphere: Observations above a forest canopy in a polluted environment, *J. Geophys. Res.*, *108*(D6), 4197, doi:10.1029/2001JD001199.

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South Central Regional Center

South Central Regional Report
Tulane University

South Central Regional Center

I. BACKGROUND INFORMATION:

The South Central Regional Center (SCRC) was established in 1991 with Professor Robert G. Watts as Director. In 1997, Professor David Sailor became the SCRC Director. In 2002, Professor Efstathios E. (Stathis) Michaelides became the last Director of the Center.

The South Central region consists of the states of Arkansas, Louisiana, Mississippi, New Mexico, Oklahoma, and Texas. In addition, the South CentralRegional Center (SCRC) shares funding responsibilities for the state of Colorado with the Great Plains Regional Center. The majority of the region's population is in the state of Texas and there are significant regional resources and agricultural crops spread throughout the region. The region is also characterized by significant gradients in temperature, moisture and precipitation. It ranges from wet and humid climates in the southeast (greater than 120 mm of annual precipitation) to arid regions in New Mexico (less than 40 mm of annual precipitation). While the precipitation gradient is primarily east-west, the temperature gradient is predominantly north-south. The economy of the region is similarly diverse with states in the region accounting for a significant portion of the nation's important resources and agricultural products: 80% of natural gas production; 45% of crude petroleum production; 26% of cattle; 18% of gross farm income; and 15% of national fishery production.

As a result of the temperature and moisture gradients, there is an impressive diversity in ecosystems and agricultural crops within the region. Consequently, the region grows a significant fraction of many of the nation's important crops: 81% of rice (all varieties); 63% of cotton; 46% of sorghum; 37% of winter wheat; 11% of soybeans; and 6% of corn (data from USDA NASS, 1999). Arkansas leads the region in total acreage for rice and soybeans. Texas is the region's dominant producer of corn, sorghum, and cotton. Oklahoma and Texas have most of the region's acreage of winter wheat. All of these crops are sensitive to climate in complex ways and could be affected by increases in CO_2 concentration and temperature, as well as by changes in the spatial distribution, frequency, and magnitude of precipitation events. Grasslands are also an important land cover of great significance to the region (as well as the Great Plains Region to our north), and would also be impacted by climatic changes.

Climate change resulting from fossil fuel consumption will likely lead to increased temperatures and changes in precipitation within our region. The current models exhibit a degree of uncertainty on the seasonal distribution of climate change for the region, especially with respect to precipitation. For instance, recent transient runs of the Canadian Climate Center GCM and the Hadley Center model agree that annual precipitation across most of our region will increase, with as much as a 30% increase in northern Texas and Oklahoma. In contrast, these same models disagree with respect to the sign of annual precipitation changes throughout the western portion of our region and much of the southeast: CCC predicts a 10-20% decrease and Hadley a 10-20% increase for New Mexico. Discrepancies in seasonal predictions are more pronounced: In some cases one model predicts a 100% increase in precipitation, while the other model predicts a slight reduction. In addition to these uncertainties in future climate conditions there are significant uncertainties in models that assess how ecosystems will respond to environmental change. Key issues include model validation and applicability across ecosystems and space/time scales, as well as challenges associated with coupling of the components of models. As a result we are not yet in a good position to make detailed assessments of climate change impacts on the region. Rather, our focus is on developing the scientific framework for such assessments with an emphasis on improving ecosystem models and reducing the uncertainty of the measured data.

II. CENTER'S STRATEGIC VISION

The South Central Regional Center (SCRC) will provide sound scientific findings at the highest degree of attainable accuracy to enhance understanding of the response of key forested, agricultural, and grassland ecosystems to environmental changes associated with energy production.

III. RESEARCH FOCI

The SCRC refined its focus and developed value-added interactions among the suite of funded projects. Given NIGEC's budgetary constraints, we saw value in having a program focused around a few thrust areas with significant interaction and synergy among the projects. The main foci of the research are: (1) To increase our understanding and reduce uncertainty with terrestrial ecosystem carbon exchange processes; and (2) To improve our knowledge on the effects of multiple environmental changes associated with energy production on

important terrestrial ecosystems in the region; and (3) To partly support the new DOE thrust on aerosols.

Focus 1: To increase our understanding and reduce measurement uncertainty with terrestrial ecosystem carbon exchange processes.

Specific objectives in this area are as follows:

- To continue the long-term flux measurements at the Niwot Ridge AmeriFlux site using the eddy covariance method.
- To continue the NEE measurements in the Freeman Ranch (TX) AmeriFlux site and to compare the findings of the two sites.
- To quantify and compare diurnal and seasonal changes in NEE and energy balances of an oak juniper savanna and grassland ecosystems.
- To develop functional relationships in order to establish how environmental factors affect NEE and to find out how contributions of dominant plant species to NEE change with climate and phenology, by observing changes in an oak juniper savanna and grassland.
- To quantify the uncertainty and experimental errors associated with the application of the eddy covariance method.
- To investigate the effect drainage flows have on field measurements using the eddy covariance method and to suggest methods for the correction of the data.
- To investigate the effect of complex terrain on field measurements related to CO_2 budget and NEE in general.

Focus 2: To improve our knowledge on the effects of multiple environmental changes associated with energy production on important terrestrial ecosystems in the region.

Specific objectives in this area are as follows:

- To investigate the ecological mechanisms that establish the response of the key grass and tree species to altered precipitation and temperature patterns in a southern oak savanna.
- To examine the effects of altered temperature and precipitation patterns in grasslands, shrublands and mixed grass-shrub vegetation.
- To quantify the diurnal and seasonal changes in the photosynthesis and water use of the live oak and Ashe Juniper and to quantify seasonal soil changes and leaf respiration.
- To investigate the effects of woody plant encroachment into desert, grassland and savannas and to determine the effect of increased plant biomass carbon in woody vegetation by changes in soil organic carbon.
- To examine the combined effects of increased CO_2 concentration, precipitation and temperature changes as well as UV-B on C_3 and C_4 grass species that are native to the South Central region.
- To examine the effects of increased CO_2 concentration and temperature on plant chemistry, insect pests and their associated food webs in alfalfa fields and grasslands.

Focus 3: Partial support for the DOE thrust on aerosols.

We are providing support for one of the projects that are pertinent to aerosol measurements.

IV. ACCOMPLISHMENTS (SCRC FUNDED PROJECTS):

D.D. Briske, M.G. Tjoelker, and A. Volder of Texas A&M University conducted a project on the "Impact of altered precipitation distribution and warming on tree and grass life forms in oak savanna." They concluded that climate models predict that altered seasonality of rainfall may be an important component of climate change coupled with global warming. Southern oak savanna may be especially sensitive to climate change owing to the role of summer drought and because the dominant species possess contrasting photosynthetic pathways and leaf habit. *Quercus stellata* (post oak) and *Juniperus virginiana* (juniper) are C3 species while *Schizachyrium scoparium* (little bluestem) is C4. We hypothesized that combinations of rainfall redistribution and warming that exceed the limits of acclimation will have the largest effects on growth, function, and competitive ability of these species. The research infrastructure is comprised of eight permanent rainfall exclusion shelters. Simulated rainfall regimes include two patterns that vary in seasonal distribution and event size, but not in total annual rainfall or number of events. Rainfall redistribution withholds 40% of the summer rainfall (May – September) and redistributes it over the two preceding spring and two subsequent autumn months. Three monocultures and two tree-grass combinations were planted in each shelter in plots warmed with infrared lamps and controls. This design enables us to evaluate plant responses to altered rainfall patterns and warming both alone and in combination. Rainfall redistribution significantly decreased soil water by 31 % during the dry summer phase and increased soil water by 3 % in the spring and fall. Warming increased soil temperature about 0.5 °C at a depth of 3 cm, but depended on canopy type. In the first year, warming and rainfall redistribution had minimal direct effects on tree height and diameter growth, but tree growth was reduced in the presence of grass. Additional spring and fall rainfall increased grass tiller density, resulting in higher tiller density during summer drought. These initial data indicate that rainfall redistribution and warming differentially affect tree and grass growth and function. Rainfall redistribution

and warming had both direct and indirect effects on leaf level gas exchange. Intensified summer drought reduced rates of net photosynthesis for oaks, but did not affect them in little bluestem or juniper compared to the ambient rainfall regime. Net photosynthesis of little bluestem responded positively and rapidly to single large rainfall events applied during the summer drought, but both tree species showed only a weak negative response to large summer rainfall events. Juniper was the only species to show a positive response of net photosynthesis to warming. Like juniper, the warm-season C4 grass also had actively photosynthesizing leaves during the winter months, regardless of whether the plants were warmed or not. Rainfall redistribution strongly affected pre-dawn and mid-day water potentials of all three species, especially during intensified summer drought periods. Mid-day water potentials were most negative for oak and least negative for little bluestem. Summer data suggest that juniper incurred severe competition from little bluestem while little bluestem may have benefited from the presence of juniper. Pre-dawn water potentials were most negative for little bluestem and least negative for oak. The presence of grass increased water stress during intensified summer drought for both woody plants, while there was no effect of woody plants on pre-dawn water potential of the grass. These data document the occurrence of a strong interactive effect between global change driver and species combination on plant-soil water relations that will mediate savanna responses to climate warming and rainfall redistribution.

Lee Dyer of Tulane University conducted a study on "Effects of climate change on multi-trophic interactions in agriculture and grasslands in the Southwestern United States" and concluded that data collected with NIGEC support provided tests for the general hypotheses that insect outbreaks are expected to increase in frequency and intensity with projected changes in atmospheric gases, global warming, and climatic variability. These outbreaks may occur through direct effects of climate change on insect populations and through disruption of parasites, predators and competitors. They compared caterpillar-parasite interactions across a broad gradient of climatic variability and found that caterpillars from fifteen geographically dispersed forests experience a decrease in levels of parasitism by wasps as climatic variability increases. Given the central role of parasitic wasps in regulating insect herbivore populations in natural and managed systems, we predicted an increase in the frequency and intensity of herbivore outbreaks as climates become more variable. Further investigation revealed that decreases in parasitism can cause lower overall diversity and lower primary productivity in a grassland, forest, or agricultural ecosystem. They also compared interactions between herbivorous insects and predators in agricultural versus natural systems and found that there are no differences in the strength of predation in natural versus managed systems, despite many biological differences between insects in these habitats. This result suggests that the effects of climate change on predator-herbivore relationships in natural forests will be similar for agricultural systems.

Robert Jackson of Duke University conducted a study on the Woody encroachment and carbon storage across regional gradients in precipitation and land use. He and his co-workers tested three hypotheses of the interaction of precipitation and land use with woody plant encroachment for plant productivity and carbon storage. Complete carbon balances and productivity above and belowground are underway across sites, with plant and soil measurements linked to characterizations of the soil microbes that process plant litter into soil organic matter. They examined different soil carbon fractions to understand where the changes in SOC occurred within the soil (active, passive, or intermediate pools), established measurements of plant productivity to determine the causes of altered soil carbon stocks with woody encroachment, and located six additional field sites for sampling (see below). Examining the SOC pools for changes in fast, intermediate, and slow pools provides insight into what part of the SOC pool is changing and whether the changes occur in the shorter-term pools alone, or in longer-term pools as well, where sustained carbon storage may occur. This analysis is underway for each site. The woodland site at Engeling has approximately 20% less than the grassland when examining particulate organic carbon (the intermediate size pool). These data are consistent with the changes in the total SOC pool but suggest that other changes in other SOC pools (active or passive) must be occurring. No significant difference in POM-C between grasslands and shrublands suggests changes in other SOC pools (active or passive) must be occurring. A larger proportion of soil C residing in POM-C in shrublands may indicate a fundamental shift in the physical characteristics and chemistry of SOC inputs has occurred with woody plant encroachment.

Biomass partitioning is another important variable in terrestrial ecosystem carbon modeling. However, geographic and interannual variability in f_{BNPP}, defined as the fraction of below-ground net primary productivity (BNPP) to total NPP, and its relationship with climatic variables had to our knowledge not been explored previously. We addressed these issues by synthesizing 94 site-year field biomass data at 12 grassland sites around the world from a global NPP database and from the literature. Results showed that f_{BNPP} varied from 0.40 to 0.86 across 12 sites. In general, savanna and humid savanna ecosystems had smaller f_{BNPP} but larger interannual variability in f_{BNPP}, and cold desert steppes had larger f_{BNPP} but smaller interannual variability. While mean f_{BNPP} at a site decreased with increasing mean annual temperature and precipitation across sites ($p<0.05$ for both), no consistent temporal response of f_{BNPP} with annual temperature and precipitation was found within sites. Based on these results, both geographic variability in

f_{BNPP} and the divergent responses of f_{BNPP} with climatic variables at geographical and temporal scales should be considered in global carbon modeling.

The production of CO_2 by soil microorganisms is also an important component of carbon cycling, and its temperature sensitivity is poorly constrained in global models. To improve our understanding of the factors controlling the temperature dependency of soil CO_2 production, we analyzed the temperature sensitivity of decomposition for 77 soils collected from a wide array of ecosystem types. Across all of the soils, the average Q_{10} value (the factor by which decomposition rates increase for a 10°C increase in temperature) was 3.0. but the range in Q_{10} values was substantial (2.2 to 4.6). A large portion of the variability in Q_{10} values was explained by a single variable, carbon quality, which we define as the relative rate of microbial respiration per unit organic carbon (r = -0.67, P = 0.001). This result provides support for the "carbon quality-temperature" hypothesis that links the temperature dependency of microbial decomposition and the biochemical recalcitrance of soil organic carbon. A smaller percentage of the variability in Q_{10} values could be explained by the mean monthly temperature at the time of sampling (r = 0.41, P = 0.01), suggesting that microbial communities may adapt seasonally to the antecedent temperature regime. By showing that the Q_{10} of soil microbial respiration is largely predictable, this work improves our understanding of the temperature sensitivity of soil organic carbon stores. Our results should also improve global carbon models, which typically have used a single Q10 value to predict the effects of climate change on microbial respiration.

Carbon sequestration programs, including afforestation, reforestation, and woody encroachment are gaining attention globally and will alter many ecosystem processes, including water yield. Some previous analyses have addressed deforestation and water yield, and the effects of afforestation on water yield have been considered for some regions. However, to our knowledge no systematic global analysis of the effects of afforestation on water yield had been undertaken. To assess and predict these effects globally, we analyzed 26 catchment datasets with 504 observations, including annual runoff and low flow. We examined changes in the context of several variables, including original vegetation type, plantation species, plantation age, and mean annual precipitation (MAP). All of these variables should be useful for understanding and modeling the effects of afforestation on water yield. We found that annual runoff was reduced on average by 44% (±3%) and 31% (±2%) when grasslands and shrublands were afforested, respectively. Eucalyptus had a larger impact than other tree species in afforested grasslands (p=0.002), reducing runoff by 75% (±10%), compared with 40% (±3%) average decreases with pines. Runoff losses increased significantly with plantation age for at least 20 years after planting, whether expressed as absolute changes (mm) or as a proportion of predicted runoff (p<0.001). For grasslands, absolute reductions in annual runoff were greatest at wetter sites, but proportional reductions were significantly larger in drier sites (p<0.01 and p<0.001, respectively). Afforestation effects on low flow were similar to those on total annual flow, but proportional reductions were even larger for low flow (p<0.001). These results clearly demonstrate that reductions in runoff can be expected following afforestation of grasslands and shrublands and may be most severe in drier regions. Our results suggest that, in a region where natural runoff is less than 10% of mean annual precipitation, afforestation should result in a complete loss of runoff; where natural runoff is 30% of precipitation, it will likely be cut by half or more when trees are planted. The possibility that afforestation could cause or intensify water shortages is a tradeoff that should be explicitly addressed in carbon sequestration programs.

Christopher Kucharick and Tracy Twine of the University of Wisconsin and University of Illinois respectively conducted a study on Improving and Evaluating Dynamic Models of Natural and Managed Ecosystems over the Central and Southern U.S. Using AmeriFlux and MODIS Data. Their research may be summarized by the following:

Collected and processed satellite greenness information from the MODIS sensor from the Boston University Vegetation Remote Sensing group (this includes leaf area index [LAI] and fraction of absorbed photosynthetically active radiation [fPAR])

Compared this dataset with that from the AVHRR sensor provided by the same remote sensing group.

Collected and processed a new climate-driver dataset from the Climate Research Unit (CRU) at the University of East Anglia that contains data from the years 1901-2002. The previous dataset ended in 2000, before data was collected from MODIS. This is a new dataset with re-processed information from 1901 to 2000 so we have extensively compared this dataset with the previous dataset and we have derived quantities from these data that are needed as input to Agro-IBIS.

Nearly completed an intercomparison between the AVHRR and MODIS datasets of LAI and fPAR that rely on different land cover class maps for each sensor. We are finding that MODIS uses a significantly more accurate placement of agroecosystems within the Corn Belt region than the AVHRR data.

Completed Agro-IBIS simulations with new CRU climate dataset and begun processing output into monthly mean and ~8-day mean values for comparison with AVHRR and MODIS datasets.

Created a continuous precipitation dataset from 1997-2003 from the Willard Airport station that is used to drive Agro-IBIS over the Bondville Ameriflux site.

A series of girdled lodgepole for the determination of CO_2 exudate.

Monique Leclerc of the University of Georgia and several of her co-investigators conducted a study on the Impact of complex environmental flows on carbon sequestration measurements in non-ideal terrain. They conducted field measurements above and within forest with height of 11.5 m and nearby clearcut at AmeriFlux Florida site at Gainesville Florida during 2004-2005, in an effort to provide boundary conditions and CO_2 flux measurements and initialize the models. Two towers were set up: one was in the forest 200 m away from the forest-clearcut edge, and another was in the clearcut 50 m away from the edge. We installed a battery of measuring devices such as fast-response omni-directional three-dimensional sonic anemometers at four levels on each tower in order to detect any signal of flows. The position and height of these devices were determined from the results of numerical simulations. Sonic anemometers, thermometers, fast-response open–path IR CO_2 analyzers, sodar/RASS measurements, tethered balloons, and other ancillary measurements were used to achieve this objective.

The effects of the clearcut on the flow and turbulence at the downwind tower were analyzed with statistics, wavelet analysis, and model simulation. We had several meetings with Tulane PI Prof. Michaelides and his post doc and we have provided them the collected data necessary for the simulation. Large Eddy Simulation (LES) was used to investigate the effects of a clearcut-canopy (forest edge) on air flow and scalar flux footprint. A central concern is to establish the characteristic motions in canopy and to accurately estimate flux footprint and concentration across the interface. The footprint results in this study provide valuable clues to examine the uncertainties in the interpretation of measurements associated with the net ecosystem-atmosphere exchange (NEE) of carbon dioxide and other scalars. In addition, the LES results are compared against both experimental data and analytical methods such as the Lagrangian stochastic (LS) simulation. The general results from our modeling can be applied to much complicated patched-soil and heterogeneous ecosystems and to provide information to reduce the measurement uncertainties in flux measurements.

Marcy Litvak of the University of Texas at Austin conducted a field study on quantifying changes in ecosystem structure and carbon storage associated with woody plant expansion on the Edwards Plateau. Her preliminary estimates from the encroaching savanna site support that NEE, GEE and ecosystem respiration in this system are strongly controlled by total precipitation and precipitation pulses. Annual precipitation in the first two years of this study was very different, with approximately 60% above normal during 2004 (1453 mm between DOY 120 and DOY 365) and 20% below normal in 2005 (720 mm). The strength of the annual carbon sink paralleled the amount of rainfall, with

a carbon gain of 413 gC/m2 for the first year and a reduction to 213 gC/m2 in the second year. In the summer drought of 2005, with only three large rainstorm events, the ecosystem showed strong pulse-responses with immediate strong increases in respiration followed by increases in net ecosystem uptake and gross primary productivity. These pulse responses caused overall increased uptake of carbon. During the winter months (January-March), Ashe juniper stays active and offsets the carbon source stemming from the inactive herbaceous layer, keeping the system near carbon neutral. Carbon uptake by Ashe juniper and Honey mesquite persists throughout the summer and is responsible for a small net carbon uptake of the entire system during drought conditions. The herbaceous layer net ecosystem exchange reaches values up to 60 percent of ecosystem level NEE during favorable conditions in the spring and fall when soil moisture is adequate, but reverts to a carbon source during drought conditions in the summer.

Stathis Michaelides of the University of North Texas conducted a computer simulation study on the Improvement of carbon flux measurements interpretation using a combination of numerical modeling and field measurements. The results of his and his co-workers show that numerical modeling is an effective tool for the numerical simulation of turbulent flow in canopies for weak stably stratified conditions, where it has been observed that a low-level jet appears inside the plant canopy. Even though certain simplifying assumptions were used in the simulations, the results of the study are reasonable and agree qualitatively and quantitatively with field measurements and experimental observations. The wind shear and turbulent mixing effect associated with the jet in the canopy were the driving mechanisms for the mass, turbulent energy, heat flux and CO_2 flux exchange within and above the canopy. The low-level jet draws the CO_2 mass from sources that are at higher levels of the canopy. A strong momentum flux was also observed in a shallow layer close to the ground surface of the canopy, while very weak turbulence intensity was observed above the canopy. Across the top of the canopy a shear layer was formed.

The numerical results for the low-level jet flow showed that two flow regions exist in a nocturnal drainage flow: a relatively strong advective motion close to the ground, and a shear flow above the canopy. A thin, rather stable layer, which is associated with the maximum foliage density in the canopy, was formed. This layer impedes the vertical transfer of momentum and the scalar fluxes. The low-level advection plays an important role in the transport of carbon dioxide in the ecosystem. The flow structures cause strong inhomogeneities in the concentration of CO_2. The numerical results showed that the difference of the concentration of CO_2 at two heights of the same longitudinal position (z/h =0.8 and 2.0) is significant and may reach 30%. The simulations also show that the horizontal mean advection term is two orders of magnitude higher than the vertical mean advection term for the CO_2 transport. Regarding the turbulent contributions, while the lateral turbulent advection may be negligible for weak shear flow fields, the laterally averaged values of the concentration and velocity showed a significant influence (2-5%) of the lateral turbulent fluctuation for the low-level jet flow on inhomogeneous terrain conditions. LES can be an effective tool for the study of turbulent flow in canopies at very high Reynolds numbers. A new method, based on LES, was used to simulate a complex, weakly stratified canopy flow. Continuous turbulence may be assured by this method, and better computing efficiency was obtained compared to the direct LES of nocturnal drainage flow, where higher computation resolution is required than that in neutral and convective canopy flow.

A typical wall jet (low-level jet) within a plant canopy, which is a good approximation of nocturnal drainage flow, was simulated and the results of the flow were discussed in detail. The wall jet acted as sink of mass, which drew mass from high levels within the canopy. Strong vortices were completely restricted within the canopy, and very weak turbulence was shown far from the top of the canopy. Strong momentum fluxes were also developed in the wall jet flow. A thin stable layer above the low-level jet nose or secondary wind speed maximum impedes the vertical turbulent mixing across the top of the canopy, and the CO_2 flux exchange within and above the canopy is weak.

The numerical results of the wall jet flow showed that the laterally averaged process resulted in an influence up to 5% due to inhomogeneous terrestrial conditions. The results also showed positive CO_2 fluxes both above and within the canopy, due to the wall jet velocity field. The numerical results demonstrated that the difference of the concentration of CO_2 at two heights (z/h =0.8 and 2.0) could be up to 15% under slightly unstable conditions, due to the vertical fluxes. At the same time the horizontal advection played a very important role to the transport of CO_2. The difference between mean advection terms of CO_2 transport in the horizontal and vertical directions is one or two orders of magnitude from our numerical simulation a fact that is corroborated by SF_6 tracer experiments.

Russel Monson of the University of Colorado conducted a long-tem study in the Niwot Ridge site on the Forest-Atmosphere Carbon Fluxes in a Colorado Subalpine Forest. His results show that in the subalpine conifer forest of the Rocky Mountains of Colorado USA, it has been determined that rhizodeposition increases soil C availability more beneath the spring snowpack than at any other time of year. Our goal was to determine the extent to which rhizodeposition controls soil respiration in the low temperature conditions beneath the spring snowpack of this forest. We found that rhizosphere respiration was highest in the spring, when rhizodeposition was also highest. However, our results indicate that soil C availability is not the sole driver of rhizosphere respiration, as rhizosphere respiration did not increase in proportion to C availability, the correlation between

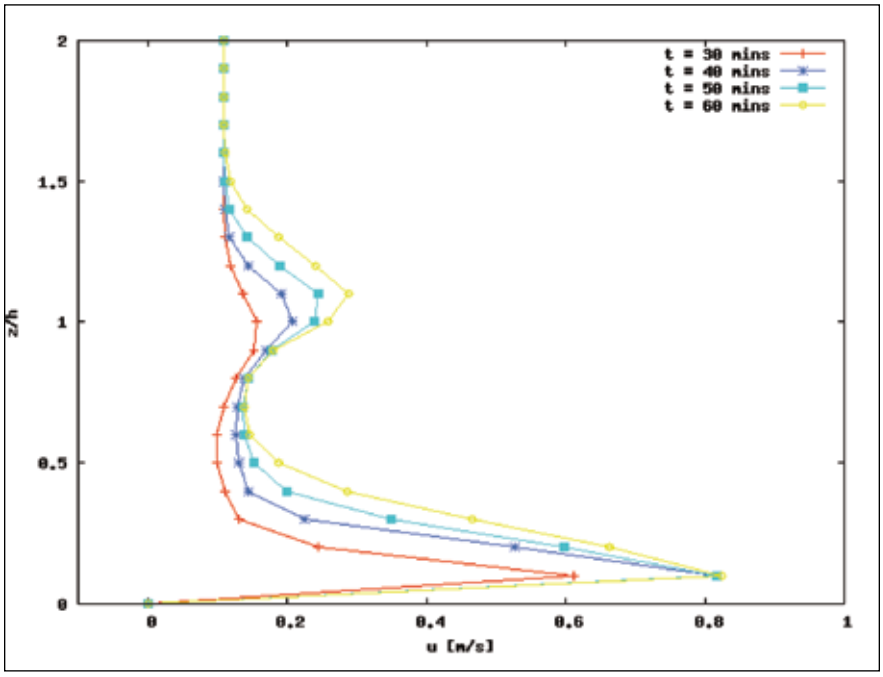
One of the controlled conditions sites at Texas A&M.

rhizosphere respiration and dissolved organic C (DOC) was not significant, and the responses of respiration and DOC to girdling followed different temporal patterns. Rhizosphere respiration was also not significantly correlated with rhizosphere concentrations of dissolved organic nitrogen (DON), microbial biomass C and N (MB-C and MB-N), ammonium (NH_4^+), and nitrate (NO_3^-). Surprisingly though, the variability in rhizosphere respiration was explained by a generalized linear model containing rhizosphere DOC, DON, MB-C, MB-N, and NO_3 as independent variables; R^2 = 0.99. Thus rhizosphere respiration in this soil is dependent not only on the availability of not only C, but also N and the size of the microbial biomass. Furthermore, the dramatic increase in microbial biomass beneath the spring snowpack in response to rhizodeposition indicates that a large proportion of rhizodeposits were going into the construction of microbial biomass rather than respiration at this time. These results suggest that both N limitation and the response of the rhizosphere microbial community to rhizodeposition created a disconnect between rhizosphere C availability and respiration beneath the spring snowpack.

Fundamental questions exist about the effects of climate on terrestrial net ecosystem CO_2 exchange (NEE), despite a rapidly growing body of flux observations. One strategy to clarify ecosystem climate-carbon interactions is to partition NEE into its component fluxes, gross ecosystem CO_2 exchange (GEE) and ecosystem respiration (R_E), and evaluate the responses to climate of each component flux. In a separate line of studies, we developed model-data fusions approaches to partition the NEE signal from our site into its fundamental components. We separated observed NEE into optimized estimates of GEE and R_E using an ecosystem process model combined with six years of continuous flux data from the Niwot Ridge AmeriFlux site. In order to gain further insight into the processes underlying NEE, we partitioned R_E into its components: heterotrophic (R_H) and autotrophic (R_A) respiration. We were successful in separating GEE and R_E, and less successful in accurately partitioning R_E into R_A and R_H. Our failure in partitioning R_E was due to the lack of adequate contrasts in the assimilated data set to distinguish between R_A and R_H. The model-data fusion showed that most of the interannual variability in NEE was due to variability in GEE, and not R_E. In contrast to several previous studies in other ecosystems, we found that longer growing seasons at Niwot Ridge were correlated with *less* net CO_2 uptake, due to a decrease of available snowmelt water during the late springtime photosynthetic period. Warmer springtime temperatures resulted in increased net CO_2 uptake only if adequate moisture was available: when warmer springtime conditions led into mid-summer drought, the annual cumulative GEE and net uptake declined. Because of the correlations between spring and mid-summer conditions, different measures of growing season length gave opposing results, highlighting the complexity of explaining interannual variability based on any single measure of annual conditions.

We conducted studies to analyze differences among lodgepole pine, subalpine fir and Englemann spruce with regard to photosynthetic water-use efficiency. We collected phloem and leaf sugar samples from all three tree species once a week during the 2006 growing season. From April through October, samples were collected from the same trees in order to track changes in sugar carbon isotope through the growing season. Phloem samples were collected by coring a 2 cm diameter bark disk and placing it into an exudation solution. Sun needles from the corresponding tree were collected and frozen in liquid nitrogen. In the lab, leaf sugars were extracted following past protocols. To prepare the sugar samples for carbon isotope analysis, phloem and leaf sugars were pipetted into tin capsules and dried. Bulk leaf material was also analyzed. The samples were run at the Stable Isotope Laboratory at the University of California, Berkeley.

The bulk leaf carbon isotope data showed two important trends. First, there was a significant difference in carbon isotope ratios among fir, pine and spruce for both years. Fir had the most negative $\delta^{13}C$ values, followed by pine and then spruce. This suggested that in both years, spruce had the highest WUE, followed by pine, and then fir. Second, there was an interannual difference in carbon isotope values. The $\delta^{13}C$ values for 2005 were more negative than for 2003 across all three species, suggesting that interannual variability in WUE



Flow field resulting from the combination of drainage flow and a weak breeze over the ecosystem, obtained from the spectral method code. The top of the canopy is at z=h

was detected from bulk leaf tissue. Since needles for both years were collected in July, needles from 2003 had higher WUE than needles from 2005. The early spring leaf sugar isotope data had a different trend than the bulk leaf data. In early April, prior to snowmelt, fir had significantly lower WUE than spruce and pine. However, once the snowpack began to melt, all three species had similar WUE. One possible explanation for this result is that the leaf sugars from the first two collection dates still reflected the trees' water status from the previous growing season. In May, as the trees began to fix carbon, the combination of cool temperatures and high soil moisture content may have influenced all three species to converge on a common WUE. As temperatures increase and soil moisture content decrease through the late summer, species differences in WUE should become more pronounced.

Sap flow data for 2006 showed that differences in interannual transpiration patterns during the growing season reflected differences in soil moisture. At the Niwot Ridge site, significant decrease in soil water content during July is a common occurrence: during this time, soil moisture from snowmelt is depleted, but monsoon rains have yet to come. During the summer of 2006, this dry-down period did not occur. In both years, transpiration rates remained elevated until fall. In addition to interannual differences in transpiration patterns, differences in species transpiration patterns were also observed. For all size classes of trees, fir had lower transpiration rates than spruce and pine.

William Pockman of the University of New Mexico conducted a study on the Impact of rainfall variability and woody encroachment on productivity in a semiarid grassland in New Mexico. His results may be summarized as follows:

Water-addition plots: design and construction.

During the first year of the project, a significant effort were devoted to establishing the water addition plots, instrumenting them with soil moisture sensors and runoff flumes, designing a suitable plot-scale irrigation system and initiating data collection and treatment. Construction of our water-addition plots expanded our experimental system to a network of 27 plots (~9 m x ~14 m) with nine plots each in grassland, shrubland and the mixed grass-shrub ecotone. Like the existing rainout and control plots, the water-addition plot perimeters were trenched to 1.2 m, vertical profiles of thermocouple psychrometer moisture sensors have been installed under canopy and bare soil cover and measurements have begun to provide a pre-treatment period of comparison with control plots. Each vertical profile includes sensors at 15, 30, 45, 60 and 80 cm below the soil surface. Vegetation measurements have also been completed twice per year to document the cover and abundance of all species in three 1 m wide swaths across each plot. Overhead photos of all plots have been collected in spring and fall since September 2004, providing us with a record of the vegetation and soil surface changes over the course of our treatments (e.g. fig.16).

Irrigation system and water source.

Our irrigation system consists of a series of square-pattern nozzles attached to overhead pipes that can be suspended from steel wires permanently mounted above each plot (fig. 2). These irrigation arms are put in place before each irrigation event and stored in shelters near the plots between events. Storage tanks (1100 gal) have been placed at each water-addition plot to allow us to move sufficient water for each treatment to the site in advance. By storing all necessary water supplies at the site, we can position all irrigation systems in advance and rapidly move between plots in grassland, shrubland and ecotone to apply all water additions in a short period of time, facilitating comparisons among plots in different vegetation communities. We use application rates of 50 mm/hour, a reasonable intensity for New Mexico storms that yields a spatially homogenous pattern with realistic drop sizes.

We evaluated a range of water sources and finally chose to use drinking water from the City of Albuquerque, treated with a reverse

osmosis system to produce near rainfall quality water. Chemical analyses of water after it was delivered to plots showed that electrical conductivity was roughly 7 $\mu S\ cm^{-1}$ with concentrations of Cl- contributing less than 1% of the total amount present in our soils. We produce 9000 gallons of RO water and arrange for a commercial trucker to transport 8000 gallons from the UNM campus to the field site for delivery to plot-side tanks (fig. 2).

Data collection and research findings

Data collection on the water-addition plots was continued through the second year of the project. These measurements include measurements of grass and shrub productivity on all plots, automated measurements of soil moisture using soil psychrometers, and physiological measurements of the water status and performance of grasses and shrubs across treatments. Below we summarize our findings to date, noting that tests of many of our hypotheses require multiple years of treatment.

Productivity

Aboveground net primary productivity (ANPP) is measured annually for grasses and 3 – 5 times per year for shrubs (March, late June, and October). Shrub ANPP is measured using allometric methods based on the change in size of first order twigs. This method is appropriate because it has greater sensitivity for measuring growth over shorter periods than measurements of whole canopy dimensions. Twigs to be measured are marked with paint and the basal diameter and length are measured. Then regressions are used to convert twig dimensions into biomass. A second set of regressions relating the number of first order twigs per plant to plant volume are used to obtain whole plant biomass. Incremental changes in whole plant biomass can then be estimated by repeated sampling. Grass ANPP is measured with destructive sub-sampling of 5, 10 x 10 cm areas per plot. Samples are sorted to separate green biomass before drying and weighing. These samples also allow us to calculate LAI for grasses by separating leaf tissue and using a regression between leaf area and mass. Over the treatment period, shrubs did not exhibit significant differences in twig growth between control and rainout plots. In contrast, we have observed a significant decrease in NPP between control and rainout plots at the grassland site. This trend has also been observed at the ecotone plots. Although the decrease was not significant through two years of treatment it was significant after the third year of treatment. In both years of water addition treatment, increases in growing season water availability have significantly increased productivity in the grassland but have produced only small increases in the shrubland.

Vegetation transects

For comparison with productivity data and overhead photos (see below), the Sevilleta LTER field crew measures belt transects (1 m width, 3 per plot) across the narrow dimension of each plot to measure the abundance and cover of all plant species. Transects are measured at peak activity during the spring and fall of each year. Each transect is measured by placing a 1 m square frame, sub-divided into 100 cm^2 cells to aid in measurement of percent cover. All species in the frame are measured, providing the data required to assess changes in composition over the course of the study. Plant cover, litter and bare soil are be measured at ground level across the transect while shrub canopy cover is taken as a separate measurement layer. This permits ground-level cover measurements to sum to 100% while shrub canopy can be treated separately in analyses of cover change.

Species cover and abundance

For comparison with species productivity data, plot scale plant cover and bare soil are assessed with overhead photos collected using a digital camera and analyzed using ArcGIS software. Three cover types have been identified: (1) shrub canopy; (2) grass canopy and surrounding litter; and (3) interspace. The amount and spatial distribution of different cover types are measured using digital photos (3.34 megapixel) of each plot, collected at peak biomass to capture species dynamics and changes in the drainage network. A Nikon CoolPix 990 camera mounted on a specially designed boom achieves sufficient elevation (7 m) to cover an entire plot with a set of 6 photos. After rectification and assembly, ArcGIS software is used to measure total grass and shrub cover. These mosaics allow detailed, field checked, measurements of changes in grass and shrub size, stone cover, and interspace connectivity. Mosaics are assembled for each plot on a yearly basis. Drought treatment led to decreases in cover in the first treatment years and these decreases have continued with subsequent years. These cover changes are consistent with the decreased productivity observed in the grass drought plots. Although the decrease in cover may have been exacerbated by low precipitation and late and below-average summer monsoon, no such differences were detected in the control plots over the same period. Increases in productivity during the first season of water addition suggest that we may expect to observe similar increases in grass cover but the images have not yet been analyzed at this writing.

Plant and Soil Water potential

Soil water potentials, measured in vertical profiles under grass and shrub canopies and under bare soil, have continued to exhibit the pattern that we have observed in this system. For a given storm > 2 mm, infiltration is greater under plant canopies than under bare soil. The spatial pattern of infiltration is thus linked to the pattern of vegetation. As our treatments begin (water-addition) and continue (rainout), we will be able to determine how changes in plant cover influence these patterns of redistribution and the final soil moisture pattern that drives ecosystem response to a pulse of precipitation.

Through the project period, we have continued to observe differences in soil moisture between bare soil and sub-canopy micro-sites and with depth. Infiltration is shallower in bare soil patches than in vegetated patches. We expect that at a given depth these patterns are non-linear across storms of different sizes and as the rainfall history preceding a given storm varies. We now have a long term database of soil moisture profiles through several years that we can use to test these ideas. These differences in infiltration translate into differences in moisture available for plant uptake. Increased plant gas exchange in response to pulses of soil moisture derived from precipitation are correlated with increased productivity in water addition plots.

Belowground responses

Belowground responses are difficult to measure in long term studies such as ours because of the need to maintain the integrity of the soil system to prevent artifacts related to destructive soil sampling etc. In our ecotone plots, we installed minirhizotron tubes in all treatments in Fall 2003 and began collecting data from these tubes in Spring of 2004. Data collection has continued in the ecotone plots. We recently completed visual processing of the video tapes collected in the field and these data will be analyzed for publication or inclusion in another paper in the near future.

Tingjun Zhang of the University of Colorado investigated the Spatial and Temporal Variations of the Seasonally Frozen Ground in the Contiguous United States. His work resulted in a validated code for the freezing of the ground in the Continental U.S. Based on the validated frozen soil algorithm with new numerical model, we conducted investigation on the near-surface soil freeze/thaw cycle in the contiguous United States from 1978 through 2004 using SMMR and SSM/I data. As proposed, we investigated the timing (onset of soil freeze in autumn and last day of soil freeze in spring), frequency of freeze/thaw cycle, number of days of soil freeze, and daily area extent. The thickness of daily soil freeze will be investigated through numerical modeling. When we say the near-surface soil freeze/thaw cycle, we mean it is approximately 10 cm or less from the ground surface.

Understanding cold season atmosphere-hydrosphere interactions and their feedbacks in Earth's weather and climate system is essential for assessing variations in the regional and global energy and water cycles. This is a critical and integral component of the Global Energy and Water Cycle Experiment (GEWEX) program. Important components of the terrestrial hydrology are soil water freezing and thawing processes. The long-term average maximum area extent of the seasonally frozen ground, including the active layer over permafrost, is approximately 48.12 x 10^6 km^2 or 50.5% of the land mass in the Northern Hemisphere. Seasonal freezing and thawing processes of soils have a great impact on the thermal and hydrologic characteristics of the soils, which have a significant impact on the surface energy and water balance, and hence on weather and climate systems, and surface and subsurface hydrologic processes such as river runoff and soil moisture. However, study on seasonally frozen ground has received little attention. In this study, we will give a brief review on study of seasonally frozen ground in the past decades. We will estimate annual and inter-annual variation of distribution of seasonal frozen ground using annual freezing and thawing index of air temperature. Preliminary results indicate that area extent of seasonally frozen ground has decreased about 15 to 20% during the past few decades. Based on annual freezing index, we will estimate the potential maximum freezing depth at each grid pixel and areal extent of seasonally frozen ground. Over the permafrost regions, active layer thickness will be estimated using simplified Stefan solution. We will further investigate inter-annual/inter-decadal variability of areal extent of seasonally frozen ground in the Northern Hemisphere. Annual freezing index of air temperature will be calculated based on daily ERA-40 reanalysis data. Over the daily air temperature using ground-based measurements. Comparison of the results from two data sets will be conducted to evaluate the accuracy of the ERA-40 reanalysis data over the contiguous United States and its applicability in the Northern Hemisphere.

Means and Trends of Seasonally Frozen Ground Thickness in the Northern Hemisphere: Seasonal freezing and thawing processes of soils have a great impact on surface energy balance, hydrological cycle, carbon exchange, and serious natural hazard at middle and high latitudes. In this study, we will investigate spatial and temporal variability of seasonally frozen ground thickness from 1950 through 2000 in the northern hemisphere. Seasonally frozen ground thickness is estimated by a simplified Stefan solution using the "edaphic factor" and the annual freezing and thawing index of air temperature. Over the permafrost regions, the "edaphic factor" is determined using ground-based active layer thickness from 31 stations from 1950s through 1990 in the Russian Arctic, 103 CALM stations since the early 1990s, and six stations over the Tibetan Plateau from 1996 through 2002. Over the non-permafrost regions, the "edaphic factor" is determined based on ground-based measurements of seasonally frozen ground depth from 350 stations in Russia, 150 stations in China, 40 stations in Mongolia, and 30 stations from the United States. Annual freezing and thawing index were calculated from gridded monthly mean air temperature. After comparing with annual freezing and thawing index obtained using daily air temperature, errors of annual freezing and thawing index obtained from mean monthly air temperature are relatively small. We will present climatology, standard deviation, and trends of the "edaphic factor", annual freezing and thawing index, and seasonally frozen ground thickness in the northern hemisphere using all available data. Seasonally frozen ground thickness obtained from this study will also be compared with ground-based measurements and modeling outputs.

SOUTH CENTRAL REGIONAL CENTER
Research Program

Principal Investigator Co-Investigators	Institution	Project Title	Years of Funding
ARCHER, Steve	Texas A & M University	Land cover change & regional troposheric chemistry	1992-1995
BAKWIN, Peter	University of Colorado at Boulder	Regional climatology of carbon dioxide & methane in the continental boundary layer	1992-1994
BAKWIN, Peter	University of Colorado at Boulder	Regional Atmosphere/Forest Exchange & Concentrations of CO2	1994-1997
BHATTACHARYA, Sanjoy Ronald DeLaune	Tulane University	Flux of methane from natural wetlands: experimental study & modeling analysis	1991-1995
BHATTACHARYA, Sanjoy	Tulane University	Pediction of global methane generation from wetlands	1993-1995
BHATTACHARYA, Sanjoy	Tulane University	Pilot study in integrated assessment related to global warming	1994-1995
BIANCHI, Thomas Katherine Freeman	Tulane University	Paleoclimatic & Paleoeco change: a molecular & carbon isotopic record	1995-1996
BRISKE, David	Texas A & M University	Impact of altered precipitation distribution and warming on tree and grass life forms in oak savanna	2005-2005
BUCKELS, William Fred Petry	Tulane University - Dir Fund	Cloud parameter optiization	1991-1992
CAMERON, Guy	University of Houston	Impact of global environemntal change on biodivers of mammals in the South Central U.S.	1990-1993
COLE, Julia	University of Colorado at Boulder	Incorporating tracers in the hydrologic cycle of the GENESIS Earth system model	1993-1997
COTTON, William Graeme Stephens	Colorado State Universtiy	Quantification of cloud/radiative responses to variations in CCN development of parameterizations schemes	1994-1996
CROWLEY, Thomas	Texas A & M University	Utilizing Paleoclimate Data to Constrain System Response to Carbon Dioxide Increases	1995-1998
CUTTER, Greg	Old Dominion University	Production & sea-air flux of carbonyl sulfide in the coastal environment	1990-1992
CURRY, Judith	University of Colorado at Boulder	Thermodynamic feedback processes between the atmosphere & sea-ice	1992-1995
DEMING, David	University of Oklahoma	Climate Change in North Central OK from analysis of borehole temperature	1993-1995
DENNING, A. Scott	Colorado State University	Regional and Global Estimation of Terrestrial CO2 Exchange from NIGEC Flux Data	1997-2000
DENNING, A. Scott	Colorado State University	Regional Estimation of Terrestial CO2 Exchange from NIGEC Flux Data, Satellite Imagery, and Atmospheric Composition	2000-2002
DUNBAR, R LINSLEY, B.	Rice Universtiy-Director's Fund	Coral Drilling	1993-1994
DUNBAR, R. LINSLEY, B.	Rice University	Documenting Changes in Eastern Pacific Climate Using Corals	1994-1997
DYER, Lee	Tulane University	Effects of climate change on multi-trophic interactions in agriculture and grasslands in the Southwestern United States	2004-2006
ELLIOT, Edward T.	Colorado State University	Coordination of the Central US Agricultural Sector Assessment	1998-2000
FINGERMAN, Milton	Tulane University - Director's Fund	The effects of startospheric ozone depletion	1993-1994
GILL, I HUBBARD, D.K.	Tulane University - Director's Fund	Evaluations of proxy paleotemperature records from corals	1991-1993
GILL, I HUBBARD, D.K.	University of New Orleans	Millenia-Scale Coral Records of Sea-surface Temperature & An Evaluation of Sclerochronologic Techniques	1995-1997
GUSTCHICK, Vincent Baskar Choudhury	New Mexico State	Predicting Large-Scale Patterns in Vegetated-Surface Conductance for CO2 & Water Vapor	1994-1997
GUSTCHICK, Vincent Baskar Choudhury	New Mexico State	Regularities in Plant Control of Evapotranspiration and C Gain Across Sites: Tests With Scaling Up, and Modelling Consequences for Water and Carbon Balances	1997-2000
HEILMAN, James	Texas A & M University	Net Carbon Dioxide Exchange in Live Oak-Ashe Juniper Savanna and C4 Grassland Ecosystems on the Edwards Plateau, Texas: Effects of Seasonal and Interannual Changes in Climate and Phenology	2003-2006
HODGES, Harry F. Reddy, K. Raja	Mississippi State University	Impact of Climate Change on Flower & Fruit Production in Cotton	1995-1998
HOLLAND, Elizabeth Bobby Braswell Alan Townsend	Universtiy Corporation for Athmospheric Research	Nitro and Phosphorous Deposition and Terrestrial Storage : Linking Atmospheric Chemistry and the Global Carbon Budget	1995-1997

JACKSON, Robert	University of Texas at Austin	Below Ground Responses to Elevated CO2 in C3-C4 Grassland	1995-1998
JACKSON, Robert	Duke University	Precipitation and carbon storage with woody plant encroachment into grasslands	2005-2005
JACKSON, Robert	University of Texas at Austin	Belowground Carbon and Water Dynamics from Subambient to Elevated CO2 in a C3-C4 grassland	1998-2000
JAKUBAUSKAS, Mark David Legates	Univesity of Kansas	Interaction Between Land Cover/Land Use Dynamics and Climatological Variability in the Western Oklahoma/Kansas/Texas Indicator Region	1997-2000
JUSTIC, Dubravko TURNER, R.E.	Louisiana State University	Effects of Climate Change on Hypoxia in Coastal Waters	1995-1998
JUSTIC, Dubravko TURNER, R.E.	Louisiana State University	Impacts of Climate Variability on Coastal Fisheries in Low Oxygen Environments	2000-2002
KOPLITZ, Brent	Tulane University	Photochemistry relevant to ozone depletion & global warming	1990-1992
KOPLITZ, Lynn	Loyola University New Orleans	Chemical controls on the sinks & sources of carbon dioxide: the role of iron	1990-1992
KREIDENWEIS, Sonia	Colorado State University	Effects of clouds in troposheric chemistry	1992-1994
KREIDENWEIS, Sonia	Colorado State University	Effects of clouds in troposheric levels of radiatively-important species	1994-1996
KREIDENWEIS, Sonia Hans Moosmuller	Colorado State University	Laboratory measurements of aerosol scattering and extinction properties	2005-2006
KENNY, Ray Vera Markgraf James White	University of Colorado at Boulder	Pass changes in CO2 and climates in terrestrial records from southern SA	1992-1995
KEELING, Ralph	UCAR, University of Colorado, *Scripps Institution of Oceanography* *University of California, San Diego*	Development of field instrumentation for atmospheric oxygen measurements	1992-1994
KUCHARICK, Christopher Johnathan Foley	University of Wisconsin-Madison	Evaluating Integrated Models of Natural and Managed Ecosystems over the Central and Southeastern US	2001-2004
KUCHARIK, Christopher Tracey Twine	University of Wisconsin-Madison	Refinement and Evaluation of the IBIS Dynamic Vegetation Model using AmeriFlux and MODIS data: Assessment of simulated vegetation structure, plant phenology, NDVI, and varied temporal CO2 and H2O vapor exchange	2005-2006
LAW, Victor Sanjoy Bhattacharya	Tulane University	Formation & emission of methane in rice soils: exper. determination & modeling analysis	1990-1994
LAW, Victor	Tulane University	Estimation of Global Methane Emissions from Rice Agriculture	1994-1996
LeCLERC, Monique Karippot, A.	University of Georgia	Impact of complex environmental flows on carbon sequestration measurements in non-ideal terrain	2005-2006
LINDAU, Chuck	Louisiana State University	Methane emissions and mitigation from LA and Phillipines system model	1993-1996
LITVAK, Marcy M. Crawford	University of Texas at Austin	Quantifying changes in ecosystem structure and functions associated with woody plant expansion in the Edwards Plateau, Texas	2005-2006
LUO, Yiqi	University of Oklahoma	Interannual Variability in Net Ecosystem Exchange in Colorado Subalpine Forest: Partitioning into Causes between Climatic Variability and Functional Changes	2003-2004
LUO, Yiqi	University of Oklahoma	Modeling Studies of Forest/Atmosphere Carbon Fluxes in a Colorado Subalpine Ecosystem	2000-2003
LUNA, Ronaldo Laura J. Steinberg	Tulane University	Summer Program in Environmental Engineering Science	1998-2001
MENAWAT, Anil Robert Watts	Tulane University	Carbon dioxide, climate & the deep ocean circulation: carbon chemistry model	1991-1993
MEYER, Judith	University of Georgia	Methane emission from natural wetlands	1991-1993
MEYER, Judith	University of Georgia	Soil /atmosphere exchange of methane from natural and agriculturally impacted ripearing wetlands	1993-1995
MICHAELIDES, Stathis Leclerc, Monique	Tulane University	Improvement of the accuracy of carbon flux measurements by using a combination of numerical modeling and field measurements	2004-2006
MONSON, Russell	University of Colorado at Boulder	The Influence of Elevated CO2 in Climate Warming on Forests Non-Methane Hydrocarbon Emission and the Lifetime of Methane	1995-1998
MONSON, Russell	Universtiy of Colorado at Boulder	Forest/Atmosphere Carbon Fluxes in a Colorado Subalpine System	1998-2006
MORANTINE, Michael Watts, Robert	Tulane University	Rapid climate change (The Transcient Response of the Climate System during Abrupt Events)	1992-1996
MurCRAY, Frank Ronald Blatherwick	University of Denver	Analysis of ultra high resolution infrared solar spectra for the early detection of a change in atmosphereic capacity	1992-1995
NORTH, Gerald	Texas A & M University	Delay of Climate Change by Oceanic Processes	1991-1993
NORTH, Gerald	Texas A & M University	Seasonal cycle of variability of surface temperature: studies with EBM's and data	1992-1994
NORTH, Gerald	Texas A & M University	Interannual Variability of monthly averages precipitation and temperature in Gulf Coast Region	1995-1998

OJIMA, Dennis	Colorado State University	Process based ecosystem model of CH4 & NO2 fluxes in the U.S. central grasslands region	1992-1994
PAPADOPOULOS, Kyriakos	Tulane University	Effects of climatic change on the interfcial properties & texture of soil	1990-1992
PATRICK, William Carl Crozier Zhengping Wang	Louisiana State University	Factors affecting formation, emission, secondary reactions of nitrous oxide and methane in the flooded soil profiles of Gulf coast wetlands and flooded rice fields	1993-1996
PAULL, Charles	University of North Carolina at Chapel Hill	Sampling the marine gas-hydrate reservoir: assessing the methane inventory, internal dynamics, & potential of methane discharges to the atmosphere	1991-1993
PENDERGRAFT, Curtis	Tulane University - Dir Fund	Model/analysis human-induced climate change	1991-1992
PENDERGRAFT, Curtis	Tulane University	The Political Economy of Science: The Case of General Circulation Models	1993-1994
PENDERGRAFT, Curtis Robert Watts David Sailor	Tulane University - Dir Fund	Oak Ridge Conference on Global Environmental Change	1993-1994
PENDRGRAFT, Curtis	Tulane University	Resources and Risk:Correlations for Risk Communication	1994-1998
PENDRGRAFT, Curtis Louis Campomenosi	Tulane University	A Proactive Approach to Controversy: Cultural Factors in Advocacy Coalitions	1994-1998
POCKMAN, William Small, Eric	University of New Mexico	Impact of rainfall variability and woody encroachment on productivity in a semirarid grassland in New Mexico	2003-2006
RAMIREZ, Jorge A. Roger Pielke	Colorado State Universtiy	Impact Assessment Schemes for Studies of Regional Climate Change	1992-1995
RAMIREZ, Jorge A. Roger Pielke	Colorado State University	Application of a Statistical-Dynamical Water Balance Model to Regional-Scale Integrated Impact Assessment of Climate Variability and Change in the United States Great Plains	1996-1999
RAMIREZ, Jorge A. Roger Pielke	Colorado State University	Regional-Scale Integrated Impact Analysis of Climate Variability and Change in the Central United States	1998-2001
REDDY, K. Raya Harry F. Hodges James M. McKinion	Mississippi State University	Impacts of Climate Change on Cotton Production: a South CentralAssessment	1998-2001
REDDY, K. Raja Kakani, V.G.	Mississippi State University	Responses to climate change of C4 and C3 species native to South-central Region	2004-2006
SAILOR, David J.	Tulane University	Energy Use Implications of Climate Change	1994-1997
SAILOR, David J.	Tulane University	Energy Use Implications of Climate Change	1994-1997
SAILOR, David J.	Tulane University	Downscaling GCM Results for Regional Precipitation Studies: Implications for Hydrological Studies in the South CentralU.S.	1997-2000
SASS, Ronald Frank Fisher	Rice University	Trace gas exchange with the atmosphere from the gulf coast agricultural wetlands	1991-1995
SCHWARZ, Stephen Vijay John	Tulane University	Global warming effects on the release of light hydrocarbons from gas hydrate deposits	1990-1993
SIEVERING, Herman	University of Colorado at Boulder	Nitrogen Atmosphere - Forest Canopy Exchange at Coniferous (Niwot) and Eastern Mixed Forest Ameriflux Sites: Relationship to CO2 Fluxes	1999-2002
SLOAN, Lisa	University of California, Santa Cruz	Paleodata Calibration of Greenhouse Gas Forcing Effects on Climate	1994-1996
SMITH, Thomas H.H. Shugart	University of Virginia	Modeling patterns of CO2 flux from forest ecosystems: implication of climate change	1991-1994
THOMPSON, David Richard Peterson	Texas Tech Universtiy	Use of GCM predictions of climate change to assess impacts on water res systems	1995-1998
WATTS, Robert	Tulane University	Engineering response to global climate change: planning a research & development agenda	1990-1995
WATTS, Robert	Tulane University	Recent and Paleo-climatic variations and the Greenhouose Gas-climate signal: Detecting Climate Change	1991-1992
WATTS, Robert	Tulane University	Detection of Greenhouse Climate Change	1992-1995
WATTS, Robert	Tulane University	Minimum Entropy Hypothesis: Can It Be Used to Constrain Climate Models?	1994-1996
WHITBECK, Julie Jay Gullege	University of New Orleans	Effects of Seasonal Flooding and Sea Level Rise on the Relative Contributions of Plants Roots and Microbial Respiration to Soil CO2 Emission in a Bottomland Hardwood Forest in Southeast Louisiana	1999-2002
WIGLEY Thomas	Universtiy Corporation for Athmospheric Research	The importance of climate feedbacks in determining future Methane concentrations	1993-1995
WURBS, Ralph A. Ranjan S. Muttiah	Texas A & M University	Hydrologic Analysis in an Uncertain Climate: Refining Tools for Integrated Assessment of Climate Change Impact on Regional Water Resources	1998-2000
ZHANG, Tingjun	University of Colorado at Boulder	Investigation of the Spatial and Temporal Variations of the Seasonally Frozen Ground in the Contingent United States	2005-2005
ZHANG, Renyi	Texas A & M University	Laboratory Investigation of Mixing States and Physical and Optical Properties of Soot-Containing Aerosols	2005-2006

SOUTH CENTRAL REGIONAL CENTER
Generated Publications

AchutaRao, Krishna and R.G. Watts (1995), An Investigation of Natural Climate Variability, Sensitivity, and Poleward Flux using COADS Data Set: Part 1: The Surface Flux, *Journal of Geophysical Research*.

AchutaRao, Krishna and R.G. Watts (1995), An Investigation of Natural Climate Variability, Sensitivity, and Poleward Flux using COADS Data Set, Part II: Poleward Flux in the Ocean, *Journal of Geophysical Research*.

Andrew A. Turnipseed, Dean E. Anderson, Peter D. Blanken, William M. Baugh and Russell K. Monson (2003), Airflows and turbulent flux measurements in mountainous terrain, Part 1: Canopy and local effects, *Agricultural and Forest Meteorology, 119*, 1-2, 1-21.

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Arnold, J. G., R. S. Muttiah, R. Srinivasan, and P.M. Allen (2000), Regional estimation of base flow and groundwater recharge in the Upper Mississippi river basin, *J. Hydrology, 227*, 21-40.

Atkin, O.K., Tjoelker, M.G. (2003), Thermal acclimation and the dynamic response of plant respiration to temperature, *Trends in Plant Science, 8*, 343-351.

Baldocchi, D., J. Fuentes, D. Bowling (1999), A. Turnipseed, R. Monson, Scaling Isporene Fluxes from Leaves to Canopies: Test Cases over a Boreal Aspen, and a Mixed Species Temperate Forest, *American Meterological Society, 38*, 885-898.

Baldocchi, D.D., J.D. Fuentes, D.R. Bowling, A. Turnipseed, and R.K. Monson (1999), Scaling isoprene fluxes from leaves to canopies: test cases over a boreal aspen and a mixed-species temperate forest, *Journal of Applied Meteorology*, *38*(7): 885-898.

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Bowling, D.B., Turnipseed, A.A., Baldocchi, D.D., Delany, A.C., and Monson, R.K.(1998), Modification of the relaxed eddy accumulation technique to maximize measured scalar mixing ratio differences in updrafts and downdrafts, *Journal of Geophysical Research, 104,* 9121-9133.

Bowling, D.R., Turnipseed, A.A., Delany, A.C., Baldocchi, D.D., Greenberg, J.P., Monson, R.K. (1998), The use of relaxed eddy accumulation to measure biosphere-atmosphere exchange of isoprene and other biological trace gases, *Oecologia, 116*, 3, 306-315.

Bowling, D., D. Baldocchi, and R. Monson (1999), Dynamics of isotopic exchange of carbon dioxide in a Tennessee deciduous forest, *Global Biogeochemical Cycles, 13*, 903-922.

C.W. Lindau, P.K., Bollich, R.D. DeLaune, W.H. Patrick, Jr., and V.J. Law (1991), Effect of urea fertilizer and environmental factors on CH4 emissions from a Louisiana, USA rice field, *Plant and Soil, 136*, 195-203.

C.W. Lindau and P.K. Bollich (1993), Methane emissions from Louisiana first and ratoon crop rice, *Soil Sci.*.

C.W. Lindau, P.K. Bollich, R.D. DeLaune, A.R. Mosier, and K.F. Bronson (1993), Methane mitigation in flooded Louisiana rice fields, *Biology and Fertility of Soils*.

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Constable, J., Alex Guenther, D. Schimel, and R. Monson (1999), Modelling changes in VOC emission in response to climate change in the continental United States, *Global Change Biology, 5*, 791-806.

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Davidson, E.A., K. Savage, P. Bolstad, D.A. Clark, P.S. Curtis, D.S. Ellsworth, P.J. Hanson, B.E. Law, Y. Luo, K.S. Pregitzer, J.C. Randolph, D. Zak (2002), Belowground carbon allocation in forests estimated from annual litterfall and IRGA-based soil respiration measurements, *Agricultural and Forest Meterology, 113*, 39-51.

Davis, K.J., P.S. Bakwin, C. Zhao, W.M. Angevine, D.F. Hurst, and J. Isebrands (1996), Monitoring regional forest-atmosphere exchange of carbon dioxide, Proceedings of the 22nd Conference on Forest and Agricultural Meteorology, p. 302-305, American Meteorological Society, January 28-February 2, 1996.

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Gill, R.A., R.H. Kelly, W.J. Parton, K.A. Day, R.B. Jackson, J.A. Morgan, J.M.O. Scurlock, L.L. Tieszen, J. van de Castle, D.S. Ojima, and X.S. Zhang (2002), Using simple environmental variables to estimate belowground productivity in grasslands, *Global Ecol Biogeog , 11*, 79-86.

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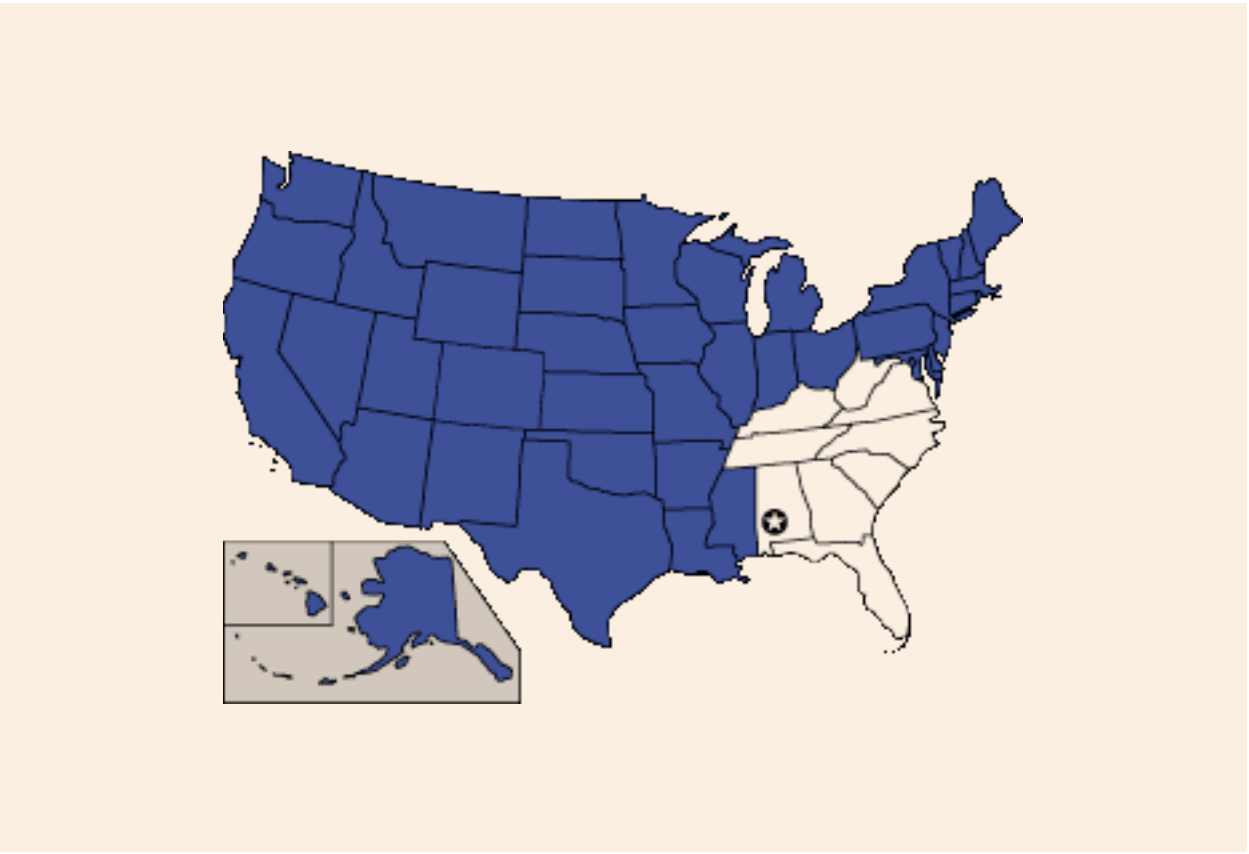


Southeast Regional Center

Southeast Regional Center Report
University of Alabama—Tuscaloosa

Southeast Regional Center

I. BACKGROUND INFORMATION:

The Southeastern Regional Center (SERC) was established in 1992 with Dr. Robert Griffin as Director and Mr. William Herz as Assistant Director. Associate Directors included Dr. Carl Ferguson, Dr. Joe Benson, and Dr. C. Everett Brett. In 1997, Dr. Anne Carey assumed the position of Assistant Director, followed by Dr. Karen Boykin in 1999. Duane Johnson became the SERC Director, after Dr. Griffin retired from the host institution at the University of Alabama in 2005.

The SERC includes Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia along with the Commonwealth of Puerto Rico and the U.S. Virgin Islands Territory. Major terrestrial ecosystem types are forests, wetlands, and managed ecosystems including farmland. Significant land features include the Appalachian Mountains, lakes and river systems, large estuaries including swamps and marshes, coastal plains, and barrier islands in the Atlantic Ocean and Gulf of Mexico. Forests and agriculture are the predominant landuses combining for over 80% of the total, the largest percentage of woody biomass in North America[1]. Farming is diverse and typical crops range from tobacco in Virginia, cotton, peanuts, soybeans, peaches and onions from the Carolinas to Georgia, and oranges, bananas and mangroves in Florida and the Island Territories. Climate change concerns include: economic and recreational effects of global climate change on forest and agricultural ecosystems, coastal and wetland responses to climate change; sea level rise; and related ground water and water resource issues. Climate change in the Southeast is expected to change species composition and dominance. Distributions, populations, sizes/density, and behavior in wildlife have been and will continue to be affected by changes in vegetation. Droughts sustained for several months encompassing large areas can have a significant agricultural affect as well as increase the occurrences of forest wildfires. Soil salinization in the island territories make agriculture vulnerable to climate change and increases the dependence of these areas on imported food. Insects, especially beetle populations, continue to encroach on forests and are exacerbated by drought. Alabama offers the nation's most diverse aquatic ecosystems. According to Vital Signs[2], beach erosion remains an issue in the coastal states along with erosion of their barrier islands with erosion rates reaching 35 feet per year, due especially to hurricanes. An increase in coral deaths appears to parallel the well-documented rise in desertification in Africa (beginning in the 1970's). This has allowed aerosol transport of xeno-biotics, such as spores and bacteria, that have likely contributed to coral reef mortalities throughout the Caribbean basin. Water resources in the Southeast are threatened by rises in sea level due to global warming[3]. The Southeast represents a unique collection of ecosystems, from coastal to forest, whose response to climate change will be one variable in determining the future ecological diversity of the region.

II. CENTER'S STRATEGIC VISION:

The SERC scientific strategic vision has been to conduct a high-quality focused research program directed at understanding the consequences of climatic and atmospheric changes associated with energy production on major terrestrial ecosystems and resources in the Southeast U.S. Specific questions of interest are: What are the net carbon exchanges in terrestrial ecosystems in the southeast and how do southeastern ecosystems contribute to the global carbon cycle and other greenhouse gas fluxes? What are the effects of environmental change on southeastern terrestrial ecosystems?

Researchers are asked to assist in achieving this vision by analyzing and predicting impacts of climate and atmospheric change, and the science that has been used to quantify these changes, on southeastern natural resources through examining chemical, physical, and biological processes.

III. RESEARCH FOCI:

The primary purpose has evolved to support a research program that increases basic understanding of how forest, farmland, and aquatic ecosystems exchange carbon with the atmosphere and how environmental change is likely to impact key ecosystems in the region. Specific research foci are described below:

Research Focus 1: To increase understanding of southeastern terrestrial ecosystem carbon exchange. The SERC supports research to determine the roles of major Southeastern ecosystems in the global carbon cycle,

1 Albritton, D.L., et al., A Report of Working Group 1 of the Intergovernmental Panel on Climate Change, Third Assessment Report: Climate Change 2001, World Meteorological Organization, 7bis Avenue de la Paix, C.P. 2300, CH-1211, Geneva, Switzerland, http://www.ipcc.ch/.

2 Abramovitz, J.N., et al., Vital Signs 2001, The World Watch Institute, W.W. Norton and Co., London.

3 The United States Geological Survey, 2001; http://www.usgs.gov.

greenhouse gas fluxes, and processes controlling atmospheric CO_2, including belowground carbon exchanges. The specific goal is to answer the following questions: Are southeastern terrestrial ecosystems sources or sinks of atmospheric carbon and how might their source/sink status be affected by environmental change? What are the important processes and mechanisms controlling the exchanges of CO_2 between the atmosphere and the terrestrial biosphere of the Southeast, particularly belowground carbon exchanges? Projects examining process-based parameters at specific sites are asked to conduct work in terms of variability across the regional landscape.

Research Focus 2: To investigate the ecological effects of environmental change. The SERC supports research on the effects of climatic and atmospheric changes (particularly increases in the atmospheric CO_2) on major terrestrial ecosystems in the Southeastern U.S. Work in this area should answer one of the following questions: What are the effects on terrestrial ecosystems, especially water use, of environmental changes associated with energy production? What are the effects of environmental changes associated with energy production on interactions between plants, insects, and diseases?

Research Focus 3: To develop and evaluate the tools needed to identify regional impacts of environmental change. The SERC supports development and testing of terrestrial ecosystem models needed for analysis of effects of environmental changes associated with energy production on the region. The specific question of interest is: What are the effects of climatic and atmospheric change associated with energy production on forest ecosystems in the Southeast, including their water use? When practical and logical, model testing efforts are to use data from SERC-sponsored process studies for parameterization or validation.

Research Focus 4: To evaluate effects of sulfur-based and/or carbon-based aerosols on earth's radiation balance. The SERC promotes collaboration with the other regional centers to fund projects in the new NIGEC aerosol climate interaction research initiative.

IV. ACCOMPLISHMENTS (SERC FUNDED PROJECTS):

Albertson of Duke University is focusing on the development of a system in which mechanistic forward models, varying in complexity from detailed canopy process models to simple resource use efficiency formulations, may be run in real-time to produce accurate predictions of carbon and energy sources and sinks. This research addresses the need to constrain these models with readily available observables, such as eddy covariance flux estimates and scalar concentration profiles. Currently, flux measurements at any point in time are treated as being either completely reliable or completely unreliable, with a binary reliability index defined by indicators such as the friction velocity (u*). When data are unreliable, empirical gap-filling techniques are employed. With respect to models, the confidence in predictions is limited by the ad hoc nature of the comparisons with data. Throughout the completion of this project, advancements in several areas contributing to the overarching goal of robust flux estimation have been made. A critical link in the interactions between a plant canopy and its environment is the turbulent transport of CO_2, water vapor and heat. This has ramifications for the utilization of concentration profiles for model constraint (i.e. data assimilation).

Significant advances in the probabilistic formulation of canopy turbulence and dispersion have been reported by our group. A model coupling turbulent transport theory with ecophysiological principles was then used in the development of a technique to identify model error sources, providing the basis for a new set of constraints (canopy profiles of CO_2 and H_2O concentrations and temperature) on flux estimates. Insights into the effectiveness of environmental classification in the model constraint process were another product of this work. We are now making strides in flux uncertainty estimation, utilizing tools developed in the hydrological sciences (i.e. the generalized likelihood uncertainty estimation framework) in combination with information theoretic measures for improved parameter identifiably and reduced flux uncertainty.

Billings of the University of Kansas is measuring how soils in a pine forest exposed to increased carbon dioxide process the carbon added to soil via plant litterfall and roots. This is important, because the microbes that live in soils perform two functions important for future climate change: they transform soil carbon into carbon dioxide, a greenhouse gas, and they can transform soil carbon into compounds that retain the carbon in the soil. The research team wanted to know how pine forest soil microbes would function in the future, with increased carbon dioxide in the atmosphere. To accomplish this, they measured how quickly soil carbon has been accumulating in these soils; about 20% of the accumulated soil carbon appears to be of the kind that remains in the soil for long time periods. The rest, ~80%, can be relatively quickly transformed back into carbon dioxide, and emitted to the atmosphere. Fertilization with nitrogen in the field generally reduced soil respiration by 28% in laboratory incubations of soil, but the kind of carbon the microbes in the fertilized soils respired is typically that which is well-retained in soils. Results therefore suggest fertilization may alter the type and amount of carbon returned back to the atmosphere as carbon dioxide.

Chanton and Conte et al. of the Florida State University and The Ecosystems Center, Marine Biology Laboratory study Southeastern pine forests, which are among the largest terrestrial sinks of carbon dioxide in the US. Their research specifically addresses the carbon isotopic signatures of the large fluxes of carbon taken up by photosynthesis and given

off by respiration in this ecosystem. Using carbon isotopes to trace fluxes at the ecosystem level, the study helps to more accurately quantify carbon fluxes at the regional scale and how these fluxes respond climatic parameters such as rainfall and air temperature. The research on the isotopic signature of biogenic (wax) aerosols that are emitted by terrestrial ecosystems will produce data that is directly applicable to modeling studies employing variations in the concentration and carbon isotopic composition of atmospheric carbon dioxide to quantify the magnitude and spatial and temporal patterns of carbon uptake on the global scale.

Durrans (Williamson and Kirby) of the University of Alabama conducted work over the past three years to expand our understanding of the relationship between land-use heterogeneities, water availability, and climate change / variability in the Southeastern United States. Integrated analyses of the potential effects of climatic change, since they deal with predicting the impacts of future climate scenarios, must be accomplished with simulation models of various types. In predictions / analyses of potential water availability changes, spurred by climatic change, the robustness and effectiveness of model simulations are critically dependent on the ability of a model to represent the hydrologic response characteristics of watersheds. In the Southeastern United States, where large watersheds have heterogeneous land-use characteristics, it is important to account for that heterogeneity to provide physically meaningful predictions of water availability. This research couples a hydrologic / forest productivity model (PnET-II3SL) with a hydrologic / agricultural model (SWAT)

to better represent the actual characteristics of large spatial areas in the southeast. Furthermore, this project addresses enhancement of the coupled model (PnET-II3SL / SWAT) to simulate the potential effects of biological adaptation, particularly with respect to water availability and the process of evapotranspiration.

Martin of the University of Florida is using above-canopy eddy covariance measurements to determine the net movement of carbon, water and energy in pine forests of three different ages in north central Florida. In addition, they are utilizing physiological and ecological measurements at each site to aid in interpreting the tower data. Together, these measurements will help us understand how carbon exchange changes with forest age, management scenarios, and climate fluctuations. In addition to our three permanent sites, the team has selected a number of additional stands to initiate a series of shorter term campaign measurements. Measurements from these "replicate" sites will allow us to characterize how carbon gain in similarly-aged forest plantations varies from place to place in this landscape. They will continue development of a computer model of forest growth, incorporating new data and phenomena as research progresses. The resulting improved model will be useful for summarizing the results of our research, as well as for predicting how changes in climate or management might affect the regional carbon balance over a typical 25-year forest management cycle.

Oren of Duke University plans to combine the relationships between net ecosystem carbon exchange (NEE) and evapotranspiration (ET) from eddy covariance with a river basin-wide ET to estimate the basin's NEE. Basin-wide Estimates of annual ET were inverted from continuous stream-flow (Q) records using a simplified watershed water balance and nonlinear reservoir model.We focused on the uppermost section (~2000 km^2) of the Neuse River Basin in North Carolina U.S., where the climate is warm and humid and land cover is dominated by forests and agricultural land (totaling 79% in 1999). Scaled to the sub-basin, the stream-flow-based estimates of annual ET (for 2001 - 2004) agreed well with the estimates based on scaled eddy-covariance measured nearby at the three Duke Forest AmeriFlux sites. Based on the longest stream-flow datasets, no clear overall trend in Q or the parameters of the reservoir model were found suggesting that the hydrologic properties of the watersheds have been stationary. Inter-annual variation in precipitation typically explained more than half of the variation in ET; ET was mostly uncorrelated with measured pan evaporation. Thus, annual ET was more closely related to the replenishment of the water storage available for ET than its climatic driving force. We demonstrate that stream-flow records can be useful for providing continuous estimates of ET and, thereby, benchmarks for modeling regional fluxes of water and of other elements, e.g. carbon, that are closely coupled with water.

Pritchard of the College of Charleston is in the process of mining an archive of minirhizotron images for information regarding the influence of atmospheric CO_2 enrichment on mycorrhizas and extraradical fungal hyphae. Minirhizotrons are cameras that are inserted into clear tubes installed into the soil that facilitate study of roots growing along the interface of the soil and the tube. Repeated measurements of soil fungal structures and roots through time allows relatively non-invasive quantification of soil biological processes. Archived images for both a loblolly pine forest experiment (Duke University FACE site, Chapel Hill, NC) and a model regenerating longleaf pine ecosystem (National Soil Dynamics Laboratory, Auburn, AL) are being subjected to computer assisted image analyses in order to determine how rising concentrations of carbon dioxide gas in the atmosphere will influence soil processes. Data on soil fungi at the Duke experiment indicate that elevated atmospheric CO_2 concentrations predicted for the middle of the 21st century will increase the growth of soil fungi, especially in deep soil. Increased fungal growth may speed up decomposition of leaf litter and could increase the supply of soil resources, such as water and nutrients, to forest trees.

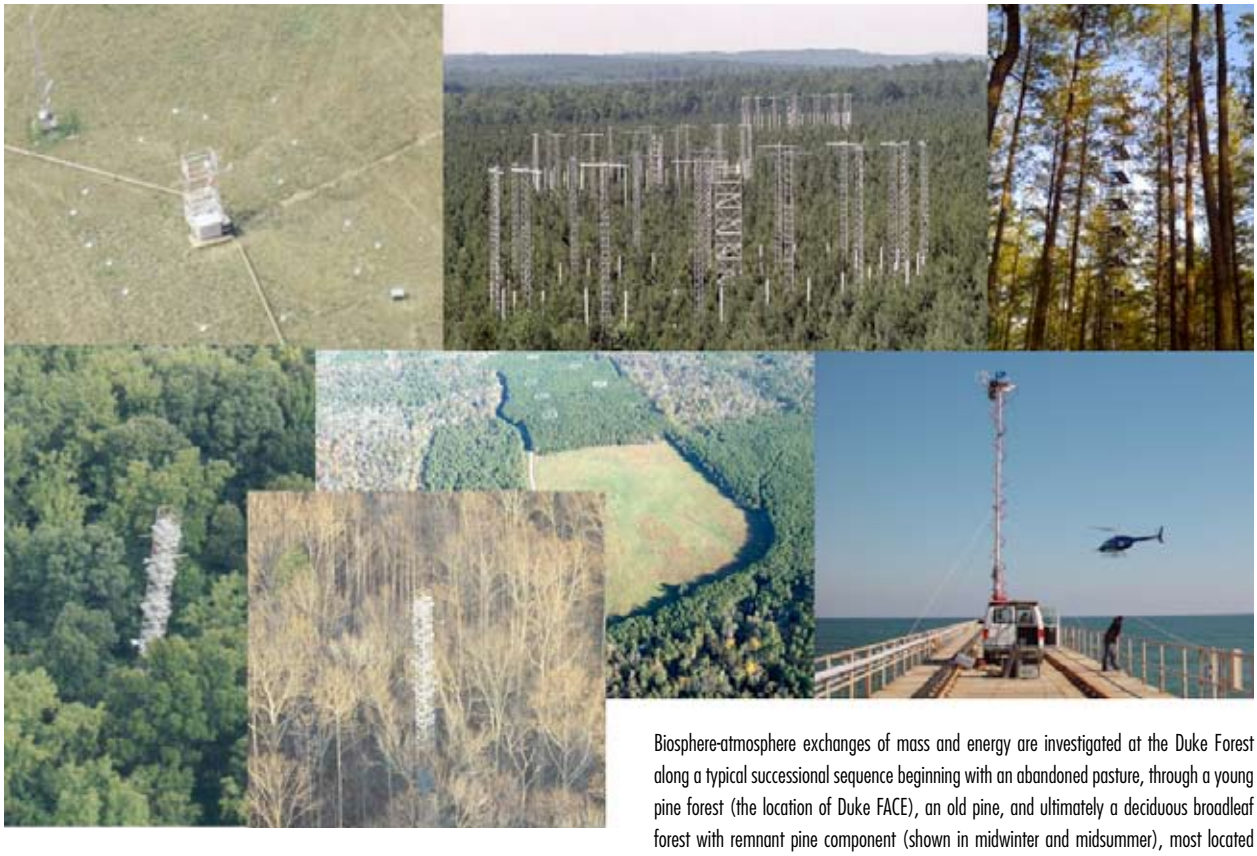
Ray of the University of Kentucky is examining the uncertainty about the role of soot particles on the global climate. Some studies suggest that global warming effects of soot may be higher than most greenhouse gases, except for carbon dioxide. In atmosphere, soot particles combine with other aerosols, and adsorbs various gas phase chemicals. As a result, soot particles exist mixed with hydrophilic and hydrophobic compounds in various physical states that include aggregates of soot, or soot distributed inside liquid droplets, or soot in cores or shells of layered droplets. In some physical states soot can absorb significantly more solar radiation than other states, thus can increase global warming effects. Currently, we know little about the effects of various physical states. Although soot is hydrophobic, the presence of hygroscopic chemicals increases the water absorbing capacity of soot aerosols, and the water content of soot aerosols influences visibility as well as the global climate. The researchers have examined scattering and absorption characteristics as well as hygroscopic properties of aerosols at various physical states by suspending a simulated soot-particle in an electrodynamic balance under a controlled environment. By observing scattering of laser light by many such particles, they are deciphering the effects of soot aerosols on the global climate. *They have determined adsorption of water molecules on soot particles at various humidity, and shown that soot particles can retain significant amount of moisture at high humidity.*

Rogers (Runion) of Auburn University examined invasive plants as a major threat to the Earth's biodiversity. While considerable effort is being spent studying these exotic plant pests, little consideration of how invasive plants might react to the increasing carbon dioxide (CO_2) concentration in the

Florida AmeriFlux co-PI Dr. Gregory Starr supervises a prescribed fire treatment in a 70-year-old, naturally-regenerated longleaf pine / slash pine stand. The Florida AmeriFlux project has quantified the role of disturbances such as prescribed fire, drought, harvest and fertilization on patterns of carbon, water and energy exchange in southern pine

Dr. Robert Griffin (center picture), the original Director and architect of the SERC NIGEC program, examines sap flow gauges at the Florida AmeriFlux project's mid-rotation slash pine site. Drs. Henry Gholz, Tim Martin, Wendell Cropper and Greg Starr's work made extensive use of physiological measurements, such as sap flow, and structural data, such as leaf area index, to better understand the mechanisms controlling carbon, water and energy balances.

Flux tower in a plantation stand of slash pine. Research at the Florida AmeriFlux slash pine plantation sites has shown that the within-rotation range in annual net ecosystem exchange of carbon (from a large source at establishment to a large sink at maturity) is larger than the total across-site variation observed in the entire Fluxnet network.



Biosphere-atmosphere exchanges of mass and energy are investigated at the Duke Forest along a typical successional sequence beginning with an abandoned pasture, through a young pine forest (the location of Duke FACE), an old pine, and ultimately a deciduous broadleaf forest with remnant pine component (shown in midwinter and midsummer), most located within four km2. The mobile system, together with the helicopter observation platform (HOP) are used to fill gaps in the sequence.

atmosphere has been given. The researchers have been growing a variety of invasive plants under ambient and elevated levels of CO_2. To date, study has concluded for two species (Johnson grass [*Sorghum halepense*] a C_4 grass and sicklepod [*Cassia obtusifolia*] a C_3 N_2-fixing legume). Results show that, while both plants grew larger under the high level of CO_2, the response of sicklepod was much greater (average increase in aboveground dry weight = 37%) than did Johnson grass (20%). In addition, both species showed a delay or decrease in reproduction when exposed to elevated CO_2 as evidenced by reduction in both numbers and dry weights of reproductive structures. These results suggest that, while invasive weeds may grow larger under a future, high CO_2 environment, their ability to spread might be reduced.

Stiling of the University of South Florida is examining biodiversity changes with elevated CO_2 in eight open-top chambers in a scrub-oak forest at Kennedy Space Center, Florida. Normal levels of CO_2 are maintained inside eight other open-top chambers. Diversity of plants, insect herbivores, insect natural enemies and litter dwellers will be compared between ambient and elevated CO_2. Previous experiments at Cape Kennedy Space Center, Florida, revealed that higher atmospheric CO_2 concentration increases plant growth in some plant species more than others. This suggests that elevated CO_2 can directly impact plant diversity while indirectly impacting insect diversity via changes in plant diversity, foliage quality and, for litter feeders, increased litter fall. Project goals are: (1) To quantify changes in plant diversity under elevated CO_2 using whole chamber counts of total plants, chamber transects and litter fall traps, (2) to quantify changes in insect herbivore diversity of leaf miners, leaf chewers, gall makers, sap suckers, acorn feeders, and other insect herbivores by means of counts on green foliage, (3) to quantify changes in insect predator and parasitoid diversity at the third trophic level including parasitoids of leaf miners, aphids and gall makers and predatory spiders, and (4) to document changes in insect detritivore communities and ground dwelling species by using both pitfall traps and litter bags.

Williamson (Continuation of Durrans) of the University of Alabama sponsored a small spatial variability project that evolved from the recognition that soil moisture availability is a major climate change response as well as a driver of ecosystem processes. More specifically, a previous SERC grant by Durrans and Kirby indicated the importance of stratified soil moisture profiles on model predictions of vegetation productivity and stream flow. The impact of soil moisture heterogeneity and dynamics on model estimates of productivity (though variation in input parameters) and streamflow itself may improve model predictions through developing uncertainty estimates. The goal of this project was to collect a statistically relevant set of soil profile data during a growing season in row crops. This work was performed at the Bondville Ameriflux site, leveraging funds as part of a larger DOE and NASA funded effort. Soil moisture access tubes and portable resistivity probes were used to measure soil moisture profiles in corn and soybean twice a week and in response to heavy rains. The product of this research is a unique data set for later model testing. This data (collection only possible through this NIGEC project), will allow the variation in soil moisture content to be assessed over

a growing season and spatially throughout a field. In addition, the impact of this variation on model predictions can be assessed using the coupled PnET/SWAT model.

Williamson of the University of Alabama conducted a second project representing a small addendum to a larger and separately funded effort (through DOE's TCP program) to examine the spatial behavior of landscape emissions of two greenhouse gases: carbon dioxide and water. While flux towers measure emissions of these gases from vegetation (e.g., row crops and trees), they do not provide much information about the behavior of flux over areas larger than approximately 1-2 square kilometers. However, continental-scale climate change models need descriptions of flux at larger scales and need estimates of the uncertainty of tower-based flux measurements applied to larger areas. Therefore, this small project focused on acquiring spatially distributed fluxes over a common southeastern landscape (pine plantations of various ages) interspersed with wetlands and pasture and grazing lands. The University of Alabama flux aircraft was mobilized to Gainesville Florida and flown (including ferrying time) for approximately 25 hours to gather flux data. The data represents a continued southeastern data set that otherwise would not be available. The major accomplishment here was very cost-effectively supporting a Florida flux campaign and providing useful southeastern data for later variation analysis using tools being developed in an ongoing DOE project. This data will allow a new method for spatial flux aggregation to be tested using a dominant Southeastern land use and will allow multi-year assessment of spatial flux behavior in a dominant southeastern landuse.

V. WORKSHOP SPONSORED:

- **Annual SERC PI Workshops.** The aim of the annual workshops was to facilitate interactions among investigators and to stimulate exchanges of data and information. Workshops were rotated at PI institutions allowing for site visits and tours of research facilities. Meeting formats varied depending on current issues, site specific information presented, and prior year NTAC comments and suggestions. No workshop was held in 2006 as no funding was allocated in the budget.
- **Joint Workshop MWRC-SERC, Oak Ridge National Laboratory, Oak Ridge, TN, May 16-17, 2005**. The last workshop held by the SERC was held at the Oak Ridge National Laboratory. In breaking with prior meetings, this site did not house actively funded research sponsored by the SERC. However, researchers at the Oak Ridge facility were collaborating on the SERC sponsored Williamson work and the AERO Center at the University of Alabama. Meeting organizers believed ORNL provided an opportunity for researcher networking important to new facilities being constructed at the site including the Through fall Displacement Experiment, Walker Branch Flux Tower, Chestnut Ridge Flux Tower, and the FACE Facility.

Information for the Overall NIGEC Executive Summary
(Most Important Accomplishments from CURRENT SERC-funded Projects)

- At the Florida Ameriflux site, significant relationship was observed with tree height spanning a 7 fold range and the ^{13}C of foliage respired CO_2 and the ^{13}C of foliage organic matter. C_F and the ^{13}C of foliage organic matter become enriched for taller (older) trees. As trees age and grow taller, resistance to water transport increases and there is apparently a corresponding decrease in stomatal conductance. These results suggest that as forests age the isotopic ratio of assimilated carbon will become progressively enriched. At a single site we found no seasonal variation in the ^{13}C of foliage respired CO_2 and the ^{13}C of foliage organic matter despite variation in vapor pressure deficit.
- The isotopic studies of leaf waxes in aerosols have confirmed the large-regional spatial scale of the wax aerosol signature in boundary layer air masses. Using molecular and isotopic data on individual wax compounds, we estimated that approximately 60% of the carbon isotopic variations observed in wax aerosols we collected arises from change in the relative proportions of C_3 and C_4 plant sources, and 40% from change in the mean photosynthetic discrimination of the C_3 plant source.
- Of the soil C accrued under elevated CO_2 conditions, a significant (~20%) of that C is incorporated into soil organic matter pools typically assumed to be recalcitrant. We also show, through short- and long-term incubations, that microbial respiration can be increased with elevated CO_2; this has not been demonstrated at this site previously. Fertilization appears to induce microbial populations to metabolize C substrates that are isotopically enriched, suggesting that they can shift to N-poor substrates when nutrient limitations are relieved; this process may result in increased microbial usage of substrates that otherwise may be better retained in the soil profile, though overall respiration with fertilization was reduced.
- A method was developed for isolating errors in radiation, turbulence, and photosynthesis components of forest models for carbon and water exchange by forest vegetation. This approach jointly analyzes forward model predictions and CO2 concentration profiles. This represents a large increase in information over typical approaches that only examine total fluxes. The core of the method relies on the empirical orthogonal function (EOF) analysis of an ensemble of model error profiles Environmental

Lt. Col. USMC (ret.) Karl Elebash and Ph.D. Candidate Scott Kirby of UA's AERO (Atmospheric Environmental Research Operation) program collect flux data over Midwest landscapes to better understand spatial variability in fluxes and hence carbon budgets. AERO is direct by Dr. Derek Williamson, Assoc. Prof. Civil, Construction, and Environmental engineering.

classification of photosynthetically active radiation and wind speed regimes was effective at untangling error influences for the tightly coupled photosynthetic, radiation, and stomatal conductance parameters. Data analysis of measured concentration profiles was used to derive the environmental classes.

- To date, the Gainesville, FL AmeriFlux program has documented the broad range of variation in fluxes in both plantation and naturally-regenerated pine forests in our region, and has used this information to derive landscape-level estimates of C sequestration. The network of three permanent and one roving eddy covariance systems has been the first in the region to characterize the effects of stand development, management intensity, and prescribed fire on pine forest C dynamics.
- Ray and his research team, as a new group within the SERC, worked this past year to develop techniques for generation of soot particles of various mixing states. These techniques can be used to study light absorbing abilities of soot particles.
- Long-term stream-flow records can be used to estimate continuous and reasonably constrained estimates of annual evapotranspiration over entire river basins. Moderate variation in land cover has little effect on evapotranspiration, yet inter-annual variation in precipitation strongly affects evapotranspiration. Because CO_2 uptake is closely related to transpiration, and transpiration can be extracted from evapotranspiration, evapotranspiration can be used to assess the effect of climate variation on basin-wide CO_2 uptake.
- SERC funding enhanced collaborations among numerous researchers across the U.S., leveraging funding from various agencies to complete work that would not have been possible otherwise. An example during the past funding cycle was the creation of a focused set of researchers increasing data sharing from the Bondville Ameriflux site, including researchers from UIUC, USDA, Illinois State Water Survey, NOAA and UA and UAB.

SOUTHEASTERN REGIONAL CENTER
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SOUTHEAST REGIONAL CENTER
Research Programs

P.I. Co-I.(s)	Institution(s)	Project Title	Year of Funding
ABT, Robert . J.E de Steiguer	North Carolina State University	Spatial Modeling of the Biological and Economic Consequences of Climate Change on Forested Ecosystem of the Southeastern U.S.	1996-1998
ABT, Robert Steve McNulty Rocky Durrans Brian Murray	North Carolina State University U.S. Department of Agriculture University of Alabama Research Triangle Institute	Spatial Modeling of the Ecophysiologic, Hydrologic and Economic Impacts of Climate Change on Forested Ecosystems of the South	1999-2001
ADDY, Samuel Adam Rose	University of Alabama The Pennsylvania State University	Climate Change Impacts on the Southeastern U.S. Forest and Economy	2000-2003
AUGE, Robert	University of Tennessee	Nonhydraulic Signaling of Soil Drying and Stomatal Regulation in a Forest Ecosystem	1995-1998
BILLINGS, Sharon A. Susan E. Ziegler	University of Kansas University of Arkansas	Linking Microbial Activity and Soil Organic Matter Transformations in Forest Soils Under Elevated CO2	2005-2006
BOOTE, K.J. L.E Solenberger L.H. Allen, Jr. T.R. Sinclair	University of Florida	Carbon Balance and Growth Adaptation of Contrasting C3 and C4 Perennial Forage Species to Increased CO2 and Temperature	1994-1996
BROOK, George	University of Georgia	The Consequences of Continued Global Warming on the Vegetation of the Southeastern USA: Evidence from the Last Interglacial	1992-1993
CHANTON, Jeffrey	Florida State University	Isotopic Signatures of Atmospheric Methane at NIGEC Tower Sites and of Anthropogenic Sources of Methane to the Atmosphere: SE Landfills, Combustion, Gas Transmission and Waste Water Treatment	1996-1998
CHANTON, Jeffrey Yang Wang	Florida State University	Isotopic Studies at AmeriFlux Tower Sites: Estimating Exchange and Anthropogenic CH4	1999-2001
CHANTON, Jeffrey Maurine Conte Behzad Mortazavi	Florida State University Marine Biology Laboratory Florida State University	Carbon Isotopic Studies of Assimilated and Ecosystem Respired CO2 in a Southeastern Pine Forest	2004-2006
CHRISTY, John McNider, Richard	University of Alabama in Huntsville	Analysis of Climate Variability and Its Relationship to Atmospheric Carbon Concentrations	1996-1998
CROPPER, Wendell Henry Gholz Eric Allen	University of Florida	Exchange of Energy and Radiatively-Active Gases Between Slash Pine and Cypress Ecosystems and the Atmosphere in the SE U.S.	1994-1997
ELLIOT	Colorado State University	Director's Fund Nominal Assistance for Analysis Coordination	2001
GHOLZ, Henry	University of Florida	Carbon, Water, and Energy Fluxes for a Slash Pine Ecosystem in Florida: Effects of Management and Environment	1997-1999
GHOLZ, Henry CROPPER, Wendell Timothy Martin	University of Florida	Long-term Dynamics of Carbon, Water, and Energy Fluxes for Managed and Natural Pine Ecosystems in Florida	2000-2003
GHOLZ, Henry	University of Florida	Director's Fund Nominal Assistance for Infrastructure to Site	2001
GREENING, Lorna	Lawrence Berkeley National Laboratory	Cost/Benefit Analysis Incorporating Distributional Issues of Policy Options Available to the Transportation Industry for the Reduction of Greenhouse Gases in the Southeastern United States	1992-1993
GREENING, Lorna	Lawrence Berkeley National Laboratory	Integrated Resource Greenhouse Planning for the Electric Utility Industry in the Southeastern United States	1993-1994
HERZ, William Robert Griffin William Gunther	University of Alabama	EPA Sponsored Report: Alabama EPA Climate Change Program: Policy Planning to Reduce Greenhouse Gas Emissions (Phase 2)	1997

HERZ, William Robert Griffin William Gunther	University of Alabama	EPA Sponsored Report: Policy Planning to Reduce Greenhouse Gas Emissions (Phase 1)	1996
HUNT, Raymond	University of Wyoming	Responses of Southeastern Forests to Increased CO2 and Climate: Experimental Test of an Ecosystem Model and Its Use for Impact Analysis	1996-1998
HUNT, Raymond	University of Wyoming	Responses of Southeastern Forests to Increased CO2 and Climate Experimental Test of an Ecosystem Model and Its Use for Impact Analysis	1996-1998
JOHNSON, Jon D.	University of Florida	Hydrocarbon Emissions from Southern Pines and the Potential Effects of Global Climate Change	1992-1995
JOHNSON, Dale	Desert Research Institute	Effects of Elevated CO2 on Nutrient Cycling in a Sweetgum Plantation	1997-1999
KATUL, Gabriel Ram Oren	Duke University	Spatial Variability of Carbon Dioxide Fluxes in a Homogeneous Pine Forest	1997-1998
LECLERC, Monique Henry Gholz David Hollinger Stewart Goltz	University of Georgia University of Florida University of New Hampshire University of Maine	Enhancement and Intercomparison of CO2 and H2O Measurements from Soil and Canopy at Two Ameriflux Sites	1999-2001
LECLERC, Monique	University of George	Director's Fund Nominal Assistance for Sensor Array	2001
LECLERC, Monique	University of Georgia	Cross Regional Enhancement of CO2 Flux at Three Ameriflux Sites in the Presence of Flow Circulations	2001-2004
LECLERC, Monique Tim Martin Kyaw Tha Paw U Anandakumar Karipot	University of Georgia University of Florida University of California, Davis University of Georgia	Impact of Complex Environmental Flows on Carbon Sequestration Measurements in Non-Ideal Terrain	2004-2005
LINCOLN, David	University of South Carolina	Interactive Effects of Elevated CO2 and Temperature on the Insect Consumers of Forest Trees	1996-1998
MARTIN, Tim Gregory Starr Wendell Cropper	University of Florida	Dynamics of Carbon, Water, and Energy Fluxes for Pine Ecosystems in Florida: Recovery from Perturbation and Variation Across the Landscape	2003-2006
MASSMAN/LEE		Director's Fund Assistance for Night Flux Workshop	2001
OREN, Ram G.G. Katul D. Ellsworth	Duke University	Carbon Fluxes in a Managed Pine Forest Under Ambient and Elevated CO2	1996-1998
OREN, Ram	Duke University	Water Use of Managed Southern Pine and Natural Hardwood Forest: Scaling Ground-Based Measurements to the Ecosystem Level with Climate Data and Information from NASA's AIRSAR	1992-1995
OREN, Ram Gabriel Katul	Duke University	Measurements and Modeling of Net Carbon, Exchange over a Southern Loblolly Pine Plantation at the Duke Forest Ameriflux Site (Last Year Director Supplement)	2002-2006
PRITCHARD, Seth G. Strand E. Allen	College of Charleston	Effects of Elevated Atmospheric CO2 Enrichment and N Fertilization on Extraradical and Mycorrhizal Fungi: Implications for Carbon Flow into Southeastern Forest Soils	2005-2006
RINGLEBERG, David David White	University of Tennessee	Director's Funded Project: Analysis of the Effect of Increased CO2 on Biomass, Community Structure and Nutritional Status of the Rhizosphere Microbiota of White Oaks, Long Leaf Pine and Cottonwood	1993
SMITH, Thomas	University of Virginia	Modeling Patterns of CO2 Flux from Forest Ecosystems	1993-1994
STERNBERG, Leonel da Silveria Tara Greaver Bruce Schaffer Tomas Moreno	University of Miami	Free Air Respiratory Carbon Isotope Enrichment Experiment	2003-2004
WAKEHAM, Stuart	Sidaway Institute of Oceanography	Isotopic Studies of the Biogenochemical Cycle of Carbon: Relationship Between pCO2 and the Abundance of 13C in Sedimentary Organic Matter	1992-1993
WILLIAMSON, Derek	University of Alabama	Director's funded Aircraft-Based Assessment of Spatial Representation of Ameriflux Towers Outside Gainesville, Florida	2003-2004

Students Supported by the Southeast Regional Center

NAME	UNIVERSITY, CITY, STATE
Brooks, Melissa – M.S.	Auburn University, Auburn, AL
Fadroski, Karrie Anne – M.S.	Auburn University, Auburn, AL
Pritchard, Seth – PhD	Auburn University, Auburn, AL
Cagle, Trina – BS	Auburn University, Auburn, AL
Dorman, Barry – BS	Auburn University, Auburn, AL
Cleveland, Philip - BS	Auburn University, Auburn, AL
Nance, John – BS	Auburn University, Auburn, AL
Sullivan, Evan – BS	Auburn University, Auburn, AL
Starr, Tiffanie – BS	Auburn University, Auburn, AL
Padget, Daniel	Auburn University, Auburn, AL
Runion, Brett	Auburn University, Auburn, AL
Henning, Frank	Auburn University, Auburn, AL
Lazarus Ekpo, Ene	Auburn University, Auburn, AL
Achutavarier, Deepthi – M.S.	University of Georgia, Athens, GA
Prabha, Thara – Post Doc	University of Georgia, Athens, GA
Peavy, Kenneth – Teacher Certification Student	University of Georgia, Athens, GA
Albarracin, Terre – M.S.	University of South Florida, Tampa, FL
Cornelissen, Tatiana – Ph.D.	University of South Florida, Tampa, FL
Moon, Dan – Post Doc	University of South Florida, Tampa, FL
Kirby, Jason Thomas – M.S.	University of Alabama, Tuscaloosa, AL
Micu, Elena Celina – M.S.	University of Alabama, Tuscaloosa, AL
Young, Bryan – MS	University of Alabama, Tuscaloosa, AL
Bryant, Jackson – MS	University of Alabama, Tuscaloosa, AL
McGraw, Sean – MS	University of Alabama, Tuscaloosa, AL
Mui, Ngai-Wa – MS	University of Alabama, Tuscaloosa, AL
Jennings, Matthew – BS	University of Alabama, Tuscaloosa, AL
Tomic, Sasa – MS	University of Alabama, Tuscaloosa, AL
Majors, Robert – MS	University of Alabama, Tuscaloosa, AL
Miller, Mitchell – MS	University of Alabama, Tuscaloosa, AL
Davis, Robby – PhD	University of Alabama, Tuscaloosa, AL
Bell, Greg – MS	University of Alabama, Tuscaloosa, AL
Chen, Zuojun – MS	University of Alabama, Tuscaloosa, AL
MacEwen, Kevin – StudentAide	University of Florida, Gainesville, FL
Gorsuch, Dennis – Ph.D.	University of Florida, Gainesville, FL
Obrien, Katherine – StudentAide	University of Florida, Gainesville, FL
Richmond, Sherry – Res. Assoc.	University of Florida, Gainesville, FL
Starr, Greg – Post Doc	University of Florida, Gainesville, FL
Fritschi, Felix – MS	University of Florida, Gainesville, FL
Clark, Kenneth –Post Doc	University of Florida, Gainesville, FL
Loescher, Hank – MA	University of Florida, Gainesville, FL
Liu, S. – PhD	University of Florida, Gainesville, FL
Brock, Susie; Hierro, Jose; Wafford, Nate; Carpenter, Sonia; Harris, Ryan Konopacky, Amy – Student Interns	University of Florida, Gainesville, FL
Kim, Jo-Chun – PhD	University of Florida, Gainesville, FL
Baker, Jeffery – Post Doc	University of Florida, Gainesville, FL
Pickering, Nigel – Post Doc	University of Florida, Gainesville, FL
Song, Yan – MS	University of Miami, Miami, FL
Kim, Hyun-Seok – Ph.D.	Duke University, Chapel Hill, NC
Hsieh, Cheng-I – PhD	Duke University, Durham, NC
Phillips, Nathan - PhD	Duke University, Durham, NC
Pataki, Diane – PhD	Duke University, Durham, NC
Ewers, Brent – PhD	Duke University, Durham, NC
Swanson, Jenny	Duke University, Durham, NC
Todd, Philip – MS	Duke University, Durham, NC
Tsao, Cheng-Chung – MS	Duke University, Durham, NC
Bulbulkaya, Ahmet	Duke University, Durham, NC
Ce, Huang	Duke University, Durham, NC
Ahn, SoEun – PhD	North Carolina State University, Raleigh, NC
Brogan, Sean – MNR	North Carolina State University, Raleigh, NC
He, DeQuan - MS	North Carolina State University,Raleigh, NC
Pacheco, Gerardo - PhD	North Carolina State University, Raleigh, NC
Shaocai, Yu - MS	North Carolina State University, Raleigh, NC
Anderson, John	North Carolina State University, Raleigh, NC
Logie, Brian	North Carolina State University, Raleigh, NC
Wenny, Brian	North Carolina State University, Raleigh, NC
Schafer, Shannon	North Carolina State University, Raleigh, NC
Deininger, Catherine	North Carolina State University, Raleigh, NC
Grovenstein, J.D.	North Carolina State University, Raleigh, NC
Burns, Kerry – MS	North Carolina State University, Raleigh, NC
Ulman, James – MS	North Carolina State University, Raleigh, NC
Croker, Jennifer – MS	University of Tennessee, Knoxville, TN
Johnson, Brandon –MS	University of Tennessee, Knoxville, TN
Olinick, Joshua – BS	University of Tennessee, Knoxville, TN
Spann, Amy – MS	University of Tennessee, Knoxville, TN
Stair, Julia – MS	University of Tennessee, Knoxville, TN
Liptay, Karen – MS	Florida State University, Tallahassee, FL
Hasse, Patricia –BS	Florida State University, Tallahassee, FL
Egolf, Suzanna – BS	Florida State University, Tallahassee, FL
Epp, Michelle – MS	Florida State University, Tallahassee, FL
Harden, Harmon – MS	Florida State University, Tallahassee, FL
Popp, Trevor – BS	Florida State University, Tallahassee, FL
Pearcy, Kim – BS	Florida State University, Tallahassee, FL
Prater, James – Ph.D	Florida State University, Tallahassee, FL
Smith, Matthew – M.S.	Florida State University, Tallahassee, FL
Malheur, Julia – BS	Florida State University, Tallahassee, FL
Williams, Robin – PhD	University of Alabama in Huntsville,Huntsville, AL
Hafner, Jan – PhD	University of Alabama in Huntsville, Huntsville, AL
Goodrick, Scott – PhD	University of Alabama in Huntsville, Huntsville, AL
England, David – Post Doc	University of Alabama in Huntsville, Huntsville, AL
Hnilo, Justin – MS	University of Alabama in Huntsville, Huntsville, AL
Hinkelday, Heidi – BS	Emory University, Atlanta, GA
Press, Sky – BS	Emory University, Atlanta, GA
Peavy, Kenneth	Emory University, Atlanta, GA
Legros, Jason	Emory University, Atlanta, GA
Ogle, Stephen	Emory University, Atlanta, GA
Summy, Kirsten –MS	West Virginia University
Stowinsky, Jamie –BS	West Virginia University
Rizzo, Brian – PhD	University of Virginia, Charlottesville, VA
Williams, Ray – Post Doc	University of South Carolina
Echols, Catarina – PhD	Old Dominion University
Zhang, Li – MS	Old Dominion University

Western Regional Center (WESTGEC)

Western Regional Report
University of California, Davis

Western Regional Center (WESTGEC)

I. REGIONAL DESCRIPTION

At the beginning of the NIGEC program, the Western Region encompassed 9 western states including: Alaska, Arizona, California, Hawaii, Idaho, Nevada, New Mexico, Oregon, and Washington, along with the Pacific Territories. In 1991 the Regions were reorganized. New Mexico was transferred to the South CentralRegion and Utah was moved to WESTGEC from the Midwestern Region.

The Western Region is unique on all environmental criteria for NIGEC: it is the most highly diverse ecologically, physiographically, and economically in NIGEC. The Western Region spans far greater spatial extent (54% of the land area of the U.S.) and latitudinal (arctic to tropics), geographic (highest, lowest elevations; longest coastlines, open ocean, islands, lakes, streams and estuaries), biotic diversity (arctic tundra, tiaga, alpine, temperate conifer forests, semi-arid shrublands and grasslands, temperate and tropical rainforests, wetlands and bogs, agriculture, and others) and climate gradients (maritime, continental, arctic, tropical, desert) than any other NICCR region. It is the most climatically diverse region (hottest, Arizona; driest, Nevada; wettest, Hawaii, coldest, Alaska) and incorporates most major ecosystem types in the U.S (Figures 1-2). This climatic, ecologic geographic, and topographic diversity presented unique challenges to WESTGEC management for programs that would lead to ecological synthesis and scaling-up which are relevant at both the regional and the national scale.

The exceptional importance of the natural diversity in the west is illustrated by the fact that 12 of 17 UNESCO World Heritage sites in the U.S. are in the Western Region.

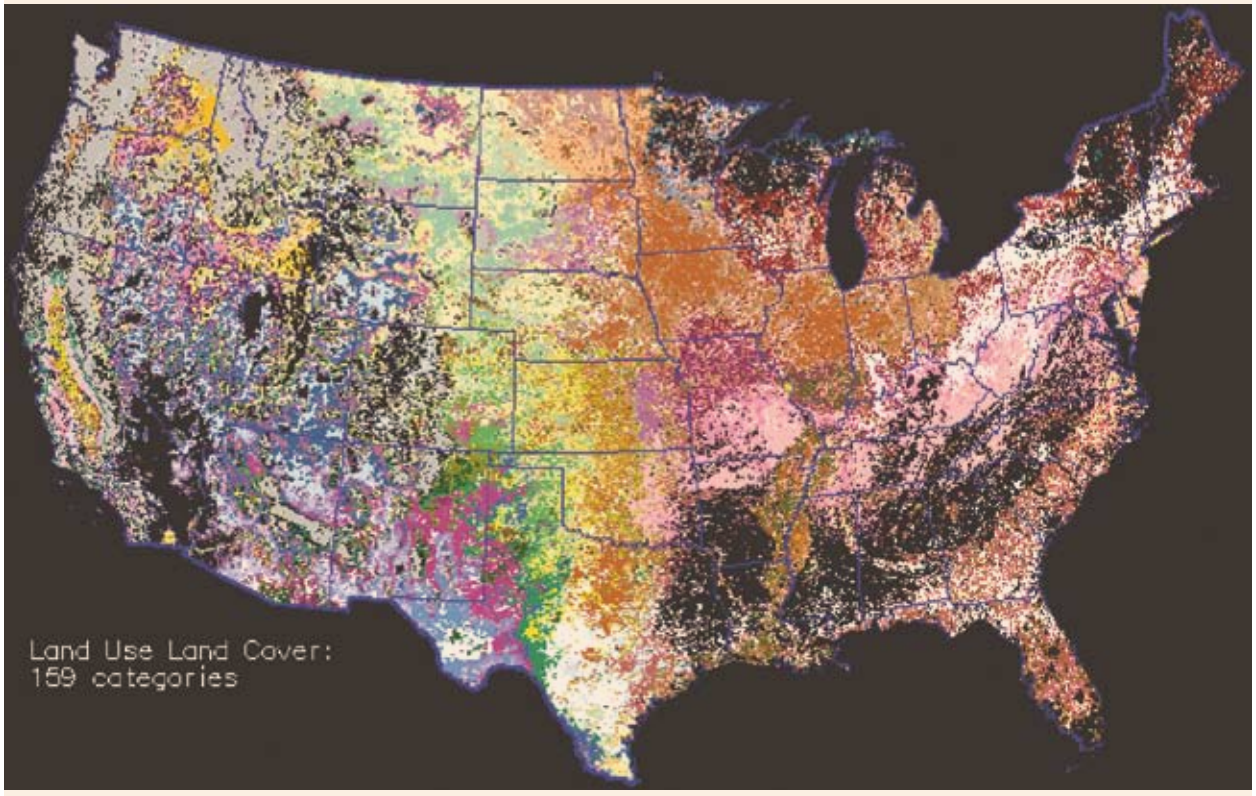


Figure 1. Ecosystems and land cover types in the contiguous United States. [www.cast.uark.edu/.../lulc_CALMIT.gif. This database of US land cover types was created by the US Geological Survey from Landsat Thematic Mapper satellite data at 1 km resolution and 30 meter resolution and mapped in the Albers Conic Equal Area projection, NAD 83]

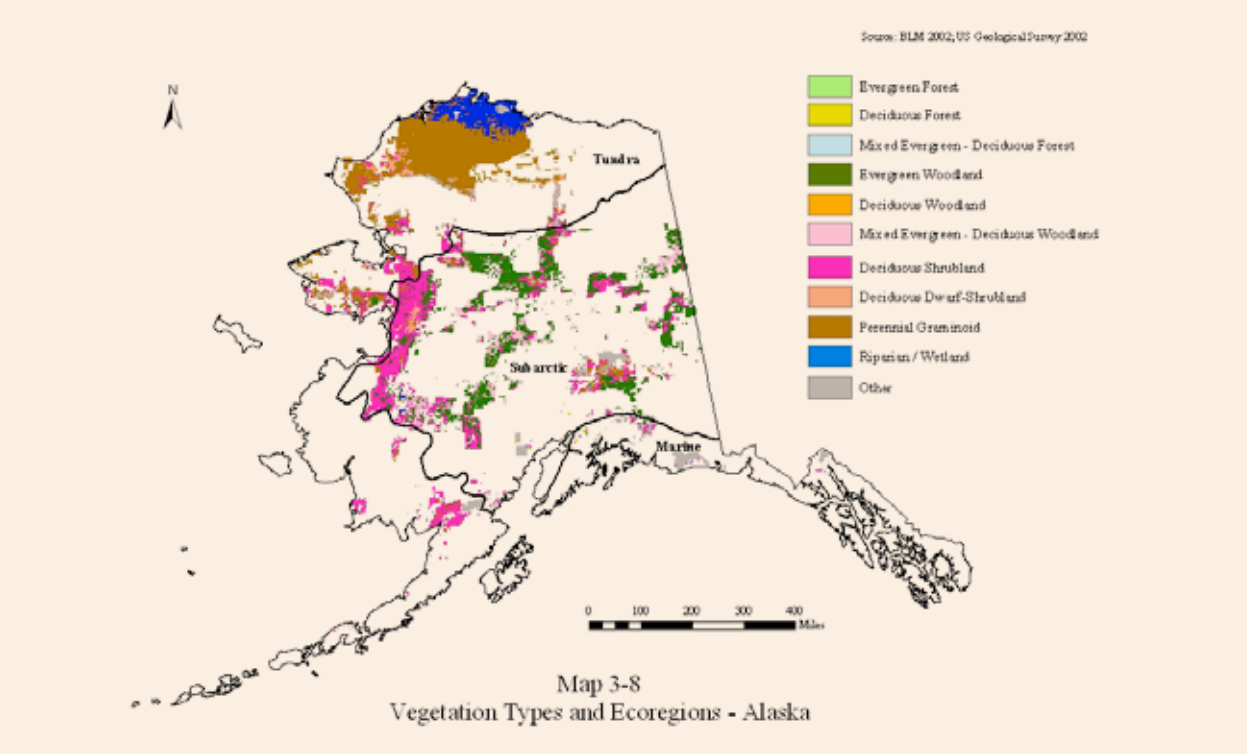


Figure 2. Ecosystem and land cover types in Alaska. [www.blm.gov/.../Fig_38_VegEcoRegionsAlaska.jpg]

The greatest biological diversity in the United States is found in just one state: California (Myers et al., 2000). In fact, more than 25% of all the vegetation types in the conterminous U.S. exist within California alone (Küchler, 1964, 1987) which also has the largest number (257) of threatened and endangered species. The program management conundrum produced by this diversity is that every research project tends to become "unique" and a "case study" with limited capacity to predict quantifiable effects of climate change.

The great range of environmental conditions defines significant differences between states within the Western Region and underlies their relative importance to the U.S. economy. The economies of states within the Western Region vary widely, but rely heavily upon tourism, timber, agriculture, fisheries, grazing, mining, and other extractive products, hence highly dependent on ecological goods and services. As with the physical environment, the WESTGEC Region encompasses wide economic disparity, with California having the largest economy (and largest in NIGEC), being the 5th largest in the world (Los Angeles Development Corp.), while the Pacific Territories have the smallest economy in the nation.

Another unique aspect to the WESTGEC Region is the greatest extent of federally owned land in the U.S. (> 57% of the land surface) is found in the Western Region (U.S. Census Bureau, *http://quickfacts.census.gov/qfd/*) a circumstance unique to this region but an opportunity for engaging in joint research programs and for conducting manipulative and/or experimental studies on federal land. The USDA Forest Service, Bureau of Land Management, and the USDI National Park Service exert sometimes conflicting management actions, priorities, and goals over much of this region. DOE has a majority of its research investments in the WESTGEC Region, with three DOE National Environmental Research Parks (Idaho, Nevada, Hanford), and six National Laboratories in the region at Idaho Engineering and Environmental Laboratory, Sandia-Livermore, Stanford Linear Accelerator, Lawrence Livermore, Lawrence Berkeley, and the Pacific Northwest Laboratory.

There is no one simple climate system that describes the Western Region. The range in climate conditions is exceptional, from the wettest place in the U.S. on Mt. Waialeale, Kauai Hawaii to the driest in Yuma, Arizona, and from the hottest location in Death Valley, California, to the coldest in Barrow, Alaska. This diversity is illustrated by the fact that half (four of eight) of the chapters in the U.S. National Assessment were on potential impacts in the Western Region (U.S. National Assessment Synthesis Team, 2001). There is accumulating evidence that western states are experiencing the initial phases of climate impacts. Alaska in particular has experienced changing patterns of permafrost, earlier spring thaws, increases in wildfires, and pest outbreaks, with hundreds of papers citing various evidence for climate change and ecosystems impacts. The severe four year drought (2001-2005) in the southwest brought widespread mortality to pine forests in Arizona (Breshears et al., 2006). Lastly, there is evidence for a long term trend in earlier snow melt in the mountains of the western states combined with lower snowpack (Knowles et al., 2006).

Water resources in the west are particularly vulnerable to climate change and variability. Variability in the amount and timing of precipitation drives ecosystem functioning throughout the western region. Precipitation variability occurs at many overlapping space and time scales, from seasonal to decadal, due to interactions among three principal climate systems that cause anomalous weather patterns: the Pacific Decadal Oscillation (PDO), El Nino-Southern Oscillation (ENSO) and the North American Monsoon (NAM). Other weather patterns operating at different frequencies may yet be described (the PDO was only defined in 1996). Identifying the contribution of anthropogenic forcing in the presence of climate systems of such extreme variability and complexity remains a significant challenge.

Climate change in the form of global warming has been documented to be unequivocal by the recent Intergovernmental Program on Climate Change (IPCC, 2007) from ocean and atmospheric temperatures, melting of glacier and ice, and rising sea levels. Consistent with observations of arctic warming two times the global average (up to 3°C since 1980s in permafrost and summer melting of the arctic sea ice), nowhere in the United States has the impact of climate change become as evident as in Alaska during the NIGEC era.

II. WESTGEC CENTER HISTORY

WESTGEC began functioning in 1989 under the joint leadership of Dr. Marvin Goldman, a professor of radiation and toxicology at the University of California Davis and Dr. F. Sherwood Rowland, the Donald Bren professor of chemistry at University of California Irvine and noble prize recipient for his path-finding work on atmospheric chemistry, particularly ozone chemistry. Administrative centers were placed on both campuses. In 1989 WESTGEC held three workshops to (1) explore global climate change and its effects on California, (2) energy policies to address global climate change, and (3) Pacific Rim research development strategies related to global climate change. In this early period, the program was California centered. WESTGEC held its first call for proposals in 1990 after establishing its administrative structure in 1989.

On January 1, 1994, Dr. Thomas Suchanek, an ecologist-ecotoxicologist from UC Davis became the second director of WESTGEC. The appointment of Dr. Suchanek to lead WESTGEC was an outgrowth of changing research priorities associated with environmental priorities of the Clinton administration. Following Dr. Suchanek's appointment, the UC

Irvine office was closed, and the UC Davis WESTGEC office was moved from its off-campus co-location with the NIGEC office to the Division of Environmental Studies on the Davis campus, where Dr. Suchanek held an academic appointment. The physical separation of the NIGEC and WESTGEC offices was intended to eliminate an appearance of bias favoring the Western Region, relative to the other NIGEC Centers. Dr. Suchanek later transferred to the Department of Wildlife, Fish and Conservation Biology (WFCB) and the WESTGEC office was transferred with him.

Late in 1994, Dr. Susan Ustin, an ecologist with expertise in remote sensing and an Assistant Professor in the Department of Land, Air, and Water Resources at UC Davis was appointed Acting Associate Director of WESTGEC and Associate Director in 1995. Dr. Ustin remained as Associate Director of WESTGEC until she was appointed to succeed Dr. Suchanek as Director in 2002. The WESTGEC office continued to be located in WFCB space from 2001 until 2005 when it was moved to its current location in "The Barn" and was finally co-located with Dr. Ustin. Dr. Robert Pearcy, a plant ecophysiologist and Professor of physiological ecology in the Section of Evolution and Ecology was appointed Associate Director in 2002, a position he held until his retirement in 2006.

III. WESTGEC'S STRATEGIC VISION

The research themes and objectives of WESTGEC were established by DOE with program directors having latitude to modify the overarching NIGEC goals to meet regional science objectives. Throughout its history, the primary objectives of WESTGEC were to promote high-quality, innovative interdisciplinary research related to global climatic change. In 1990 the theme areas established by Goldman and Rowland were: (1) Agricultural, hydrological and ecological effects of global climate change, (2) Atmospheric and oceanographic modeling of global climate change, (3) Climate forcing by trace gasses, (4) Impact assessment and communication pertaining to global environmental change and (5) Policy/education and the human dimension in response to global environmental change.

During the first several years of its existence WESTGEC research focused primarily on radiative forcing effects and climate. In 1991 the research themes were modified by combining themes 4 and 5 into one policy and education oriented theme. These research themes continued to be the focus of funding in years 1992 and 1993. Focus was assessment of the impacts of global environmental change, policy/education aspects of the human response to change. The program emphasis was roughly 70-75% in physical and biological science programs, 20-25% in policy related programs, and 5% in educational programs. In 1993 WESTGEC co-sponsored an International Conference on UV Radiation and a Methane Conference.

In 1994-1995, the WESTGEC research themes were modified as: (1) Studies of factors that influence atmospheric concentrations of greenhouse gases with emphasis on geochemical studies that help diagnose global processes affecting greenhouse gases, (2) Studies of the dynamics and variability of terrestrial hydrological factors which influence global climate change, and (3) Studies on the dynamics of the coupling of the atmospheric system with the ocean/land system including the role of aerosols and/or clouds, including relevant chemistry modeling or observational approaches which reduce uncertainties in controlling processes.

In 1995 the Research themes continued to emphasize (1) Radiative forcing effects of greenhouse gases, aerosols, and clouds and their regulation, (2) Quantitative role of the terrestrial biosphere in greenhouse gases and (3) Impacts of climate change on natural and human-influenced systems.

The 1996 NIGEC's research foci emphasized for the first time, development of a coherent focused research program at each of the Centers, in contrast to previous mechanisms that supported funding the highest ranking of existing proposals, following an NSF style funding model. This change in format was undertaken at the direction of the DOE Program Manager for NIGEC, Dr. Jerry Elwood who was concerned that the dispersed funding profile caused NIGEC to loose visibility and leadership in climate change research at the national level. The goal of developing NIGEC focused research was to increase funding that would allow centers to reach a critical mass on the topic of impacts of climate change on terrestrial ecosystems at a level that would be sufficient to "make a difference". It was also hoped that it would lead to increased coordination and cross-collaboration of research among the Regional Centers by sharing common focused research themes. One of the most significant and lasting contributions of NIGEC during this period was the decision by the Regional Center Directors to develop an eddy flux program in each of their regions as an integrating theme for NIGEC focused on climate change and terrestrial carbon. This network rapidly evolved into the large AmeriFlux and Fluxnet networks of flux towers. The WESTGEC supported flux tower (Figure 3) at Wind River is located in one of the most challenging forests in the network (Hargrove and Hoffman, 2004), due to the height of the canopy (~65m), limited fetch, and topographic gradients. As a result of these demands, significant theoretical and measurement advances have been made to handle this complex environment. These advances have led to current NSF NEON planning and deployment for a national flux tower network, many to be placed in heterogeneous and complex environments.

The specific WESTGEC research thrusts in 1996 were (1) Effects of Atmospheric and climatic changes on ecosystems, (2) terrestrial carbon exchange, (3) integrative assessment and lastly (4) radiative forcing effects and climate, although only

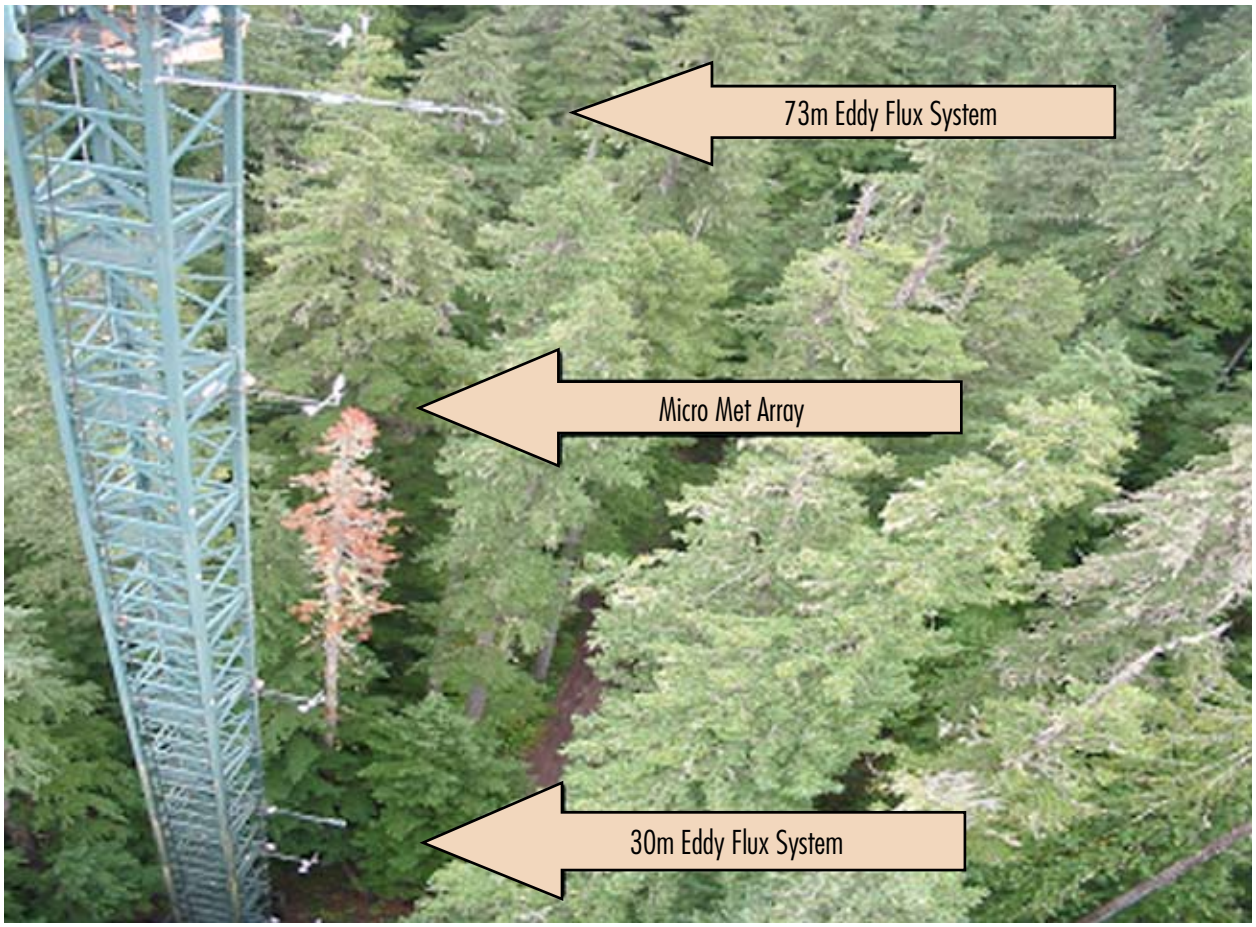


Figure 3. Location of eddy flux systems on the Wind River Crane.

the first two were emphasized due to the decision to focus research at particular sites.

Because forests are a dominant component of the economies of the western states and play a significant role in carbon management, WESTGEC placed a high priority on forest research in response to global change processes. The site selected to be the center of the WESTGEC focused program was the Wind River Canopy Crane Research site, located in the T.T. Munger Research Natural Area within the Gifford Pinchot National Forest of southwestern Washington. This site was chosen because it represented a different type of forest system (old-growth evergreen conifer forest) than forest types in other Regional Centers, but also because the remaining old-growth forest emblematic of the Western Region and has become a totem representing ecological stewardship and sustainable management. The old growth forest represents an end-point on the carbon continuum and the WESTGEC site is a ~500 year old forest dominated by Douglas-fir and western hemlock, the primary and climax successional species of the Western Hemlock forest ecosystem. Due to longevity of these forest species, it is only at this stage of mature development that the dominance of the primary successional species, Douglas-fir is transitioning to dominance of western hemlock, the climax forest type of this region. These forests are the dominant ecosystem of the middle-elevation western slopes of the Cascades and Northern Sierra Nevada Ranges and the interior Coast Ranges of the Pacific Northwest. The site is the location of an 85m tall construction crane which was erected to allow three-dimensional access to this 65m tall forest. The eddy flux study at Wind River was initiated in 1997 and has remained operational to 2007. WESTGEC also maintained a small program at the Sky Oaks Free Air CO_2 Experiment (FACE) program in southern California, a mixed chaparral ecosystem, during the mid-nineties until 2001.

WESTGEC also initiated a secondary focal site area, the Pacific coastal marine ecosystem. The extensive coastline of the Western Region makes this a dominant ecosystem of the WESTGEC Region and one identified to be at risk for actual and predicted climate change. The emphasis for these studies was on community impacts, particularly linked to paleoclimate and paleobiologic data and to those examining climate impacts on extant populations.

From 1997 to 2000 the two thrust areas for WESTGEC were (1) terrestrial carbon exchange which was focused on the Wind River conifer forest ecosystem and (2) effects of climate change on ecosystems which were focused on the coastal margin ecosystem and to a lesser effect on other forest ecosystems. WESTGEC also supported an educational curriculum project through the Globe program at this time.

The original concept developed by Suchanek and Ustin for WESTGEC's direction was to develop a series of studies from Alaska to Mexico that would lead toward a comprehensive understanding of the impacts of climate change on major Pacific Coast ecosystems. While limited funding prevented accomplishing the full implementation of this goal, it remained our vision until the termination of NIGEC.

From 2001 to 2004 the two thrust areas for WESTGEC were (1) terrestrial carbon exchange which was focused on the Wind River conifer forest ecosystem and (2) effects of climate change on ecosystems, and the emphasis on coastal marine ecosystems was discontinued. The work was primarily focused at Wind River and emphasized an integration of above ground canopy and ecosystem processes, at and below ground processes, and ecosystem level processes and modeling. The success of this effort led to special journal issues in *Tree Physiology*, *Ecosystems* and *Tree* that integrated much of the research WESTGEC funded at this site.

In 2005 and 2006 WESTGEC was encouraged to broaden its research portfolio to include other areas within the region. WESTGEC's strategic vision in 2005 emphasized (1) understanding the mechanisms of carbon dynamics and response to climate change in Northwest conifer forests of various ages, (2) understanding carbon dynamics in other ecosystems of the western U.S. and contrasting these with NW conifer forests, and (3) understanding ecosystem sensitivity to climate change and variability through manipulative experiments.

The primary focus of WESTGEC's research program at this final stage emphasized to a greater extent, regional ecosystem responses in relation to actual or predicted climate change and modeling. A significant element was to provide local to regional scale data on the flux of carbon dioxide within forest and woodland ecosystems of the west. Studies expanded to include climate reconstruction of forest growth rates in Alaska and the Pacific region, interactions with pathogens and insects in Alaska, Washington and Oregon, research at the Nevada FACE and Global Change Facility, and new flux tower and biogeochemical cycling studies in the central Sierra Nevada range of California.

IV. STRUCTURE AND SCOPE OF WESTGEC PROGRAM

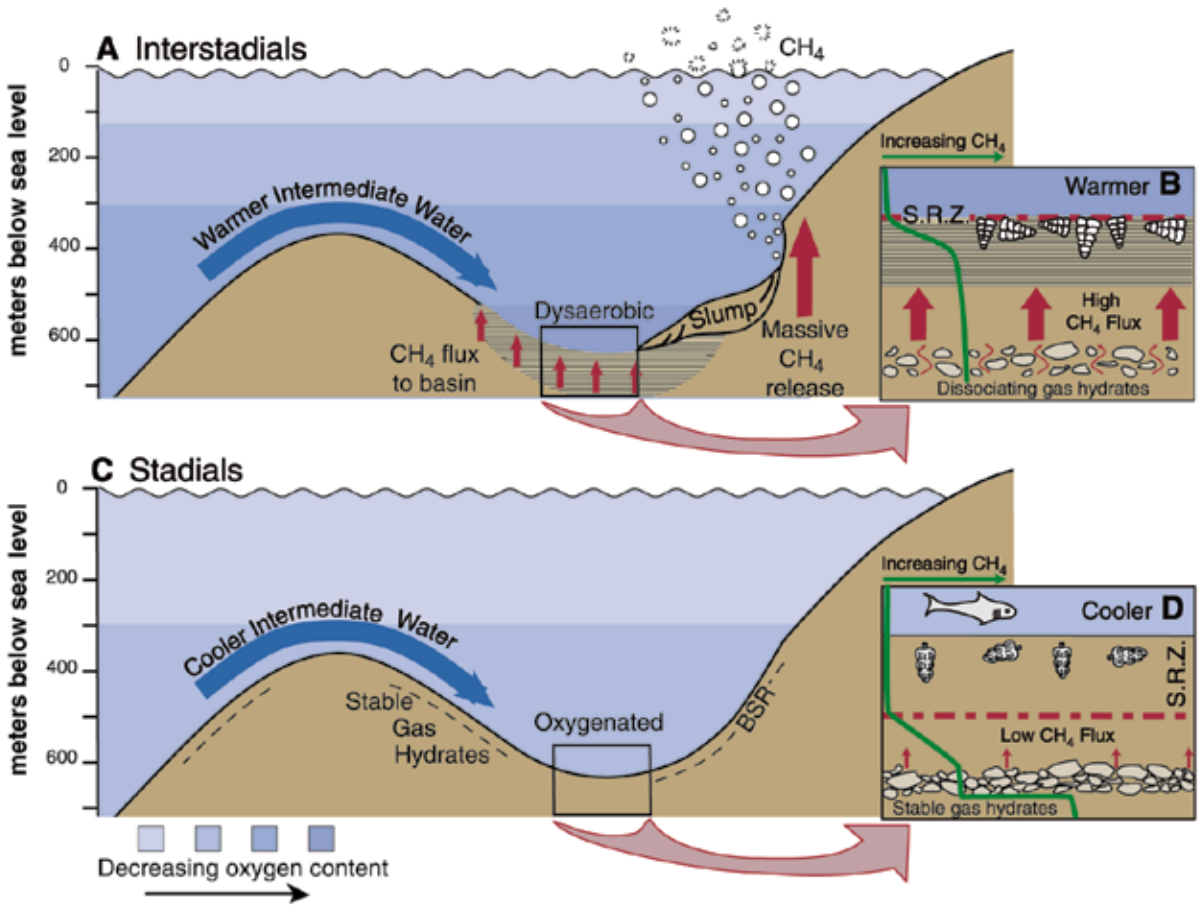
From the beginning in 1989, WESTGEC worked with DOE to determine the research thrusts and a regional advisory board to help focus the research for the region. A Request for Proposals (RFP) was issued, with evaluation from peer mail reviews and or a regional panel was established to aid the directors in reviewing and guiding proposal selection to achieve an integrated program. In most years a preproposal was used to provide initial screening of projects for suitability and consistency with the RFP. In later years, because of declining funding and the increasing integration of the program, the number of full proposals declined (also due to preproposal screening). Nonetheless, typically the number of proposals ranked fundable was three to ten times the number of projects that could be approved. In the first funding year (1990-1991) 14 projects were funded with a budget of $1,283,000. WESTGEC had a maximum of 28 PIs in 1991-1992 and budget of $2,013,069. The least number of PIs funded occurred in 2002-2003 with only nine funded projects and a budget of $1,240,158. Over the 17 years of NIGEC, WESTGEC funded 255 Principal Investigators (Appendix B), averaging 16 per year from 29 universities at a total budget of $22,320,004.

V. MAJOR ACCOMPLISHMENTS OF WESTGEC RESEARCH 1990-2007

Throughout its existence, WESTGEC's research mirrored research foci of DOE's Office of Biological and Environmental Research (OBER). During the early years of WESTGEC research focused on atmospheric chemistry and aerosols. This emphasis was phased out starting in 1994 and for most of the remaining years of WESTGEC, research focused on environmental impacts of climate change and variability and feedbacks to the climate system. In the final two years of WESTGEC, our program had resumed interest in and funding of atmospheric aerosol chemistry.

WESTGEC has funded a large number of notable research projects that have made major contributions to understanding global change. We cite three different types of research to illustrate the range of these contributions: atmospheric aerosols, paleoclimate and marine coastal margin, and eddy flux responses in terrestrial ecosystems.

Research on trace gases and atmospheric chemistry funded in the early 1990-1995 period significantly contributed to understanding of ozone precursors and other atmospheric pollutants contributing to smog. Research by Blake and Rowland has remained active and in 1995, they published a highly cited paper in Science identifying the previously unrecognized significance of unburned and incompletely combusted liquid petroleum gas as ozone precursors in urban areas, substantially contributing to declining urban air quality in Mexico City, and applicable to many cities in third world countries. In the final year of the WESTGEC program, we returned full-circle to include a focus on aerosol chemistry. It is premature to judge the significance of the two projects we funded. However, in this final period we supported Alan Goldstein's AmeriFlux site at Blodgett Forest, California whose research demonstrated the

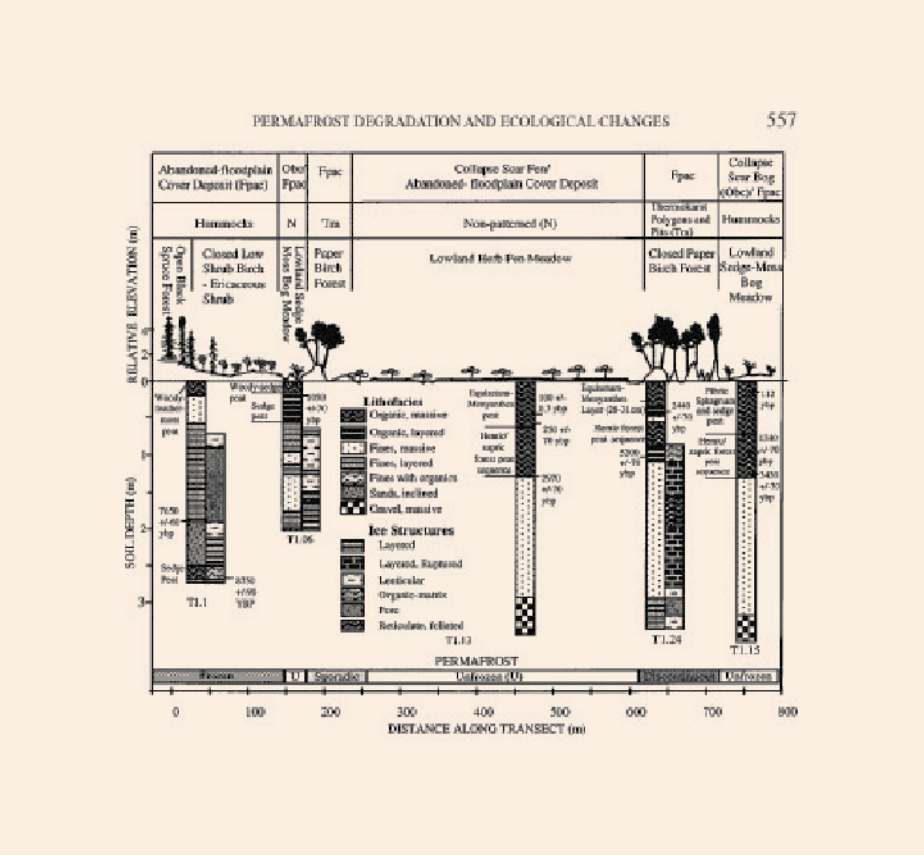


Schematic diagram illustrating stadial-interstadial modes of CH4 flux for Santa Barbara Basin. (A and B) During interstadials, warmer intermediate waters destabilized gas hydrates and activated CH4 flux through basin sediments. This led to increased upward CH4 flux through surface sediments to basin bottom waters. Episodic deroofing of gas hydrates caused massive CH4 releases into water column and atmosphere [bubbles in (A)]. (C and D) During stadials, cooler intermediate waters lead to gas hydrate stability and build-up, an expanded sulfate reduction zone (S.R.Z.), and reduced upward CH4 flux into basin. Green line in (B) and (D) represents inferred CH4 gradient within sediments. Changing flux rates through basin sediments are reflected by the 13C of benthic foraminifera and faunal composition of assemblages living in surface and near-surface sediments (A, B, and D). BSRs are bottom-simulating reflectors inferred to represent gas accumulations beneath gas hydrates. [Figure and legend from Kennett et al., 2000]

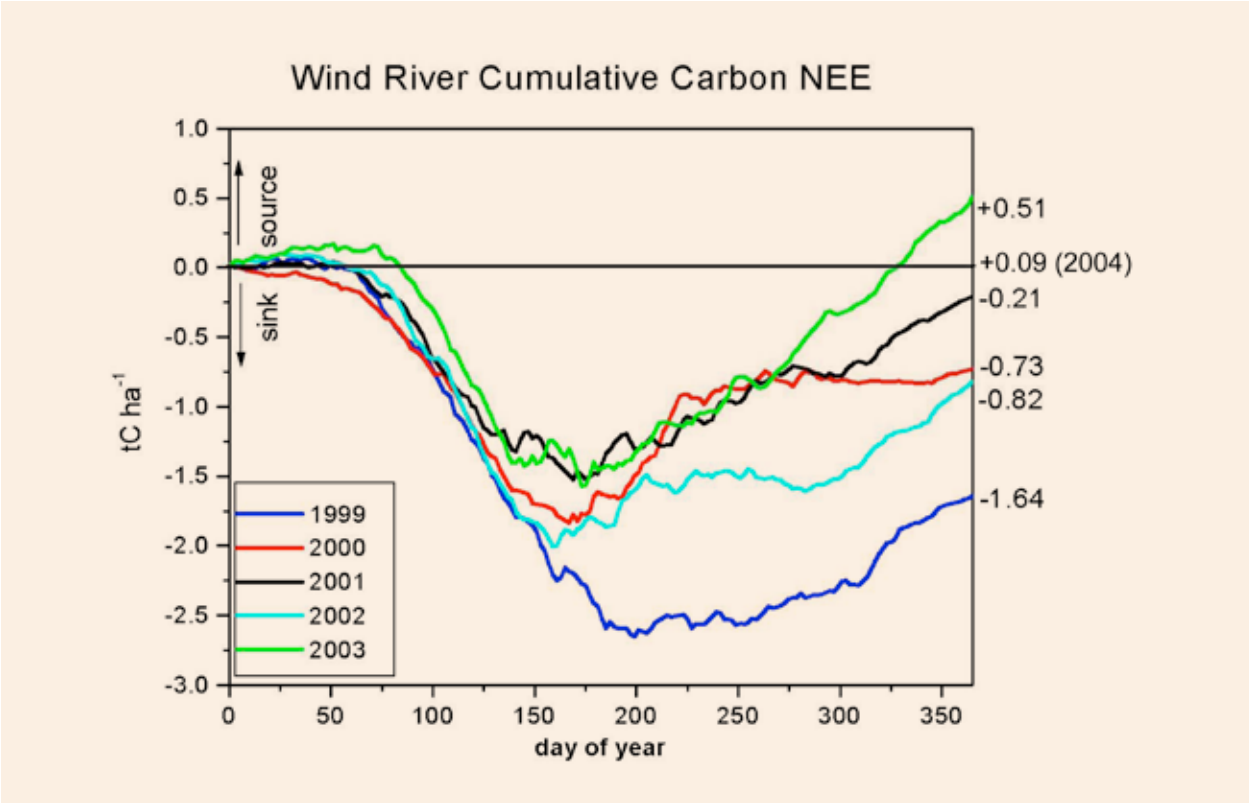
impact of aerosols on the radiation budget and consequent inhibition of photosynthesis and NEE on western forests. Lastly, we funded Lynn Russell whose project extended the earlier work by Blake and Rowland examining air chemistry in Mexico City.

To develop a better understanding of past global changes and evaluate the dynamic interactions between ocean and atmosphere, in the middle years (1992-2001) WESTGEC supported research on past climates with particular focus on factors related to abrupt climate change. Among these studies, Kennett and colleagues (2000) identified large and rapid oscillations in atmospheric methane in relation to climate warming epochs, derived from unstable methane hydrate, marine clathrate deposits. This highly cited study has spurred extensive research into this previously unrecognized climate forcing mechanism leading to rapid increases in atmospheric methane concentrations. Seasonal and interannual climate variability in coastal upwelling e.g., conditions related to El Niño and La Niña cycles, along the continental shelf and from deepwater canyons have been shown to have major impacts on plankton productivity and the highly productive ocean margin ecosystem. Croll et al. (2005) demonstrated the dependence between this productivity and blue whale (as top ecosystem predators) foraging that depends upon this productivity.

Another area of WESTGEC accomplishment is related to research on climate warming on permafrost in Alaska. Among all regions in the U.S., Alaska alone has experienced strong and directional changes in temperature and climate in the past half-century. Osterkamp and colleagues have published a series of highly cited papers that have identified the impact of warming on discontinuous permafrost and its implications for the active soil layer and consequent ecological implications



Toposequence at Transect 1 illustrating the relationships among topography, geomorphology, surface form, vegetation, soil stratigraphy, and permafrost. For each core, lithofacies are portrayed in left column and ice structure in right column when present. [Figure from Jorgenson et al. 2001]



Biomicrom eteorological estimates of cumulative old-growth forest-atmosphere net ecosystem exchange as a function of day-of-year from January 1999 through December 2003. The data shown include a correction for low wind speed conditions, using a soil temperature-respiration model typically used in most other eddy-covariance studies. [Paw U et al. unpublished results]

for the dominant boreal black spruce forest ecosystem (Zhang et al., 1997; Osterkamp and Romanovsky, 1999; Osterkamp et al., 2000; Jorgenson et al., 2001). The 2007 IPCC summary report concludes that permafrost temperatures have increased by up to 3ºC, with the seasonal area of permafrost decreasing by 7% since 1900 and earlier spring thaw (spring decrease in area of 15%).

In the mid-1990s, the NIGEC regional directors were challenged by DOE to find a mechanism to develop greater institutional recognition. We chose to focus on regional climate impacts on the carbon budgets of significant ecosystems within each region using eddy flux measurements but which could contribute to establishing a national carbon budget. Over the past decade, WESTGEC focused on climate change impacts on carbon dynamics in conifer forests in the Cascade Mountains of Washington and Oregon. At the time we started the dominant paradigm was that it was possible to characterize a "standard state" for carbon dynamics of different ecosystems after a period of observation, likely a length of a few years. In 1993 Oechel et al. published a significant paper showing that arctic tundra ecosystems had switched from a carbon sink to a source in response to warmer summer temperatures. At the time only Harvard Forest had been instrumented and followed continuously for more than one year. We now know that for most ecosystems carbon sequestration and release is highly dynamic in response to variability in weather and climate at scales of seasons to years.

The conifer forests in the Pacific Northwest represent the endpoint of several important ecological gradients/biophysical parameters: oldest age, greatest biomass, height, leaf area index, structural complexity, gross primary productivity and lowest albedo of all global forest biomes. The old-growth conifer forests in Washington today occupy 4.12 million hectares or ~17% of the area at the time of western settlement. Globally, rapid harvesting has changed the age class distribution of forest ecosystems, without a clear understanding of the consequences of this activity on their carbon budgets. This opened the opportunity to evaluate the carbon sequestration of an old-growth forest and contrast it with younger forests, presumably having higher rates of carbon sequestration. The prevailing paradigm was that young forests are the largest sinks of atmospheric carbon and mature forests are carbon neutral or sources of atmospheric carbon and that in the absence of directional change, ecosystems have characteristic and predictable patterns of sequestration. To investigate this question, WESTGEC funded a tightly focused series of projects to examine constraints on forest productivity in an old-growth forest using complementary and independent approaches at scales from leaf to branch to stand levels. Estimates of forest productivity were compared using four independent approaches over a wide range of spatial and temporal scales: (1) a ground-based approach combining inventory data with estimated respiration rates (Parker et al., 2004), (2) an eddy covariance approach measuring stand level CO_2 fluxes (Paw U et al., 2004), (3) a leaf model scaling up from short-term leaf-level measurements to annual net photosynthesis at the ecosystem level (Winner et al., 2004), and (4) an ecosystem model to explore the balances of energy, water and carbon (Field and Kaduk, 2004). In addition, remotely sensing biomass and water flux estimates were scaled from leaf to landscape levels (Roberts et al., 2004).

This ecosystem scale study showed for the first time, a direct comparison of these methods, which were shown to be in full agreement, within the uncertainty or error of their measurement and model systems. This finding is remarkable given the difficulty in applying eddy flux measurements in this forest because of three-dimensional complexity of this ecosystem, including tree height (65 m), fetch problems, and the surrounding terrain relief. This ecosystem was demonstrated to have exceptionally dynamic variability in inter-annual net ecosystem exchange (NEE), with rapid shifting between source and sink states, in response to climate variability (Paw U et al., 2004). The evidence for rapid inter-annual shifts in sink strength, even switching between sources and sinks has triggered research at other sites, investigating flux data for similar patterns. This variability is a common occurrence and a consequence of climate variability, requiring many years of observations to determine the magnitude of fluxes and the direction of change. Among WESTGEC investigators, Oechel (Luo et al., 2007) has shown strong variability in sink strength in semi-arid chaparral and Baldocchi et al. (2006) has shown similar patterns in soil respiration in a grassland-savanna in the foothills of the Sierra Nevada Mountains. Besides significant advances in understanding western ecosystem responses to climate variability, WESTGEC research has made major contributions to the Ameriflux program in understanding advective flows in complex mountainous terrain and calculating nighttime fluxes under low windspeed conditions, which are key factors in correctly estimating NEE (Paw U et al., 2000; Baldocchi et al., 2000).

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WESTERN REGIONAL CENTER (WESTGEC)
Research Programs

PI & Co-I	Institution	Project	Years Funded
AMUNDSON, Ronald Susan Trumbore	University of California, Berkeley Universtiy of Calirornia, Irvine	Climate and Land use controls on Carbon turnover rates in soils of the Sierra Nevada, California.	1994-1996
ARAKAWA, Akio Carlos R. Machoso	University of California, Los Angeles	Parameterization of convective down drafts and its applications to numerical simulations of global hydrology	1991-1992
ARAKAWA, Akio Carlos R. Machoso	University of California, Los Angeles	Development of an improved cumulus parameterization and its applications to numerical simulations of global hydrology.	1992-1993
BALDOCCHI, Dennis	University of California, Berkeley	Roles of temperature, soil moisture, rain events and plant functional type on carbon exchange of oak-grass savanna ecosystems at two AmeriFlux sites in California	2003-2006
BALDWIN, Ransom C.C. Calvert	University of California, Davis	Modeling analyses of methane and emissions from ruminants.	1990-1992
BALDWIN, Ransom	University of California, Davis	Modeling analyses of methane and emissions from ruminants.	1991-1992
BARRETT, Katharine	University of California, Berkeley	Global Systems Science: final review and publication.	1998-1999
BARTLEIN, Patrick Cathy Whitlock	University of Oregon	Potential magnitude and rate of future vegetation change in the western United States in response to global warming.	1992-1993
BERGER, Wolfgang Arndt Schimmelmann,	University of California, San Diego University of California, San Diego	History of sea surface temperature and El Nino intensities off southern California on an annual to biannual scale, A.D. 1450-1910.	1992-1993
BERK, Richard Robert Fovell	University of California, Los Angeles	Estimating the costs of climate change on a regional scale	1994-1995
BERTNESS, Mark S. Pennings	Brown University Univiversity of Georgia	Climate driven process and pattern in coastal salt marsh plant communities.	1996-1999
BOND, Barbara Michael Ryan Mathew Williams	Oregon State University U.S. Forest Service Marine Biological Laboratory, Woods Hole	Stand age, productivity and hydraulic conductance of Douglas-fir in the Wind River Basin.	1998-2004
BORYS, Randal Douglas Lowenthal David Mitchell	Desert Research Institute, University of Nevada	The relationship between CCN chemistry, CCN sources, cloud microphysics, and precipitation in the eastern Sierra Nevada.	1993-1995
BOTKIN, Daniel Robert Nisbet	University of California, Santa Barbara	The relationship between CCN chemistry, CCN sources, cloud microphysics, and precipitation in the eastern Sierra Nevada.	1990-1991
CAYAN, Daniel	University of California, San Diego	Recent trends in plankton in the California current: Global change or natural variability?	1996-1998
CHAPIN, Stuart	University of California, Berkeley	Effects of treeline movement in the circumpolar Arctic on global climate change.	1995-1996
CHARLSON, Robert David S. Covert	University of Washington	Design and installation of a monitoring station for assessing the impact of anthropogenic aerosols on climate.	1991-1992

CHARLSON, Robert David S. Covert	University of Washington	Measurement and assessment of the impact of anthropogenic aerosols on climate.	1992-1993
CHARLSON, Robert David S. Covert	University of Washington	Analysis of the measured variability in integral aerosol properties in the marine boundary layer.	1993-1994
CHEN, Jiquan	Michigan Technological University	Continuing Carbon and Energy Budget Exchange Measurements at the Wind River Crane Facility	1997-1998
CICERONE, Ralph Mary Lidstrom	University of California, Irvine California Institute of Technology	Search for marine sources of atmospheric nitrous oxide.	1991-1992
CICERONE, Ralph Mary Lidstrom	University of California, Irvine California Institute of Technology	Search for marine sources of atmospheric methyl halides.	1992-1993
COAKLEY, James Gang Luo	Oregon State University	Empirical model for the effect of clouds on the earth's radiation budget.	1991-1992
COOPER, Charles	San Diego State University	Effects on Alaska ecological and social systems of observed warming, 1961-1990.	1993-1994
CRAIG, Harmon Kyung-Ryul Kim	University of California, San Diego	Isotopic characterization of the sources of atmospheric nitrous oxide.	1991-1993
CRAIG, Paul Mark Levine	University of California, Davis Lawrence Berkeley Laboratory	Analysis of global energy studies.	1990-1991
CROLL, Donald B. Marinovic M. Mangel	University of California, Santa Cruz	Climate change and trophic links in coastal upswelling centers.	1999-2000
D'ARRIGO, Rosanne Gordon Jacoby	Columbia University	Response of Pacific Northwest and Alaskan Forests to Recent Multiple Environmental Changes.	2002-2005
DAWSON, Todd	University of California, Berkeley	The effects of rainfall variability on C sequestration and ecosystem-atmosphere CO2 exchange in a California grassland	2003-2006
DENNING, Scott Joseph Berry	University of California, Santa Barbara Carnegie Institution of Washington	Regional and global estimation of terrestrial CO2 exchange from NIGEC flux data.	1997-1999
DICKINSON, Robert Lisa J. Graumlich	University of Arizona	Interactive vegetation for climate models over the seasonal cycle.	1991-1993
EHLERINGER, James	University of Utah	Forest CO2 cycling and global CO2.	1992-1993
EHLERINGER, James	University of Utah	Stable isotope analyses at the Wind River Canopy Crane	1998-2001
EPSTEIN, Samuel	California Institute of Technology	Environmental information in the isotopic record in trees.	1992-1993
EPSTEIN, Samuel Xiahong Feng	California Institute of Technology	Environmental information from the isotopic composition of hydrogen and carbon in the western USA and Alaska.	1993-1995
FEDDEMA, Johannes	University of California, Los Angeles	Assessing the impacts of global warming on California water resources.	1995-1997
FIELD, Christopher Joe Berry	Carnegie Institution of Washington	Linking the CASA and SiB global terrestrial models: Improved estimates of global carbon stocks and fluxes and CO2 responses.	1995-1996
FIELD, Christopher Joe Berry	Carnegie Institution of Washington	Effects of increased CO2 on ecosystem water balance: experimental and modeling studies.	1996-1997
FIELD, Christopher Joe Berry	Carnegie Institution of Washington	Integrating models and data in a synthesis of ecosystem carbon balance in the western United States.	1998-2000

FISHER, Anthony W.M. Hanemann	University of California, Berkeley	Adjusting to global climate change: a theoretical analysis with an application to California water resources.	1994-1995
FISHER, Anthony W.M. Hanemann	University of California, Berkeley	Adjusting to global climate change: managing increased variability in anadromous fisheries in the Pacific Northwest.	1996-1997
FLATAU, P.J	University of California, San Diego	Physics and parameterizations of cirrus clouds.	1993-1995
FOSTER, Theodore	University of California Santa Cruz	Convection in the ocean.	1992-1993
GAINES, Steve Sergio Navarette	University of California, Santa Barbara	Climate change and marine ecosystems: the integrity of biogeographic boundaries.	1995-1996
GAINES, Steve	University of California, Santa Barbara	Climate change and marine ecosystems: the integrity of biogeographic boundaries.	1996-1998
GENG, Shu Richard E. Plant Robert Loomis	University of California, Davis	Analysis and synthesis of models for the effect of climate change on agricultural systems.	1990-1991
GHIL, Michael J. David Neelin	University of California, Los Angeles	Global warming trends and internal climate oscillations: Detection and modeling.	1990-1996
GOLDMAN, Marvin T.E. McKone J.I. Daniels L.R. Anspaugh	University of California, Davis Lawrence Livermore National Laboratory	Critical uncertainties in the links between global environmental change and regional effects: Implications for policies affecting the western U.S.	1991-1992
GOLDSTEIN, Allan	University of California, Berkeley	Carbon exchange in a Ponderosa Pine Plantation: Strategies of Water Use, Seasonality of Plant Physiology, and the Impact of Aerosols on Photosynthesis	2004-2006
GOULD, Alan	University of California, Berkeley	Global Systems Science Science Reviews.	1999-2000
HALL, Anthony E	University of California, Riverside	Interactive effects of heat stress and elevated carbon dioxide concentration on plant reduction.	1990-1992
HARMON, Mark E.	Oregon State University	Seasonal and long-term carbon dynamics of woody detritus in forests surrounding the Wind River canopy crane site.	1996-1999
HARMON, Mark E.	Oregon State University	Controls of autotrophic and heartrot-related respiration in a Western coniferous landscape.	2003-2006
HARTE, John	University of California, Berkeley	Global warming and carbon dioxide: An experimental investigation of ecologically-mediated feedbacks from a terrestrial ecosystem.	1994-1995
HARTE, John	University of California, Berkeley	Global warming and ecosystem carbon storage: combining transect studies of CO2 flux with an experimental investigation of ecologically-medicated feedbacks to climate	1995-1996
HASTINGS, Alan	University of California, Davis	Effects of climate changes on ecological communities in fragmented habitats.	1995-1998
HINCKLEY, Tom	University of Washington	Scaling up from leaf to stands: Coupling ecophysiological models with remote sensing in Populus.	1995-1997
HINCKLEY, Tom	University of Washington	Scaling up from leaf to stands: Coupling ecophysiological models with remote sensing in Populus., deciduous broadleaf, and old-growth Pseudotsuga menziesii evergreen needleleaf.	1997-2000

HIRSCHBOECK, Katherine K.	University of Arizona	A scaling-sensitive strategy for the detection and analysis of changing hydrologic extremes in response to changing global climate regimes.	1992-1993
INGRAM, Lynn B Roger Byrne	University of California, Berkeley	A high resolution analysis of salinity change and wetland development in the San Francisco estuary: 1000 B.P. to the present.	1995-1998
JOHNSTON, Robert	University of California, Davis	An economic analysis of adaptations to global warming and policies to mitigate it in the Sacramento region.	1995-1996
KAVAAS, M.L. Gerald Orlob Henry Vaux	University of California, Davis	Impacts of global warming on the hydrology and the aquatic environment of California.	1990-1991
KAVAAS, M.L. Gerald Orlob	University of California, Davis	Impacts of global warming on the hydrologic and aquatic environment of a mesoscale geographic region.	1991-1992
KEELING, Charles	University of California, San Diego	Possible influence of climate change on recent increase in non-industrial CO2 emissions to the atmosphere.	1991-1992
KEELING, Ralph	University of California, San Diego	Development of field instrumentation for atmospheric oxygen measurements.	1993-1995
KENNETT, James Richard Behl	University of California, Santa Barbara	Relations between catastrophic changes in the benthic ecosystem and late quaternary global climate change, Santa Barbara Basin.	1995-1998
KENNETT, James	University of California, Santa Barbara	California margin marine ecosystem sensitivity studies in response to global climate change during the Holocene and Pleistocene.	1998-2000
KLOPATEK, Jeffrey	Arizona State University	Below-ground carbon pools and processes at the Wind River canopy crane research site.	1995-1997
KLOPATEK, Jeffrey	Arizona State University	Soil and litter carbon processes in old-growth and young plantation Douglas-fir ecosystems.	1998-2000
KOONIN, Steven E. Harold Zirin	California Institute of Technology	Earthshine measurements of the global albedo.	1993-1995
KREIDENWEIS, Sonia	Colorado State University	Development of a gas-to-particle conversion model for use in three-dimensional global sulfur budget studies.	1991-1992
LAL, Devandra	University of California, San Diego	Exploring the use of cosmogenic 10Be and 36Cl as tools for delineating extreme natural prehistoric variability in the polar stratosphere, related to volcanic aerosol, Cl and 03 chemical reactions.	1993-1995
LAMB, Brian Hal Westberg Candis Claiborn	Washington State University	The role of volatile organic emissions in terrestrial carbon exchange.	1996-2000
LETTENMAIE, Dennis	University of Washington	Parsimonious parameterization of land hydrology for climate models.	1993-1995
LEVINE, M.D.	Lawrence Berkeley Laboratory	Energy, energy policy, and greenhouse warming in China.	1990-1991
MOONEY, Hal Peter M. Vitousek Christopher Field Joseph Berry	Stanford University Stanford University Carnegie Institution of Washington Carnegie Institution of Washington	Plant and ecosystem respiration in a changing climate: modeling and empirical studies.	1991-1993

MOONEY, Hal	Stanford University	Carbon partitioning with an emphasis on the below-ground component: an integrated view with the SIB Model.	1998-1999
MOONEY, Hal	Stanford University	Root distribution, phenology, and carbon balance.	1999-2000
OECHEL, Walter	San Diego State University	Effects of global climate and atmospheric change on the structure and function of Mediterranean shrub ecosystems and associated forest ecotones in California.	1991-1993
OECHEL, Walter	San Diego State University	Impacts of global change on CO2 source/sink activity, H2O Flux, function, and structure of semi-arid shrubland ecosystems.	1995-1996
OECHEL, Walter	San Diego State University	Response of carbon balance in Adenostoma fasciculatum- dominated chaparral to elevated atmospheric CO2 using free-air CO2 enrichment (FACE) technology.	1996-1998
OECHEL, Walter	San Diego State University	Effects of elevated CO2 on the structure and function of a semi-arid ecosystem using FACE technology.	1998-2000
OSTERKAMP, Thomas Keith Van Cleve Mary Edwards David Hopkins Yuri Shur Leslie Viereck	University of Alaska Fairbanks	Ecological consequences of thermokarst development in boreal forests.	1995-1996
OSTERKAMP, Thomas Yuri Shur Leslie Viereck Richard Boone	University of Alaska Fairbanks	Ecological consequences of thermokarst development in boreal forests.	1996-1998
PAW U, Kyaw Tha Susan Ustin J. Chen	University of California, Davis University of California, Davis Michigan Technological University	Instrumentation proposal, crane site.	1995-1997
PAW U, Kyaw Tha Susan Ustin Ted Hsiao Thomas Suchanek Roger Shaw Jiquan Chen	University of California, Davis Michigan Technological University	Continuing carbon and energy budget exchange measurements at the Wind River Crane Facility	1997-2000
PAW U, Kyaw Tha Susan Ustin Ted Hsiao Thomas Suchanek Roger Shaw Jiquan Chen	University of California, Davis University of Toledo	Micometerological Studies and long-term carbon and energy exchange at the Wind River Canopy Crane Research Facility.	2000-2003
PAW U, Kyaw Tha Susan Ustin Ted Hsiao Shu-Hua Chen Bryan Weare Monique Leclerc	University of California, Davis University of Georgia	Regional scale modelling and turbulence measurements of long-term carbon and energy exchange.	2003-2006
PERRY, David A. William Winner	Oregon State University	Forests as sinks for, or sources of, atmospheric CO2 the role of warming-induced soil nitrogen transformation.	1992-1993

PUSHNIK, James Richard Demaree James Houpis Paul Anderson	California State University, Chico	Sink-source characteristics of two distinctly different forest species as affected by elevated carbon dioxide.	1992-1993
PUSHNIK, James Richard Demaree James Houpis Paul Anderson	California State University, Chico	Sink-source characteristics of two distinctly different forest species as affected by elevated carbon dioxide. (Phase 2: Interactions with available soil moisture).	1993-1994
PUSHNIK, James Richard Demaree James Houpis Paul Anderson	California State University, Chico	Sink-source characteristics of two distinctly different forest species and riparian species as affected by elevated carbon dioxide and soil moisture.	1994-1995
REEBURGH, William	University of California, Irvine	Sensitivity of tundra methane emissions to water table level: Field manipulation experiments at different sites.	1992-1993
REEBURGH, William	University of California, Irvine	Sensitivity of tundra methane emissions to water table level: Continued field manipulation experiments at permanent sites.	1994-1996
ROADS, John Shyh-Chin Chen	University of California, San Diego	A study of hydrological extremes in California.	1991-1992
ROADS, John Shyh-Chin Chen Duane Stevens	University of California, San Diego University of Hawaii	Regional climatologies of California and Hawaii.	1993-1994
ROBERTS, Dar Susan Ustin	University of California, Santa Barbara University of California, Davis	Scaling up from leaves to stands: coupling ecophysiological and hydrological models with remote sensing.	1998-2000
ROWLAND, F.S.	University of California, Irvine	Global studies of trace gas concentrations.	1990-1991
ROWLAND, F.S.	University of California, Irvine	Global studies of trace gas concentrations: measurement of the oxidative capacity of the Earth's atmosphere.	1991-1993
ROWLAND, F.S. Donald Blake	University of California, Irvine University of California, Irvine	Global studies of trace gas concentrations in urban locations.	1993-1995
ROY, Barbara (Bitty)	University of Oregon	Will global warming alter plant parasite loads in the boreal understory?	2004-2006
RUSSELL, Lynn	University of California, San Diego	Organic Aerosol Effects on Radiative Forcing of Climate	2005-2006
SARACHIK, Edward	University of Washington	Advective and convective ocean ventilation processes in climate changes.	1993-1996
SARACHIK, Edward F.L. Yin,	University of Washington	The role of the ocean in climate variability: Ocean ventilation processes, thermohaline variability and feedbacks of the ocean to ice and to the atmosphere.	1993-1996
SHERWOOD, F. Rowland, F.S.	University of California, Irvine	Global studies of trace gas concentrations.	1990-1991
SHERWOOD, F. Rowland, F.S.	University of California, Irvine	Development of an experiment to measure the oxidation capacity of the Earth's atmosphere.	1990-1991
SHERWOOD, F. Rowland, F.S.	University of California, Irvine	Global studies of trace gas concentrations in urban locations.	1992-1994
SNEIDER, Cary	University of California, Berkeley	Phase 2: development of Global Systems Science, an interdisciplinary course for high school students.	1994-1995

SNEIDER, Cary	University of California, Berkeley	Global Systems Science, an interdisciplinary course for high school students.	1995-1997
SNEIDER, Cary	University of California, Berkeley	Global Systems Science: The role of scientific collaboration in understanding atmosphere-biosphere interactions.	1997-1998
SOMERVILLE, Richard Pares-Sierra, A.	University of California, San Diego	Modeling the response of the California current system to global greenhouse warming.	1990-1992
SOONG, Su-Tzai Robert Lee W. Lawrence Gates Marvin Dickerson Michael MacCracken Jim Kao Sumner Barr	University of California, Davis Lawrence Livermore National Laboratory Los Alamos National Laboratory	Global greenhouse forcing of the California climate.	1990-1991
SOONG, Su-Tzai Robert Lee Marvin Dickerson	University of California, Davis Lawrence Livermore National Laboratory	Effects of global warming on California climate.	1991-1992
STAMNES, Knut Thomas Osterkamp Tingjun Zhang	University of Alaska Fairbanks	An investigation of atmosphere-land interactions under Arctic conditions.	1993-1995
STAMNES, Knut Tingjun Zhang	University of Alaska Fairbanks University of Alaska Fairbanks, 1995-1997 University of Colorado, 1997-1998	Investigation of the impact of climate change on the ecosystem at high latitudes.	1995-1998
STARK, Lloyd	University of Nevada	The Effects of Global Change and Disturbance on the Health and Regeneration of the Mojave Desert Biological Soil Crust	2004-2006
STONE, Jeffrey	Oregon State University	The effects of a foliar fungal pathogen on carbon dioxide flux within a forest ecosystem	2001-2004
STONE, Jeffrey	Oregon State University	Factors influencing the distribution of a foliar fungal pathogen and its effect on carbon dioxide flux in multiple~aged Douglas-fir forests	2004-2006
STUIVER, Minze	University of Washington	Holocene 13C, climate and carbon cycling.	1993-1995
TUNG, Ka Kit Margaret Brown	University of Washington	Objective deduction of the spatial and temporal distribution of the methane sources.	1993-1995
UNSWORTH, Michael H. Danny Marks	Oregon State University U.S. Geological Survey	Measurement and modeling of soil moisture in relation to the carbon exchange at the Wind River Canopy Crane Research Facility.	1997-2000
USTIN, Susan Dar Roberts Thomas Hinckley	University of California, Davis U.C. Santa Barbara University of Washington	Scaling up from leaf to stands; coupling ecophysiological models with remote sensing observations.	1995-1998
USTIN, Susan Michael Whiting	University of California, Davis	Hyperspectral Measurements of Surface Soil Inorganic Carbon and Biological Crust under Experimental Climate Change Treatments at the Desert FACE Experiment and Mojave Desert Global Change Experiment	2004-2005
USTIN, Susan Michael Whiting	University of California, Davis	Quantifying Surface Soil Inorganic Carbon and Biological Crust	2005-2006
VEROSUB, Ken	University of California, Davis	Correlation of continental and marine paleoclimate records using the paleointensity of the geomagnetic field.	1991-1993
VEROSUB, Ken Andrew Roberts	University of California, Davis	Correlation of marine and continental paleoclimate records.	1993-1994
VEROSUB, Ken	University of California, Davis	Analysis of data: Paleoclimate records.	1994-1995

WAHLEN, Martin	University of California, San Diego	D18O of atmospheric CO2 within coniferous forest canopies.	1996-1997
WEARE, Bryan	University of California, Davis	Uncertainties in ISCCP C1 cloud/radiation feedback parameters.	1990-1991
WEARE, Bryan	University of California, Davis	Comparisons of observed and model cloudiness and model climate sensitivity.	1993-1996
WESTBERG, Hal Kris Johnson Brian Lamb	Washington State University	Methane emissions from ruminant livestock.	1993-1994
WINNER, William	Oregon State University	Canopy photosynthetic and respiration processes in Pacific Northwest forests.	1996-1997
WINNER, William Sean Thomas	Oregon State University University of Washington	Canopy photosynthetic and respiration processes in Pacific Northwest forests.	1997-1999
WINNER, William Sean Thomas	Oregon State University University of Washington	Carbon uptake in relation to climate variation in an old growth coniferous forest.	1999-2000
YUNG, Y. L. Mark Theimens	California Institute of Technology University of California, San Diego	Isotopically labeled CO2 from the stratosphere: a tracer of carbon biogeochemistry.	1991-1991

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Abdulla F. A. and Lettenmaier D. P. (1997), Development of regional parameter estimation equations for a macroscale hydrologic model, *Journal of Hydrology, 197*(1-4): 230-257.

Abdulla F. A. and Lettenmaier D. P. (1997), Application of regional parameter estimation schemes to simulate the water balance of a large continental river, *Journal of Hydrology, 197*(1-4): 258-285.

Abdulla F. A., Lettenmaier D. P., Wood E. F., and Smith J. A. (1996). Application of a macroscale hydrologic model to estimate the water balance of the Arkansas Red River basin, *Journal of Geophysical Research-Atmospheres, 101*(D3): 7449-7459.

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Appendix A: NIGEC Principal Investigators

PRINCIPLE INVESTIGATOR	INSTITUTION(S)
Aber, John D.	University of New Hampshire
Abt, Robert C.	North Carolina State University
Achuta Rao, Krishna	Tulane University
Addy, Samuel N.	University of Alabama
Albertson, John D.	University of Virginia
Albertson, John D.	Duke University
Allen Jr., L. H.	USDA-ARS, Gainesville, FL
Allen Jr., L. H.	University of Florida
Allen, Eric R.	University of Florida
Amthor, Jeffrey S.	Lawrence Livermore National Laboratory; Woods Hole Research Center
Amundson, Roland	University of California, Berkeley
Andersen, Jeffrey A.	Michigan State University
Anderson, John	North Carolina State University
Anderson, Paul D.	University of California, Berkeley
Aneja, V. P.	North Carolina State University
Anspaugh, Lynn R.	Lawrence Livermore National Laboratory
Antle, John M.	Montana State University
Arakawa, Akio	University of California, Long Beach
Archer, Steve	Texas A&M University
Arkebauer, Timothy J.	University of Nebraska
Armstrong, Marc P.	University of Iowa
Arnold, David W.	
Arnold, Jeffrey G.	US Meat Animal Research Center, USDA-ARS; USDA - ARS, Temple, TX
Augé, Robert M.	University of Tennessee
Bahrmann, Chad P.	North Carolina State University
Bailey, Mary Timney	University of Cincinnati
Bakwin, Peter S.	University of Colorado
Bakwin, Peter S.	Harvard University
Baldocchi, Dennis	University of California, Berkeley
Baldwin, Roger L.	University of California, Davis
Barford, Carol C.	Harvard University
Barr, Sumner	Los Alamos National Laboratory
Barrett, Katherine	
Barthelmie, Rebecca J.	Indiana University
Bartlein, Patrick J.	University of Oregon
Bartlett, Karen B.	University of New Hampshire
Batchelor, William D.	Iowa State University
Bator, Aaron	University of Illinois at Urbana-Champaign
Battle, Mark	
Bazzaz, Fakhri A.	Harvard University
Behl, Richard J.	California State University, Long Beach
Bell, Stuart R.	University of Alabama
Belnap, Jayne	
Bender, Michael L.	Princeton University; University of Rhode Island
Berger, Wolf H.	Scripps Institution of Oceanography
Berk, Richard A.	University of California, Long Beach
Bernston, Glenn M.	University of New Hampshire
Berry, Joseph A.	Carnegie Institution of Washington, Stanford, CA
Bertness, Mark	Brown University
Beverland, Iain	University of Edinburgh, Edinburgh, Scotland
Bhattacharya, Kaustuve	Tulane University
Bianchi, Thomas S.	Lamar University
Biegalski, Steven	University of Illinois at Urbana-Champaign
Billesbach, David P.	University of Nebraska
Birks, John W.	University of Colorado
Blair, John M.	Kansas State University
Blake, Donlad R.	University of California, Irvine
Blatherwick, Ronald D.	University of Denver
Bledsoe, Caroline	National Science Foundation
Bogardi, Istvan	University of Nebraska
Bohren, Lenora	Colorado State University
Bolstad, Paul V.	University of Minnesota
Bonan, Gordan B.	National Center for Atmospheric Research
Bond, Barbara J.	Oregon State University
Boone, Richard D.	Harvard University; University of Alaska Fairbanks
Boote, Kenneth, J.	University of Florida
Borys, Randolph D.	Desert Research Institute, Reno, NV
Bostrom, Ann	Carnegie Mellon University
Botkin, Daniel B.	University of California, Santa Barbara
Bowman, Kenneth P.	
Boyle, Edward A.	Massachusetts Institute of Technology
Bradley, Raymond S.	University of Massachusetts
Brandle, James R.	University of Nebraska
Braswell, Bobby H.	University of New Hampshire
Brett, C. Everett	University of Alabama
Briske, David D.	Texas A&M University
Broadus, James M.	Woods Hole Oceanographic Institution
Broecker, Wallace S.	Lamont-Doherty Earth Observatory
Brook, George A.	University of Georgia
Brown, Margaret K. M.	University of Washington
Brown, Robert	Battelle Pacific Northwest Laboratories
Brown, Sandra	University of Illinois
Buonora, Paul T.	Lamar University
Burke Jr., Roger A.	USEPA
Burke, Ingrid C.	Colorado State University
Burns, K. L.	North Carolina State University
Buyanovsky, G. A.	University of Missouri
Byrne, Roger	University of California, Berkeley
Cairns, David M.	University of Iowa
Calderia, Ken	Pennsylvania State University
Cambardella, Cynthia	Iowa State University; National Soil Tilth Laboratory
Cameron, Guy N.	University of Houston
Capalbo, Susan M.	Montana State University
Carey, Anne E.	Ohio State University; University of Alabama
Carey, William	Auburn University
Carleton, Andrew M.	Indiana University
Carreiro, Margaret M.	University of Louisville

Carrico, Christian M.	University of Illinois at Urbana-Champaign
Caspersen, John	
Castro, Mark S.	University of Maryland
Cayan, Daniel R.	Scripps Institution of Oceanography
Ce, Huang	Duke University
Chang, Edmund K. M.	Massachusetts Institute of Technology
Chanton, Jeffrey P.	Florida State University
Chapin III, F. Stuart	University of California, Berkelely
Charlson, Robert J.	University of Washington
Chassignet, Eric P.	University of Miami
Chayes, Abram	Harvard University
Chen, Jiquan	University of Toledo
Chen, Jiquan	Michigan Technological University
Chen, Shu-Hua	
Chen, Shyh-Chin	University of California, Long Beach; Scripps Institution of Oceanography
Chen, Tsing-Chang	Iowa State University
Chen, Zuojun	University of Alabama
Cheng, David C.	University of Alabama
Cheng, Wei	University of California, Santa Cruz
Choudhury, Bhaskar J.	NASA, Goddard Space Flight Center
Christensen Jr., Norman L.	Duke University
Christy, John R.	University of Alabama in Huntsville
Cicerone, Ralph J.	University of California, Irvine
Claiborn, Candis	Washington State University
Clark, Kenneth L.	University of Florida
Clark, William C.	Harvard University
Clement, Robert J.	University of Nebraska
Coakley Jr., James A.	Oregon State University
Coe, Michael T.	University of Wisconsin
Cole, C. Vernon	Colorado State University; Natural Resource Ecology Laboratory
Collett Jr., Jeffrey L.	University of Illinois
Conte, Maureen H.	Woods Hole Oceanographic Institution
Cooper, Charles F.	San Diego State University
Cota, Glenn F.	University of Tennessee, Institute of Agriculture
Cotton, William R.	Colorado State University
Covert, David S.	University of Washington
Cox, Gregory N.	University of Alabama in Huntsville
Craig, Harmon	Scripps Institution of Oceanography
Craig, Paul P.	University of California, Davis
Crane, Robert G.	Pennsylvania State University
Crill, Patrick M.	University of New Hampshire; Institute for the Study of Earth, Oceans and Space, University of New Hampshire
Croll, Donald A.	University of California, Santa Cruz
Cropper Jr., Wendell P.	University of Florida
Croppley, Ford D.	University of Edinburgh, Edinburgh, Scotland
Crowley, Thomas J.	Texas A&M University
Crozier, Carl R.	Louisiana State University
Curley, A. P.	University of Alaska Fairbanks
Curry, Judith A.	University of Colorado
Curtis, Peter S.	Ohio State University
Cutter, Gregory A.	Old Dominion University
Dail, Bryan D.	University of Maine
Daly, Christopher	Oregon State University
Daniel, K.	
Daniels, Jeffrey I.	Lawrence Livermore National Laboratory
D'Arrigo, Rosanne D.	
Daube, Bruce C.	Harvard University
Davidson, Eric A.	Woods Hole Research Center
Davis, Anthony	University of Alabama
Davis, Kenneth J.	University of Colorado; University of Minnesota; Pennsylvania State University
Davis, Michael A.	University of Southern Mississippi
Davis, Robert E.	University of Alabama
Dawson, Todd	
De Stasio Jr., Bart T.	University of Wisconsin
De Steiguer, Joseph E. (Ed)	North Carolina State University
DeFelice, T. P.	University of Wisconsin
Deininger, Catherine E.	North Carolina State University
DeLaune, Ronald D.	Louisiana State University
Demaree, Richard S.	California State University, Chico
Deming, David	University of Oklahoma
Demoz, Belay B.	University of Illinois at Urbana-Champaign
DeNicola, Dean M.	University of Nebraska
Denning, A. Scott	Colorado State University
Dewey, Kenneth F.	University of Nebraska
Dick, Richard P.	
Dickerson, M.	Lawrence Livermore National Laboratory
Dickinson, Robert E.	University of Arizona
Dickson, Nancy M.	Harvard University
Dobermann, Achim R.	University of Nebraska
Doering, Otto C.	Purdue University
Donovan, K. C.	University of California, Davis
Dowlatabadi, Hadi	Carnegie Mellon University
Doyle, A. P.	University of Alaska Fairbanks
Doyle, Geoffrey L.	Kansas State University
Dronamraju, M. M.	Tulane University
Duckstein, Lucien	University of Arizona
Dunbar, Robert B.	Rice University
Durkee, P. A.	Naval Postgraduate School
Durrans, S. Rocky	University of Alabama
Dyer, Lee	
Dyke, Paul	Texas A&M University
Easterling, David R.	Pennsylvania State University
Easterling, Mary Mckenney	EA Engineering, Science and Technology, Inc.
Easterling, William E.	Pennsylvania State University
Ehleringer, James	University of Utah
Elkins, James William	National Ocean and Atmospheric Administration, Boulder
Elliott, Edward T.	Colorado State University; University of Nebraska; Natural Resource Ecology Laboratory
Ellis, John T.	Texas A&M University
Ellsworth, David S.	Duke University; Brookhaven National Laboratory

Emani, Srinivas	Center for Technology, Environment, and Development, Clark University
Emanuel, William R.	University of Virginia
Enman Jr., Richard M.	Tulane University
Epstein, Daniel	Battelle Pacific Northwest Laboratories
Epstein, Samuel	Jet Propulsion Laboratory, California Institute of Technology
Ernst, Stephen G.	University of Nebraska
Fajer, Eric	Harvard University
Fan, Song-Miao	Harvard University
Fan, Weihong	Indiana University
Fang, Changming	University of Edinburgh, Edinburgh, Scotland
Farrell, Brian F.	Harvard University
Fay, Philip A.	Kansas State University
Feddema, Johannes J.	University of California, Long Beach
Feingold, Graham	Colorado State University
Feng, Xiahong	California Institute of Technology
Field, Christopher B.	Carnegie Institution of Washington, Stanford, CA
Fiering, Myron	Harvard University
Fischhoff, Baruch	Carnegie Mellon University
Fisher, Anthony	University of California, Berkeley
Fisher, Frank M.	Rice University
Fitzhugh, Ross D.	
Fitzjarrald, David R.	Atmospheric Sciences Research Center, State University of New York
Flatau, Pitor J.	Scripps Institution of Oceanography
Foley, Jonathan	University of Wisconsin
Fontaine, Thomas A.	South Dakota School of Mines and Technology
Formby, John P.	University of Alabama
Foster, David R.	Harvard University, Harvard Forest
Foster, Theodore D.	University of California, Santa Cruz
Fovell, Robert	University of California, Long Beach
Frolking, Steve	University of New Hampshire
Gaines, Steven D.	University of California, Santa Barbara
Galambosi, Agnes	University of Arizona
Galimba, Nelson	University of Illinois at Urbana-Champaign
Galvin, Kathleen A.	Colorado State University
Garcia, R.	
Gates, W. L.	Lawrence Livermore National Laboratory
Geng, Shu	University of California, Davis
Gewin, Virginia	
Ghil, Michael	University of California, Long Beach
Gholz, Henry L.	University of Florida
Gill, Ivan P.	University of Puerto Rico, Mayaguez; Tulane University
Giorgi, Filippo	National Center for Atmospheric Research
Gjerstad, Dean H.	Auburn University
Goldberg, Richard	Center for Climate Systems Research, Columbia University
Goldman, Marvin	University of California, Davis
Goldstein, Allen H.	Harvard University, University of California, Berkeley
Goltz, Stewart Michael	University of Maine
Good, David	Indiana University
Goodin, Douglas G.	Kansas State University
Goody, Richard	Harvard University
Gorham, E.	University of Minnesota
Gorman, Tony	The World Bank
Gosnold Jr., William D.	University of North Dakota
Gosselin, David C.	University of Nebraska
Gould, Alan	University of California, Berkeley
Goulden, Michael L.	Harvard University
Gower, S. T.	
Graumlich, Lisa J.	University of Arizona
Greenberg, Jim	National Center for Atmospheric Research
Greening, Lorna A.	University of Alabama
Griffiths, R. P.	Oregon State University
Grimmond, C. Susan B.	Indiana University
Grovenstein, J. D.	North Carolina State University
Guenther, Alex B.	National Center for Atmospheric Research
Guertin, David S.	University of Nebraska
Gulledge, Jay	Tulane University
Gutschick, Vincent P.	New Mexico State University
Gwiadza, Roberto H.	Lamont-Doherty Earth Observatory
Hadley, Julian L.	Harvard University, Harvard Forest
Hahn, G. Leroy	US Meat Animal Research Center, USDA-ARS
Hahn, Kris	University of Illinois at Urbana-Champaign
Haitjema, Hendrik M.	Indiana University
Hall, Anthony E.	University of California, Riverside
Ham, Jay M.	Kansas State University
Han, Quingyuan Y.	South Dakota School of Mines and Technology
Hanan, Niall P.	Colorado State University
Hanemann, W. Michael	University of California, Berkeley
Harcourt, Ramsey	University of California, Santa Cruz
Harley, Peter C.	National Center for Atmospheric Research
Harmon, E. Mark	Oregon State University
Harrington Jr., John A.	Kansas State University
Harrington, Lisa M. B.	Kansas State University
Harrison, Kevin G.	Duke University
Harriss, Robert C.	Institute for the Study of Earth, Oceans and Space, University of New Hampshire
Harte, John	University of California, Berkeley
Haskew, Tim A.	University of Alabama
Hastings, Alan	University of California, Davis
Hatch, L. Upton	
Hayes, John M.	Indiana University; Indiana State University
Haynes, Charles D.	University of Alabama
Hays, Cynthia J.	University of Nebraska
Hedin, L. O.	Michigan State University
Hendrey, George	Brookhaven National Laboratory
Hewitt, Julie A.	Montana State University; United States Environmental Protection Agency
Hirschboeck, Katherine K.	University of Arizona
Hites, Ronald A.	Indiana University
Hnilo, Justin J.	University of Alabama in Huntsville
Hoagland, Kyle D.	University of Nebraska

Hodges, Harry F.	Mississippi State University
Hoffert, Martin I.	New York University
Holland, Elisabeth A.	National Center for Atmospheric Research
Hollander, David J.	Northwestern University
Hollinger, David Y.	University of New Hampshire; USDA, Forest Service North Eastern Experiment Station
Houpis, James L. J.	California State University, Chico
Hsiao, Theodore C.	University of California, Davis
Hu, Q. Stephen	University of Nebraska
Hu, Qi	University of Nebraska
Hubbard, Dennis K.	Virgin Islands Marine Advisors, St. Croix, VI
Hubbard, Dennis K.	University of New Orleans
Hui, Dafeng	
Hunt Jr., E. Raymond	University of Wyoming
Hunter, Mark D.	University of Georgia
Hurd, Brian	Hagler-Bailly Services, Inc., Boulder, CO
Hurtt, George	
Huxman, Travis E.	
Jackson, Robert B.	Duke University; University of Texas
Jacob, Daniel J.	Harvard University
Jacoby, Gordon	
Jacoby, Henry D.	Massachusetts Institute of Technology
Jairell, R. L.	USDA, Forest Service
Jakubauskas, Mark E.	University of Kansas
Janssens, J. A.	University of Minnesota
Jariell, R. L.	USDA, Forest Service
Jelinski, Dennis E.	State University of New York at Buffalo
Jeng, Hann Tarn	National Chung Cheng University, Taiwan
Jensen, E. J.	Scripps Institution of Oceanography
Jiang, Ning	
Joern, Anthony	University of Nebraska
John, Vijay T.	Tulane University
Johnson, D. W.	Desert Research Institute, Reno, NV
Johnson, Jon D.	University of Florida
Johnson, Kristen A.	Washington State University
Johnson, Philip W.	
Johnston, Jerry J.	Indiana University
Johnston, Robert A.	University of California, Davis
Jones, Joseph W.	University of Florida; Ecological Research Center
Joslin, J. D.	University of Tennessee
Justic, Dubravko	Louisiana State University; Coastal Ecology Institute, Louisiana State University
Kammen, Daniel M.	Princeton University; Harvard University
Kao, J.	Los Alamos National Laboratory
Kasperson, Jeanne X.	Center for Technology, Environment, and Development, Clark University
Katul, Gabriel G.	Duke University
Kavvas, M. L.	University of California, Davis
Keeling, Charles D.	Scripps Institution of Oceanography
Keeling, Ralph C.	University of California, Long Beach; Scripps Institution of Oceanography
Kenner, Scott J.	South Dakota School of Mines and Technology
Kennett, James P.	University of California, Santa Barbara
Kenny, Ray	New Mexico Highlands University
Kerrigan, Julia	
Kesavan, Padmanaban	Tulane University
Kidder, Stanley Q.	University of Alabama in Huntsville
Killalea, James	Tulane University
Killian, Kendrick	Colorado State University
Kim, Jinwon	University of Nebraska
Kim, Joon	University of California, Irvine
Kim, Kyung-Ryul	Scripps Institution of Oceanography
Kimball, John S.	University of Montana
Kindscher, Kelly	University of Kansas; Kansas Biological Survey
Klinger, Lee	National Center for Atmospheric Research
Klopatek, Jeffrey M.	Arizona State University
Klug, Michael J.	Michigan State University
Kluke, Andrea	Center for Technology, Environment, and Development, Clark University
Knapp, Alan K.	Kansas State University
Knapp, J. R.	University of California, Davis
Knopf, Sherri	Desert Research Institute, Reno, NV
Kociygit, Rasim	Kansas State University
Koloutsou-Vakakis, Sotiria	University of Illinois at Urbana-Champaign
Kolstad, Charles D.	University of California, Santa Barbara
Koonin, Steven E.	California Institute of Technology
Koplitz, Brent	Tulane University
Koplitz, Lynn Vogel	Loyola University
Kratz, Timothy K.	University of Wisconsin
Kreidenweis, Sonia M.	Colorado State University
Krutilla, Kerry M.	Indiana University
Kucharik, Christopher	University of Wisconsin
Lal, Devendra	University of California, Long Beach
Lamb, Brian K.	Washington State University
Landsberger, Sheldon	University of Illinois at Urbana-Champaign
Langford, John S.	Aurora Flight Sciences
Larson, Susan M.	University of Illinois at Urbana-Champaign
Law, Beverly E.	
Law, Victor J.	Tulane University
Laymon, Charles A.	Universities Space Research Association, Institute for Global Change Research and Education
Leathers, Daniel J.	University of Delaware
LeBlanc, David C.	Ball State University
Leclerc, Monique Y.	University of Georgia - Griffin
Lee, Jae K.	Indiana University
Lee, R.	Lawrence Livermore National Laboratory
Lee, Xuhui	Yale University
Lefer, Barry L.	University of New Hampshire
Legates, David L.	University of Delaware
Lenihan, James	Oregon State University
Lettenmaier, Denis P.	University of Washington
Levine, Mark D.	Lawrence Berkeley National Laboratory
Li, Zhidong	University of Illinois at Urbana-Champaign
Lidstrom, Mary E.	California Institute of Technology
Lillesand, Thomas M.	University of Wisconsin
Lin, Xijian	Oregon State University

Lincoln, David E.	University of South Carolina
Lindau, Charles W.	Louisiana State University; Tulane University
Lindly, Jay K.	University of Alabama
Lindzen, Richard S.	Massachusetts Institute of Technology
Linsley, Braddock K.	State University of New York
Litvina, Irina V.	Agrophysical Research Institute, St. Petersburg, Russia
Loomis, Robert S.	University of California, Davis
Lowenberg-DeBoer, Jess	Purdue University
Lowenthal, Douglas	Desert Research Institute, Reno, NV
Luna, Ronaldo	Tulane University
Luo, Yiqi	University of Oklahoma
Lussenhop, John	University of Illinois at Chicago
MacCracken, M.	Lawrence Livermore National Laboratory
Mackay, D. S.	
Mader, Terry L.	University of Nebraska
Magnuson, John J.	University of Wisconsin
Malanson, George P.	University of Iowa
Mangel, Mark	University of California, Santa Cruz
Maring, Hal B.	University of Miami
Marino, Bruno D. V.	Harvard University
Marinovic, Baldo	University of California, Santa Cruz
Markgraf, Vera	University of Colorado
Marks, Danny	USDA
Marotzke, Jochem	Massachusetts Institute of Technology
Marsh, Mark L.	University of Nebraska
Martin, Timothy A.	University of Florida
Massman, W. J.	
Matthews, Elaine	NASA, Goddard Space Flight Center
Matyasovszky, Istvan	University of Nebraska
Mausel, Paul W.	Indiana University
Mausel, Paul W.	Indiana State University
Mazzocco, Michael A.	University of Illinois at Urbana-Champaign
McCreight, Richard W.	Oregon State University
McElroy, Michael B.	Harvard University
McKinion, James M.	USDA-ARS; Crop Simulation Research Unit, USDA-ARS; Mississippi State University
McKone, Thomas E.	Lawrence Livermore National Laboratory
McNider, Richard T.	University of Alabama in Huntsville
McNulty, Steven G.	USDA, Forest Service
Mearns, Linda O.	National Center for Atmospheric Research
Mechoso, Carlos R.	University of California, Long Beach
Melillo, Jerry M.	The Ecosystems Center at the Marine Biological Laboratory
Melillo, Jerry M.	Marine Biological Laboratory
Menawat, Anil S.	Tulane University
Menon, Surabi	North Carolina State University
Meyer, Judith L.	University of Georgia
Meyer, Steven J.	University of Wisconsin; University of Wisconsin–Green Bay; University of Nebraska
Michaelides, Stathis E.	
Miller, Arthur J.	Scripps Institution of Oceanography
Min, Qilong	State University of New York
Min, Qilong	Atmospheric Sciences Research Center, State University of New York
Mitchell, David L.	Desert Research Institute, Reno, NV
Mitchell, Robert B.	Texas Tech University
Mitchell, Robert J.	Auburn University; Jones Ecological Research Center, Newton, GA; Ecological Research Center
Mitter, Eric L.	Indiana University
Moncrieff, John B.	University of Edinburgh, Edinburgh, Scotland
Monson, Russel K.	University of Colorado
Moody, Jennie L.	University of Virginia
Mooney, Harold A.	Stanford University
Mooney, Sian	
Moorcroft, Paul R.	
Moore, Kathleen E.	State University of New York
Moore, Kathleen E.	Atmospheric Sciences Research Center, State University of New York
Moran, Emilio F.	Indiana University
Morantine, Michael C.	Tulane University
Morgan, Granger	Carnegie Mellon University
Morgan, Jack A.	USDA-ARS, Fort Collins, CO
Morgan, M. Granger	Carnegie Mellon University
Mosier, Arvin R.	USDA-ARS, Fort Collins, CO; NOAA-ARS, Fort Collins, CO
Mulder, Christa	
Munger, J. William	Harvard University
Murcray, Frank J.	University of Denver
Murray, Brian C.	Research Triangle Institute
Muttiah, Ranjan S.	Texas A&M University
Nadelhoffer, Knute J.	The Ecosystems Center at the Marine Biological Laboratory
Narayanan, Ram M.	University of Nebraska
Nealson, Kenneth H.	Indiana University
Neelin, J. David	University of California, Long Beach
Neelin, J. David	University of California, Davis
Neilson, Ronald	Oregon State University
Nicholls, Melville E.	Colorado State University
Nisbet, Robert A.	University of California, Santa Barbara
Norby, Richard J.	Oak Ridge National Laboratory
O'Brien, Edna W.	University of Miami
O'Connor, Kim C.	Tulane University
Oechel, Walter C.	San Diego State University
Ojima, Dennis S.	Colorado State University; Kansas State University
Oliver, Melvin J.	
Ollinger, Scott V.	University of New Hampshire
Olyphant, Greg	Indiana University
Omar, Ali H.	University of Illinois at Urbana-Champaign
Oren, Ram	Duke University
Orlob, G. T.	University of California, Davis
Oster Jr., Clinton V.	Indiana University
Osterkamp, Thomas E.	University of Alaska Fairbanks
Otto, Ralf D.	Scripps Institution of Oceanography

Owensby, Clenton E.	Kansas State University
Ozelkan, C. E.	University of Arizona
Palecki, Michael A.	University of Nebraska
Palmroth, Sari	University of Michigan
Pan, Zaitao	Iowa State University
Papadopoulos, Kyriakos D.	Tulane University
Paplawsky, Bill	Scripps Institution of Oceanography
Pares-Sierra, Alejandro	University of California, Long Beach
Pares-Sierra, Alejandro	Scripps Institution of Oceanography
Park, Richard A.	Indiana University
Parton, William J.	Colorado State University
Pasumarti, S. P. R.	North Carolina State University
Patrick Jr., William H.	Louisiana State University
Patwardhan, Anard	Carnegie Mellon University
Paudel, Krishna P.	
Paull, Charles K.	University of North Carolina
Paustian, Keith H.	Colorado State University; Michigan State University; W.K. Kellogg Biological Station, Michigan State University; Natural Resource Ecology Laboratory
Paw U, Kyaw Tha	University of California, Davis
Peake, Jeffrey S.	University of Nebraska at Omaha
Pendall, Elise	University of Colorado
Pendergraft, Curtis A.	Tulane University
Pennings, Steven	University of Georgia
Perkins, Betty Jean	Center for Technology, Environment, and Development, Clark University
Perry, D. A.	Oregon State University
Peteet, Dorthy M.	Lamont-Doherty Earth Observatory
Petersen, Richard	Texas Tech University
Peterson, Gary A.	Colorado State University
Peterson, Thomas	Colorado State University
Pfeifer, Rebecca A.	Purdue University
Phillips, Nathan	Duke University
Pielke Sr., Roger A.	Colorado State University
Piper, Stephen C.	Scripps Institution of Oceanography
Plant, Richard E.	University of California, Davis
Pockman, William T.	
Poreda, Robert J.	University of Rochester
Porporato, Amilcare	
Post, Wilfred M.	University of Tennessee
Pottenger, John R.	University of Alabama in Huntsville
Pratt, Lisa M.	Indiana University; Indiana State University
Pregitzer, Kurt S.	University of Michigan
Prinn, Ronald G.	Massachusetts Institute of Technology
Prior, Stephen A.	Auburn University
Prior, Stephen A.	National Soil Dynamics Laboratory, USDA-ARS,
Pritchard, Seth G.	Belmont University
Pryor, Sara C.	Indiana University
Pushnik, James C.	California State University, Chico
Rabalais, Nancy N.	Louisiana Universities Marine Consortium
Ramankutty, Navin	University of Wisconsin
Ramírez, Jorge A.	Colorado State University
Rampino, Michael	New York University
Randolph, J. C.	Indiana University
Rao, Xin	University of Illinois
Ratick, Samuel J.	Center for Technology, Environment, and Development, Clark University
Read, Daniel	Carnegie Mellon University
Reddy, K. Raja	Mississippi State University; University of Florida
Reeburgh, William S.	University of California, Irvine
Reed, Bradley C.	EROS Data Center
Reeder, Jean	USDA-ARS, Fort Collins, CO
Reich, Peter B.	University of Minnesota
Reimer, Paula J.	University of Washington
Renn, Ortwin	Center for Technology, Environment, and Development, Clark University
Rice, Charles W.	Kansas State University
Roads, John O.	University of California, Long Beach
Roads, John O.	Scripps Institution of Oceanography
Robarge, W. P.	North Carolina State University
Roberts, Andrew P.	University of California, Davis
Roberts, Dar A.	University of California, Santa Barbara
Robertson, G. Philip	W.K. Kellogg Biological Station, Michigan State University
Robertson, G. Philip	Michigan State University
Robeson, Scott M.	Indiana University
Robinson, David A.	Rutgers State University of New Jersey
Robock, Alan D.	University of Maryland
Rogers, Hugo H.	Auburn University; Harvard University; National Soil Dynamics Laboratory, USDA-ARS
Rogers, Peter	Harvard University
Rood, Mark J.	University of Illinois at Urbana-Champaign
Rose, Adam Z.	Pennsylvania State University
Rosen, Richard D.	Atmospheric and Environmental Research, Inc.
Rosenberg, Norman J.	Battelle Pacific Northwest Laboratories
Rosenzweig, Cynthia	NASA/Goddard Institute for Space Studies
Rowland, F. Sherwood	University of California, Irvine
Roy, Barbara	
Rubin, Barry M.	Indiana University
Rundquist, Donald C.	University of Nebraska
Runion, G. Brett	Auburn University
Running, Steven W.	University of Montana
Ryan, Michael G.	USDA, Forest Service, Rocky Mountain Research Station
Rygiewicz, Paul	USEPA
Sadler, Leon Y.	
Sailor, David J.	Tulane University
Salstein, David A.	Atmospheric and Environmental Research, Inc.
Sarachik, E. S.	University of Washington
Sasek, Thomas	Northeast Louisiana University
Sass, Ronald L.	Rice University
Savoie, Dennis L.	University of Miami
Saxena, Vinod K.	North Carolina State University
Schimel, David S.	National Center for Atmospheric Research

Schimmelmann, Arndt	Scripps Institution of Oceanography
Schlesinger, William H.	Duke University
Schlosser, P.	Lamont-Doherty Earth Observatory
Schmid, Hans Peter	Indiana University
Schmidt, Ralph A.	USDA, Forest Service, Rocky Mountain Research Station
Schoeneberger, Michele M.	USDA, Forest Service
Schultz, Peter	National Research Council
Schuman, J.	USDA-ARS
Schwarz, Stephen G.	Tulane University
Seastedt, Timothy R.	Kansas State University
Shankman, David	University of Alabama
Shannon, Robert D.	Indiana University
Shaw, Roger H.	University of California, Davis
Shlyakhter, Alexander I.	Harvard University
Shrestha, B. P.	University of Arizona
Shrestha, Rajendra	University of Illinois at Urbana-Champaign
Shugart Jr., Herman H.	University of Virginia
Shur, Yuri L.	University of Alaska Fairbanks
Shure, Donald J.	Emory University
Siccama, Thomas	Yale University
Sievering, Herman	University of Denver
Sinclair, T. R.	USDA-ARS
Skific, Matthew	University of Illinois at Urbana-Champaign
Skolnikoff, Eugene B.	Massachusetts Institute of Technology
Sloan, Lisa C.	University of California, Santa Cruz
Small, Mitchell	Carnegie Mellon University
Smith, Ronald B.	Yale University
Smith, Stanley D.	
Smith, Thomas M.	University of Virginia
Sneider, Cary I.	University of California, Berkeley
Sollenberger, L. E.	University of Florida
Sollins, P.	Oregon State University
Solow, Andrew R.	Woods Hole Oceanographic Institution
Somerville, Richard C. J.	University of California, Long Beach; Scripps Institution of Oceanography
Soong, Su-Tzai	University of California, Davis
Srinivasen, Raghavan	Texas A&M University
Stamnes, Knut	University of Alaska Fairbanks
Stangenberger, Alan	University of California, Berkeley
Stark, Lloyd	
Steiguer, Ed de	North Carolina State University
Steinberg, Laura J.	Tulane University
Stenchikov, Georgiy	Rutgers State University of New Jersey; University of Maryland
Sternberg, Leonel de Silveira Lobo	
Steudler, Paul A.	Marine Biological Laboratory
Steudler, Paul A.	The Ecosystems Center at the Marine Biological Laboratory
Stiling, Peter	University of South Florida
Stone, Peter H.	Massachusetts Institute of Technology
Stuiver, Minze	University of Washington
Stute, M.	Lamont-Doherty Earth Observatory
Su, Hong-Bing	Indiana University
Suarez, Donald L.	University of California, Riverside
Suchanek, Thomas H.	University of California, Davis; United States Fish and Wildlife Service, Sacramento, CA
Sulte, M.	Lamont-Doherty Geological Observatory
Sun, Jielun	
Sun, Wen-yih	Purdue University
Sundquist, Eric T.	United States Geological Survey, Woods Hole, MA
Sweets, P. Roger	Indiana University
Takle, Eugene S.	Iowa State University
Talbot, Robert W.	University of New Hampshire
Tanaka, Noriyuki	Yale University
Tans, Pieter P.	National Oceanic and Atmospheric Administration, Climate Monitoring and Diagnostics Laboratory
Taras, Curt	University of Illinois at Urbana-Champaign
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