U.S. Department of Energy Office of Science
Office of Biological and Environmental Research
Climate and Environmental Sciences Division

Terrestrial Carbon Cycle Research

Summary of projects awarded in 2010 and 2011 under the Terrestrial Ecosystem Science Funding Opportunity Announcement DE-FOA-0000287.

Funding Opportunity Announcement Overview

The Office of Biological and Environmental Research's (BER) Terrestrial Ecosystem Science (TES) program is the result of the consolidation of its former Terrestrial Carbon Processes (TCP) program and Program in Ecological Research (PER). The goal of the TES program is to provide scientific knowledge of terrestrial ecosystems to:

- Provide accurate predictions of their roles in influencing the atmospheric concentration of greenhouse gases;
- Quantify terrestrial carbon sources and sinks and how they are changing in relation to other atmospheric, climatologic and hydrologic influences; and
- Assess terrestrial feedbacks on carbon cycle and climate change.

The Funding Opportunity Announcement **DE-FOA-0000287**, released in the Spring of 2010, considered applications on terrestrial carbon cycle research that will improve the understanding of the role of terrestrial biomes in the global carbon cycle and aid carbon cycle predictions related to climate change. Applications were expected to utilize a suite of measurements, experiments, modeling and synthesis that provide improved quantitative and predictive understanding of the terrestrial ecosystem that can affect atmospheric greenhouse gas concentration changes and thereby affect the anthropogenic forcing of climate. The emphasis of this FOA is to understand the impacts of, and feed backs from a changing climate on non-managed terrestrial ecosystems. Authors were required to pose their research applications in the context of representing terrestrial carbon cycle processes in Earth system models. Authors were encouraged to consider utilization of, or collaboration with, sites that have existing support (e.g., former FACE or existing AmeriFlux projects) thereby leveraging existing investments, archived samples and long-term data sets.

While the program supports a broad spectrum of fundamental research in terrestrial ecosystem science and considered research applications within this scope, this FOA particularly encouraged applications in the following Science Areas:

- The role of disturbance in carbon cycling, particularly disturbance associated with changing climate (changes in atmospheric carbon, precipitation, ecosystem type).
- Changes in the rate and nature of soil carbon accretion associated with potential climate change.
- Controls of transformation of biomass into soil organic matter and stabilization mechanisms of the long-lived carbon components in soil.
- New and improved approaches to develop relationships between flux measurements and

Overall, proposed research was intended to fill critical knowledge gaps, including the exploration of high-risk approaches. BER encouraged the submission of innovative exploratory applications with potential for future high impact on terrestrial ecosystem science.

Through this Funding Opportunity Announcement, nine awards were made in FY 2010 followed by sixteen awards in FY 2011 (four of which were exploratory awards) totaling $11,124,636 over four years.

Funded Projects

Fiscal Year 2010

Using a Regional Cluster of AmeriFlux Sites in Central California to Advance Our Knowledge on Decadal-Scale Ecosystem-Atmosphere Carbon Dioxide Exchange

- **Principle Investigator:** Dennis Baldocchi (University of California, Berkeley)
- **Collaborators:** John Battles (University of California, Berkeley)
- **Award:** $1,002,405 over 3 years

This multi-faceted research project seeks to answer a set of hypothesis-driven research questions relating to the 'Effects of projected precipitation changes on NPP, NEP, and changes in soil carbon storage in western semi-arid ecosystems' using a suite of eddy covariance flux measurements, field and laboratory manipulation studies and biophysical modeling. The research will be conducted at a regional cluster of AmeriFlux field sites in central California. The field sites reside in a Mediterranean type climate with wet, cool winters and hot, dry summers. This climate space is an ideal natural laboratory for studying the effects of precipitation on ecosystem function (e.g. assimilation and respiration) and structure (e.g., leaf area index, tree mortality) because the sites receive greater inter-annual variability in annual precipitation (548 ± 196 mm) than long-term trends in precipitation that have occurred or are predicted by regional climate change models. The primary objective of this research proposal is to extend the duration of our time series on eddy covariance flux measurements of carbon dioxide, water vapor and energy beyond a decade at the oak savanna and annual grassland AmeriFlux sites; we have been conducting carbon flux measurements at these AmeriFlux sites since 2001. The second objective of this research proposal is to study the interactive effects between rainfall and ecosystem-scale carbon dioxide exchange. The third objective is to use our seasonal carbon flux measurements to study how photodegradation of litter primes rain-induced soil/litter respiration pulses (sunny vs shady sites) and how variations in soil water availability (wet spring vs dry summer) alters the photosynthetic priming of soil respiration. Together, we intend to use these ecosystem-scale carbon flux data and manipulative experiments to develop, test and improve a hierarchy of land-surface models that compute the biophysical fluxes (carbon, water and energy) in climate models. One objective of this modeling work is to work in tandem with our experimental dataset to produce new insights on the relative accuracy/inaccuracy of using simple, one-dimensional radiative transfer schemes to compute photosynthesis and the surface energy balance in heterogenous canopies, like savanna. A second objective of the modeling work is to use the three-dimensional model to produce a simpler one-dimensional model that parameterizes spatial clumping of oak trees. The third objective of the modeling work is to develop and incorporate new algorithms and models that simulate how ecosystem respiration responds to conditional rain events and how access to ground water moderates ecophysiological drought stress.

Developing Model Constraints of Northern Extra-Tropical Carbon Cycling Based on Measurements of the Abundance and Isotopic Composition of Atmospheric CO_2

- **Principle Investigator:** Ralph Keeling (University of California, San Diego)
- **Award:** $1,048,537 over 3 years

This project has the overall goal of producing datasets relevant for documenting changes in the global carbon cycle and improving understanding of how land ecosystems may influence and be influenced by future CO_2 changes and climate changes. It also has a more focused goal of using these and other data to challenge models that depict the response of changing climate and human forcing (e.g. rising CO_2) on northern extra-tropical ecosystems over multi-decadal time scales, using records extended over the past 50 years. Targets for model improvement include improved depiction of the response of northern extra-tropical ecosystems to rising CO_2 levels and climate changes. The project provides partial support for continuing core elements of the program initiated by Charles D. Keeling in the late 1950's, to measure changes in the concentration of atmospheric CO_2 at remote sites, and which expanded to include measurements of the stable isotopes and radiocarbon content of CO_2. In addition to sustaining these observations, which have global importance, the project supports interpretive activities focused on improving the understanding of changing climate on northern extra-tropical ecosystems, via a model/data comparison spanning more than 50 years. The project will have the following benefits and outcomes: 1) Extension and dissemination of datasets relevant to documenting global and hemispheric changes in the carbon cycle and for unraveling the underlying mechanisms. 2) Improved depiction of the impact of climate changes and rising CO_2 on northern terrestrial ecosystems 3) Extension of datasets of the isotopic composition of atmospheric CO_2, relevant to improving estimates of gross primary production, canopy conductance, and water-use efficiency of northern extra-tropical ecosystems.

Carbon Cycling Dynamics in Response to Pine Beetle Infection and Climate Variation

- **Principle Investigator:** Russell Monson (University of Colorado)
- **Collaborators:** Alan Townsend (University of Colorado), Scott Lehman (University of Colorado), David Moore (King's College, London), David Bowling (University of Utah), Stuart Grandy (Michigan State University)
- **Award:** $1,033,242 over 3 years

At present, two of the key stresses that determine atmospheric CO_2 uptake by ecosystems in western North America are climate warming and widespread tree mortality due to mountain pine beetle outbreaks. Our past research of regional carbon budgets has shown that mountain forest ecosystems, sustained by the melt water from winter snowpacks, are the principal sites of carbon sequestration in the Western US. Our research in the subalpine forest at the Niwot Ridge AmeriFlux site in Colorado has shown that warmer winters over the past five decades, with associated decreases in winter snowpack, have likely caused reduced forest CO_2 uptake. In 2009, the Niwot Ridge forest showed evidence of mountain pine beetle infection, with the most stressed trees the first to be attacked. We have just completed eleven years of continuous measurement of forest-atmosphere CO_2 exchange in the absence of beetle infection. Now, we have the opportunity to study CO_2 exchange patterns as the infection spreads, and ultimately, as the forest recovers. We propose to use this opportunity to better elucidate the changes that will occur in soil carbon pools, as a result of tree mortality due to beetle infection, and the ease by which those pools release CO_2 to the atmosphere. We will utilize forest plots at two sites – the Niwot Ridge AmeriFlux site and the Fraser Experimental Forest site, both in Colorado. At the Niwot Ridge site we will use a series of plots on which trees have been killed by simulated beetle attack over the past 8 years. At the Fraser Forest site we will use forest plots that have experienced widespread tree mortality due to natural beetle outbreaks. We propose to use advanced analysis techniques utilizing stable isotope (^{13}C and ^{12}C) dynamics in atmospheric CO_2, radioactive isotope dating (using ^{14}C in soil organic matter) and pyrolysis-gas chromatography-mass spectrometry to analyze patterns of soil CO_2 release and changes in the soil carbon pools as a result of tree death due to simulated or real beetle attacks. The results from these observations will then be used to modify a computer simulation model in which we can explore the potential interactions between future beetle outbreaks and climate change in the Rocky Mountain region, particularly with regard to the effect of these stresses on atmospheric CO_2 uptake by forests. This computer simulation analysis will allow us to better assess the potential for western U.S. forests to remove CO_2 that is emitted by the combustion of fossil fuels, from the atmosphere given potential future changes in the climate and frequency of beetle outbreaks.

The Effects of Climate, Forest Age, and Disturbance History on Carbon and Water Processes at AmeriFlux Sites Across Gradients in Pacific Northwest Forests

- **Principle Investigator:** Beverly Law (University of Oregon)
- **Collaborators:** Christoph Thomas (University of Oregon)
- **Award:** $1,049,381 over 3 years

Our goal is to continue investigating the effects of disturbance and climate variables on processes controlling carbon and water processes at AmeriFlux cluster sites in semi-arid and mesic forests in Oregon to address a new set of hypotheses. The observations will be made at three existing and productive AmeriFlux research sites that represent climate and disturbance gradients as a natural experiment of the influence of climatic and hydrologic variability on carbon sequestration and resulting atmospheric CO_2 feedback that includes anomalies during the warm/ dry phase of the Pacific Decadal Oscillation. Our objectives are to (1) Combine tower and biological observations at the semi-arid mature and young pine sites to investigate climatologic and hydrologic influences on NPP, NEP and component processes in different aged forests over multiple years that include anomalies in precipitation and temperature (disturbance history/age gradient); (2) Compare climatologic and hydrologic control on measured carbon and water fluxes in forests of the same functional type and similar age (mature pine and Douglas-fir sites), but in different ecoregions over multiple years that include variability in precipitation phase and timing (climate gradient). The research products from observations and experiments in this study and integration with modeling done outside of this proposal will provide new data on carbon cycle mechanisms controlling CO_2 exchange with the atmosphere; quantification of terrestrial carbon sources and sinks and how they change in relation to climatologic and hydrologic influences across a climatic gradient; and quantification and explanation of trajectories of change in carbon storage and NEP of forests following disturbance.

Improving Representation of Drought Stress and Fire Emissions in Climate Carbon Models: Measurements and Modeling with a Focus on the Western USA

- **Principle Investigator:** James Ehleringer (University of Utah)
- **Collaborators:** Chun-Ta Lai (San Diego State University), James Randerson (University of California, Irvine)
- **Award:** $1,049,850 over 3 years

The study proposed a series of measurement and modeling efforts that will improve our understanding of drought effects on ecosystem fluxes and fire emission at multiple scales. Novel aspects of our measurement program include: long-term isotope data collections from two ecosystems with contrasting levels of anthropogenic modification (Wind River and Salt Lake Valley ecosystems) and a mobile laboratory for quantifying the isotopic and trace gas composition along urban to natural forest ecosystem gradients and emissions from large wildfires. We will target three types of ecosystems for field campaigns on wildfires: cheatgrass steppe, chaparral shrubland, and mid-elevation conifer forest. Modeling work will focus on using these observations and other data sources to understand the imprint of drought stress on the observing network across North America. For these simulations, we will focus on atmospheric CO_2 and $^{13}CO_2$ variability drawing upon observations from NOAA, the Total Carbon Column Observing Network, and the stable isotope time series described above. We also plan to synthesize information on drought effects from multiple sources, including from our measurements and from other AmeriFlux sites. We will use this information to develop new evaluation modules for the Carbon-Land Model Intercomparison Project (C-LAMP) diagnostics system. We will then apply this improved version of C-LAMP to the Community Land Model version 4 with the aim of improving the process level description of ecosystem fluxes in the western U.S. For this activity we will work closely with both the AmeriFlux and Community Climate System Model communities, sharing results during annual meetings. Field data collection was designed with the aim to contribute to the development of carbon-land model diagnostics modules, ensuring a strong synergistic interaction between models and observations.

Ecosystem-Atmosphere Exchange Over a Mixed Deciduous Forest in the Midwest: How does the Carbon Budget Respond to Short- and Long-Term Climate Variability?

- **Principle Investigator:** Danilo Dragoni (Indiana University)
- **Collaborators:** J.C. Randolph (Indiana University), Richard Phillips (Indiana University), Faiz Rahman (Indiana University), Hans Peter Schmid (KIT/IMK-IFU, Germany), Craig Wayson (USDA – Forest Service)
- **Award:** $457,706 over 1 year

Predicting the degree to which temperate deciduous forests will continue to offset anthropogenic CO_2 emissions by storing carbon (C) requires a more complete understanding of the controls and feedbacks that regulate interactions between the C cycle and climate over both short (seasonal and annual) and long (decadal) time-scales. Key to this approach is investigating whether regional changes in climate are tracked by changes in phenology and carbon cycling, and the consequences of such changes on short- and long-term net ecosystem productivity (NEP). Most observations and ecosystem models suggest that rising temperatures will increase forest productivity due to the lengthening of the vegetative season, with the majority of this increase occurring due to the earlier onset of photosynthetic activity in spring. However, increases in growing season length may also occur due to the delayed onset of senescence (e.g. autumn warming) which may have the opposite effects on ecosystem C balance if respiratory losses exceed C gains from photosynthesis. Understanding the physiological controls underlying inter-annual variability in phenology and C allocation are critical for predicting how short- and long-term climate variability influence C balance in temperate deciduous forest ecosystems. At the Morgan Monroe State Forest (MMSF), our decadal records using eddy-covariance method provide compelling evidence for increased annual NEP owing to an increase in late-summer air temperature and the delayed onset of senescence (about 3 days yr^{-1}). Given that such increase cannot be accounted for by increases in aboveground biomass (measured by biometric approaches), we argue that the vast majority of this additional C is being allocated belowground during late-summer. In addition, we have observed an equivalent amount of C accumulated in the soil (5 gC m^{-2} $year^{-1}$) over this time period due to decreased ecosystem respiration during winter months. These trends have resulted in a 30% increase in the sink strength of this forest (~100 gC m^{-2}) over the last ten years. Collectively, our data suggest that despite greater amounts of C assimilation and belowground allocation in this forest, the additional C inputs are likely getting stored in pools with annual or longer turnover rates. Whether such changes in allocation will result in negative or positive feedbacks to long-term forest productivity is unknown, but likely depends on whether such phenological and physiological changes result in enhanced uptake of growth-limiting resources (thereby sustaining productivity) or enhanced C accumulation in slow-turnover C pools (e.g. soil organic matter). Thus, the goal of our proposed research is to enhance the understanding of the mechanisms, controls, and feedbacks that regulate the response of phenology and ecosystem productivity and respiration to short- and long-term climate variability at MMSF. The three key questions that this work will address are: I. What are the mechanisms and controls that regulate the phenology, NEP, Re and GEP trends at MMSF? II. How have C allocation patterns changed in response to these trends? And what are the feedbacks of these changes on forest productivity? III. How will the trajectory of phenology and NEP trends change?

Seasonal and Inter-Annual Controls on CO_2 Flux in Arctic Alaska

- **Principle Investigator:** Walter Oechel (San Diego State University)
- **Award:** $370,185 over 3 years

The Arctic landscape holds massive potential to affect the global carbon balance. Soils of the northern permafrost region account for approximately 50 percent of the estimated global below-ground organic carbon pool. The total soil organic carbon in the first 3 m in northern circumpolar permafrost, excluding yedoma, is ca.1,024 PgC. Under a projected warmer and drier climate, the decomposition and release of even a fraction of these massive quantities of soil carbon in Arctic soils could create an additional positive feedback and further warming of the planet. It is critical to continually assess the rate of carbon flux from the Arctic landscape, and study how the thawing and rising ground temperature over the region affect the atmospheric concentrations of CO_2 and CH_4. Long-term measurements are especially critical as Arctic terrestrial ecosystems are changing dramatically in response to persistent and accelerating regional warming trends. Dramatic changes in Arctic hydrology have become evident in recent years. Changes in hydrology including soil water content, lake formation, and lake loss have profound effects on CO_2 and CH_4 fluxes. We have maintained eddy covariance flux towers at three sites in Arctic Alaska: Barrow, Atqasuk, and Ivotuk. The three sites form a 300 km N-S transect on the North Slope of Alaska, each site representing distinct vegetation communities common to the Arctic. These towers will measure net fluxes of CO_2, H_2O vapor, sensible heat, latent heat, and momentum in addition to standard meteorological and environmental variables (MET data), and all data will be made available in the public domain through direct access via selected online databases, including the Carbon Dioxide Information Analysis Center website. Data collected by the project will be used to determine the seasonal and inter-annual patterns of CO_2 flux, and their relationship to changes in environmental factors. The data will also be used to identify important differences in carbon flux at different Arctic landscape types. Project results have the potential to contribute to the refinement global carbon flux models. The information on spatial, annual, and inter-annual variation in sensible and latent heat flux and CO_2 fluxes is critical to better inform ecosystem and land surface models and to improve and make more realistic their operation under current and likely future conditions.

Long-Term Soil Warming and Carbon Cycle Feedbacks to the Climate System

- **Principle Investigator:** Jerry Melillo (Marine Biological Laboratory)
- **Award:** $508,000 over 1 year

The objectives of the proposed research are to: 1) quantify and explain the effects of a sustained in situ 5°C soil temperature increase on net carbon (C) storage in a northeastern deciduous forest ecosystem; and 2) use new process-level understanding gained in the project to improve a terrestrial ecosystem model (TEM) that is part of an extant Earth system modeling framework, the MIT Integrated Global Systems Model (IGSM). The research will be done using two established soil warming experiments at the Harvard Forest in central Massachusetts, where the responses of the plant and soil carbon pools to soil warming will be quantified and the long-term response of microbial soil respiration to warming will be explored. Field studies, laboratory experiments and simulation modeling will be combined in the proposed research. In the field, a series of plant and soil measurements will be made to quantify changes in C storage in the ecosystem and provide insights into how those changes may be related to nitrogen (N) cycling changes in the warmed plots. Field studies will include measurements of: 1) annual woody increment; 2) litterfall; 3) carbon dioxide (CO_2) and $^{14}CO_2$ efflux from the soil surface; 4) root biomass and respiration; 5) microbial biomass; and 6) net N mineralization and net nitrification rates. The response of microbial soil respiration to warming will be tested with short-term soil assays under controlled conditions in the laboratory. The soils will come from the heated and control plots of the two established soil-warming studies at the Harvard Forest. In addition to measuring respiration rates at a range of incubation temperatures, the soils will be analyzed for labile soil organic carbon (SOC) pools and microbial biomass, extractable inorganic and organic N pools, and soil moisture. The relative capacities of the microbial communities in the heated and control plots to decompose more recalcitrant soil organic matter will also be tested. Results from the field and laboratory studies will be used to inform the restructuring of the soil module of TEM to include multiple soil carbon pools (from labile to recalcitrant). The improved TEM will retain a structure that will continue to allow it to be a coupled component of MIT's Integrated Global System Model, an integrated assessment model used widely in climate change analyses. This research is designed to increase our understanding of how global warming will affect the capacity of temperate forest ecosystems to store C. The work will explore how soil warming changes the interactions between the C and N cycles, and how these changes affect land-atmosphere feedbacks.

Evaluating the Contribution of Climate Forcing and Forest Dynamics to Accelerating Carbon Sequestration by Forest Ecosystems in the Northeastern U.S.

- **Principle Investigator:** William Munger (Harvard University)
- **Collaborators:** Steven Wofsy (Harvard University), David Foster (Harvard Forest), Paul Moorcroft (Harvard University), Andrew Richardson (Harvard University), David Fitzjarrald (State University of New York, Albany)
- **Award:** $450,000 over 3 years

The proposed work seeks to improve quantitative understanding of the terrestrial ecosystem processes that control carbon sequestration in unmanaged forests and to demonstrate better representation of key terrestrial ecosystem processes in models. It builds upon the comprehensive long-term observations of CO_2 fluxes, climate and forest structure and function at the Harvard Forest in Petersham, MA. This record includes the longest CO_2 flux time series in the world. The site is a keystone for the AmeriFlux network. Project Description The project includes a strong component of observational and data synthesis driven by ecological hypotheses. At the Harvard Forest HFEMS and Hemlock towers, which represent the dominant mixed deciduous and coniferous forest types in the northeastern United States, we will continue measuring eddy-covariance fluxes of energy, water, and CO_2 exchange, meteorology at the two towers and surroundings, forest composition, biomass, and woody debris adjacent to the towers; implement enhanced measurements of light quantity and quality affected by cloud cover; and expand recording of canopy phenology using analysis of high-resolution images supplemented by observer reports. Project benefits include the improved quantitative understanding of terrestrial ecosystem carbon cycling is critical to evaluate the risk that forest carbon sequestration might slow in the future as forests reach maturity and allow a larger fraction of CO_2 emitted by fossil fuel combustion to remain in the atmosphere. The comprehensive data set is fully available to the public and serves as in important resource for data synthesis and model evaluation for researchers worldwide.

Fiscal Year 2011

Supporting Carbon Cycle and Earth Systems Modeling with Measurements and Analysis from the Howland AmeriFlux Site.

- **Principle Investigator:** David Hollinger (USDA Forest Service, Northern Research Station)
- **Collaborators:** Eric Davidson (Woods Hole Research Center), D. Bryan Dail (University of Maine), Andrew Richardson (Harvard University), Neil Scott (Queens University, Canada), Chun-Ta Lai (San Diego State University)
- **Award:** $1,048,730 over 3 years

The overall goal of the proposed work is to understand how a changing climate affects the functioning of a spruce-fir forest in central Maine. This forest is representative of an important component of the North American boreal forest, and presently taking up increasing quantities of carbon dioxide (CO_2) from the atmosphere. By doing this, such forests reduce the rate of build-up of CO_2 in the atmosphere and help to slow the progress of the greenhouse effect and climate change. Some models have identified processes within forest ecosystems that will change as climatic conditions change, reducing the rate of CO_2 uptake or even causing forests to lose CO_2 to the atmosphere, accelerating the greenhouse effect. Presently a range of outputs from such models is possible because we do not have the necessary data to decide if model predictions are plausible. In this work we will make measurements of the isotopic discrimination of CO_2 within and above the forest. When combined with our present measurements this will provide a dataset that models will find more challenging to simulate correctly, but if models can do this, they will have achieved an improved ability to predict the future trajectory of atmospheric CO_2. The primary methodologies to be used include eddy flux measurements from several forest towers, measurements of carbon isotope discrimination from a new type of field-deployable isotope analyzer, and various modeling activities known as data-model fusion. The outcome of successful completion of this work would be 1) wider adoption of our proposed methods, 2) increased knowledge about how carbon cycles through the environment, 3) an improved capacity to predict how forests will operate in a changing climate, and 4) better prediction of future atmospheric CO_2 levels. Benefits include better protection of our forests, and, improved information to inform policy decisions.

Partitioning CO_2 Fluxes with Isotopologue Measurements and Modeling to Understand Mechanisms of Forest Carbon Sequestration

- **Principle Investigator:** Scott Saleska (University of Arizona), Eric Davidson (Wood's Hole Research Institute), Adrien Finzi (Boston University), Paul Moorcroft (Harvard University)
- **Collaborators:** Rick Wehr (University of Arizona)
- **Award:** $1,039,878 over 3 years

Terrestrial ecosystems are an important and dynamic component of the Earth's climate system, and models are the primary basis for understanding the future interactions between terrestrial ecosystems and the climate. Although temperate forests in the northern mid-latitude of the United States are important net sinks for anthropogenic CO_2 , the balance between sinks (GPP) and sources (respiration) may change under future climate change scenarios. Two key facts about temperate forests, that they sequester substantial carbon, but that their long-term trends in sequestration are poorly predicted by models, alludes to the importance of understanding these ecosystems. Model simulations of belowground processes are difficult to test, largely because of the intractable difficulties associated with making the necessary observations. Integrating traditional observations (plot trenching and root rhizotron observations), new experimental methods (artificial roots that can trickle isotopically labeled model "exudate" into soil), and recent technology (highly sensitive laser absorption spectrometers) that brings new capability for real time observations of the isotopologues of CO_2, will bring new and more reliable insights into belowground processes. These will in turn enable new and more rigorous tests of model-simulated processes belowground, thereby providing new data and tools to the broader modeling community. We will integrate a newly developed instrumentation for continuous insitu observations of the isotopologues of CO_2, together with the trenching technique to partition components of belowground carbon flux (autotrophic and heterotrophic). The calculated $13CO_2$ in the trenched plot will provide an estimate of the 13C signature of the heterotrophic soil CO_2 source endmember in undisturbed soil. The difference in $13CO_2$ between the trenched and control plots will provide an indication of the root/rhizosphere/ mycorrhizal endmember of respiration of fresh photosynthate, which will be compared with more direct measurements obtained from the root respiration chambers. The relative contributions of heterotrophic and root/rhizosphere/mycorrhizal to total soil respiration can be solved from estimating the 13C endmember signature of each and knowing the total flux and its 13C signature. These measurements, in conjunction with measurements made by our colleagues, of the isotopic composition of NEE using the eddy covariance technique will provide a new method for partitioning NEE between GPP and ecosystem respiration, as well as partitioning of respiration between aboveground and belowground, and partitioning of belowground respiratory fluxes between components influenced by autotrophic and heterotrophic processes. This data will provide valuable insight into belowground carbon cycling processes.

Quantifying Carbon-Climate Processes at the Regional Scale Using Atmospheric Carbonyl Sulfide

- **Principle Investigator:** Elliott Campbell (University of California, Merced)
- **Collaborators:** Joe Berry (Carnegie Institution for Science), Ulrike Seibt (University of California, Los Angeles), Margaret Torn (Lawrence Berkeley National Laboratory)
- **Award:** $149,848 over 1 years

The proposed work will quantify the climate sensitivity of carbon flux processes at the regional scale using atmospheric carbonyl sulfide (COS) models and measurements. Atmospheric COS-CO_2 analysis has the potentially transformative capability for partitioning the regional carbon flux into respiration and photosynthesis components. This emerging approach is based on the observation that continental CO_2 gradients are dominated by net ecosystem fluxes while regional gradients in atmospheric COS are dominated by photosynthesis-related plant uptake. Regional flux partitioning represents a critical knowledge gap due to a lack of robust methods for regional-scale flux partitioning and large uncertainties in forecasting carbon-climate feedbacks. The proposed collaboration between modeling and measurement groups would employ chamber and canopy field measurements at the DOE ARM Climate facility to calibrate a COS component to multiple land carbon models that are used in Earth Systems models. These land carbon models will be assessed for their regional photosynthesis and respiration fluxes using an atmospheric inversion with a North American model domain and multi-year airborne measurements of COS and CO2 across North America. These multi-year airborne measurements are complementary to short-term airborne intensives because they provide inter-annual and seasonal carbon cycle constraints through a range of climate regimes. In additional to regional flux estimates, we will also assess the local-scale flux partitioning of the eddy flux data at the ARM Climate facility using the COS canopy measurements. While the proposed free troposphere, soil, leaf, and canopy measurements will be useful for resolving COS budget uncertainties, our early results suggest that plant uptake is the dominant source of variability for continental budgets. The project team has a high impact publication record with this tracer, a unique high-precision laser for measuring COS, a 4D-Var inverse model for simultaneous assimilation of COS and CO_2 observations, and extensive experience with measurement and modeling campaigns at the ARM facility. The ARM site is particularly well suited for this project because of the multi-year airborne COS/CO_2 measurements and the legacy of surface measurements and modeling on carbon-climate processes. The proposed research would address the knowledge gap of quantifying ecosystem functioning at a regional scale, assess multiple land carbon models which are used in integrated Earth Systems models addressing the goal of quantifying carbon-climate feedback processes.

Carbon-Water Cycling in the Critical Zone: Understanding Ecosystem Process Variability Across Complex Terrain

- **Principle Investigator:** Holly R. Barnard (University of Colorado)
- **Collaborators:** Paul Brooks (University of Arizona), Thomas Pypker (Michigan Technological University)
- **Award:** $647,020 over 3 years

One of the largest knowledge gaps in environmental science is the ability to understand and predict how ecosystems will respond to future climate variability. The links between vegetation, hydrology, and climate that control carbon sequestration in plant biomass and soils remain poorly understood. Soil respiration is the second largest carbon flux of terrestrial ecosystems, yet there is no consensus on how respiration will change as water availability and temperature co-vary. To address this knowledge gap, we use the variation in soil development and topography across an elevation and climate gradient on the Front Range of Colorado to conduct a natural experiment that enables us to examine the co-evolution of soil carbon, vegetation, hydrology, and climate in an accessible field laboratory. The goal of this project is to further our ability to combine plant water availability, carbon flux and storage, and topographically driven hydrometrics into a watershed scale predictive model of carbon balance. We hypothesize: (i) landscape structure and hydrology are important controls on soil respiration as a result of spatial variability in both physical and biological drivers: (ii) variation in rates of soil respiration during the growing season is due to corresponding shifts in belowground carbon inputs from vegetation; and (iii) aboveground carbon storage (biomass) and species composition are directly correlated with soil moisture and therefore, can be directly related to subsurface drainage patterns.

Constraining the Simultaneous Effects of Elevated CO_2, Temperature, and Shifts in Rainfall Patterns on Ecosystem Carbon Fluxes Using Multi-Scale Resource Optimization Theories

- **Principle Investigator:** Gabriel Katul (Duke University)
- **Collaborators:** Ram Oren (Duke University), Sari Palmroth (Duke University), Amilcare Porporato (Duke University), Danielle Way (Duke

University), Stefano Manzoni (Duke University)
- **Award:** $826,270 over 3 years

Increases in atmospheric carbon dioxide concentrations (ca) will lead to changes in the climate that alter mean air temperature (Ta) and precipitation (P) patterns. The ability of terrestrial ecosystems to absorb ca is sensitive to these climatic conditions, as well as to ca, thereby creating a feedback that has the potential to accelerate warming. To describe the feedback, the primary pathways by which elevated ca, Ta, and changing P patterns simultaneously impact ecosystem photosynthesis and respiration must be quantified. This work will produce a synthesis that capitalizes on the strengths of different models and incorporates the important feedbacks of the soil-plant-atmosphere system at pertinent spatial and time scales. An optimization modeling approach will be used to capture stomatal responses to simultaneous elevated ca, changes in Ta, vapor pressure deficit and leaf water potential. Scaling-up from leaves to the canopy to provide a mathematically usable form for coarse-scale models will be completed at two time scales: at short time scales (<1 h), where leaf area density and autotrophic biomass can be assumed constant, and at longer time scales (e.g., seasonal or longer), where changes in these quantities are large. Autotrophic respiratory processes reflect changes in biomass in pools determined using standard biomass budget equations, which will be modified to include carbon allocation rules derived from resource optimization theories that explicitly consider soil and foliage nutrition. For heterotrophic processes, at minimum, three interacting soil carbon pools must be considered: litter, more stabilized SOM, and microbial biomass. Rates of decomposition, nitrogen mineralization, nitrification, and de-nitrification will be modeled together with soil moisture and temperature. Lastly, we will use a novel dimension reduction approach to simplify the multi-dimensional phase-space of this detailed model to a system of a few ordinary differential equations and prepare this simplified model for incorporation into existing climate-carbon models.

Effects of Warming the Deep Soil and Permafrost on Ecosystem Carbon Balance in Alaskan Tundra: A Coupled Measurement and Modeling Approach

- **Principle Investigator:** Edward Schuur (University of Florida)
- **Collaborators:** Yiqi Luo (University of Oklahoma)
- **Award:** $1,024,426 over 3 years

Humans are altering the global cycle of carbon (C) on Earth by burning fossil fuels and altering the land surface. The addition of billions of tons of C greenhouse gases to the atmosphere is changing its heat-trapping capacity, which, in turn, is changing the Earth's climate. While a large proportion of the modern increase in the size of the atmospheric C pool is due to human activities, the future trajectory of the atmosphere also depends, in part, on the response of terrestrial and ocean systems to climate change. Recently, attention has been drawn to permafrost (permanently frozen ground) thaw as a mechanism that could move significant quantities of land C into the atmosphere in response to a changing climate. There are 1,672 billion tons of C stored in soils in the northern permafrost zone. This represents more than a third of the soil C stored in terrestrial ecosystems globally, and is several orders of magnitude greater than current annual anthropogenic CO_2 emissions. Release of permafrost C to the atmosphere in a warming world may have significant implications for the trajectory of future climate change, but this depends on the vulnerability of the permafrost C pool. Our overarching question is: Will the response of permafrost ecosystems to warming and thaw cause significant changes in C cycling that can feed back to affect atmospheric CO_2 concentrations and future climate? We hypothesize that the transfer of old soil C to the atmosphere will occur as a result of permafrost thaw and the microbial decomposition of soil organic matter. Most importantly, this highly significant change in ecosystem C cycling will be detectable in the Δ14C and δ13C isotopic signature of respired C. We also predict that old C loss will offset increases in plant C uptake with warming (so-called 'greening' of the Arctic) and cause this ecosystem to be a net C source to the atmosphere during this century. We propose to test these hypotheses using a combination of field and laboratory experiments to measure isotope ratios and C fluxes from a tundra ecosystem in Alaska where permafrost is degrading. Field measurements will center on two experimental systems at this site. First, an established, two-factor warming manipulation using snow fences and open top chambers to increase winter and summer temperatures alone, and in combination. Our second inter-related experimental system is a permafrost thaw gradient where permafrost thaw and ground subsidence has been documented over the decadal time scale that is relevant to change in these northern ecosystems. Three important measurement tools will be used to address our hypotheses. The first is a dual isotope approach with Δ14C and δ13C to quantitatively partition respiration and detect old C loss. The second is an eddy covariance tower to quantify whole ecosystem C balance across the permafrost thaw gradient over longer time and larger spatial scales. The third is data assimilation techniques and an ecosystem model to make projections of the response of tundra ecosystem C balance to future climate scenarios. Key parameters derived from this will be targeted for future incorporation into regional and Earth System models.

The Response of Soil Carbon Storage and Microbally Mediated Carbon Turnover to Simulated Climatic Disturbance in a Northern Peatland Forest: Revisiting the Concept of Soil Organic Matter Recalcitrance

- **Principle Investigator:** Joel Kostka (Georgia Tech)
- **Collaborators:** Jeffrey P. Chanton (Florida State University), William T. Cooper (Florida State University), and Christopher W. Schadt (Oak Ridge National Laboratory)
- **Award:** $1,049,977 over 3 years

Peatlands sequester one-third of all soil carbon and currently act as major sinks of atmospheric CO_2. The ability to predict or to simulate the fate of stored carbon in response to climatic disruption remains hampered by our limited understanding of the controls of C turnover and the composition and functioning of peatland microbial communities. Given their global extent and uncertain fate with climatic change, boreal forests are considered a high priority for climate change research. The overall goal of this project is to investigate the lability of soil organic matter and the composition of decomposer microbial communities in response to the climatic forcing of environmental processes that determine carbon storage and sequestration in peatlands. The project will be conducted at the Marcell Experimental Forest (MEF) where ORNL has established a Climate Change Response Scientific Focus Area known as Spruce and Peatland Response Under Climatic and Environmental Change (SPRUCE). Our objectives are to: 1) conduct a comprehensive interrogation of organic matter recalcitrance and the functional diversity of keystone microbial guilds that are likely to control organic matter decomposition at the ecosystem scale in a boreal peatland forest, 2) validate the molecular-based Aromaticity Index (AI) as an indicatory of DOM recalcitrance, 3) directly link the phylogenetic identity and metabolic function of keystone microbial guilds that mediate soil carbon turnover in response to perturbations in climate change variables (temperature, redox, pH) under controlled conditions in the laboratory, 4) determine the response of DOM recalcitrance, decomposition, and the functional diversity of keystone microbial decomposers to climate change manipulation in the field at the ecosystem scale. The proposed project will leverage existing infrastructure and will be organized around an ecosystem-scale climate change manipulation experiment to be conducted by the SPRUCE program in a black spruce-Sphagnum forest in northern Minnesota. The flux of carbon from peatlands to the atmosphere is projected to increase with climate change, but acceleration of the C cycle does not necessarily mean that peat soils are losing a greater proportion of their large carbon stores to the atmosphere. The proposed research on soil C processes will leverage SPRUCE datasets on ecosystem response to address the question of whether the response of decomposition to climate change is driven by higher carbon inputs to the soil from plants or rather by the mobilization of stored older carbon, thereby constituting a positive feedback loop. Through a close collaboration with SPRUCE investigators at ORNL, these new insights will be embodied in improvements to the land component of Earth system (CCSM) models and in climate projections derived from these improvements.

Permafrost Thawing and Vegetation Change Effects on Cryoturbation Rates and C and CH_4 Dynamics

- **Principle Investigator:** Miguel A. Gonzalez-Meler (University of Illinois, Chicago)
- **Collaborators:** Tim Filley (Purdue University), Lina Taneva (University of Alaska, Anchorage), Jeffery Welker (University of Alaska, Anchorage), Neil Sturchio (University of Illinois, Chicago)
- **Award:** $1,034,150 over 3 years

The melting of polar ice is an indication of a warming trend in the Arctic and Antarctic regions. In the Arctic, continental soils cover 8.6% of the Earth land area but may as much as 50% of the total global soil organic carbon. Most of this Carbon is permanently stored because soils are frozen forming the so-called permafrost. The current and predicted warming trend in northern latitudes may lead to deterioration of permafrost Carbon, eliciting its decomposition and increasing the levels of greenhouses gases in the atmosphere, potentially creating a positive feedback on the warming trend of the whole climate system. In Arctic Alaska, current and predicted atmospheric air warming will likely lead to increases in winter precipitation, resulting in a deeper snow cover. A thicker snow layer over the soil will act as a thermal insulator, further enhancing the degradation of permafrost and stored soil C, decreasing the Arctic C pool. However, warmer soils will also release soil nutrients which may elicit increases in the productivity of vegetation, enhancing Carbon inputs to soils and creating a negative feedback on the warming trend of the climate system. The balance of these two feedbacks will determine to what extent Arctic ecosystems will become a major source of greenhouse gases in the atmosphere. To evaluate the positive and negative feedbacks we will use artificial winter snow accumulation using snow fences at the LTER research stations at Toolik Lake, Alaska. These treatments emulate the increased snow winter accumulation and the winter thermal insulation of the soils. We used an experiment set in 1996 and a new one established in 2006. In these long- and short-term experiments we will investigate the strength of the positive and negative feedbacks on greenhouse emissions from Arctic soils. Using weapon-derived and natural radioisotope tracers combined with biogeochemical techniques, our first year results suggest that increased emissions of carbon dioxide from permafrost soils maybe compensated for by increased C inputs from growing vegetation. However, increased emissions of methane (a more potent greenhouse gas than carbon dioxide) at the warmer sites suggest tundra will become a source of greenhouse gas equivalents in the future.

Quantifying the Control of Photosynthesis on Root Respiration by Measuring and Manipulating Photosynthate Transport Rates in the Tree Phloem

- **Principle Investigator:** Jianwu Tang (Marine Biological Laboratory)
- **Award:** $149,805 over 2 years

Understanding the processes and controls of ecosystem photosynthesis and respiration is critical in describing ecosystem carbon cycles and developing next-generation earth system models. Recent findings on the control of recent photosynthate on root respiration require us to revisit traditional respiration models, which are largely driven by external climatic factors, but not internal physiology. Our limited understanding of the relationship between photosynthesis and respiration on a diel and weekly scale has formed a knowledge gap in constructing process-based ecosystem models. The objectives of this proposed study are 1) to explore a novel method to measure the photosynthate transport in the tree phloem, 2) to explore the manipulation of the photosynthate transport by chilling stems, and 3) to quantify the control of photosynthesis on respiration and the time lag between the peak values. The study site will be at Harvard Forest in Massachusetts, one of the AmeriFlux sites. Continuous soil respiration measurement will be made in a control plot and a trenched plot to obtain the difference between soil respiration with roots and without roots. Continuous measurement of canopy photosynthesis will be obtained from the existing eddy flux measurement on the site. The relationship between photosynthesis and respiration will be explored and the time lag between the peak values of photosynthesis and respiration will be examined. A new method will be developed to measure photosynthate transport in the phloem based on a non-destructive laser-based optical heating system. A non-destructive stem chilling system will be developed to physiologically block the carbohydrate flow through the phloem. Measured photosynthate transport rates will be used to examine the time lag between peak photosynthesis and peak root respiration. The manipulation of the photosynthate transport will help to develop a model to quantify the control of photosynthesis on respiration while considering the soil temperature effect. This is an exploratory proposal because the proposed work is a high-risk, high-payoff project. This proposed research will contribute to a model that describes the correlation between ecosystem carbon uptake (photosynthesis) and carbon emissions (soil respiration). The proposed new soil respiration model will improves our ability to predict the global carbon cycle under a changing climate. The proposed research will enrich the AmeriFlux dataset and improve our understanding in soil carbon processes.

Interactive Effects of Climate Change and Decomposer Communities on the Stabilization of Wood-Derived Carbon in Soils: Catalyst for A New Study

- **Principle Investigator:** Sigrid C. Resh (Michigan Technological University)
- **Collaborators:** Evan Kane (Michigan Technological University), and Dana Richter (Michigan Technological University)
- **Award:** $149,397 over 2 years

Globally, soils contain twice as much carbon (C) as the atmosphere, with forest soils comprising about 17% of this soil C pool or 350 Pg of C. The sequestration of soil organic carbon (SOC) is the residual between inputs from plant production and outputs from decomposition. In forested ecosystems, the dominant C inputs to the soil are derived from litter, woody debris, and roots. Increased wood removal for biofuel, among other uses, leads to the question, how important is wood (both above- and belowground sources) to soil C sequestration? Additionally, what mechanisms mediate SOC sequestration, particularly in the face of an altered climate predicted for the future? Woody biomass removals have the potential to affect the rate at which SOC is stored or lost, which could either attenuate or exacerbate increases in atmospheric CO_2. Our primary objectives directly investigate consequences of the expected future atmospheric chemistry (increased CO_2 and O_3) on the stabilization of woody biomass in terrestrial pools (soil C) versus being lost to atmospheric pools (CO_2). Taking advantage of isotopically labeled wood, our overall research objectives are: 1) To determine the contribution of woody biomass produced under predicted future elevated levels of CO_2 and O_3 to stable SOC pools in forest soils, and 2) To assess the impact of different fungal decay pathways (i.e., white-rot versus brown-rot) in interaction with varying soil texture and soil temperature and initial contact with mineral fractions (i.e., buried versus surface wood) on the transformation of this woody material into long residence-time SOC components. In 2010, in Rhinelander, WI, the trees at the Aspen FACE (Free Air CO_2 Enrichment) site were cut, providing large quantities of aspen woody biomass with unique ^{13}C signatures (depleted by 14‰) and with biochemical characteristics altered by the treatments. The FACE wood was chipped and will be applied in a series of field decomposition experiments involving two soil types (coarse and fine textured), two types of integration (buried in the mineral soil vs. soil surface), two temperature treatments (warmed and ambient), three fungal inoculation treatments (white-rot, brown-rot, and natural rot), and three wood quality treatments (wood from $+CO_2$, $+CO_2+O_3$, and ambient atmosphere). We will also include control plots with no added woody detritus. To our knowledge, this study will represent the first field study directly investigating fungal priority effects on the ushering of wood-derived C into discrete soil fractions. As such, the results of this study will represent a true breakthrough in our understanding of controls on the transformation of biomass into long-lived SOC pools. Moreover, we will be able to directly measure changes in woody biomass pools, and the wood-derived C into SOC, with changes in climate (passive warming treatment).

Exploratory Research - Using Volatile Organic Compounds to Separate Heterotrophic and Autotrophic Forest Soil Respiration

- **Principle Investigator:** Jeffery Hatten (Mississippi State University)
- **Collaborators:** Karen McNeal (Mississippi State University), Scott Roberts (Mississippi State University), Janet Dewey (Mississippi State University)
- **Award:** $149,978 over 2 years

Soils contain about twice as much carbon as does the atmosphere and soil respiration is about 9 times that of global fossil fuel emissions. As a result, small increases in soil respiration driven by the mineralization of soil organic matter (heterotrophic respiration) caused by climate change could lead to elevated levels of atmospheric carbon dioxide and positive feedback on global warming. Research on soil respiration is complicated by the fact that carbon dioxide carries little information about its source. Therefore, determining whether carbon dioxide is being derived from autotrophic (e.g. roots) and heterotrophic (e.g. decomposition) sources requires methods that are destructive, invasive, and/or expensive. Our project proposes to investigate a new method using volatile organic compounds (VOCs) as indicators of carbon dioxide source. Our overall objective is to determine whether the composition and quantity of soil VOCs can be used to separate the respiration associated with roots (autotrophic respiration) and respiration associated with heterotrophic processes (i.e. decomposition of soil organic matter, dead roots, and root exudates). We propose to conduct a greenhouse study of soil respiration and VOC efflux where each respiration component is isolated utilizing pots with and without plants, litter bags, and destructive sampling. The results of this study will allow us to measure or calculate soil respiration and VOC efflux of each component. The impact of tree species, diurnal cycles, and soil moisture regime will be assessed within the boundaries of this greenhouse study. The specific objectives of the project are to: 1) Determine the VOCs that uniquely indicate each component of soil respiration; 2) Test the effectiveness of this method over a range of soil moisture conditions;

3) Determine if diurnal cycles affect soil respiration and soil VOC efflux; and 4) Determine if VOCs can uniquely indicate below ground root production of biomass. This exploratory study has the potential to create a method that greatly improves the measurement of autotrophic and heterotrophic respiration as well as reduce the efforts required to determine these important fluxes. As a result, this work could increase the possible number of measurements that can be made and ecosystems monitored. Ultimately, the proposed study will improve our understanding of terrestrial carbon cycle processes and provide better predictions regarding the effect of climate change on soil organic matter pools.

Quantifying the Effect of Nighttime Interactions Between Roots and Canopy Physiology and Their Control of Water and Carbon Cycling on Feedbacks Between Soil Moisture and Terrestrial Climatology Under Variable Environmental Conditions

- **Principle Investigator:** Jean-Christophe Domec (North Carolina State University)
- **Collaborators:** John King (North Carolina State University), Asko Noormets (North Carolina State University), Sari Palmroth (Duke University), Jennifer Swenson (Duke University), Ram Oren (Duke University)
- **Award:** $462,546 over 3 years

An underlying assumption for reduced sensitivity to rainfall and drought and increased carbon sequestration for unmanaged forest is that deep root systems provide a stable supply of water to plants. Plants do not only lose water from the canopy through transpiration, but may also lose a portion of water taken up at night from deep, moist soil layers through flux from roots to shallow, dry soil layers. This process is termed 'hydraulic redistribution' (HR). Recent studies suggest that HR can significantly delay further drying of the upper portion of the soil profile by replacing more than 25% of the water utilized during the day with water taken up by deep roots. Furthermore, recent numerical studies have shown that the daily replacement of transpired water by HR can potentially affect land-surface climatology and so the linkages between soil moisture dynamics and rainfall imply that HR may serve as a mechanism for the interaction between deep layer soil-moisture and regional climate dynamics. The climate projections indicate increasing atmospheric CO_2, higher mean and night temperatures and higher vapor pressure deficit (VPD), contributing to greater evaporative demand for plants. The first objective of this proposed research will be to investigate the temporal variability of HR in three active Ameriflux sites and to use published data of fluxes, soil moisture, root profiles and tree hydraulic characteristics of two inactive Ameriflux sites. Specifically, it will be determined how water redistributed at night by deeper roots increases carbon sequestration and reduces the sensitivity of carbon, water and energy exchange to drought. The second objective will be to study the soil-root interactions and hydraulic interdependence between plant communities. Using a soil-plant-atmosphere model, the third objective will be to forecast how the predicted increases in temperature, vapor pressure deficit and CO_2 will affect gross ecosystem productivity and net ecosystem exchange as well as the flux partitioning between understory and overstory species through changes in HR. The fourth objective will be to incorporate HR into a large scale model for further evaluation of the impact of root functioning in land-surface climatology by examining the effect of soil moisture on convective rainfall triggers. Existing sites that are part of the FLUXNET network we will be used to fit these objectives. The three sites will include two uneven-aged and unmanaged forests: a 80–100-year old oak/hickory forest growing on low fertility, acidic clay-loam soil, and a

60–150-year old tupelo/pine/baldcypress forest growing on deep organic soil (Alligator River Site), as well as one drained pine plantation growing on thick organic soil (> 1.8 m). The magnitude of HR will be measured using soil moisture probes installed at several depths. Extensive measurements of root profiles and root resistances to drought will help answer the question of whether deep roots provide sufficient water to maintain photosynthesis and transpiration during drought. Eddy covariance and sapflow data from these different ecosystems will be analyzed via top-down approaches in conjunction with a mechanistic ecosystem soil-plant-atmosphere model to test current understanding of the effects of soil types, drought, VPD, elevated temperature and elevated CO_2 concentration on ecosystem respiration and canopy CO_2/H_2O exchange. Sap flux and gas exchange (leaf-level and chamber) measurements will also be used to evaluate responses of small woody plants and herbaceous components of the ecosystems to VPD and water deficits. Data collected at the Duke free-air CO_2 enrichment (FACE) site will also be incorporated to assess the effect of elevated CO_2 on HR. This project will provide quantitative information on carbon, water and energy exchange in response to water deficits, elevated future temperature, vapor pressure deficit and atmospheric carbon dioxide across non-managed ecosystems. In addition, coupling the soil-plant-atmosphere model with a biosphere model will predict whether those unmanaged stands will have a greater influence on possible feedback mechanisms between soil moisture and convective rainfall triggers. This will have significant impact on determining whether future climate scenario would affect carbon sequestration of unmanaged stands.

Water-Carbon Links in a Tropical Forest: How Interbasin Groundwater Flow Affects Carbon Fluxes and Ecosystem Carbon Budgets

- **Principle Investigator:** David Genereux (North Carolina State University)
- **Collaborators:** Chris Osburn (North Carolina State University), Steven Oberbauer (Florida International University)
- **Award:** $768,331 over 3 years

This project is quantitatively exploring the importance, for carbon cycling, of the link between the tropical rainforest and the deeper hydrogeological system on which it sits. Tropical forests are an important component of the global carbon cycle, and yet even the basic issue of whether they operate as net sources or sinks with respect to carbon remains a primary research question and the subject of sometimes-conflicting analyses. Full accounting of carbon inputs and outputs is a critical issue and one closely linked to the hydrologic cycle. Recent water and carbon data from the lowland rainforest at La Selva Biological Station in Costa Rica suggest that interbasin groundwater flow (IGF, regional groundwater flow beneath watershed topographic boundaries) strongly influences concentrations and fluxes of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). The influence of IGF on carbon dioxide degassing from streams, wetlands, and soils is presently not known but may be significant. The project focuses on the potentially significant links between IGF (a common groundwater process detected at watersheds world-wide) and carbon cycling in tropical forests. We have begun collection of new data (carbon concentrations, chemical and isotopic characteristics, soil respiration, net ecosystem exchange (NEE) of carbon dioxide between the atmosphere and forest, carbon dioxide degassing rates in streams, and stream discharge) to show how IGF influences carbon fluxes and the overall carbon budget of this tropical rainforest ecosystem. Two small watersheds (one with significant inputs by IGF, the other without) are being used as the field study units for flux and budget accounting in the ecosystem. Preliminary analyses show, for example, that IGF increases streamwater DIC concentration by a factor of about 12 and stream-based watershed export of DIC by a factor of about 70; for DOC, concentration was actually reduced by a factor of about 0.67 while export increased by a factor of 3.5. A significant quantity of carbon is moving into the ecosystem via IGF, and out of the ecosystem via other fluxes (including streamflow and atmospheric exchange of carbon dioxide). Data collection and analysis related to carbon chemistry and fluxes is ongoing. We are beginning to study the impact of IGF on DOC quantity and quality, including whether "old" DOC from IGF is relatively "protected" from biological degradation, thus facilitating its hydrologic export from watersheds via stream flow.

Forecasting Carbon Storage as Eastern Forests Age: Joining Experimental and Modeling Approaches at the UMBS AmeriFlux Site

- **Principle Investigator:** Peter Curtis (Ohio State University)
- **Collaborators:** Gil Bohrer (Ohio State University), Knute Nadelhoffer (University of Michigan), Christopher Gough (Virginia Commonwealth University), Christoph Vogel (The University of Michigan)
- **Award:** $1,030,767 over 3 years

The future trajectory of the North American carbon sink remains highly uncertain as mixed deciduous forests of the U.S. Midwest and east transition from early to mid and late successional communities. Following heavy disturbance in the 19th and early 20th centuries, dominant early successional canopy species are reaching maturity and beginning to senesce, giving way to a canopy that is more species diverse and structurally heterogeneous. Large-scale mortality is also forcing redistribution of carbon and nitrogen, with the consequences for forest carbon cycling processes largely unknown. We are incorporating novel physical and biological mechanisms into an Earth system atmosphere-biosphere model to improve regional forecasts of future forest carbon storage in response to disturbance and succession, and to current and long-term climate variation. We are using novel structure-function relationships derived from our long-term ecological and meteorological carbon cycling studies at the University of Michigan Biological Station to parameterize the ecosystem model, ED2, for stand to regional simulations of forest carbon storage over a range of forecasted climates. By incorporating the dynamic effects of canopy structure on forest ecosystem function in an earth system model, our results are contributing to continental and global scale modeling efforts that aim to improve the quantitative certainty of predictions of future terrestrial carbon storage, and to advance the formulation of forest management prescriptions for enhancing carbon sequestration in older forests.

Effects of Disturbance on Carbon Sequestration in the New Jersey Pine Barrens

- **Principle Investigator:** Karina Schafer (Rutgers University)
- **Collaborators:** Gil Bohrer (Ohio State University), Kenneth Clark (USDA Forest Service), Nicholas Skowronski (USDA Forest Service)
- **Award:** $549,343 over 3 years

Disturbance events directly affect carbon (C) uptake through loss of leaves and needles, and indirectly by altering detrital pools, nutrient dynamics, and nutrient availability, which in turn can affect leaf biochemical function. An increase in temperature and changes in precipitation regimes are expected with global climate change. Hurricanes and droughts, which increase tree falls and forest fires, may also increase in the future. In temperate regions, higher temperatures are also likely to increase the frequency and severity of insect outbreaks. Epidemic insect outbreaks have been recently shown to reduce C-uptake by forests significantly, and will affect long-term C storage. We study of two contrasting disturbances - gypsy moth outbreak and prescribed forest fire and their effects on the structure, dynamics, microclimate and resulting carbon budget of an east-coast oak/pine forest, in the New Jersey Pine Barrens. Eddy-covariance measurements are used to determine the carbon budget, evapotranspiration, and canopy microclimate before and after the disturbances. Sap-flow measurements will be used to determine tree-level transpiration and hydrodynamic stresses. Remote sensing of the canopy will be used to measure the extent and pattern of reduction in leaf area and change of vertical and horizontal structure following each disturbance type. These measurements will be used to parameterize and validate tree-scale large-eddy simulations and tree-crown hydrodynamic modeling of the canopy and the processes that drive changes to C budget and ecosystem dynamics after the disturbances. Canopy net assimilation will be simulated with the Canopy Conductance Constrained Carbon Assimilation model (4C-A). The 4C-A model will be modified to allow modeling future disturbance effects in the NJ Pine Barrens by linking it to a high-resolution 3D explicit canopy domains, and the Finite-Elements Tree-Crown Hydrodynamics (FETCH) model, which resolves branch-level water flow within the tree system, and hydrodynamic limitations to transpiration. The results of these models will be dynamically linked to the Ecosystem Demography model (ED2) which is a plot-scale ecosystem land-surface model that is driven by above canopy meteorological measurements, or by a large-scale meteorological models. The Pine Barrens contain the largest area of forest in New Jersey and, as such, contain the largest C sink in NJ as well. However, disturbances such as fire, insect outbreak, and windfall hamper C uptake and storage. The coupled model that will be developed here will help to further account for effects of climate change-induced disturbances such as fire and herbivory in order to improve the predictability of regional forest C balance . Model development and evaluation will be done at the Silas Little Experimental Forest, which is a part of the Ameriflux network.

Direct, Indirect and Interactive Effects of Warming and Elevated CO_2 on Grassland Carbon Metabolism

- **Principle Investigator:** Elise Pendall (University of Wyoming)
- **Collaborators:** Kiona Ogle (University of Wyoming), David Williams (University of Wyoming), Jana Heisler-White (University of Wyoming), Jack Morgan (USDA-ARS), Feike Dijkstra (USDA-ARS), William Parton (Colorado State University)
- **Award:** $1,044,170 over 3 years

Our project will assess direct, indirect and interactive effects of elevated CO_2 and warming on C metabolism and its components at the Prairie Heating and CO_2 Enrichment (PHACE) experiment, with particular emphasis on quantifying the role of soil water availability. To achieve this, we will integrate extensive and diverse field observations from a state-of-the art experiment with process models to address the following objectives: 1) Characterize “fast” processes underlying diurnal to seasonal dynamics of C metabolism components, as driven by soil moisture, temperature, substrate and nutrient availability, plant activity, root and microbial activity, and root-microbe feedbacks such as priming. 2) Characterize “slow” processes underlying interannual and long-term (>5 yr) dynamics of C metabolism components, as driven by precipitation variability, plant community composition, and nutrient status. 3) Evaluate and inform the representation of these slow and fast processes in Earth system models by applying hierarchical Bayesian data-model assimilation methods. At the PHACE experiment we investigate how multiple global change factors interact to influence a native mixed-grass prairie ecosystem by deploying well-replicated, state-of-the-art Free-Air CO_2 Enrichment (FACE) and infra-red warming manipulations. Additional shallow (summer) and deep (spring) irrigation treatments allow evaluation of how seasonality of precipitation influences mixed-grass prairie, and how the magnitude of indirect water effects compares to direct effects of CO_2 and warming. To understand mechanisms underlying ecosystem responses, we make extensive use of gas exchange, stable isotope, soil water and nitrogen monitoring, and computer simulation models. Results from the first four years (2006-2009) of manipulations have enhanced mechanistic understanding of ecosystem responses to global changes. This project integrates detailed field experiments with process-based modeling, which is expected to yield a predictive framework for 1) evaluating how changes in water availability control ecosystem responses to other global changes such as elevated CO2 and temperature and 2) quantifying ecosystem responses that cannot be explained by water availability. This project will provide new information about how increasing atmospheric CO2 and associated climate change alters greenhouse gas emissions and C storage potential of a widespread terrestrial ecosystem.

Further information on TES objectives along with a listing of past and current funding opportunities discussed in this document, is available at http://tes.science.energy.gov/.

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