Terrestrial Ecosystem Science

Summary of projects awarded in spring 2013 under Funding Opportunity Announcement DE-FOA-0000749.

Funding Opportunity Announcement Overview

The Office of Biological and Environmental Research's (BER) Terrestrial Ecosystem Science (TES) program seeks to improve the representation of terrestrial ecosystem processes in Earth system models thereby improving the quality of climate model projections and providing the scientific foundation needed to inform DOE's energy decisions. TES uses a systems approach to understand ecosystems over multiple scales that can be represented in models (e.g., single process models, ecosystem models, and the CESM). This emphasis on the capture of advanced understanding in models has two goals. First, it seeks to improve the representation of these processes in coupled models, thereby increasing the sophistication of the projections from those models. Second, it encourages the community to exercise those models and to compare the results against observations or other data sets to inform future research directions.

The Funding Opportunity Announcement **DE-FOA-0000749**, was jointly supported by the Terrestrial Ecosystem Science, Earth System Modeling (ESM) and Regional and Global Climate Modeling (RGCM) programs and was released in the summer of 2012. Overall, the FOA sought research that focused on measurements, experiments, modeling, synthesis and analysis that provide improved quantitative and predictive understanding of the terrestrial ecosystems. In addition, research that focused on development and coupling of the Community Earth System Model(CESM) land model component was sought.

Applicants were required to pose their research applications in the context of representing terrestrial ecosystem processes in Earth system models. Given extensive efforts by DOE to develop the CESM (including the CLM) applicants were encouraged to link their activities to these efforts where appropriate as well as 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 programs support 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 belowground processes and mechanisms across scales (e.g., soil carbon transformation/stability, root dynamics, mycorrhizal interactions, and plant mediated (e.g. root exudates, priming, hydrological) biogeochemical transformations) associated with a changing climate;
- New or improved understanding of carbon pathways, fluxes and ecosystem function with particular emphasis on Arctic and tropical ecosystems;
- The role of natural disturbances in carbon cycling, particularly disturbances associated with changing climate (e.g.,

changes in atmospheric carbon, precipitation, nutrients);

- New or improved understanding of critical carbon processes at the terrestrial-aquatic interface which have the potential for direct feedbacks to the climate system (e.g., soil carbon transformation, methane biogeochemistry). Research under this science area was required a direct link to terrestrial processes and is limited to terrestrial ecosystems and their immediate interface with freshwater and brackish water systems, such as riparian zones, hyporheic zones and wetlands. Research that focuses on aquatic processes, agricultural systems, ocean systems, and ecosystem services were not be considered;
- CLM developments, including development, coupling and testing of submodels related to land biogeophysics, the hydrologic cycle, biogeochemistry, and ecosystem dynamics. Attention to scale-aware and scale-appropriate parameterization development is a priority; and
- Synthesis activities that draw broad insights into, and improve our understanding of, terrestrial ecosystems and their role in forcing climate change will be considered (and should leverage existing models, sites and datasets).

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.

Fifteen awards (three of which were exploratory awards) were made through this Funding Opportunity Announcement totaling $12,272,345 over three years.

Funded Projects

Terrestrial Ecosystem Sciences (TES)

Incorporating Rhizosphere Interactions and Soil Physical Properties into a Soil Carbon Degradation Model through Experimenting Across Ecotypes

- **Principle Investigator:** Aimee Classen (University of Tennessee)
- **Collaborators:** Melanie Mayes (Oak Ridge National Laboratory)
- **Award:** $987,328 over 3 years

Per unit area, soils harbor the greatest diversity on earth largely in the fungal and bacterial pool. These communities, which also harbor a diversity of functions, are responsible for degrading and mineralizing the carbon and nutrients that enter the soil. Soil microbial communities are directly and indirectly responsible for the mineralization of terrestrial soil carbon and nutrients, thus understanding the links between soil communities and root function and soil processes is a major theme in ecosystem and global change ecology, but one that remains poorly understood. Soil properties and biological communities vary significantly by ecosystem and soil type, but current soil carbon cycling models fail to incorporate these interacting factors. For example, mycorrhizal fungi, which associate with plants and are important for nutrient uptake, are an integral link to carbon cycles in ecosystems because they exchange soil organic matter-derived nutrients for plant-assimilated carbon, yet their activity, and how their regulation of carbon dynamic might change by soil type, is often not considered in models. The failure to consider the role of the integrated biological community – microbes, mycorrhizal fungi, and plant roots – on soil carbon turnover may render models incapable of predicting local-scale responses to environmental change. Our project will fill this knowledge gap by modeling and experimentally manipulating the biological community in situ across temperate, tropical and boreal ecosystems, thus increasing our ability to predict and model the extent to which soils in terrestrial ecosystems will be an atmospheric net C source or sink.

Changes in Soil Carbon Dynamics in Response to Long-Term Soil Warming - Integration Across Scales from Cells to Ecosystems

- **Principle Investigator:** Jerry Melillo (Marine Biological Laboratory)
- **Collaborators:** Kristen DeAngelis (University of Massachusetts, Amherst), Jeffrey Blanchard (University of Massachusetts, Amherst)
- **Award:** $1,049,000 over 3 years

Soils contain an estimated 2,500 Pg carbon, about three times as much as in the atmosphere as carbon dioxide and five times as much as in terrestrial vegetation in various organic carbon forms. A substantial fraction of the soil carbon occurs in relatively complex compounds. How the decay of these compounds will change in a warmer world is not clear. A major question in Earth System Science is: Will global warming accelerate the decomposition of these complex compounds by microorganisms, releasing carbon dioxide, a powerful heat-trapping gas, to the atmosphere, thereby creating a self-reinforcing (positive) feedback to the climate system? Put another way, will warming beget warming, with microorganisms as the central "actors?" This research will address this question by leveraging an ongoing climate-change experiment in which the soil in a 100-year old forest has been heated in situ, year-round for the past 22 years. Soil temperatures in the experimental plots have been raised 5 degrees Celsius above ambient temperatures in a deciduous forest stand at the Harvard Forest Long-term Ecological Research (LTER) site in central Massachusetts. Soils from the heated and control plots are being analyzed to evaluate both biogeochemical and microbial mechanisms of altered C cycling with warming on an ecological time scale. The study will employ a range of techniques including microbial genomics and compound-specific stable isotope analyses. Information gained from the study will be used to develop a new model of soil organic matter decay so that it represents the soil decay responses to climate change in a more mechanistic way.

Dryland Feedbacks to Future Climate Change: How Species Mortality and Replacement will Affect Coupled Biogeochemical Cycles and Energy Balance

- **Principle Investigator:** Sasha Reed (US Geological Survey)
- **Collaborators:** Jayne Belnap (USGS), Thomas Painter (University of California, Los Angles)
- **Award:** $1,049,357 over 3 years

Drylands (arid and semi-arid lands, such as deserts and many grasslands) make up about 35% of the United States and over 40% of the terrestrial surface globally. Indeed, drylands are our planet's largest biome. These relatively arid ecosystems also maintain very large stocks of carbon; for example, dryland soils store nearly twice as much soil organic carbon as temperate forest soils. In addition, due to high solar irradiance, drylands have the potential to affect future climate not only via changes to carbon cycling, but also through changes in albedo and energy balance. Nevertheless, research on the potentially shifting contribution of drylands to regional and global carbon and energy budgets has received relatively little scientific attention. This lack of attention represents an important deficit in our understanding and ability to forecast the effects of global change: climate models predict rapidly rising temperatures for the already hot and moisture-limited dryland regions, and such changes could dramatically affect these extensive landscapes. For example, a recent study showed that biological soil crusts (the soil surface community of mosses, lichens and cyanobacteria, which form a critical component of dryland ecosystems) can respond to climatic change with rapid mortality events. In spite of the importance of such eventualities, what they could mean for carbon cycling and storage, for coupled nutrient cycling, and for energy balance across the widespread dryland biome remains almost wholly unknown. Our lack of understanding of the direction, magnitude, and mechanisms behind these projected changes – as well as the absence of a theoretical framework for incorporating biocrusts into global models – greatly constrain our ability to appropriately represent drylands in modeling efforts. At the same time, the main message from the limited existing data is that dryland ecosystems have the potential to respond dramatically to climatic change, and that such changes could, in turn, affect climate at the global scale.

This project will make great strides in advancing our understanding of the role drylands play in global climate, both now and into the future. To elucidate the mechanisms behind and the consequences of climate-induced change to dryland communities, we have planned a multi-disciplinary yet integrated approach that combines in situ field manipulations; cross-ecosystem comparisons; the creation of ‘libraries’ of dryland vascular plant, biocrust, and soil spectral data; and a small-scale modeling effort (to be followed in later years by a larger-scale modeling effort). In particular, we propose to test the following four hypotheses: Hypothesis 1) Climate-induced changes to the composition and cover of vascular plant and biocrust communities will have dramatic effects on carbon and nutrient cycling; Hypothesis 2) Biogeochemical drivers of and responses to these changes in communities will be inconsistent across different dryland ecosystems; Hypothesis 3; Changes to vascular plant and biocrust communities in drylands will have significant effects on energy balance; and, Hypothesis 4) Introducing a predictive representation of biocrust structure and function into the Community Land Model (CLM4.5), including physical and biological biocrust properties, will improve predictions of water, energy, and carbon fluxes between dryland systems and the atmosphere.

Rigid Nanostructured Organic Polymer Monolith for In Situ Collection and Analysis of Plant Metabolites from Soil Matrices

- **Principle Investigator:** Nishanth Tharayil (Clemson University)
- **Award:** $127,497 over 2 years

Release of photosynthates from plant roots and decomposing litter forms a major conduit through which atmospheric carbon dioxide reaches belowground ecosystems. These metabolites mobilizes the unavailable nutrients in soil matrices and thus assist in resource foraging in plants; also they from the major source of energy for soil fauna that facilitates the formation and stabilization of carbon in soil, thus regulating the soil carbon sequestration in terrestrial ecosystems. Despite the profound implication of these metabolites in the organismal- and ecosystem-level interactions, the complexities of soil matrices hinder the current efforts to delineate the specific chemical composition of these plant inputs. Such information is vital as the biological functions of these plant inputs and the interactions they facilitate are strictly governed by their composition and molecular identity. To transcend this problem, the project aims to develop new polymeric probes that will be highly effective in the in-situ capture of plant metabolites from soil matrices. The polymeric matrix of the probes will be optimized using various monomer combinations that would confer optimal balance between high porosity, high sorption capacity and the versatility of functional group attachments, while maintaining rigidity and reusability of the probes. The probes will be tested in both managed and non-managed ecosystems for the efficient capture of plant metabolites, which then will be characterized using advanced analytical techniques. The proposed probes will be instrumental in gaining a better understanding of the chemical environment in soils to which the roots are exposed to, and would help scientist to measure the real-time fluxes of plant exudates in different ecosystems, which in turn will enable an accurate classification of the labile pools of carbon in biogeochemical models.

Determining the Drivers of Redox Sensitive Biogeochemistry in Humid Tropical Forests

- **Principle Investigator:** Whendee Silver (University of California, Berkeley)
- **Collaborators:** Peter Thornton (Oak Ridge National Laboratory)
- **Award:** $869,143 over 3 years

Humid tropical forests are often referred to as the lungs of the Earth. The long growing season and high plant biomass of these ecosystems helps regulate the chemical composition of the global atmosphere, and by extension, global climate. The availability of oxygen in soils and associated oxidation-reduction dynamics play important roles in carbon cycling and greenhouse gas fluxes in tropical forests. Changes in climate are likely to affect soil oxygen availability in tropical forests and in turn affect the flow of carbon and nutrients. Few studies have measured soil oxygen availability over time and space in tropical forests, and thus this important factor is absent or poorly represented in Earth systems models. In this study we will use field and laboratory experiments in humid tropical forests to develop a new component for the Community Land Model (CLM) that explicitly covers the relationships among soil oxygen, carbon cycling, and greenhouse gas fluxes. Research will be conducted in the Luquillo Experimental Forest, Puerto Rico. We will make near continuous measurements of soil processes to capture background patterns, as well as ‘hot spots’ and ‘hot moments’. The data and modeling efforts associated with this work will improve the prediction of carbon and nutrient cycling and greenhouse gas dynamics in humid tropical forests.

Spatial Variation in Microbial Processes Controlling Carbon Mineralization within Soils and Sediments

- **Principle Investigator:** Scott Fendorf (Stanford University)
- **Collaborators:** Christopher Francis (Stanford University), David Lobell (Stanford University), Markus Kleber (Oregon State University), Peter Nico (Lawrence Berkeley National Laboratory)
- **Award:** $1,50,857 over 3 years

Soil plays a critical role in global carbon (C) cycling, having one of the largest dynamic stocks of C on earth—3300 Pg of C are stored in soils, which is three-times the amount stored in the atmosphere. An important control on soil organic matter (SOM) quantities is the rate of carbon utilization by microorganisms (SOM mineralization). The rate and extent of SOM mineralization is affected by climatic factors influencing microbial metabolic rates in combination with SOM chemistry, mineral-organic matter stabilization, and physical protection. What remains elusive is to what extent constraints on microbial metabolism induced by the respiratory pathway, and specifically the electron acceptor in respiration, control overall rates of carbon mineralization in soils. The complex physical structure of soils and sediments result limited oxygen ingress, resulting in anaerobic environments even within seemingly aerobic systems. The overarching goal of this study is to determine if variations in microbial metabolic rates induced by anaerobic microsites in soils are a major control on SOM mineralization rates and thus carbon storage. A combination of laboratory experiments and field investigations will be performed to fulfill our research goal. Model, laboratory studies will be performed to examine fundamental factors of respiratory constraints (i.e., electron acceptor) on organic matter mineralization rates. We will ground our laboratory studies with both manipulation of field samples and in-field measurements. Moreover, we will use reactive transport modeling to integrate our micro-scale measurements to deduce the field-scale (macroscopic) observable redox induced metabolic controls on carbon mineralization. A major outcome of our research will be the ability to quantitatively place the importance of cm-scale variation in microbial metabolisms on the rate of carbon mineralization in soils. Further, we will provide the ability to upscale our results into ecosystem models that can couple with global carbon models using well mapped or remotely sensed inputs such as soil texture, soil moisture, and plant ecosystem.

Understanding Litter Input Controls on Soil Organic Matter Turnover and Formation are Essential for Improving Carbon-Climate Feedback Predictions for Arctic, Tundra Ecosystems

- **Principle Investigator:** Matthew Wallenstein (Colorado State University)
- **Collaborators:** Richard Conant (Colorado State University), Francesca Cotrufo (Colorado State University), Eldor Paul (Colorado State University), William Riley (Lawrence Berkeley National Laboratory)
- **Award:** $1,049,996 over 3 years

The Arctic has experienced substantial regional warming over the past 30 years that could turn the Arctic into a net source of carbon to the atmosphere as soil organic matter (SOM) decomposes. But in addition to temperature-driven acceleration of decomposition, several additional processes could either counteract or augment warming-induced SOM losses. For example, increased plant growth under a warmer climate will increase organic matter inputs to soils, which could fuel further soil decomposition by microbes, but will also increase the production of new SOM. Whether Arctic ecosystems store or release carbon in the future depends in part on the balance between these two counteracting processes, which this project focuses on. By differentiating SOM decomposition and formation and understanding the drivers of these processes, we will better understand how these systems function. We will integrate this new knowledge into a process-based biogeochemical model to improve our ability to forecast global change impacts on Arctic carbon stocks.

Multi-scale Carbon Cycle Observations and Ecosystem Process Modeling at Niwot Ride, Colorado

- **Principle Investigator:** David Bowling (University of Utah)
- **Collaborators:** Charles Koven (Lawrence Berkeley National Laboratory), Britton Stephens (National Center for Atmospheric Reserach), Mark Williams (University of Colorado)
- **Award:** $991,445 over 3 years

This project is a multi-scale investigation of carbon cycling at Niwot Ridge, Colorado, and application of the data to improve key components of a large earth system model called the Community Land Model (CLM). Our observations leverage and extend existing continuous long-term CO_2 concentration and CO_2 isotope records. The study involves a paired-site design, including measurements at an alpine tundra location and a nearby subalpine forest (the Niwot Ridge AmeriFlux tower). Measurements of CO_2 and its stable isotope composition at these sites are ongoing and the record is now > 8 years. The analyses within this project will guide improvements to the representation of vegetation and belowground carbon cycling in CLM and provide important tests of modeled terrestrial ecosystem responses to disturbance and climate change. We will investigate linkages between ecosystem processes and atmospheric CO_2 and CO_2 isotopes. We will directly examine the isotopic composition of major land surface carbon sources and sinks and below ground carbon pools. This will provide essential understanding of mechanisms of carbon transfer that will allow us to improve the representation of within-plant isotopic changes and soil carbon decomposition pathways in CLM.

Confronting Models with Regional CO_2 Observations Principle I

- **Principle Investigator:** James Ehleringer (University of Utah)

- **Collaborators:** John Chun-Han Lin (University of Utah), Britton Stephens (National Center for Atmospheric Research), Peter Thornton (Oak Ridge National Laboratory), Robert Andres (Oak Ridge National Laboratory)
- **Award:** $1,048,742 over 3 years

This research addresses an important DOE science area: the role of natural disturbances in carbon cycling. Our project includes both (a) modeling and field measurements and (b) strengthening ties between DOE national laboratories and universities. Our focus is on understanding the consequences of drought and emissions (fire and urban) to atmospheric trace gas composition (carbon dioxide, carbon monoxide, and methane), including both concentration and stable isotope composition. Measurements of these atmospheric gases are used to infer the spatial and temporal patterns of both sources and sinks in the carbon cycle. As part of this effort, we will maintain two long-term monitoring networks along a geographic gradient in Utah and Colorado that spans montane forests, urban regions, and oil/gas fields. In this research, we expand on a well-accepted atmospheric model (STILT-WRF) as a tool to evaluate fluxes in CLM/CESM-related models through (a) existing long-term data sets, (b) ongoing monitoring networks, and (c) field campaigns using a mobile observatory. We will use the STILT model to provide a strong linkage between point atmospheric measurements and the surface parameterizations/emissions that are part of the CLM/CESM models. Since trace gases associated with source and sink fluxes differ in their stable isotope composition, our isotopic analyses of trace gases will allow us to partition changes in carbon dioxide, carbon monoxide, and methane fluxes in CESM into natural (drought and fire related) versus anthropogenic components. Overall, this project benefits and supports the DOE Long Term Mission and Goals in four distinct ways: (a) testing of carbon cycle models, (b) testing and evaluating model mechanisms whereby factors in CLM influence trace gas composition in CESM, (c) acquiring high-quality, long-term data on concentrations and isotope ratios of carbon dioxide, carbon monoxide, and methane in western USA ecosystems, and (d) by reducing uncertainties associated with the representation of climate-carbon feedbacks in Earth System models through the development of new methods for evaluating model performance.

Above and Belowground Connections and Species Interactions: Controls Over Ecosystem Fluxes

- **Principle Investigator:** Amy Trowbridge (HyPerspectives Inc.)
- **Collaborators:** Richard Phillips (Indiana University)
- **Award:** $150,000 over 2 years

Forests represent the primary source of volatile organic compounds (VOCs) globally, and VOCs significantly impact ecological and atmospheric processes, including the production of ozone. Most of what is known about VOC production in forests comes from studies of live canopy foliage. However, recent work indicates that roots and soil microbes can be considerable sources of VOCs, with implications for models of atmospheric chemistry and ecosystem carbon budgets. In this project, soil and canopy VOC fluxes will be quantified in situ in forests dominated by different tree species. The mycorrhizal fungi associated with tree roots differ in their response to environmental variability and their effects on soil organic matter decomposition, with likely consequences for soil VOC emissions. In addition, we will partition soil emissions into autotrophic (i.e. root and mycorrhizal-derived) versus heterotrophic sources and determine underlying biological mechanisms controlling emission dynamics. Driven by our knowledge of plant-fungal dynamics, microclimate, VOC emission and transport rates, and atmospheric hydroxyl radical (OH) concentrations, we will improve ecosystem models and assess the potential for soil VOC emissions to influence ozone production. By understanding the important links between environmental variation, plant species composition, and the underlying mechanisms controlling soil VOC fluxes, we will be able to make predictions as to how future changes in regional stand types, land use, and climate will impact atmospheric chemistry, air quality, and ecosystem function. Thus, the results from this project will contribute a comprehensive mechanistic understanding of biological and physical controls over VOC emissions from the molecular-to-ecosystem-to-atmospheric scales and improve the predictive capabilities of land surface models and global carbon cycling.

Regional and Global Climate Modeling (RGCM)

Biogeochemical Responses and Feedbacks to Climate Change: Synthetic Meta-Analyses Relevant to Earth System Models

- **Principle Investigator:** Bruce Hungate (Northern Arizona University)
- **Collaborators:** Craig Osenberg (University of Florida), Jeff Dukes (Purdue University), and Yiqi Luo (University of Oklahoma)
- **Award:** $932,746 over 2 years

Soil is one of the largest reservoirs of carbon, and could potentially buffer climate change by storing some of the extra carbon dioxide humans are releasing to the atmosphere. Yet, the stability of soil carbon is unsure, and its sensitivity to environmental change poorly understood at broad, general scales, despite decades of global change research projects. One critical problem is that the soil carbon pool is large and changes very slowly, making it hard to determine whether changes observed in experiments are real or are “noise” caused by plot-to-plot variation. At the same time, small changes are important, and could indicate substantial impacts on the future capacity of the biosphere to store carbon. The research we propose holds promise for surmounting this problem, by synthesizing results from multiple experiments using “metaanalysis” (quantitative data synthesis), increasing our ability to detect whether changes are real and whether they are general across ecosystems and environments. Another critical challenge is how carbon storage in ecosystems is influenced by other essential resources, and particularly nutrients, which through various pathways could amplify or dampen changes in carbon storage. Earth system models have identified these interactions as crucial, but disagree about how large they are, and even in which direction they operate. The research we propose combines metaanalysis with theory of element cycling to examine these questions using data from real, on-the ground, experiments conducted over the past several decades. Our proposed approach extends beyond standard modes of data interpretation in experiments, with the goal of tying inferences directly to the Earth system models that provide our best understanding of possible future climate scenarios. In this way, our proposed research contributes to accomplishing the long-term measure of the Department of Energy’s BER.

Objectives of the Project

This project will examine the sensitivity of carbon in land ecosystems to environmental change, focusing on carbon contained in soil, and the role of carbon-nitrogen interactions in regulating ecosystem carbon storage. The project will use a combination of empirical measurements, mathematical models, and statistics to partition effects of climate change on soil into processes enhancing soil carbon and processes through which it decomposes. By synthesizing results from experiments around the world, the proposed approach will provide novel insight on ecological controls and responses across broad spatial and temporal scales. In this way, a second objective of the project is to develop new approaches in meta-analysis using principles of element mass balance and large datasets to derive metrics of ecosystem responses to environmental change. The project will use meta-analysis to test how nutrients regulate responses of ecosystems to elevated CO_2 and warming, focusing on processes that regulate longterm C balance.

Finally, the project will create a platform for data distribution in climate change research, designed specifically to facilitate future syntheses of results relevant to Earth system models

Estimating Carbon Flux and Storage: Constraint of the Community Land Model Using Observations at Different Temporal Scales

- **Principle Investigator:** David Moore (University of Arizona)
- **Collaborators:** Ave Arellano (University of Arizona), Valerie Trouet (University of Arizona), Andrew Richardson (Harvard University), Andrew Fox (National Ecological Observatory Network)
- **Award:** $970,020 over 3 years

We present a research plan to improve land surface models (LSMs) using new and existing data collections and modeling infrastructure that we have helped to develop. To achieve this goal, we will build upon a data assimilation system under development for the Community Land Model (CLM) and augment the available carbon and water flux observations with data products derived from (1) a network of already installed phenology monitoring webcams (2) seasonal measurements of tree growth and (3) tree-ring based estimates of primary productivity. We will use these data to constrain short (intra daily), medium (seasonal to intra-annual) and long (inter annual to decadal) term processes in the model This research will build on established data collection and data assimilation capabilities to constrain land surface processes using ensemble techniques. The constrained model will be used to test hypotheses related to the utility of observations representing different timescales to constrain seasonal, interannual, and decadal carbon dynamics. Finally, carbon uptake and storage and associated uncertainty constrained by observations will be produced and validated at a regional scale.

Hypotheses to be tested and project tasks:H1. If eddy covariance data provides information on short-term processes, then assimilating eddy covariance data by itself will lead to improved short term model performance but large uncertainties in seasonal and long-term carbon dynamics. H2. If seasonal variation in carbon allocation is a key determinant of inter-annual variability in carbon fluxes, then a model constrained by cambial and leaf phenology should show improved estimates of year to year variance in tree growth and annual NEE. H3. If plant functional types represent robustly distinct functional units which share common parameters in a LSM, then estimates of carbon cycling derived from a LSM constrained using data from different locations with the same PFT should not be statistically different from each other, but should differ from parameterizations derived from ecosystems with different PFTs. Task 1 (a) Collate and estimate uncertainty in each Ameriflux and Fluxnet-Canada site observation record including phenocam observations and ancillary information, produce these as data products. (b) Collate biometric data from eddy covariance sites (Fig. 1) and collect new biometric data including tree-ring data to estimate Annual Net Primary Productivity (ANPP) dynamics and uncertainty at inter annual to decadal scale. Task 2 (a) Implement and test an ensemble based data assimilation system for CLM using synthetic data and data from task 1 (b) Test and parameterize different models to predict bud burst, canopy development, and senescence and develop forward operators or transfer functions to link in to CLM estimates of carbon and water fluxes, leaf carbon, and aboveground biomass. Task 3 Produce estimates of carbon uptake and storage for the North America using the optimized version of CLM in ensemble mode to characterize spatial uncertainty.

Earth System Modeling (ESM)

Towards Parameterization of Root-Rock Hydrologic Interactions in the Earth System Model

- **Principle Investigator:** Inez Fung (University of California, Berkeley)
- **Award:** $149,915 over 2 years

The degree of carbon-climate feedback by terrestrial ecosystems is intimately tied to moisture availability for photosynthesis, transpiration and decomposition. Extreme weather will be the "new normal" in a warming climate. During downpours, the rapid penetration of rainwater through the soil and weathered bedrock will dampen delivery to channels, increase pore pressures that lead to land sliding, and leave behind reservoirs of plant-available moisture in rock fractures and the weathered rock matrix. In an extended drought, tree survival and hence the magnitude of carbon-climate feedback depends on the availability of subsurface moisture and the ability of plant roots to access that moisture.

Our proposed work is focused on CLM, the land module in the Earth System Model. The immediate goal is to develop and test algorithms of "rock moisture" and root-rock interaction that could improve the CLM in changing precipitation extremes. The lack of relevant global datasets on the geology and hydraulic properties of the heterogeneous subsurface below the soil layer has necessitated many assumptions in current CLM algorithms.

We propose to employ a three-pronged approach. The first aims to develop a 1D model of "rock moisture" and transpiration using the large volume of continuous (over 4 years) high-frequency (<30 minute) hydrologic data (water table of 12 wells, sapflow, soil moisture) from our hillslope study site in northern California. The data also include repeated campaigns to measure the variations in "rock moisture" down to the water table. We will start with CLM4.0 and incorporate a saprolite layer and several weathered rock layers between the soil mantle and the water table. We will explore scenarios of hydraulic conductivity of the rock layers, with a mean value based on geology and a stochastic component that mimics flow through fractures. We will also experiment with varying rooting depths of plant functional types as a function of hydroclimate and geology. The model algorithm will be tested against transient response of water table and transpiration to winter storms and dry summers. A second prong analyzes the high-frequency USGS data in the western US to quantify the fast and slow response of streamflow and water table to intense precipitation and extended droughts. A third prong upscales the 1D model of rock moisture to the western US and assess its ability to simulate the transient dynamics in the USGS data.

Significance: Warming climate will force a co-evolution of vegetation and water resources that feedback on atmospheric CO_2 and climate. That trajectory in hilly landscapes underlain by bedrock may be strongly influenced by the yet unexplored rock moisture zone. The rock moisture model developed here will be easily coupled with global earth system models and regional climate models used to predict the vigor of ecosystems and their exchange of water and CO_2 with the atmosphere.

Improving Land-Surface Modeling of Evapotranspiration Processes in Tropical Forests

- **Principle Investigator:** Gretchen Miller (Texas Engineering Experiment Station)
- **Collaborators:** Anthony Cahill (Texas A&M University), Gergianne Moore (Texas A&M University), Ruby Leung (Pacific Northwest National Laboratory)
- **Award:** $869,801over 3 years

Land surface models are used to represent terrestrial processes that shape global climate; examples of these processes include evaporation, plant water use, and photosynthesis. While much progress has been made to improve and refine these models, some hydrological processes are not well captured, which hinders our ability to understand land-atmosphere interactions and ultimately to predict impacts of climate change on water resources. The inadequate representation of evapotranspiration may partly explain why global climate models do not match observed precipitation patterns. Multiple factors contribute to this problem. In moist tropical regions, high humidity, leaf wetness, and cloud cover combine to suppress forest water use and possibly reduce forest growth in ways that are poorly understood. Mountainous areas pose additional difficulties, as standard modeling and measurement techniques are not readily applied in rough terrain. The overall goal of this project is to improve the modeling of fluxes of water vapor and carbon dioxide to and from tropical forests. This goal will be achieved through a combined program of field-based measurements in a mountainous tropical forest in Costa Rica and regional scale modeling of land surface fluxes in the Neotropic ecozone of South America, Central America, and the Caribbean. Specifically, the project will: 1) collect targeted hydrological and meteorological measurements along in-canopy and above-canopy profiles at locations throughout a mountainous forest watershed at the Texas A&M Soltis Center; 2) develop a new conceptual framework for modeling wet canopy processes based on the new dataset; 3) appropriately revise the Community Land Model (CLM) to improve its estimates of evapotranspiration in tropical forests; and 4) model tropical forests and their interactions with rainfall using the improved CLM coupled with the Weather Research and Forecasting (WRF) model capable of resolving processes in mountainous forests.

Scale-Aware, Improved Hydrological and Biogeochemical Simulations of the Amazon Under a Changing Climate

- **Principle Investigator:** Chaopeng Shen (Pennsylvania State University)
- **Collaborators:** John Melack (University of California, Santa Barbara), William Riley (Lawrence Berkeley National Laboratory)
- **Award:** $976,498 over 3 years

Earth System Models (ESMs) predict increased frequencies of extremely wet and dry periods in the Amazon over the next century, resulting in very uncertain Amazonian carbon budgets. Because the water cycle strongly influences the carbon cycle and other climate processes and feedbacks, we contend that accurately estimating CO_2 and CH_4 emissions from upland and floodplains in ESMs requires progress on three fronts: improved hydrologic descriptions, aquatic biogeochemistry, and improved spatial scaling of hydrologic and biogeochemical processes. This project will address these three issues by developing in the Community Land Model (CLM) a multi-scale hydrological and biogeochemical modeling framework based on a subgrid-parameterization scheme and scale-aware downscaling techniques. This approach will bridge the gap between coarse-resolution and fine-scale hydrological and biogeochemical predictions. The goal of the multi-scale framework is to predict CLM gridcell-scale states and fluxes consistent with fine-resolution simulations at orders of magnitude lower computational cost. The hydrologic descriptions will be built upon a highly efficient, physically-based model (Process-based Adaptive Watershed Simulator; PAWS) that has been applied and tested in several temperate watersheds. This framework will greatly reduce uncertainties of hydrologic-biogeochemical simulations due to spatial scaling, enhance our simulation capabilities, and enable uncertainty quantification and multi-objective optimization at climate scales. We will also integrate a novel aquatic ecosystem model based on previous studies of floodplain carbon dynamics. With these new process representations in CLM we will evaluate the impact on Amazonian carbon budgets of increased frequency of wet and dry periods. We will also develop our scaling approach in a generalizable manner so that our results will be applicable to global simulations over decadal to centennial time scales.

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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