NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2013
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The National Aeronautics and Space Administration (NASA) solicited proposals for Carbon Cycle Science investigations within the NASA Earth Science Program, the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative Competitive Grants Program (AFRI), the U.S. Department of Energy (DOE) Terrestrial Ecosystem Science Program, and the Atmospheric Chemistry, Carbon Cycle, and Climate (AC4) Program within NOAA's Climate Program Office. Proposals were requested for research and/or applied science investigations aimed at addressing six specific research themes. The six research themes solicited and the agencies participating in each of them were:

1. Carbon research in critical regions, specifically: Arctic-boreal regions, tropics, and high latitude oceans (NASA, DOE, USDA);
2. Carbon dynamics along terrestrial-aquatic interfaces, including land-ocean, land-freshwater, and coastal ocean regions (USDA, DOE, NASA);
3. Belowground carbon processes and soil carbon (USDA, DOE);
4. Carbon dynamics within urban-suburban-forested-agricultural landscapes (NOAA, USDA, DOE, NASA);
5. The impact of rising CO_2 on aquatic ecology (NASA); and
6. Carbon cycle science synthesis research (NASA, USDA, DOE)

NASA received a total of 381 compliant Step-1 proposals in response to this NRA and encouraged 308 for submission of Step-2 proposals. A total of 235 compliant Step-2 proposals was received. Forty one proposals were selected for funding. The combined total funding provided by NASA, DOE, USDA, and NOAA for these investigations is approximately $37 million over three years. The selected investigations are listed below. The Principal Investigator, institution, investigation title, agency providing the funding, and a project summary are provided. Co-investigators are not listed here.

Dennis Baldocchi/University of California, Berkeley
Connecting AmeriFlux to the Globe, Extending the Partnership with the Global Flux Network, FLUXNET (DOE funded)

We propose a project that will to extend and expand the functioning of the global FLUXNET database, which consists of data on carbon dioxide, water and energy fluxes, meteorological conditions and the structure and function of the ecosystems to beyond a decade. The production of the next FLUXNET database is critical to the activities of this ROSE's solicitation because these data will drive many of the carbon cycle synthesis activities and the model parameterization and validation activities. This data system will enable the broader biogeoscience user community to discover new information about the 'breathing' of terrestrial ecosystems across a spectrum of time and space scales.

Working with European collaborators, we will construct a new database, double the size of the La Thuile dataset, with over 2000 site-years of trace gas flux measurements, supporting meteorological and site meta-data from over 400 sites world-wide. To support this database, we will build a next-generation, data-system that will process raw data and produce value-added data products. Raw data, produced by the data providers, will be quality checked, flagged, filtered and gap-filled data at their native time steps (30 minute averages) in a standard manner. These value-added data will be integrated or averaged on daily and annual time scales. We will also partition net carbon fluxes into their constituent components, ecosystem respiration and canopy photosynthesis. Uncertainty analysis and quality control metrics will be produced in coordination with AmeriFlux and ICOS. The data system will also house, distribute and query these data. We aim to use these data in synthesis activities that improve our understanding on how climate, weather, ecological, physiological and soil factors govern the exchange of carbon, water and energy between vegetation and the atmosphere at multiple time and space scales.

The rationale for proposing this work is based on the fact that the vast databases that are produced by flux networks cannot perpetuate and evolve without continued support of the of scientists who produce data, are expert in databases, and who use data for modeling. The actuality of a flux network takes human intervention to recruit data from different countries and cultures, to build trust to share data in open-access format, to support data users, and to collaborate. This involves building a culture of data sharing and interaction across vast cultural spectrum of participating scientists. Specifically, we will re- build the data portal in a manner that easy to navigate and conducive for distributing, visualization, evaluation and discovery of the multiple types of flux and environmental data and information. We will foster collaboration and interactions with our national and international partners and the recruitment of data by: 1) continuing the periodic publication of the newsletter, FLUXLETTER; 2) hosting an international conference; 3) coordinating and launching multi-investigator data synthesis activities; and 4) developing tools that coordinate the development and tracking of research papers, through production to publication.

The interpretation of the flux data relies on good meta-data. We will work with data providers to populate and expand the meta-data archives. We will also work with collaborators to incorporate data from remote sensing products such as leaf area index MODIS and land use from Landsat, from corresponding climate and weather stations. Another goal is to incorporate new data on canopy structure, with recent LIDAR acquisitions, to populate the data archive with automated soil respiration and understory flux measurements, where available and local climate records for corresponding sites. We will collaborate with the TRY database, by merging flux data with plant trait information.

William Balch/Bigelow Laboratory for Ocean Sciences
Combining Satellite-, AUV-, and Ship-Based Measurements From the Multi-Decadal Time Series "GNATS" to Model the Carbon Cycle in the Gulf of Maine (NASA funded)

This project will continue the Gulf of Maine North Atlantic Time Series (GNATS) which is a 35+year, NASA-centric, field program that crosses the Gulf of Maine (GoM) to collect bio-optical, hydrographical, biological, biogeochemical and chemical (including carbon-relevant) data for use in satellite calibration/validation studies, as well as a long- term transect time series. We propose to use a combination of satellite and GNATS data (shipboard and autonomous underwater vehicle measurements) to constrain a coupled physical/ecosystem model of the GoM carbon cycle. The overall significance of this is that GNATS has provided critical calibration/ validation data for SeaWiFS, MODIS, and VIIRS sensors, as well as insights about the long-term oceanographic carbon cycle changes in the GoM, a semi-enclosed shelf sea, with strong land-sea connections via 25 surrounding watersheds. We direct this proposal to the second research theme of the NASA ROSES-13 Carbon Cycle Science program: carbon dynamics along terrestrial-aquatic interfaces, including land-ocean, land-freshwater, and coastal ocean regions. This is because of the major importance of river runoff to the physical, chemical, optical and biological oceanography of the GoM, including its carbon cycle. This work is primarily relevant to NASA (given the NASA-centric GNATS sampling) and secondarily to NOAA, specifically for work on productivity, algal biomass, and phytoplankton functional groups of U.S. coastal waters, as well as calibration/validation of the NPP/VIIRS sensor. Along with a whole host of environmental variables, GNATS measures all four parts of the marine carbon cycle: particulate organic carbon (POC), particulate inorganic carbon (PIC; calcite), dissolved organic carbon (DOC), and dissolved inorganic carbon (DIC; e.g., CO2, HCO3-, and CO3=, which are coupled to pH and alkalinity). These four parts of the carbon cycle (including reservoirs and fluxes) provide insights about the major processes affecting the coastal ocean, from changes in productivity (i.e. POC variability through time associated with changes in hydrography, different phytoplankton functional groups, etc.), land-sea carbon transport (i.e. DOC and POC variability caused by major riverine flood events and droughts), and changes associated with ocean acidification (i.e. variability in DIC and PIC caused by changes in carbonate saturation). Simply put, the only way to predict changes to all four parts of the marine carbon cycle as a function of long-term climate change will be through a combined measurement and modeling approach. The ecosystem model to be used for the Gulf of Maine carbon cycle consists of size-structured carbon pools of detrital material, phytoplankton functional types ranging from picoplankton to microplankton, and a size- based zooplankton predator group. Interactions between components will be determined by both size and functional role, and the model will be forced by GoM physical conditions. We will validate the model against GNATS data, and test the ability of remotely-sensed particle size distributions, coupled with the ecosystem model, to reproduce the observed dynamics. We will then use the model to test hypotheses regarding the fate of carbon resulting from climate-driven changes such as increased precipitation and temperature. Anticipated scientific outcomes from this work will be a) a longer duration, NASA-centric, coastal time series that can resolve climatological phenomena spanning time scales of days to decades and b) a coupled physical/ecosystem model based on GNATS that uses remotely-sensed, ship and autonomous underwater vehicle data to constrain the model and test hypotheses relevant to each part of the GoM carbon cycle and the impacts of climate change.

John Campbell/University of California, Merced
Scaling from Flux Towers to Ecosystem Models:
Regional Constraints on Carbon Cycle Processes from Atmospheric Carbonyl Sulfide (DOE funded)

Recent work suggests that gross primary productivity (GPP) is largely underestimated by global earth system models [Welp et al., Nature, 2011], reflecting the persistent challenge in extrapolating from local process observations to earth system models. This poor understanding of GPP at large spatial scales is of particular concern in tropical forests. In tropical forests, some earth systems models forecast a powerful feedback between a warming climate and a decline in GPP resulting in forest dieback. While this simulated feedback is intensely debated, we lack robust large-scale constraints on GPP that are needed to resolve this debate. Here we propose an integrated measurement and modeling study of regional-scale GPP in the Amazon rainforest using atmospheric carbonyl sulfide to provide a new constraint on GPP mechanisms in earth system models. Project activities include three primary components: (1) a field campaign in the Brazilian Amazon will provide the first tropical measurements of COS using eddy covariance, chamber, and airborne platforms in order to assess the relationship between CO2 GPP fluxes and ecosystem COS fluxes; (2) eddy covariance and chamber data will be used in the development and application of ecosystem models of COS and CO2 fluxes; (3) these ecosystem flux simulations and the airborne observations will be used in a mesoscale inverse model to provide top-down constrains on regional GPP and an assessment of the GPP representation in earth systems models. The project applies a unique analysis system field tested by the U.S. investigators on our team and the complementary major research instrumentation available from the Brazilian investigators on our team. This project will provide the fundamental ecosystem measurements needed to extend the COS-GPP tracer approach to the tropics and an application to a critical uncertainty for carbon-climate feedbacks. In addition to the carbon cycle, the new understanding of COS resulting from this project may have broad impacts in related scientific disciplines including its use as a conservative tracer of convection in the biophysical climate investigations of the GOAmazon campaign.

Molly Cavaleri/Michigan Technological University
Effects of Warming on Tropical Forest Carbon Cycling: Investigating Temperature Regulation of Key Tropical Tree and Soil Processes (DOE funded)

Integrated research approaches offer the best hope for improving our understanding of how ecosystem responses may have unintended feedbacks to climate. In turn, improving this understanding can greatly increase the confidence with which we can project future climate change. The project entitled ‘Effects of warming on tropical forest carbon cycling: investigating temperature regulation of key tropical tree and soil processes’ addresses this challenge by focusing on how increasing temperatures affect the way tropical rain forests cycle carbon. Tropical forests exchange more carbon with the atmosphere than any other biome. Due to these large fluxes, even subtle changes to the way tropical forests take in and release carbon dioxide (via photosynthesis and respiration, respectively) could have dramatic effects on atmospheric carbon dioxide concentrations and thus future climate. However, while these ecosystems are clearly important, our understanding of how tropical forest carbon cycling will respond to climatic change is notably poor, and this lack of understanding significantly impedes our ability to forecast climate. We strive to directly assess the effects of increasing temperature on tropical plant and soil carbon fluxes and storage over a range of time scales in order to reduce uncertainty and increase the confidence with which we can make global predictions of future climate.

The proposed set of experiments will focus on both above- and belowground processes, and will mechanistically explore temperature controls over critical carbon cycling of tropical plants, soil, and microbes. In a wet tropical forest in Puerto Rico (El Yunque National Forest), we will use canopy access towers, novel leaf and branch warming techniques, micro-meteorological monitoring, and leaf chamber gas exchange measurements to assess the temperature sensitivity of mature tree foliage physiology. We will employ both field and laboratory manipulations to assess how plant roots and soil microbes respond to increased temperature and through what mechanisms. The field soil warming experiment will be the first of its kind in any tropical forest. Overall, this research strives to assess: (1) temperature responses and acclimation potential of mature tropical tree photosynthesis, leaf respiration, and root respiration and (2) temperature responses and acclimation potential of tropical soil processes: decomposition, microbial respiration, carbon use efficiency (how microbes partition carbon to their biomass vs. to carbon dioxide), and nutrient cycling (focusing on nitrogen and phosphorus). The results of this research would represent a significant step forward in our understanding and ability to effectively model tropical forest responses to a warmer world.

The research addresses multiple goals highlighted by DOE and Carbon Cycle Science Theme 1: Carbon Research in Critical Regions. First, this work will make significant advances in our understanding of coupled biogeochemical processes in a globally important and relatively poorly understood biome. Second, the hypotheses were developed through ongoing collaborations with a cadre of modelers, and the study is designed to ensure that results will lead to invaluable improvements to the predictive capacity of existing models. Third, because we aim to focus not only on documenting responses but also on assessing the mechanisms regulating change, this work will allow us to extrapolate results beyond that of a single tropical forest site, leading to wide geographic applicability. Finally, the research strongly leverages existing support from multiple federal partners, including USDA Forest Service and the U.S. Geological Survey who share the same goal of improving our ability to forecast the effects of global warming on tropical forest ecosystems. This work will provide critical information regarding the vulnerability and adaptation potential of the only tropical forest in the US National Forest System.

Eric Davidson/The Woods Hole Research Center
Integrated Belowground Greenhouse Gas Flux Measurements and Modeling (USDA funded)

Global soil carbon stocks are 2-4 times greater than atmospheric CO2-C. Soils and wetlands are significant sources and sinks for atmospheric CO2, CH4 and N2O. Soil greenhouse gas (GHG) emissions are likely to play a significant role as biotic feedbacks to climate change. However, these complex processes, involving carbon, nitrogen, and oxygen substrates and inhibitors, interactions with plant processes, and environmental influences of temperature, moisture, and gas transport, remain challenging to simulate in earth system models. Here we propose a novel integration of measurement and modeling of these three GHGs in upland and wetland soils at the Howland Forest AmeriFlux site. Our main objective is to improve understanding of and modeling capacity for interactions of belowground temperature, moisture, and substrate supply as controllers of net soil emissions of CO2, CH4, and N2O. The proposed work is central to Theme 3, as we seek to refine the understanding of critical belowground soil processes, but is also relevant to Theme 1 due to the boreal-temperate transition forest locale, Theme 2 because of the upland-wetland transitions, and Theme 6 due to applicability of modeling to Ameriflux and NACP networks.

Because the processes of CO2, CH4, and N2O production and consumption are inter-linked through some common substrates and the contrasting effects of O2 as either an essential substrate or a potential inhibitor, the mechanistic simulation of fluxes of any one gas must be consistent with mechanistic simulations and observations of fluxes of the other gases. Simulating the fluxes of one gas alone would be a simpler task, but simulating all three gases simultaneously and linking to aboveground processes of carbon supply provides multiple constraints and affords greater confidence that the most important mechanisms are aptly simulated. We take advantage of a data-rich study site, including ongoing NASA and DOE funded measurements of soil profiles, chamber fluxes, eddy covariance fluxes, forest inventory and biomass growth, leaf area, litterfall, and other ecosystem data at Howland, to build and test an integrated modeling framework, adding functions and complexity of model structure as warranted by the data-model fusion.

We will merge two relatively parsimonious models: the Dual Arrhenius and Michaelis-Menten (DAMM) soil enzymatic kinetics model and the Forest Biomass, Assimilation, Allocation and Respiration (FOBAAR) ecosystem flux model. In addition to on-going measurements, we propose here to: (1) add soil O2 sensors to allow validation of O2 concentration simulations; (2) challenge the DAMM model with this unique multiple GHG dataset at hourly temporal resolution; (3) make new isotopic measurements of porewater 13CO2 to elucidate temporal and depth patterns of CH4 production and consumption processes for validating the CH4 components of the DAMM model; (4) integrate soil flux measurements with tower-based ecosystem measurements of CO2 and CH4 fluxes and modeling total ecosystem C dynamics with the parsimonious FO¶BAAR model; and (5) scale measurement and simulations to the landscape scale using a combination of soil drainage maps and soil moisture estimates from the NASA AirMOSS project at Howland. The project includes two post-docs and summer interns from an undergraduate program targeted for inclusion of traditionally under-represented groups.

We will use observations of soil and ecosystem fluxes of multiple GHGs to develop and validate the merged model, as well as to quantify the uncertainties, providing a new approach to simulation of climate-dependent responses of terrestrial ecosystems at both short (hourly to seasonal) and long (annual to centennial) time scales. The parsimonious structures of these models are designed to be applicable to both site-level analysis and Earth system models.

Kenneth Davis/Pennsylvania State University
Quantification of the Regional Impact of Terrestrial Processes on the Carbon Cycle Using Atmospheric Inversions (NASA funded)

Understanding the terrestrial carbon cycle remains a high priority for understanding climate change. The carbon balance of North American remains uncertain. The southeastern U.S. is one of the most biological productive, heavily managed, and poorly studied regions of the North American continent. We do not yet have an operational model-data synthesis system that we can use to diagnose and understand continental and regional net annual biogenic CO2 fluxes with confidence. The NACP Midcontinent Intensive (MCI) regional study demonstrated the potential for the creation of such an operational system. The NACP MCI utilized high-density atmospheric CO2 observations, regional atmospheric inversion modeling, and carefully constructed agricultural and forest inventories, and found convergence in the regional carbon balance of the U.S. midcontinent for 2007.

We propose to apply recent advances in atmospheric inversion methodology and observational technology to study the carbon balance of North America as a whole with special emphasis, including new terrestrial inventory assessments, on the dynamic and relatively understudied southeastern United States.

Our objectives are to:

1. Quantify net fluxes of CO_2 from the terrestrial ecosystems of the southeast using a regional atmospheric inversion for the years 2014-2015.
2. Compare the results of our 2014-2015 southeast atmospheric inversion to other regional flux estimates including forest inventories, biogeochemical models, and other atmospheric inversions.
3. Reduce uncertainty in atmospheric inverse estimates of the North American CO_2 balance for the period from 2010 - 2015.
4. Provide estimates of the seasonal and annual net CO_2 balance for 6 regions of North America.
5. Examine the interannual variability of the seasonal and annual net CO_2 balance for these 6 sub-regions of North America for the period from 2010 through 2015.
6. Compare the solutions obtained using our continental inversion system to the fluxes obtained by NOAA's CarbonTracker system and Colorado State's Geos-Chem/EnKF system.

The project will utilize the expanded North American CO_2 observational network, satellite-based (GOSAT and OCO-2) CO_2 observations, the Penn State regional atmospheric inversion system nested within two different state-of-the-art global data assimilation systems, a network of CO_2 measurements deployed in the southeastern U.S. in anticipation of the launch of OCO-2, advanced uncertainty estimation methods developed for the NACP MCI, and state-of-the-art assessments of the major terms in biomass inventories in the southeastern U.S.

The project will: 1) reduce uncertainty in the overall continental carbon balance and especially in the southeastern U.S.; 2) evaluate inventory estimates of southeastern U.S. CO_2 fluxes; 3) demonstrate a joint atmosphere- and inventory-based carbon cycle observation system which, if maintained, could be used to detect and understand changes in terrestrial fluxes; 4) explore the utility of remotely sensed atmospheric CO_2 data in regional to continental scale atmospheric inversions; and 5) motivate extension of this diagnostic approach to other regions of the continent and the world.

This project in particular focuses on research theme four of this call, "Carbon dynamics within urban-suburban-forested-agricultural landscapes (NOAA, USDA, DOE, NASA)."

Scott Denning/Colorado State University
The Tropical Terrestrial Tipping Point: Drought Stress and Resilience in Moist Tropical Forests (NASA funded)

One of the biggest sources of uncertainty in the climate of the 21st Century arises from potentially strong but poorly understood carbon-climate feedback. Under rising CO_2, some coupled climate models develop persistent drought over the Amazon, which transforms high-carbon forests to low-carbon savannas releasing enormous amounts of CO_2. We propose to test a more realistic model of drought stress and resilience in tropical forests against a wealth of experimental and satellite data, implement the new parameterization in the open-source Community Earth System Model, and use it to explore this "tropical terrestrial tipping point" under several 21st Century warming scenarios. The proposed research is responsive to Element 3.1.1 in the solicitation, and directly addresses goals and objectives of both NASA and DOE.

Carbon, water, and energy cycling in tropical forests typically have naive representation in coupled Earth System models. Simulated precipitation is distributed over large grid cells and results in light rain rates that are easily intercepted by the canopy. By contrast, real precipitation falls in torrential convective downpours over smaller areas in organized squall lines, quickly saturating canopy storage to infiltrate soils or run off. Land-surface schemes in many climate models were developed with temperate forests in mind, and fail to sustain transpiration and photosynthesis during extended tropical dry seasons. In climate models that simulate photosynthesis, net carbon uptake occurs during the rainy season with net release under severe stress during the dry season. Some Amazon sites exhibit opposite seasonal cycles. It is unreasonable that such naive models can be expected to correctly predict the strength or thresholds for positive carbon-climate feedback under enhanced evaporative demand in a high-CO2 world.

Experimental data have shown that some tropical forests are very well adapted to strong seasonal drought as well as to periods of longer-lasting drought associated with El Nino conditions. Multiyear records of carbon, water, and energy fluxes across a huge precipitation gradient in the Amazon reveal tremendous variations in drought resilience. In the wet northwest, drought is very rare and photosynthesis may be light limited by persistent clouds. Seasonal drought increases to the southeast, where drought-tolerant forests give way to savanna ecosystems. Throughfall exclusion experiments performed in two locations show that a forest ecosystem more frequently exposed to drought was more resilient to severe chronic drought that might be experienced under global warming scenarios. These observations point to the need for more nuanced representation of drought impacts on tropical carbon cycles in Earth System models.

We propose to use data from the two multiyear throughfall exclusion experiments to tune a new drought resilience parameterization based on accessibility of deep soil moisture. The research will be conducted using two ecosystem models, the Community Land Model (CLM4) and the Simple Biosphere Model (SiB4). Drought resilience will be scaled across tropical forests using climatological mean precipitation, dry season length, and the variance of annual precipitation during the GPCP record. We will evaluate the new scheme across gradients in observed precipitation and episodic drought in 2005 and 2010. We will use simulations of the MERRA reanalysis period (1979-present) to predict pan-tropical LAI, fPAR, GPP, ecosystem respiration, and chlorophyll fluorescence on a 0.5 degree grid. These will be evaluated against AVHRR NDVI (1982-present), MODIS LAI/fPAR (2000-present), and chlorophyll fluorescence (2007-present), with special attention to drought stress and resilience. Finally, we will incorporate the improved ecosystem model in a multiscale ("superparameterized") version of the Community Earth System Model to quantify carbon-climate feedback in tropical forests under several climate change scenarios.

Scott Doney/Woods Hole Oceanographic Institution
Climate-Driven Impacts on the Marine Ecology, Biogeochemistry, and Carbon Cycle of the West Antarctic Peninsula (NASA funded)

The West Antarctic Peninsula is experiencing some of the most dramatic climate change on the planet, with rapid ocean-atmosphere warming, melting of coastal glaciers, and reductions in seasonal ice cover. Substantial repercussions are occurring throughout the marine food web from phytoplankton to top predators. Based on satellite ocean color data, phytoplankton blooms have declined in the north and expanded in the south, tracking the sea-ice retreat. Plankton community structure has shifted as well, impacting key biogeochemical processes including net community production and carbon dioxide storage. With more than two decades of observational and process data, the Palmer Long Term Ecological Research (LTER) program (http://pal.lternet.edu/) provides a unique and ongoing resource to assess the ecological and biogeochemical impacts.

The research proposed here combines advanced satellite ocean color products from SeaWiFS and MODIS-Aqua, passive microwave radiometer estimates of sea ice extent from SSM/I and SSMIS, and scatterometer wind measurements from SeaWinds with the extensive Palmer LTER field data set to improve our mechanistic understanding of ocean carbon and ecosystem dynamics in Antarctic waters. Both satellite and ship-based data have major limitations in remote polar environments, logistical challenges, harsh weather conditions, persistent cloud cover, low winter light levels; therefore an interdisciplinary effort is required merging complementary data from satellites, ships, and autonomous gliders. Using new syntheses of existing remotely-sensed and in situ data combined with a hierarchy of numerical models, we will test scientific hypotheses developed from observations in the West Antarctic Peninsula ecosystem:

- Regional trends in sea-ice cover, freshwater inputs (sea-ice and glacial melt), and wind mixing modulate phytoplankton community structure (large vs. small cells, diatoms vs. flagellates), as well as bloom dynamics, leading to changes in food-web structure, net community production and export flux;
- On local scales, glacial melt and upwelling of Circumpolar Deep Water along canyons supply micro-nutrients (e.g., iron) that alter phytoplankton physiology, and drive small-scale blooms and export events;
- Positive net community production is enhanced when large-celled phytoplankton are more abundant, leading to increased export and CO_2 storage. The opposite is the case when small cells dominate.

The Palmer LTER region is an ideal natural laboratory for studying the effects of climate change on polar marine ecology and carbon cycle,with climate-warming impacts that may not begin in other parts of the Antarctic for decades. The relatively low latitude of the Palmer LTER region (64-70 deg. S) also is more accessible to polar-orbiting satellites than most other Antarctic coastal areas, and the information gained from our research will help improve projections of future impacts for the Antarctic shelf as a whole. The proposed research is directly responsive to the NASA Carbon Cycle Science Announcement Theme 1: Carbon Research in Critical Regions (High Latitude Oceans), taking full advantage of NASA satellite observations and suborbital data. The work addresses as well the broader goals of the NASA Earth Science program by connecting together marine ecology and biogeochemistry to better understand net community production and ocean CO_2 storage.

Riley Duren/Jet Propulsion Laboratory
Megacities Carbon Project: Assessing the Impact of Policy and Management Decisions on the Los Angeles Urban Dome of CO_2 and CH_4 (Funded by NASA and NOAA)

Urbanization has concentrated over 50% of the global population and more than 70% of fossil fuel CO_2 emissions in cities. Large uncertainties in Measurement, Reporting, and Verification for all carbon emissions persist due to data limitations. Recent studies using atmospheric measurements have been used to detect the net signature of urban domes of CO_2 and other gases and to provide constraints on the carbon budgets of an urban region. A concerted effort is needed to finish developing, demonstrating and applying these emerging methods towards a sustained monitoring system to support urban carbon policy and management decisions. The Megacities Carbon Project is an interagency pilot activity being established in Los Angeles to develop and test scientifically robust techniques for monitoring distributions and trends of anthropogenic carbon emissions attributed to the world's megacities and characterize the carbon dynamics spanning their complex landscapes. The project has been partially funded by NIST, NASA/JPL, KISS, and CARB to deploy a measurement network by the end of 2013. We are also developing an urban-scale carbon flux model for LA using high-resolution Hestia fossil fuel emissions data and WRF-Chem/VPRM model nested within GEOS-chem. The objectives of the proposed work are to: (1) complete, integrate, test, and validate the LA megacity observational network and modeling framework - resulting in an urban test-bed that supports the research goals of this task and others by the broader community ; (2) apply the test-bed to characterize the spatio-temporal nature of the urban dome of total CO_2 and $FFCO_2$ concentrations(secondary goal: CH_4) spanning the complex urban-suburban-agricultural-rural landscape, (3) apply the test-bed and existing satellite observations to evaluate the joint application of those assets and future remote-sensing of CO_2 and CO and in-situ ^{14}C observations to monitor urban $FFCO_2$ emissions, and (4) apply the test-bed to test hypotheses regarding emission ratios in space and time across the domain as well as between in-situ point measurements and remotely-sensed column measurements (to enable future independent testing of bottom-up inventories). The proposed task responds to solicited research theme #4: Carbon dynamics within and beyond urban landscapes. Gaps in the LA network will be filled by establishing sustained flask sample collection at multiple sites and conducting ^{14}C analysis. The paired observations of ^{14}C and continuous CO at each site will be transformed into $FFCO_2$ and CO:$FFCO_2$ relationships derived for application across the broader domain using the continuous network observations; column observations from Mt Wilson, Caltech, and Dryden; and satellite column observations from GOSAT, MOPITT, and OCO-2. Our model framework will integrate established components of NASA's Carbon Monitoring System (CMS) flux system and JPL's WRF-chem system for Southern California and the high resolution Hestia-LA emissions data product currently being developed by ASU to produce forward modeled 4D fields of CO_2 at 4km, hourly resolution. We will combine CO, ^{14}C and CO_2 data to calibrate and validate surface based in situ and remote sensing data towards separating fossil-fuel and biogenic CO_2 fluxes across a range of space-time scales. The results will be used to validate satellite observations of CO_2 and CO. We will perform synthesis analysis to evaluate these data sets and the modeled fields - towards extending the coverage and density of the information produced by the point and column measurements. This work is directly responsive to the CCSP element regarding the impact of policy and management decisions on levels of CO_2 and other gases in the atmosphere. It supports carbon cycle science objectives of NASA, NOAA, and DOE. This framework enables the application of future observations and models to aid in understanding and/or predictive modeling of carbon dynamics across urban to rural gradients.

David Eissenstat/The Pennsylvania State University
Linking Topographic Variation in Belowground C Processes with Hydrological Processes to Improve Earth System Models (DOE funded)

We will assess the influence of topography on multiple belowground processes (soil CO2 efflux, soil C, microbial biomass, root density, root production, and root turnover) and develop a coupled model capable of simulating the water and carbon dynamics in topographically complex terrain. Belowground processes are affected by soil moisture, but current studies seldom connect the impacts of natural variation in soil moisture associated with topography to multiple C cycle processes. Likewise, current Earth system models cannot resolve topographically driven hill-slope soil moisture patterns, and cannot simulate the nonlinear effect of soil moisture on soil processes, especially at high soil moisture.

We will fill these gaps by testing six hypotheses: (1) highest soil CO2 efflux will be in locations with the longest duration of optimal soil moisture. (2) Within sites of similar soil moisture there will still be substantial variation in soil CO2 efflux that is controlled by fine-scale spatial variation in root density, litter fall, and associated microbial biomass. (3) At landscape levels, root turnover can be predicted by knowledge of tree species composition alone without incorporating the effects of heterogeneous soil moisture. Alternatively, root turnover is strongly influenced by spatially variable soil moisture in addition to species composition. (4) At landscape levels, root production, root standing crop, and microbial biomass are spatially correlated with aboveground net primary productivity (ANPP), which is controlled by species-specific variation in plant growth rates. In addition, locations of periodic excess water exhibit lower root density, root production, and microbial biomass as a proportion of ANPP than that of dry regions; (5) a coupled model that combines a 1-D Earth system model (CLM) with a 3-D hydrologic model (PHIM) will improve the simulation of belowground C processes at ~10 m resolution in a first-order watershed, relative to a 1-D Earth system model; and (6) the use of spatially distributed root and soil parameters in CLM or in PIHM-CLM will improve the simulation of the spatial heterogeneities of belowground C processes, relative to models that use spatially uniform belowground root and soil parameters.

We will test these hypotheses at the Susquehanna/Shale Hills critical zone observatory (SSHOCZO), which has been intensively studied from a hydrologic, geochemical and geophysical perspective. We will measure the vertical root distribution, microbial biomass, soil CO2 efflux and root turnover in relation to topography at the SSHCZO. We will sample 50 macro-sites across the watershed with 4 micro-sites nested within each macro-site (total 200 points). We will add the Penn State Integrated Hydrologic Model (PIHM), which accounts for horizontal groundwater flow, to the Community Land Model Version 4 with terrestrial carbon-nitrogen interactions (CLM4CN), to improve the representation of the land surface and subsurface heterogeneities caused by topography. The proposed high-resolution measurements of soil C processes will provide important spatially distributed a priori parameter values and boundary conditions for modeling, and provide an unprecedented chance to comprehensively evaluate the coupled model fidelity (PIHM-CLM), improve our modeling skills at high resolution and low-order watersheds, and investigate the impacts of landscape variation on belowground C processes.
This study will determine the effects of topographic and hydrologic variation on root and microbial processes. It is expected that the key drivers of variation in belowground processes will be identified by this study, which will enable more efficient characterizations of C processes in sites that lack the wealth of data available in the SSHCZO. One of the primary products of the study will be the coupled PIHM-CLM model, a high-resolution coupled biogeochemical and hydrologic model.

Adrien Finzi/Boston University
Modeling the Effects of Warming & Elevated CO2 on Decomposition in a Northern Minnesota Black Spruce Peatland (DOE funded)

High latitude peatlands represent a particularly significant terrestrial carbon sink for atmospheric CO2, containing nearly half of the soil carbon pool on Earth. As result of anoxic conditions, however, peatlands are simultaneously a major source of CH4 to the atmosphere. The greatest rates of warming are occurring at high latitudes and warming is predicted to accelerate the loss of the C stored in peat as a result of faster rates of decomposition. The magnitude of these effects remains uncertain, as does the balance between C loss as CO2 and CH4. Methane is a powerful greenhouse gas with ~25 times the warming potential of CO2, thus it is critical to develop a robust understanding of the patterns and processes regulating climate-change associated changes in C cycling in northern peatlands. The overarching objective of this research is to characterize the response of CO2 and CH4 emissions from a boreal peatland to experimental warming and atmospheric CO2 enrichment (eCO2). This research will be conducted at the Spruce and Peatland Responses Under Climatic and Environmental Change (herein SPRUCE) experimental facility, which is located in the USDA’s Marcell Experimental Forest in northern Minnesota. By focusing on peatland responses to multiple levels of warming at ambient or eCO2 and our deployment of state-of-the-art technology to make continuous measurements of CO2 and CH4 emissions and isotopic signatures from the peat surface, the proposed research will enable the development of robust models relating trace gas emissions to changes in temperature and moisture regimes in peatlands and changes in C cycling imposed by potential increases in plant productivity at eCO2.
By collecting first-ever data on CO2 and CH4 fluxes from intact peatlands exposed to experimental warming and eCO2, this research will provide important data constraints on model structure and parameter estimation in a high-latitude boreal peatland. The proposed research therefore directly addresses NASA, DOE and USDA interests in understanding the responses and feedbacks of carbon rich, high latitude ecosystems to climate warming and atmospheric change. The proposal’s focus on belowground processes is fundamental to this understanding. The proposed data collection and collaboration with modeling groups will enable the refinement of ESMs, thus contributing to research that will aid in projecting the future state of the Earth’s climate system mediated by changes in land-surface processes. This research leverages existing federal investments in high-latitude, multifactor global change experiments, a key activity of the DOE’s Climate Research Roadmap Workshop Report. As also generally highlighted in the NASA ROSES call and specifically in the DOE Report, this research contributes directly to the design and initiation of “new process studies focused on soil organic matter dynamics and plant-microbe interactions,” as well as the implementation “for ESMs a new generation of soil organic matter submodels based on synthesis efforts and new process studies.”

Kevin Gurney/Arizona State University
Extending Top-Down, Bottom-Up Synthesis Research Through an Improved Fossil Fuel CO2 Emissions Data Product and the Latest #14CO2 Measurement in the United States (NASA funded)

The convergence of bottom-up and top-down approaches to quantifying CO2 emissions in the North American domain has taken important steps with recent studies such as the Mid-Continent Intensive (MCI) experiment. Similarly, a number of recent studies have performed comparisons of concentration observations to flux estimation at individual observing sites or in very specific locales, such as in the urban-focused efforts of INFLUX and the Megacity Project.

However, there has yet to be a direct comparison between bottom-up and top down estimation using the latest bottom-up emission data products and the complete complement of atmospheric CO2 monitoring across the entire United States. Most importantly, no study has yet to avail of the increasing amount of #14CO2 monitoring, a key constraint to fossil fuel CO2 emissions. Leveraging the large amount of research already begun, or completed, under the North American Carbon Program can fill this gap. Preliminary comparison of #14C observations with the standard version of CT fossil fuel fluxes (population downscaling approach) and an extrapolated version of Vulcan demonstrated that the spatial pattern of Vulcan agreed significantly better with #14C observations than the emission estimates previously used in CT. In the work proposed here, we would repeat this comparison with a new version of Vulcan, rigorously extended to 2012, and additionally use multiple transport models to assess the sensitivity of the comparison to transport specification in addition to an improved space/time representation of the fossil fuel fluxes.

This proposal responds to Theme 6 of the Carbon Cycle Science portion of the ROSES 2013 solicitation. Specifically, this proposal "extends and/or completes NACP synthesis research" by further synthesizing the fossil fuel CO2 emissions in North America with the NOAA monitoring and modeling capabilities in North America. This directly upports and informs three of the NACP synthesis activities: the Mid-Continent Intensive (MCI), the Regional-Continental Interim Synthesis and the Inverse Modelers (Regional-Continental) Interim Synthesis.

David Ho/University of Hawaii
Seasonal Variability in Dissolved Inorganic Carbon Fluxes in a Mangrove Ecosystem (NASA funded)

Mangroves worldwide sequester atmospheric CO2 at a rate higher than other ecosystems based on net primary production estimates. However, over 50% of the CO2 fixed by mangroves cannot be accounted for. This "missing sink" is ca. 0.1 Pg C/y, and therefore represents a significant part of the global carbon budget. It is hypothesized that this "missing sink" is due to the transformation of organic to dissolved inorganic carbon (DIC). Subsequently, this mangrove derived DIC either gets exported to the coastal ocean or goes into the atmosphere as CO2 via gas exchange. However, there is currently not sufficient data to examine this hypothesis. We aim to quantify the seasonal variability in fluxes of inorganic carbon to the coastal ocean and across the air-water interface in order to determine the fate of this CO2 sequestered by mangroves in Shark River, Florida, which is located entirely without Everglades National Park and situated in the largest contiguous mangrove forest in North America. To accomplish our goals, we will: 1) conduct Lagrangian tracer release experiments in different seasons to determine the transformation in the water column and gas transfer velocities; 2) measure spatial distributions of carbonate parameters in the mangrove ecosystem; 3) make time series measurements of carbonate parameters at a choke point between the mangrove estuary and the coastal ocean; 4) estimate photoproduction rates of DIC from field samples and ocean color remote sensing. This proposal is relevant to the solicitation as it addresses "Carbon Dynamics along Terrestrial-Aquatic Interfaces," and focuses on the "transformation and transport of carbon at the terrestrial-aquatic-atmospheric interfaces."

Chengquan Huang/University of Maryland
Role of Forest Disturbance and Regrowth in the US Carbon Budget (NASA funded)

The main focus of this proposed study is to derive improved understanding of the US carbon budget by exploiting the advances achieved in this regard under the auspices of the North America Carbon Program. Various efforts to synthesize carbon modeling estimates of the US carbon budget have produced widely varying results (CCSP 2007; Hayes et al. 2012; Pacala et al. 2001b; Schimel et al. 2000). While disagreements among these results are partly due to differences in carbon pools considered and methods and data used to complete the calculations (Houghton 2003b, 2007), incomplete information on disturbance history and lack of data on biomass density are two of the largest known uncertainty sources for carbon studies (Houghton et al. 2012; Ramankutty et al. 2007).

Building upon the NAFD results, this proposed study directly addresses these two uncertainty sources. The NAFD disturbance products will provide the best information on US forest disturbance history for the last three decades. In this study, this information will be used to substantially refine estimates of forest biomass dynamics, especially for young and middle-aged forests. The derived biomass estimates and the NAFD disturbance products will then be used in the Houghton et al (1999) Bookkeeping carbon accounting model to derive new carbon estimates for the US. It has been more than a decade since this model was used to derived carbon estimates for the US (Houghton and Hackler 2000; Houghton et al. 1999; Houghton et al. 2000).

Our specific project goals under this proposal include:

1). Biomass change from the NAFD products. We have recently achieved success in processing a 30-year Landsat data record to produce annual forest disturbance products for the full extent of the conterminous US (CONUS). This analysis can provide improved understanding of fine scale spatio-temporal patterns of forest age and biomass for more than 50% of all US forest areas. We will develop a three-tiered approach for age and biomass assessment, and will apply it to the entire CONUS region to produce an assessment of forest age and annual biomass change.
2). New US carbon estimates through carbon accounting. The NAFD disturbance products and the biomass change products derived through this study will provide substantial advances for the Houghton (1999) Bookkeeping model. Specifically, these products will provide the most comprehensive record of forest disturbances over the US, and will allow the model to calculated the carbon fluxes from these disturbances and post-disturbance recovery processes with unprecedented spatial and temporal details. We will first refine the Houghton Bookkeeping model such that it will take full advantage of these improved disturbance datasets, the biomass analysis results, as well as other best available data products. We will then use the improved model to derive carbon estimates at national and sub-national scales.

Deborah Huntzinger/Northern Arizona University
Multi-Scale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP) Phase II (NASA funded)

Terrestrial biosphere models (TBMs) are an integral tool for extrapolating local observations and process-level understanding of land-atmosphere carbon exchange to larger regions, and are expected to serve as a predictive tool for understanding carbon-climate interactions and global change. The North American Carbon Program Multi-scale synthesis and Terrestrial Model Intercomparison Project (MsTMIP) Phase I is a formal TBM intercomparison and evaluation effort focused on improving the diagnosis, attribution and prediction of carbon exchange at regional and global scales. The simulations performed through MsTMIP Phase I represent an unprecedented testbed for TBM model intercomparison, and are providing a critical opportunity for exploring simulations of carbon exchange across a large model cohort.

The MsTMIP experience has also revealed two large needs that go far beyond the scope of the Phase I project. First, Phase I focused on an intercomparison of carbon fluxes and the linking of these predictions to model structure. Beyond these data, however, the MsTMIP simulations have provided a wealth of predictions about the physical environment and about ecosystem responses to climate extremes over the 110-year simulations. These provide key links to understanding the dynamics that have controlled carbon exchange over the last century. Second, Phase I focused on the historic period in order to provide model output that could be evaluated not only against other models, but also against available observations. The next logical step is to evaluate how critical model differences dictate differences in predictions of future carbon dynamics.

Here we propose to tackle these two questions by supporting the analysis of MsTMIP Phase I simulations using new types of information (i.e. state of physical environment, response to extremes), and performing a series of forecasting simulations that use climate and emission scenarios defined by the IPCC and CMIP5. Critically, Phase II of MsTMIP will continue to be a grass-roots, community-based effort, focusing on enabling broad participation both for model simulation and analysis. As one example of MsTMIP's community focus, all of the collaborators listed on this proposal are leads of model teams that have submitted results to MsTMIP Phase I.

The two driving scientific questions will be addressed through four main activities: (1) Diagnosis of the drivers of inter-model variability, with a focus on evaluating how models reproduce the physical environment (soil and snow states), as well as how models respond to climatic extremes; (2) Evaluation of the response of TBMs to future climatic conditions, with an aim to assess the sensitivity of models and terrestrial carbon fluxes to future climate; and continuing to support and promote community engagement through (3) the development of an infrastructure for seamless data management and dissemination and (4) engagement with the modeling community through annual MsTMIP community workshops.

Overall the activities proposed here will involve a community of modelers and invest in a continued and expanded integrated assessment of the strengths and weaknesses of state-of-the-art TBMs. The analyses proposed span spatial scales (site to global) and temporal domains (historic to future); address key challenges to the TBM community; and will significantly advance carbon cycle science. This proposed effort directly responds to the call for Carbon Cycle Science Synthesis Research (Theme 6) and the need to extend and complete NACP synthesis research. The analyses and simulations proposed will address the goals of NASA by improving the understanding of the global carbon cycle and the sensitivity of terrestrial carbon storage to different environmental forcing factors, as well as the DOE by advancing the predictive understanding of Earth's climate and environmental systems through the development and testing of process-based models.

Lucy Hutyra/Boston University
Quantifying Carbon Signatures Across Urban-To-Tural Gradients: Advancing the Capacity for Monitoring, Reporting, and Verification Through Bbservations, Models, and Remote Sensing (NOAA funded)

Nearly 75% of anthropogenic CO2 emissions are generated in urban areas. The goal of the research described in this proposal is to address uncertainties and knowledge gaps in the carbon cycle of densely populated areas by developing a model-data framework for prediction and assessment of C fluxes in the Boston Metro region. The measurement component is built around an advanced network of surface CO2 observations, 14CO2 campaigns, ecological and biogeochemical measurements, and remote sensing of total column CO2 from space and from the ground. The model component integrates sub-models describing natural and human sources and sinks of CO2 (fossil fuel emissions, ecosystems fluxes, and land cover dynamics) with a high-resolution atmospheric transport model. The model-data framework will obtain optimal CO2 fluxes for the urban-to-rural domain by inverse modeling, allowing us to quantitatively characterize the spatial and temporal variations in CO2 component fluxes and net CO2 exchange with strong constraints from observed data.

The research described in this proposal responds to Theme 4 of NASA Research announcement NNH13ZDA001N-CARBON (Carbon Cycle Science: Carbon Dynamics within Urban-Suburban-Forested-Agricultural Landscapes), which seeks research to better understand "processes controlling the uptake, storage, and release of greenhouse gases along urban to rural gradients" and to "quantify the carbon signatures (spatial and temporal changes in fluxes) of ecosystems across a range of human influences." The proposed work builds upon previous and ongoing research and infrastructure.
The project deliverables include (1) regional estimates of net CO2 exchange partitioned into ecosystem and anthropogenic contributions; (2) improved characterization and modeling of the nitrogen cycle in urban environments; (3) improved models for atmospheric transport, anthropogenic emissions, and ecosystem fluxes of CO2; (4) analytical tools for greenhouse gas assessments and management in urban areas; and (5) process-level assessment of how alternative patterns of urban development and land cover change affect ecosystem and coupled human-carbon dynamics. Our end-to-end modeling and analysis framework will be scalable across a broad range of urban areas, providing an excellent basis for designing space-based and in situ monitoring of the C cycle in urban environments. Upon completion, our data sets and modeling framework will provide a comprehensive basis for quantifying, managing and reducing greenhouse gas emissions in densely populated areas and it will have immediate societal impact through existing collaborations with policymakers.

Bror Jonsson/Princeton University
Lagrangian Particle Tracking as a Unifying Framework to Study Variability of Acidification in Coastal Waters (NASA funded)

With this proposal we seek to improve our understanding of processes controlling carbonate system variability in coastal areas, and to demonstrate that ocean color satellite data are poised to play an integral role in this field of research. We will use Lagrangian tracking of virtual particles in combination with high resolution MODIS Aqua and MERIS satellite fields to distinguish the relative effects that biological and physical processes play in regulating the carbonate system of coastal waters. The proposed project expands upon novel work developed to estimate rates of biogeochemical change using ocean color data cast within the context of modeled velocity fields. Using output from a high-resolution general circulation model (GCM) we propose to track the carbonate system and biological variables from river mouths through the coastal zone onto the open ocean boundary. An application of these methods will provide estimates of processes affecting acidification including physical residence times, mixing, dispersion, and net local terms associated with community productivity.

Ralph Keeling/University Of California, San Diego
Measurements and Modeling of CO2 Concentration and Isotopes to Improve Process-Level Understanding of Arctic and Boreal Carbon Cycling (DOE funded)

This proposal seeks to understand terrestrial ecosystem processes that control the exchanges of CO2 with the atmosphere on decadal and longer time scales. The approach involves carrying out time series measurements of CO2 concentration and isotopes and uses these and other datasets to challenge and improve carbon cycle models, including earth system models. The proposal particularly emphasizes the use of these data to improve understanding of changes occurring in boreal and Arctic ecosystems over the past 50 years and to seek from these data improved understanding of large-scale processes impacting carbon cycling, such as the responses to warming, CO2 fertilization, and disturbance. This proposal is responsive to the solicited research Theme #1, specifically relating to carbon cycling in Arctic and boreal regions. It is also responsive to the need for improved observations, solicited under “cross-cutting research activities” □ by providing ar archive of CO2 samples extracted from flasks that may promote the development of novel isotopic applications related to land carbon cycling (e.g. radiocarbon).

The proposal specifically seeks support for continuing measurements of CO2 concentrations and isotopes from the Scripps CO2 program from flasks collected at an array of ten stations distributed from the Arctic to the Antarctic. It also seeks support for modeling studies and interpretive work to expand on the recent discovery based on airborne data that the amplitude of the seasonal cycle is cycle has increased by 50 to 60% since 1960 at latitudes north of 40N. This amplitude increase stands out as perhaps the most compelling evidence to date for wide-spread changes in land carbon cycling relevant for the global CO2 balance and climate change. Understanding its causes and improving terrestrial ecosystem models to depict the relevant processes is therefore clearly a high priority. This proposal will focus on key questions: 1) How is the amplitude increase related to changes in net carbon flux in boreal and arctic systems? 2) What processes are responsible for the amplitude increase? 3) How can the models be improved to incorporate the relevant processes?

Work to address these questions will entail inverse modeling activities in collaboration with colleagues in Germany (MPI Jena) and Japan (JAMSTEC) to further assess the relationship between the changing atmospheric CO2 cycles and the net CO2 fluxes over the past 50 years. These simulations will use aircraft and surface data to provide improve estimates of the relationship between the seasonal cycles and the changing northern land sink over the past 50 years. The work will also entail carrying out factorial simulations using the CLM4.5 module of CESM to explore mechanistic links between changing the phasing and amplitude changes in atmospheric CO_2 and its isotopes in relation to key parameters governing the arctic and boreal regions, assessing impacts of temperature sensitivity, CO_2 sensitivity, light-use efficiencies, and water-use efficiency. Finally, we will expand upon the insights from CLM4.5 by also examining output from available runs from a large suite of land ecosystem models recently made available from the Trendy model comparison study, particularly assessing the impact of warming and CO_2 fertilization and their interaction on CO_2 amplitudes and phasing and in relation to net carbon sinks.

John King/North Carolina State University
Improved Observation of Effects of Hydrology and Micro-Topography on Belowground C Cycling and Net Ecosystem Exchange in Natural and Managed Forested Wetlands in the Southeast U.S. to Improve Ecosystem Models (USDA funded)

Globally, wetlands store vast amounts of carbon due to their unique hydrology and biogeochemistry. Unfortunately, forested wetlands are poorly represented in monitoring networks such as Ameriflux and the North American Carbon Program (NACP), and key processes that control belowground C cycling are not fully incorporated into process-based or ecosystem models. Further, forested wetlands in the South have been less-well studied than their northern counterparts but are extremely vulnerable to rising sea-level, extreme storm events, and increasing winter/summer temperature. We propose to use our existing set of fully instrumented eddy covariance towers located in young and mature drained pine plantations and an un-drained natural forested wetland to improve understanding of controlling mechanisms of belowground carbon cycling, and their sensitivity to environmental drivers as affected by climate change and sea-level rise. Findings will be used to improve representation of belowground processed in forested wetlands in ecosystem models that will be linked to larger-scale regional models such as CLM to estimate the impacts of climate change and SLR on regional C dynamics.

Joel Kostka/Georgia Institute of Technology
Toward a Predictive Understanding of the Response of Below-Ground Microbial Carbon Turnover to Climate Change Drivers in a Boreal Peatland. (DOE funded)

High latitude peatlands cover only 3% of the Earth's land surface but store approximately 1/3 of all soil carbon (C), and act as sinks for atmospheric C. Despite their significance, wetland-specific processes are not included in global climate models, including the land component (CLM4) of the Community Earth System Model. Soil organic matter (SOM) pools and decomposition rates used in these models are derived from mineral soils, which are likely to respond very differently to climate change drivers compared to the saturated organic soils of peatland systems. The flux of C from terrestrial soils to the atmosphere is projected to increase with climate change, but acceleration of the terrestrial C cycle does not necessarily mean that soils will lose a greater proportion of their large C stores to the atmosphere.
The proposed research will address the question of whether changes in soil carbon in peatlands are driven by higher C inputs to the soil from plants or rather by the mobilization of stored older C through increased microbial activity, or both, thereby shedding light on a critical positive feedback loop. This proposal is inspired by research conducted under a

previous DOE award. We will leverage the infrastructure and site characterization conducted at the Marcell Experimental Forest (MEF), northern Minnesota, where the Oak Ridge National Lab (ORNL) has established an experimental site known as Spruce and Peatland Response Under Climatic and Environmental Change (SPRUCE). Using advanced analytical chemistry, 14C and 13C tracing, and next generation gene sequencing, the proposed project will quantify the response of SOM storage and reactivity, decomposition, and the functional diversity of microorganisms to climate change manipulation at the ecosystem scale. Through a close collaboration with SPRUCE investigators at ORNL, these new insights will be embodied into the CLM4 model to improve climate projections. For example, we propose to develop O-alkyl-C content, determined by either 13C NMR or IR spectroscopy as a better and more efficient predictor of soil decomposition rate than the operationally-defined SOM fractions currently in use.

We will test the following hypotheses: 1.) warming and elevated CO2 (eCO2) will increase growth and transpiration of vascular plants and decrease the productivity of Sphagnum and other bryophytes. These changes will alter the reactivity of SOM and microbial dynamics as outlined in H2-5, 2.) warming and eCO2 will result in the instability of buried peat C, thereby accelerating microbial respiration rates and greenhouse gas production, 3.) accelerated microbial metabolism will result in changes in the functional diversity of microbial communities leading to changes in the pathways of SOM mineralization and the ratio CH4/CO2, 4.) CO2 enrichment will lead to increased delivery of labile C substrates from enhanced primary production and root exudation, resulting in increased decomposition, mobilization and export of ancient peat C as dissolved organic carbon (DOC) from extensive belowground reservoirs, 5.) mobilization of ancient peat C in response to climate change drivers will be dependent upon interactions between microbial populations and the C-use efficiency of the microbial groups that degrade labile and/or recalcitrant SOM pools.

In response to the climate change manipulation, we will determine: 1.) changes in the reactivity of solid peat, DOC, and microbial respiration products (CO2, CH4), 2.) changes in the abundance, community structure, and function of soil microbial communities, 3.) compositional and 14C isotopic changes in the exported DOC of peatland and enclosure outflows, 4.) the response of SOM lability as indicated by infrared spectroscopy determined humification indices, the function of specific microbial groups, and the efficiency of organic matter decay to climate change manipulation under controlled conditions in the laboratory using microcosm experiments.

Bev Law/Oregon State University
Carbon Cycle Dynamics Within Oregon's Urban-Suburban-Forested-Agricultural Landscapes (Funded by DOE and USDA)

Intellectual Merit: Land management strategies and land use within urban-suburban, agricultural and forested landscapes can have significant impacts on local and regional carbon, water and energy cycles, but their gross and net effects are complex and not well understood. A better understanding of the interactions and feedbacks between ecological systems, human actions, and changes in climate is needed to drive the decision making process at local to landscape and regional scales. For example, in the western US, fire and drought and their intensification with climate change are critically important issues faced by land managers. Several states have set ambitious greenhouse gas reduction targets, including conversion of power plants to bioenergy from forests and crops, and thinning high biomass forests to reduce wildfire emissions. However, policies and management are being implemented without adequate assessment of their comprehensive environmental effects.

To address these shortcomings, an interdisciplinary team of scientists from Oregon State University proposes to study the effects of land use and land cover on the exchanges of carbon, water and energy in current and future climates across a gradient of urban-suburban agricultural and forested landscapes. Our approach integrates remote sensing observations and data from tall tower CO2 observations and flux sites with comprehensive modeling approaches using the new version of the Community Land Model, CLM4.5. We will use artificial neural network analysis to examine current spatio-temporal patterns in carbon, water and energy exchange, and enhance CLM4.5 to improve its ability to predict these processes and carbon sequestration in the future. Our study region is Oregon, as it spans strong gradients from high population/high forest productivity/mesic climate in the west to low population/low productivity/arid climate in the east, and land use is changing to reduce GHG emissions.

The project will enrich scientific understanding of the relationship between land-use decisions and climate-induced impacts on terrestrial ecosystems. A focus of our study will be on the effects of conversion of semi-arid sagebrush to irrigated bioenergy production on carbon, water and energy cycling, and resulting heating or cooling effects. We will also study and predict the effects of afforestation of idle land and rangelands deemed suitable for forests or poplar crops on exchanges of carbon, water and energy under future climate conditions. We will address these policy-relevant questions: How do current land uses and cover affect carbon dynamics, and carbon, water and energy exchanges, including cooling/warming effects? Given possible climate trajectories, what land-use strategies will reduce carbon dioxide emissions while optimizing sustainability of native vegetation and food crops? The project will enhance scientific understanding of the relationship between carbon dynamics and land-use decisions in gradients of urban to crop and native vegetation. Our contributions to innovative assessments will be the first predictions of integrated impacts of future climate and land use (management to mitigate climate impacts on forests, land use shifts to bioenergy crops) on carbon sequestration, and carbon, water and energy fluxes at local to regional scales using new downscaled CMIP5 climate data selected for the region, a new version of CLM, and new land use/land cover maps generated from remote sensing data for the region.
Broader Impacts: An important goal of the proposed research is to identify policies and management strategies that can sustain ecosystem function while addressing land use changes that are intended to reduce greenhouse gas emissions. Our observation-driven modeling approach will provide an invaluable policy analysis tool for other regions as it projects integrated impacts of land use decisions and climate change on ecosystem carbon and water processes and climate feedbacks.

Johannes Lehmann/Cornell University
Soil Organic Carbon Interactions with Organic Matter Additions: Mechanisms and Models (USDA funded)

Today's most widely-used models of the soil organic carbon (SOC) cycle including those that are part of leading Earth system models use a few key environmental and edaphic parameters to determine SOC cycling rates, but do not include mechanisms whereby different pools of SOC may affect the decomposition rate of other pools. This limitation means that so-called “priming” interactions (in which addition of an organic substrate alters the turnover rate of existing SOC) are not readily captured by current models. This restricts us from predicting how existing SOC stocks will be affected by factors such as changing above- vs. below-ground allocation in plants under future climatic scenarios, changing organic matter inputs through agricultural management practices, or pyrogenic carbon (pyC) produced through natural fires or used intentionally in land management or for carbon management.

We propose to conduct a systematic program of experiments to isolate and test for key proposed mechanisms of priming due to root-soil interactions, fresh organic matter additions, and pyC additions to soils. We will determine which mechanisms dominate SOC priming interactions in natural soils, across a broad range of globally-applicable environmental conditions, and nutrient statuses, using targeted laboratory and greenhouse studies. Results from these experiments will be used to improve two key soil carbon cycle models (CENTURY and CLM-CN, the carbon-nitrogen cycling module of the CESM’s Community Land Model) to allow for the modeling of priming effects and to calibrate and validate the new models. This model-inspired research will lead to increased understanding about fundamental mechanisms of soil C cycling, and will improve our capacity to predict potentially important effects of priming on soil C stocks now and in the future.

John Lin/University of Utah
Predicting CO2 Emissions Associated With Urban Development in the Western U.S. (NOAA funded)

The global population has recently passed the 7 billion mark, with more than half residing in urban regions. Urban expansion has also been occurring rapidly in the U.S. The rise of the global urban population has concentrated anthropogenic emissions of greenhouse gases and pollutants in urban regions, resulting in persistently elevated concentrations over urban areas.

As urban expansion proceeds, the following key questions need to be addressed:

- How can carbon emissions from urbanizing regions be determined?
- How do decisions about urban form, land use transitions, and infrastructure determine the long-term trajectory of carbon emissions?

We will address these questions in the rapidly urbanizing American West, which is experiencing major transitions from rangeland to urban and agricultural to urban land use and where population growth has been especially pronounced, with large numbers of people settling in existing metropolitan areas in the region. The nature and form of these transitions have large implications for future carbon emissions.

Specific objectives include:

- Model and understand current-day carbon emissions in multiple valleys at different stages of development in the Wasatch Range of Utah
- Critically test and calibrate a new NASA product of hi-res CO2 emissions (Hestia) with long-term, continuous CO2 and isotope data, combined with targeted mobile lab observations
- Transfer info. from calibrated Hestia product to a widely-applied urban planning model
- Infer CO2 emissions in the Salt Lake Valley (SLV) going back to 1950, using land use and urban form records and radiocarbon proxies of CO2 in tree rings

- Using an urban planning model, integrate stakeholder engagement efforts that have already yielded land use scenarios along Utah's Wasatch Range to examine resulting CO2 outcomes
- Examine the close to century-long transition of carbon emissions associated with urban development in the SLV, from 1950 to 2040
- Extend the carbon emission projections, beyond Utah, to two additional cities in the Western U.S., based on scenarios that bracket likely developmental patterns
- Deliver to the research and policymaking community a planning tool that can project the carbon emissions as a result of different urban development patterns in the Western U.S

The study region of the proposed project includes 3 contrasting valleys in Utah. By simultaneously monitoring and modeling current-day CO2 in the 3 valleys at different developmental stages, we "trade space for time". Furthermore, the quantitative relationships between urban land use and CO2 emissions, as encapsulated in Hestia, will be transferred to an urban planning model (ET+), which would both hindcast CO2 emissions within SLV in 1950 and forecast future emissions for all 3 valleys in the year 2040, providing a close to century-long transition of carbon emissions associated with urban development in the SLV, from 1950 to 2040.
The proposal directly addresses the Carbon Cycle Science Program's "carbon dynamics within urban-suburban-forested-agricultural landscapes" theme. The RFP mentions the need for understanding "processes controlling the uptake, storage, and release of greenhouse gases along urban to rural gradients" and the role of development choices that affect "energy consumption, transportation, and construction". Also, involvement of "stakeholders…throughout the study" is mentioned, as well as the "development of decision support tools", both critical components of our proposed project. The urban planning tool used in this study is an important decision support tool that is already being used across the country to help policymakers determine implications of land use choices. Our project will add a module on urban carbon emissions that will be calibrated in Utah, but provide the framework for incorporating data from other urban regions, starting in the Western U.S.

Junjie Liu/Jet Propulsion Laboratory
Estimating the Impacts of Recent Severe Amazonia Droughts on Forest Carbon Dynamics and Fluxes From Assimilating Satellite Observations in NCAR CESM With Ensemble Kalman Filter (NASA funded)

TThe objectives of the proposed work are: 1) to estimate gross primary production (GPP), respiration, net carbon fluxes, biomass, and their uncertainties over the Amazonian forests over a period of 10 years (2003-2012) by assimilating canopy structure and water content, and soil moisture from a combination of QSCAT/OSCAT2 and TRMM-PR satellite data into a coupled data assimilation model, 2) to study the impact of severe climate variability such as 2005 and 2010 droughts on the carbon dynamics and the time-scale of the response of the Amazon forest, 3) to identify poorly represented biogeochemical processes and their timings in the Community Earth System Model (CESM), and 4) to quantify the feedback of drought induced disturbances to precipitation. We will validate the results of the proposed study on carbon cycle and dynamics against independent data products, including observations from FLUXNET (http://fluxnet.ornl.gov/), MODIS GPP/NPP, and biomass spatial products (e.g., Saatchi et al. 2011). We will also verify the CO2 responses to the estimated net carbon flux against GOSAT XCO2, and examine the consistency between bottom-up flux estimation from data constrained CESM and the top-down atmospheric inversion constrained by GOSAT XCO2 observations.

The primary methodologies are ensemble Kalman filter (EnKF) coupled with Community Earth System Model (CESM) and atmospheric inversions. The EnKF-CESM includes two components: the atmospheric data assimilation (EnKF-CAM) and the land data assimilation (EnKF-CLM-CN). When these two components run in parallel, the uncertainties estimated from EnKF-CAM and EnKF-CLM-CN will propagate to each other through forecast, which makes the uncertainty quantification more realistic. This study will be the first study considering the uncertainty propagation between atmosphere and land during data assimilation process.

The proposed research activities will not start from scratch. It builds upon the ensemble data assimilation system and the atmospheric inversion tools that have been developed (Liu et al. 2009; 2011; 2012; 2013). The quantitative relationships between QSCAT/OSCAT2 and canopy properties, and between TRMM PR observations and soil moisture have been established by Saatchi et al. (2013). The sensitivities of carbon dynamics (e.g., changes in net carbon fluxes) to canopy properties (e.g., Leaf Area Index) and soil moisture have been proved by previous literatures (e.g., Brando et al. 2008) and sensitivity experiments (section 1.2.1).

At the end of the proposed research, we expect to deliver the following results: 1) the net carbon fluxes, the gross primary production (GPP), respiration, biomass, and their uncertainties over Amazonia between 2003 and 2012 at grid cells approximately 0.25° in resolution, 2) quantification of the feedback mechanisms of drought induced forest disturbance to precipitation, 3) a comprehensive validation of the net carbon fluxes, GPP, and biomass against independent observation and data products, including the net carbon flux and its uncertainties from atmospheric inversion constrained by GOSAT XCO2 between July 2009 and Dec 2012, and 4) identification of the poorly represented biogeochemical processes and their timings in CESM.

The proposed research addresses the following scientific and technical questions:

- How did the net CO2 fluxes change in Amazonian forest during the 2005 and 2010 droughts and the subsequent recovery?
- What is the feedback magnitude of Amazonian canopy disturbance from droughts to rainfall?
- Are top-down flux estimates using satellite column XCO2 consistent with bottom-up flux estimates constrained with canopy structure /water content and soil moisture observations?
- What are the main sources of uncertainty in the NCAR/DOE Community Earth System Model (CESM) when simulating the Amazonia droughts and their impacts on the carbon dynamics?

Charles Miller/Jet Propulsion Laboratory
CARVE Airborne Observations of Carbon Dynamics in the Vulnerable Arctic-Boreal Ecosystems of Northwestern Canada - CARVE-CAN (NASA funded)

Dramatic increases in warming, fire severity and frequency, and other natural disturbances have made the vast stores of carbon sequestered in the pristine Arctic-boreal ecosystems (ABEs) of NW Canada vulnerable to rapid release as atmospheric carbon dioxide (CO_2) and methane (CH_4), potentially triggering a large positive climate feedback. However, there are no long-term CO_2 or CH_4 measurements for this region, nor systematic study of the spatial and temporal variability of atmospheric CO_2 and CH_4 concentrations or total columns in ABEs of NW Canada in response to climate change.

We propose incrementing flight hours to Alaskan deployments of the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) to characterize atmospheric CO_2 and CH_4 over vulnerable ABEs in the Mackenzie River basin of NW Canada during 2014 and 2015 (CARVE-CAN). CARVE-CAN flights will be anchored by Environment Canada sites at Inuvik NT and Behchoko NT, where surface in situ measurements of atmospheric CO_2 and CH_4 will provide a temporal context for our intensive airborne measurements. We will generate observationally driven CO_2 and CH_4 flux estimates for the Mackenzie basin using state-of-the-art WRF/STILT Lagrangian particle dispersion modeling and analysis tools developed for CARVE and operational on NASA's Pleiades supercomputer

CARVE-CAN's objectives of are: Quantify surface-atmosphere CO_2 and CH_4 fluxes and the spatial and temporal variability of atmospheric CO_2 and CH_4 for the Mackenzie River basin, and Compare and contrast these fluxes with fluxes observed over Alaska and with fluxes estimated by process-based land surface models.

CARVE-CAN leverages the investment made by NASA in CARVE to achieve high impact science at substantial cost savings. The fully integrated and operational CARVE flight system would be available in Fairbanks for CARVE-CAN-funded flights during June - August in 2014 and 2015. CARVE-CAN also employs a data analysis framework that enables synergistic interactions with related Atmospheric Composition and Carbon Monitoring System studies.

CARVE-CAN addresses Theme 1: Carbon Research in Critical Regions/3.1.2 Carbon Dynamics in Arctic-Boreal Ecosystems of the solicitation by characterizing the spatial and temporal variability of CO_2 and CH_4 atmospheric concentrations, total columns and surface-atmosphere fluxes for the vulnerable, carbon-rich ABEs of the Mackenzie basin, an area for which the current and future carbon balance is highly uncertain. CARVE-CAN also addresses priorities from the US Carbon Cycle Science Plan by delivering "Short-term but focused studies in ecosystems vulnerable to carbon loss, including permafrost, forests, and ... boreal peatlands" (Sec. 5.2.1). Our observations and CO_2 and CH_4 flux estimates will provide important new insights for these undersampled and largely uncharacterized ABEs and critical baseline data for the Canadian domain (eastern transect) of NASA's Arctic-Boreal Vulnerability Experiment (ABoVE). CARVE-CAN data will challenge the detailed process models developed under DOE's Next Generation Ecological Experiment (NGEE-Arctic) given the distinct differences in soil carbon content, above ground biomass, ecosystems and climate between the North Slope tundra near Barrow, AK and the boreal forests and peatlands of the Mackenzie basin. CARVE-CAN flux estimates may be used to validate those from the OCO-2 and SMAP Decadal Survey missions. CARVE-CAN can also be used to help validate OCO-2 XCO_2 at high northern latitudes. CARVE-CAN research extends the understanding gained from the ABLE, BOREAS, ARCTAS, and CARVE field campaigns, and helps focus the spectrum of interdisciplinary assets from NASA and other agencies towards the challenges of ABoVE and NGEE-Arctic. Finally, CARVE-CAN results will accelerate understanding of the Arctic as a bellwether for the impacts of climate change on the entire Earth system.

Raymond Najjar/Pennsylvania State University
The Carbon Budget of Tidal Wetlands and Estuaries of the Contiguous United States: A Synthesis Approach (NASA funded)

Tidal wetlands and estuaries play key roles in the global carbon cycle because of their high rates of carbon burial and processing of riverine carbon. A NASA-supported coastal carbon data synthesis activity, which led to the development of preliminary coastal carbon budgets for North America, identified carbon fluxes in tidal wetlands and estuaries as an area of particularly large uncertainty. The main objective of the proposed work is to develop a carbon budget for tidal wetlands and estuaries of the contiguous US using existing field observations, remote sensing products, and statistical models. The great spatial and temporal heterogeneity of tidal systems demands novel techniques for extrapolating limited in situ data to regional scales. We propose to use NASA remote sensing products as a key resource for spatially interpolating and scaling up in situ carbon data.

We seek to determine the carbon fluxes across and between the head of tide and the seawater boundary for 139 of the estuarine-wetland systems delineated and catalogued by NOAA, which account for >90% of estuarine surface area within the contiguous US. Mass-balance equations describing the steady-state organic and inorganic carbon budgets applied to tidal wetlands and estuaries are the theoretical underpinning of the analysis. The relevant carbon fluxes are the net carbon dioxide uptake from the atmosphere by tidal wetlands; the net evasion of carbon dioxide from estuaries; input from land to tidal wetlands and estuaries; burial in tidal wetland soils and estuarine sediments; the net advective transport from tidal wetlands to estuaries, tidal wetlands to the ocean, and estuaries to the ocean; and net ecosystem production in tidal wetlands and estuaries. Specifically, we propose to develop estuarine and tidal wetland databases on carbon fluxes or measurements that allow the computation of carbon fluxes. Those fluxes will be modeled using NASA remote sensing products, data from the National Wetlands Inventory, and estuarine characteristics compiled by NOAA. These models, with well-determined error estimates, will be used to extend flux estimates to all 139 systems of interest, thereby enabling the development of regional and national coastal carbon budgets.

Particular research questions we will answer with our synthesis are: Is the oxidation of organic carbon in estuaries largely supported by wetland production and export or by the respiration of riverine organic carbon? How do flux processes vary between climatic zones, and between passive margins (Atlantic, Gulf) and active margins (Pacific)? What estuaries have the highest potential for "blue carbon" projects to conserve net CO_2 uptake by tidal wetlands? Is the combined system (tidal wetlands and estuaries) a net source or sink of CO_2 to the atmosphere?

Our research team has extensive expertise in remote sensing, wetland biogeochemistry, and estuarine biogeochemistry. Multiple team members have a history of successful collaboration through the participation in a coastal carbon synthesis activity initiated by the Ocean Carbon and Biogeochemistry Program and the North American Carbon Program. Furthermore, the team has requisite regional expertise, with research experience on the Atlantic, Gulf, and Pacific coasts, which will facilitate access to and synthesis of relevant datasets.

The proposed work will result in the development of improved remote sensing retrievals is coastal systems. Results from this work will be particularly useful for targeting optimal remote sensing design and maximizing the return of future NASA ocean color missions, including the Climate Initiative mission PACE (Pre-Aerosol, Cloud and Ecosystems) and the Decadal Survey mission recommended by the National Research Council, GEO-CAPE (GEOstationary for Coastal and Air Pollution Events). Results will also be useful for future parameterization of MODIS algorithms, specific to tidal wetlands, by NASA, NACP, and the MODIS Land Team.

Cynthia Nevison/University Of Colorado, Boulder
Understanding the Present and Future Carbon Sink in the Southern Ocean Using Atmospheric Gas Observations, Remote Sensing and Models (NASA funded)

The Southern Ocean is a key region contributing to the regulation of atmospheric CO2 through the "biological pump", in which carbon is fixed and exported out of the surface mixed layer. Deep waters become enriched in CO2 and depleted in O2 and later ventilate and equilibrate with atmospheric CO2 and O2 when they outcrop to the surface. The ~30% decrease in atmospheric CO2 during the Last Glacial Maximum (LGM) is commonly attributed in large part to a reduction in ventilation from the Southern Ocean. In the future, ocean biogeochemistry models tend to predict neutral to small increases in productivity and carbon export in the Southern Ocean, but the effect of these increases on the net air-sea CO2 flux and their interaction with future changes in deep ventilation are not well understood. Meanwhile some hindcast model simulations suggest that the current Southern Ocean CO2 sink may be weakening due to increased ventilation of naturally CO2-enriched waters around Antarctica.

The ability to detect changes in ocean ventilation and export production is critical to accurate monitoring and prediction of changes in the Southern Ocean carbon sink. Remotely sensed ocean color data and atmospheric potential oxygen (APO) are valuable and complementary metrics for evaluating the Southern Ocean carbon cycle. Ocean color products provide high-resolution spatial coverage, while APO data provide regional integrals that helps constrain the satellite-derived NCP data. APO data further provide information about subsurface ventilation processes that are not captured by satellite data. Earth System Models (ESM) are widely used tools for predicting the future evolution of ocean carbon uptake. Output from a range of ESMs is publicly available through websites created for the IPCC 5th Assessment. In our preliminary calculations, six IPCC AR5 ocean biogeochemistry component models forced with the RCP8.5 scenario predict a 5-20% decrease in the amplitude of the APO seasonal cycle in the Southern Ocean, which is due in some cases to a reduction in ventilation of O2-depleted, CO2-enriched deepwater. We propose a synthesis of models, satellite ocean color data and atmospheric observations, including APO and other trace gases, to understand why this reduction in ventilation occurs in some models but not others, what it means for ocean carbon uptake, and which ESMs provide the most credible future projections.

Specific tasks include:

1) Develop improved satellite ocean color based estimates of net community production (NCP) in the Southern Ocean, based on several recently published new

formulations and evaluate against APO data.

2) Evaluate the ocean biogeochemistry components of a suite of IPCC Earth System Models in terms of their ability to reproduce observed seasonal and spatial variability in satellite-derived NCP and APO. Examine future changes in NCP and APO predicted by the ESMs forced with the RCP8.5 future scenario.

3) Implement techniques developed for coarse resolution ocean models in past work into the eddy-resolving ECCO2-Darwin optimization system to better understand the relationship between carbon export production (EP), NCP, and surface O2 fluxes associated with ocean productivity, ventilation and thermal forcing.

The proposed project targets Theme 1 of the Carbon Cycle Science solicitation by focusing on the carbon cycle in the high latitude Southern Ocean. The research also addresses the NASA Earth Observations and Applications strategic needs for both Climate Monitoring and Research and Carbon Cycle Research: it synthesizes satellite ocean color data, surface-based observing systems and models to promote understanding of carbon exchange between the atmosphere and ocean in order to project with more confidence the future evolution of climate.

Tomohiro Oda/Universities Space Research Association
A Fine-Scale Global Fossil Fuel and Biomass Burning Emissions Using Suomi-NPP VIIRS Satellite Data (NASA funded)

We propose to develop fine-scale global emissions datasets for fossil fuel combustion (for CO2) and biomass burning (for CO2, CO and CH4). Carbon emissions datasets (e.g. for fossil fuel combustion, biospheric exchange and biomass burning) are primary inputs to any study of the global carbon budget, emissions drivers, and associated carbon cycle processes. To capture realistic emissions dynamics, such high-resolution emissions datasets need to be created/updated in a timely manner to accurately reflect emission changes. The use of satellite data for disaggregation of national emissions can allow such time-varying emissions datasets to be generated quickly. Human settlement patterns, inferred from gridded nightlights data collected by Defense Meteorological Satellite Project (DMSP) satellites, have been used as a proxy for human-induced emissions. Nightlights imagery and other data collected by the Visible/Infrared Imager Radiometer Suite (VIIRS) sensors on the Suomi National Polar-orbiting Partnership (NPP) satellite (2011-on) can now be used to significantly improve upon these DMSP-based products.
While nightlight data has been useful for mapping CO2 emissions, its availability and quality has been limited (e.g. low time frequency, pixel saturation). However, nighttime data collected by the Day/Night band of VIIRS now provides unsaturated nightlight data at higher frequently and spatial resolution than previous instruments on DMSP. The use of VIIRS nightlight data should allow us to significantly improve the current CO2 emission mapping method, giving an accurate and timely view of regions where the intensity and spatial extent of human activities are rapidly changing. We will implement this improvement using the existing Odiac emissions model that has been used to generate a global 1 km x 1 km fossil fuel emission map. In addition, the Nightfire algorithm that identifies combustion sources from VIIRS measurements gives us a unique opportunity to directly estimate emissions from single combustion events that are often missed by the current emissions reporting system. The performance of Nightfire will be tested using air-sampling measurements where available.

Leveraging the Nightfire algorithm, which estimates the burnt area of each combustion sources identified, we will also develop a 1km x 1km emissions dataset for biomass burning (for CO2, CO and CH4). The uncertainty associated with biomass burning is high. Given that most of the existing biomass burning datasets rely on data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS), this proposed work gives an alternative view, since the Nightfire method is different from the algorithm used for the MODIS fire products. We will assimilate Nightfire-derived burnt area data into the Fire INventory from NCAR (FINN) fire model to obtain a new biomass burning emissions estimate. Also, we will use the Data Assimilation Linked Ecosystem Carbon (DALEC) biosphere model to produce a second set of biomass burning emissions, as well as net ecosystem production consistent with biomass burning. By comparing these independent biomass burning products, we should be able to quantify uncertainty in a better way.

Finally, the performance of our new emissions datasets will be assessed by using them as priors in a state-of-the-art flux inversion system, then determining whether the posterior fit to independent measurements (not used in the assimilation) improves compared to the fit from earlier emissions datasets. We expect that our high-resolution emissions datasets should reduce representation errors when constituents are modeled at high-resolution, particularly when satellite observations are used.

This proposal is responsive to Theme 4 of the Carbon Dynamics call, "Urban-Suburban-Forested-Agricultural Landscapes", insofar as it attempts to "put observational constraints on the atmospheric signature of emission estimates".

Christopher Osburn/North Carolina State University
Linking Carbon Exchange Between Coastal Wetland and Shelf Environments: A Case Study in the Barataria Bay, Northern Gulf of Mexico (NASA funded)

The aim of this proposal is to optimize algorithms that integrate optical and chemical information of dissolved organic matter (DOM) based on proxies for the prediction of its flux from marshes to coastal waters through estuaries. Land use and climate are important drivers that strongly influence the transport and fate of coastal wetland DOM offshore and these transitional areas have also been recognized recently as important sinks in the global carbon pool, commonly referred to as "blue carbon." Coastal wetlands in Louisiana, (e.g., marsh-estuarine complexes such as Barataria Bay) show clear decreasing gradients of DOM quantified as dissolved organic carbon (DOC) and dissolved lignin that suggest loss of blue carbon from the marshes to the more estuarine bays and subsequent export to coastal waters.

The overarching hypothesis of this study is that changes to DOM chemistry within the marsh-estuarine complex imparts seasonal variability in the quantity and quality of DOM exported to the coastal ocean. This hypothesis we pose is important to test because light absorption by DOM chromophores (i.e., CDOM) is a function of its chemistry, allowing CDOM retrievals from remote sensing reflectances to predict DOM quantity. The next step in the advancement of our understanding of the terrestrial-marine linkage - and the potential loss of blue carbon from coastal wetland - is to predict DOM quality synoptically with remote sensing. We propose to test our hypothesis by combining co-varying chemical (dissolved lignin, stable isotopes) and optical (fluorescence) biomarkers that can deconvolve complex mixtures of DOM sources, along with optical measurements relatable to remote sensing observations. We plan to conduct seasonal (spring and fall) field campaigns in the Barataria Bay, Louisiana, and Apalachicola Bay, Florida, to modify existing algorithms for the VIIRS sensor, building on prior NASA-funded CDOM work by our team as part of the OCB and NACP programs.

Coastal wetlands are economic powerhouses, supporting local fisheries productivity, recreation, aesthetics - and their protection is a critical coastal management issue. Along the Gulf Coast of the United States, coastal wetlands are some of the most critically sensitive ecosystems under threat from anthropogenic and climatic stressors, particularly along the Louisiana coast. Apalachicola Bay is chosen as it is a region that is influenced by elevated levels of DOM/CDOM that is discharged from the Apalachicola River. These two regions encompasses a critical US ecosystem undergoing stress from land use and climate; therefore the targeted study we propose will be useful for understanding how the land-ocean linkage is responding to such stressors with respect to DOM fluxes.

This proposal specifically addresses Item 3.2 Theme 2 related to carbon dynamics along the terrestrial-aquatic interface. Together, DOM chemical and optical properties can distinguish between riverine and wetland sources. Substantial variability exists in the sea-to-air fluxes of CO2 that likely is linked to the fate of blue carbon DOM in coastal waters as contributed by coastal wetlands. Remote sensing estimates of these sources obviously would improve our understanding of the role that coastal wetlands play in the contribution of continental margin systems to global carbon budgets, especially with respect to changing patterns of climate and land use. Quantifying the exchange of DOC between wetlands and shelf regions is critical to do now, especially in light of the impending rise of sea level will alter these fluxes; particularly in regions like Louisiana where relative sea level rise (RSLR) and wetland loss rates are considerably higher than other regions in the country. This information gap will be addressed with the proposed work.

Jon Ranson/Goddard Space Flight Center
A High-Resolution Circumpolar Delineation of the Forest-Tundra Ecotone With Implications for Carbon Balance (NASA funded)

In response to NASA Carbon Cycle Science Solicitation to "improve understanding of terrestrial carbon storage, ... in Arctic/Boreal terrestrial ecosystems that may be approaching a potential tipping point with regard to the release of stored carbon" the proposed study will map and characterize the current Arctic forest-tundra transition zone and reveal its changes during the last several decades with multi-sensor satellite data and field observations. Note that the study will also consider alpine tree line, but only within the Arctic forest tundra ecotone.

Climate change has already affected the Higher Northern Latitudes, altering vegetation productivity, carbon sequestration, and many other processes. Establishing the current boundary between the Forest-Tundra biome is important yet difficult to define because vegetation form throughout the transition varies dramatically from site level dynamics including microclimate, topography, winter snow depth, wind, edaphic conditions, etc. coupled with the long-term site history of their interactions. Those processes have produced many different vegetation structure forms from sporadic forest cover patches to growth-stunted trees that resemble shrubs. Many of these growth forms are not visible from most earth observing satellites. Studies thus far, have found large differences in the location of the ecotone. Our recent study used MODIS 500 m vegetation continuous fields (VCF) data with a limited sample of QuickBird-2 data to define tree line but lacked the spatial precision needed to establish a baseline that can be used to monitor climate warming impacts to vegetation cover in the near term. In addition, due to limitations of MODIS coverage at the time, the final product extended only to 70oN. Recent advances using the global archive of Landsat data have provided vegetation continuous fields (VCF) at 30 m, and could help to define the subarctic tree line. Recent studies have found that Arctic greening is associated with densification of shrubs, increasing biomass, and establishment of new shrubs within thawing patterned ground features, but they have not been spatially comprehensive to establish a subarctic tree line. Recently granted federal civilian access to sub-meter commercial satellite data provides the means to establish an improved estimate of the subarctic tree line at an unprecedented scale. We will provide a 30-m arctic-boreal boundary map using the Landsat based global vegetation continuous field product constrained and validated with commercial sub-meter imagery.

The remotely sensing based canopy height, biomass and cover can be used to initialize and run ecosystem models.

The objectives of this proposed work are:

1. Use recently available Landsat based percent tree cover maps with estimates of uncertainty to improve our prior circumpolar arctic-boreal transition assessment.
2. Use high-resolution data in intensive study sites along the forest-tundra transition zone and characterize the spatial patterns of tree-tundra mosaic across the boundaries. These data include commercial sub-meter panchromatic and stereo imagery from WorldView-1, WorldView-2, and Quickbird-2.
3. Estimate forest cover and biomass change in intensive study site transects using high-resolution stereo satellite data, field observations, and allometry.

This proposal directly addresses NASA is interest in Carbon Dynamics in Arctic/Boreal Terrestrial Ecosystems. The implications are significant as sentinel of climate change and in developing confidence in predictions of changes in carbon balance due to a rapidly changing environment. This proposed work also contributes directly to NASA's interests in characterizing critical ecosystems, especially in high latitudes, and can contribute data and science analysis to NASA's proposed ABoVe experiment.

Curtis Richardson/Duke University
Phenolic Compounds and Black Carbon Feedback Controls on Peat Decomposition and Carbon Accumulation in Southeastern Peatlands under Regimes of Seasonal Drought, Drainage and Frequent Fire: A New Model for Management of Carbon Sequestration (DOE funded)

Earth System Models (ESMs) predict increased frequency of extreme wet and dry periods in the subtropics and tropics over the next century, resulting in uncertain carbon (C) budgets and greenhouse gases (GHG) fluxes. Globally, approximately 1/3 of peat stores are found in subtropical and tropical peatlands (STPs) formed from high-lignin woody biomass. STPs along the Atlantic coast from North Carolina (NC) to Florida (FL) to tropical Panama (PN) have persisted through climate and sea level changes over the last 4000 years and continue to accrete peat even under climate driven conditions of drought, warmer temperatures and fire. Our questions are: 1) how do these stressed non-sphagnum peatlands accumulate and store C, and 2) can insights gained from studying their natural processes and control mechanisms provide management guidelines for vast STPs and boreal peatlands subject to increasing climate forcing. While most studies focus on northern peatlands, globally important STPs remain woefully underrepresented in ESMs. We propose a 3-year experimental comparison across STPs to reveal the key process-level mechanisms controlling soil C stabilization, accumulation, and long-term storage potential (Theme 3, topic 2). Our work will foster new strategies and predictive threshold models to facilitate recovery of disturbed STPs subjected to climate change, fire and lower water tables either by drainage or drought. Elucidation of control mechanisms will also yield perspective towards understanding the effects of global warming and drought on boreal Sphagnum peatlands undergoing climate-induced shifts to wooded plant communities. Our main hypothesis is that the STP native-fire-adapted shrubs/trees communities produce higher polyphenol litter than Sphagnum/Carex communities. This production difference, in conjunction with climate induced regimes of frequent low-intensity fire, creates recalcitrant decomposition-resistant peat by a dual "latch key mechanism" consisting of high phenol and black carbon (BC, complex aromatics). Together these retardants reduce GHG flux, and C decomposition of STPs peats under altered hydrologic conditions, higher temperatures and drought. Specific objectives include: I: Identify and compare process-level mechanisms controlling peat accretion and C losses from shrub-bogs in NC, subtropical Cladium/shrub peats in FL Everglades, to tropical Myrica-Cyrilla bogs in PN. This never-before-studied latitudinal gradient will allow experimental quantification of biotic (plants type) and abiotic (low-intensity fire and drought) contributions to resultant high phenol/low carbon quality litter and specific BC aromatics; II: Assess the composition and origin of aromatic compounds in peat and porewater at the molecular level and the importance of fire derived aromatic compounds limiting peat decomposition using multiple advanced analytical techniques including Pyrolysis GC-MS, GC-MS, LC-MS, NMR, FTIR, FT-ICR-MS and 3-Dimensional Excitation-Emission Matrix (EEM) fluorescence spectroscopy; III: Experimentally (field to microcosm scale) determine peat decomposition, GHG fluxes and DOC loss integrated with soil C chemistry, soil bacterial/fungal composition, enzyme activities, and hydrologic properties to enhance our understanding of controls on C storage and fluxes. The field study will leverage data and research site infrastructure at an ongoing drainage GHG study in NC, USFWS Pocosin Lakes and with ORNL and USFS investigators working at the MN SPRUCE site and with scientists at the Smithsonian Tropical Institute in PN. Our research spans themes 3.1.1,.2 and .3. Our project provides the first N to S comparative analysis of peatland C chemistry, tests a new dual control model for sustaining C, innovative analytical C chemistry data, and integrative data for modeling in support of NASA's Earth Science Program goals to quantify changes in atmospheric CO2 and CH4 concentrations, and terrestrial and aquatic carbon storage.

Lisa Robbins/U.S. Geological Survey
Air-Sea CO2 Flux and Carbon Budget Synthesis and Modeling in the Entire Gulf of Mexico (NASA funded)

Uncertainties in coastal carbon fluxes are such that the net uptake of carbon in the coastal margins remains a poorly constrained term in global budgets. The SOCCR Report (Takahashi et al., 2009) indicated that the Gulf of Mexico (GOM) was the single largest area that was unknown with respect to the direction of CO2 flux (i.e., sink or source) in the entire US coastal margin. In 2009 and 2013 regional workshops promoted carbon cycle research in the Gulf of Mexico but a comprehensive region-wide air-sea CO2 flux product has not yet been developed, nor has a sub-regional carbon budget has been established. While good progress has recently been made in collating existing GOM in situ pCO2 data, large data sets still need to be incorporated into the database and yearly, monthly, and seasonal data need to be effectively parsed out. Further, large data gaps in specific regions need to be addressed through effective interpolation techniques utilizing remotely sensed SST, SSS (Aquarius), Color and numerical model output.

During the March 2013 Gulf of Mexico Carbon synthesis workshop, synergies between working groups were identified and the air-sea flux group and modeling group now form the basis for our research team. The team recognizes that significant forward progress and wrap-up of major aspects of the carbon budget could be achieved by a focused effort. We propose a data synthesis and modeling plan with the following goals:

- Produce a whole GOM monthly air-sea CO2 flux climatology with detail in regional and seasonal variations and associated uncertainties.

- Produce a whole GOM inorganic carbon budget based on observational and modeling approach with understanding on carbon cycling processes.
- Produce detailed regional studies in Northern GOM and West Florida shelf, focusing on seasonal and spatial changes, weather events, and ocean acidification which influence surface water CO2 distribution and air-sea CO2 fluxes.

- Compare model -derived and observation- derived estimates to understand processes that control sea-air fluxes in the different provinces.

To achieve our goals, data mining within the carbon community will be performed and datasets will be QA/QCd, formatted, and incorporated into the database. pCO2 air-sea fluxes will be calculated using computed second moment of monthly wind speeds within 5 GOM regions. Open ocean data will be gridded into 1° x 1° bins and coastal ocean data into 0.5° x 0.5° bins. A monthly climatological study centered on the most extensive yearly dataset will be produced and used for model verification.

An existing South Atlantic Bight and Gulf of Mexico (SABGOM) three-dimensional physical-biogeochemical model [Hyun and He, 2010; Xue et al., 2013] will be applied to simulate and examine temporal and spatial variability of biogeochemical cycling, and qualify air-sea CO2 flux and carbon budget in the entire GOM. The model will allow direct comparison of model solutions against in-situ observations, and fill temporal and spatial gaps. Monte Carlo methods will be used to estimate uncertainties from modeling algorithms, parameters, input data, and model coupling, and will include the effects of different approaches and scaling of wind speed products and gas transfer velocities.

We are responding to Theme 6 Carbon Cycle Science Synthesis Research to create a GOM air-sea synthesis from existing data, establishing a baseline for further exploration. This focused synthesis effort is scientifically important because it will address the current gaps within GOM air-sea CO2 flux data and address the long-standing question of sinks and sources of carbon in the entire GOM, where they are, and how they change seasonally and monthly. These high resolution data will lay the foundation for exploration how the Gulf will respond to increasing atmospheric CO2 levels and the areas most vulnerable.

Keith Rodgers/Princeton University
Synthesis of New Sea Surface pCO2 Data Products: Evaluation, Comparison, and Implications for the Global Carbon Cycle (NASA funded)

Until recently, researchers interested in a state-estimate of air-sea CO2 fluxes generally could choose between using the Takahashi et al. (1993; 2002; 2009) climatology or output from free-running ocean carbon cycle models. Now, however, a number of data-based products have emerged. These range from alternative seasonal climatologies of surface pCO2 to fully time-dependent data assimilation schemes using biogeochemical models. These products differ in the overall magnitude of the ocean carbon sink that they simulate, the spatial distribution of surface flux, in regional and global trends of the ocean sink. Furthermore, they provide little insight into the ocean interior ventilation processes that control anthropogenic carbon uptake and the implications of these products for the larger global carbon cycle. We propose to conduct a global synthesis of the new pCO2 products in order to quantify changes in ocean carbon uptake, determine ocean interior carbon subduction and obduction rates, and explore the implications of these findings on atmospheric CO2.

First, we will conduct a global synthesis of the new pCO2 products in order to quantify the extent to which the uptake of carbon is changing. We define a quantity called the Simplistic Uptake Model for Carbon (Sum-C), which is uptake expected treating anthropogenic carbon as a dye tracer that is impacted by neither changes in the physical state of the ocean, nor changes in ocean biology, nor changes in the buffering capacity of seawater. The global CO2 uptake rate implied by the various observationally-based pCO2 products will be evaluated against Sum-C as a critical diagnostic of how the ocean carbon cycle is changing relative to the behavior that would be expected in the absence of chemistry-climate feedbacks. This will lay the groundwork for analyses focused on attribution. This will include a careful evaluation of the gridded pCO2 and implied dissolved inorganic carbon (DIC) products against a number of independent observational constraints.

It is well known that the physical impedance to ocean carbon uptake posed by ocean interior ventilation processes (subduction and obduction) is significantly more important than the impedance posed by air-sea gas exchange (Bolin and Eriksson, 1958; Sarmiento et al., 1992). For this reason, in parallel to our evaluation of global air-sea fluxes, we will quantify and evaluate global subduction and obduction rates for DIC. This will be accomplished through the application of the thermodynamic framework of water mass transformation (Walin, 1982), following the application to the ocean carbon cycle presented in the modeling studies of Iudicone et al. (2011; 2013). In applying this approach to data-anchored carbon products, the following will be needed: (i) surface buoyancy forcing, consisting of net freshwater and heat fluxes; (ii) sea surface density; and (iii) sea surface DIC concentrations. Our estimate of DIC subduction and obduction will make combined use of remote sensing products, model output from the ECCO (Estimating the Circulation and Climate of the Ocean) project, the NASA MERRA reanalysis product, and the new suite of carbon data products. The goal is to quantify over the time interval 1990-2010 the net supply of DIC to the ocean interior via ventilation, and to relate this to air-sea CO2 fluxes.

Additionally, we propose to evaluate the signature of the new surface ocean carbon data products on atmospheric CO2 concentrations. We will quantify the observability of CO2 flux differences using in situ and remotely sensed atmospheric CO2 measurements using the CarbonTracker framework, through a consideration of the period 1990-2010. This will contribute directly to our final synthesis of the global implications of the new surface ocean carbon products.

Jorge Sarmiento/Princeton University
The Role of Mesoscale Eddies in Cross-Frontal Transport and Subduction of Nutrients and Carbon in the Southern Ocean (NASA funded)

Motivation - The ocean is the largest dynamic carbon reservoir at the Earth's surface, containing around 98% of the carbon in the atmosphere-ocean system as dissolved inorganic carbon (DIC), a result of oceanic carbon 'pumps' driven by a combination of physical and biological processes. Understanding the ocean's role in taking up and storing atmospheric CO2 requires an analysis of the manner in which ocean circulation interacts with photosynthesizing organisms at its sunlit surface to transport DIC, together with the inorganic nutrients that fuel photosynthesis, into and out of the ocean's surface mixed layer, where CO2 is exchanged with the atmosphere. The circumpolar Southern Ocean plays a particularly important role in the ocean's carbon pumps. This importance is a result of its unique physical circulation, which upwells DIC and nutrients from the deep ocean, transports them across the energetic fronts of the Antarctic Circumpolar Current (ACC), and subducts them into the ocean interior, both in the Subantarctic and the high Antarctic. Each of these physical processes is known to be strongly influenced by the effect of mesoscale eddies, vortices of order 10-100 km that represent the most energetic portion of the ocean's circulation. However, whilst it is to be expected that mesoscale eddies impose a strong influence on the transport of DIC and nutrients in the Southern Ocean, and thus on the dynamics of carbon cycling and ocean-atmosphere CO2 exchange, assessing this influence quantitatively has posed a formidable challenge, since mesoscale eddies have been both undersampled in observations and unresolved in the global models used to study climate and biogeochemistry.

Objective - The advent of the satellite observations of sea surface height and temperature, along with recent ultra-high resolution modeling developments, provide the opportunity for fundamental breakthroughs in our understanding of the role of mesoscale phenomena in both physical climate and biogeochemical cycles. The work proposed herein is uniquely poised to investigate the role of mesoscale eddies in cross-frontal transport and subduction of nutrients and carbon, by capitalizing on the recent development of new methodologies of eddy-tracking from satellite observations, and on a new set of model simulations including prognostic biogeochemistry and novel model diagnostic tools.

Contribution - We propose to use a combination of satellite-observation-derived analyses and a unique hierarchy of model simulations coupled to prognostic biogeochemistry, with spatial resolutions chosen to produce circulation that range from non-eddying to highly eddying. An eddy-tracking method will be applied to both satellite products and simulations to census and categorize eddies, allowing a detailed comparison of observed and simulated eddies as well as observational and model-based estimates of eddy-induced tracer transport, allowing inference of the importance of the portion of the eddy field not resolved by current satellite missions. A detailed identification and quantification of processes involved in cross-frontal transport and subduction of DIC and nutrients will be carried out using novel online model diagnostics. The hierarchy of models will allow an evaluation of the importance of explicitly resolving eddies in models, thus enabling assessment of current climate model skills. Sensitivity experiments to atmospheric CO2 increase will permit the investigation of the response of the biogeochemical tracer transport mediated by mesoscale eddies to climate change.

By addressing the role of mesoscale eddies in the cross-frontal transport and subduction of DIC and nutrients in the Southern Ocean, this work responds directly to the NASA ROSES-13 solicitation on Carbon Research in Critical Regions, helping to understand the processes that drive carbon storage in high-latitude oceans, and their response to increasing atmospheric CO_2 and attendant climate warming.

Maria Tzortziou/The City College of New York
Tidal Wetlands as Sources and Sinks of Carbon in a Changing world: Remote Sensing, Measurements and Modeling of Wetland-Ocean-Atmosphere Interactions (NASA funded)

Serving as a link between the land and the ocean, tidal wetlands are exposed to a wide variety of anthropogenic and natural stressors. Among our most valuable natural resources, these rich in biodiversity and highly productive ecosystems are hot spots of biogeochemical exchanges and transformations. Despite recent advances in remote sensing observations and modeling of biogeochemical processes in terrestrial and ocean environments, large gaps remain in our understanding of key carbon processes in tidal wetland-estuarine systems at the land-ocean interface. As a result, there are many unknowns regarding the role these ecosystems play in regional and global carbon cycling, and their potential responses and services in a changing climate.

This study will address this high priority research area by integrating advanced remote sensing observations of wetlands and coastal ocean color with new mechanistic carbon cycling modeling. Partnering with relevant stakeholders, the project aims at enhancing the capability of using remote sensing and modeling tools for adaptive resource management. Our proposed research is driven by three science objectives: (i) quantify carbon fluxes and exchanges (dissolved, particulate and gaseous CO_2 and CH_4 components) at the tidal wetland-estuarine-atmosphere interface, and assess the spatial extent of marsh influence on carbon quality along the continuum of wetlands, estuaries and the coastal ocean; (ii) quantify the relative importance of photochemistry as a key transformation process of marsh exported carbon in shallow-water terrestrial-aquatic interfaces, and its interaction with microbial transformations; (iii) assess the role of tidal wetland carbon fluxes and processes across a range of spatial and time scales. Potential influences of natural and anthropogenic pressures on these processes will be assessed under various environmental change scenarios (i.e., extreme flooding, sea-level rise, increased CO_2, and nutrient enrichment).

We will address these objectives through advanced remote sensing characterization of tidal wetland area extent, vegetation communities and inundation regimes (using Synthetic Aperture Radar, SMAP, Landsat, ASTER, UAVSAR), and refined retrievals of nearshore biogeochemical variables applied to almost two decades (1997-2016) of ocean color satellite imagery (SeaWiFS, MODIS, MERIS, VIIRS). Remote sensing will be integrated with rich field datasets and a novel coupled hydrodynamic-photochemical-biogeochemical model that we specifically designed to simulate key carbon processes along wetland-estuarine interfaces. Approaches and products from the proposed study will be applicable to tidal wetland ecosystems around the world that have been altered by growing anthropogenic pressures over the past century and are highly vulnerable to climate change and associated changes to the carbon cycle. The resulting field datasets and improved satellite retrievals will be made accessible to a variety of users. The models we develop will be disseminated as open-source code to the research and management communities through SourceForge, and so can be tailored and applied broadly to other systems around the world.

Our study specifically addresses this solicitation's Theme 2 on: "Carbon Dynamics along Terrestrial-Aquatic Interfaces", and is directly aligned with NASA, DOE and USDA objectives and strategic goals. It is also relevant to NASA's efforts to develop new applications for existing and future satellite missions, including improved environmental impact assessment and ecological forecasting. Through the proposed collaboration with relevant stakeholders, we will incorporate the remote sensing products and modeling tools developed here into enhanced decision support systems for predicting potential responses of wetlands to future pressures and assessing the services (regulating, provisioning, and cultural) these ecosystems may provide in a changing climate.

Rodrigo Vargas/University of Delaware
Reducing Uncertainty in Carbon Cycle Science of North America: A Synthesis Program Across United States and Mexico (USDA funded)

Research under the North American Carbon Program (NACP) has enhanced our scientific understanding of North America's carbon cycle dynamics. Scientists and policymakers both recognize the importance of an integrated view in order to advance carbon cycle science across North America, but studies outside the United States and Canada are often left behind. The time is ripe for synthesis activities that include information about carbon cycle science in Mexico and move towards an integrated view of North America's carbon cycle. We propose to conduct a broad-scale analysis of carbon cycle science and data across the United States (U.S.) and Mexico by synthesizing new existing datasets and models in a consistent and comprehensive analysis framework. Specifically, the research will be directed towards improving our understanding of forest and soil carbon dynamics, and the validation of terrestrial ecosystem models.

The specific objectives are: a) Harmonize available datasets describing the key components of the carbon cycle in Mexico, and produce national-scale information in a standardize way to be comparable to datasets available in the U.S.; b) Develop the synthesis approaches for scaling these new Mexican datasets using methodology consistent with and comparable to available U.S. datasets; c) Develop a consistent benchmarking framework between available datasets and state-of-the-art terrestrial biosphere and atmospheric inverse modeling and remote sensing approaches to identify uncertainties and knowledge gaps.

This research will be unique because datasets on soil carbon, forest inventory, evapotranspiration, and net ecosystem exchange across Mexico have not been widely available for North American syntheses and validation studies. This proposal will build on use existing information provided by remote sensing platforms (e.g., MODIS) and networks such as AmeriFlux, International Soil Carbon Network, NACP, and networks in Mexico (e.g., MexFlux, Mexican Carbon Program). This proposal will result in new standardized datasets of Mexican carbon cycle science (e.g., soil carbon, forest biomass, NEE) available to the scientific community, and synthesis research activities that will contribute to a broader overall understanding of carbon cycle across North America.

Data will be analyzed for synthesis activities using different analytical tools such as parametric statistics for model intercomparison, extreme values distribution theory, information theory to quantify uncertainty, artificial neural networks-self organizing maps to examine covariance between variables, and time series analysis to define temporal patterns in the observations and data-model agreement.

This proposal is scientifically and societally important because environmental problems and ecological understandings are not delineated within specific sociopolitical or economic boundaries. This proposal directly addresses the Carbon Cycle Science themes of carbon cycle science synthesis research (theme 6 solicited by NASA, USDA, DOE), and the topic of belowground carbon processes and soil carbon (theme 3 solicited by USDA, DOE). Indirectly it addresses the issue of carbon research in critical regions, specifically the tropics as a large region of Mexico falls within these latitudes (theme 1 solicited by NASA, DOE, USDA). This research addresses cross-cutting research activities (Section 3.7 in NNH13ZDA001N-CARBON call) by integrating human activities, improved observations, modeling, and coordinating with other projects. This last issue is possible because research from this proposal directly contributes towards the goals of major USGCRP activities including the NACP, and the goals of networks such as AmeriFlux, NEON, CarboNA, MexFlux, and the International Soil Carbon Network.

Mark Waldrop/US Geological Survey Vancouver
Microbe-Mineral Interactions and the Fate of Carbon Along Soil Climo-Chronosequences (USDA funded)

Whether soils become a source or sink of C under future climate and land use change is of great societal importance because soils represent the largest pool of terrestrial organic carbon (C). The response of terrestrial vegetation composition and productivity to these changes has been studied and well documented over time, but the interactions between carbon inputs, soil microbiota, and soil mineralogy that ultimately sequester carbon into stabile pools has received much less attention. The uncertainty in future projections of soil C is mirrored by the uncertainty in our understanding of the mechanisms controlling C stabilization and destabilization in soils. Molecular weight and biocomplexity of C are no longer considered indicators of its recalcitrance. Instead, the current conceptual framework highlights C flow through a ‘filter’ of soil microbes, and describes C as ‘agglomerated’ into submicron pores and/or associated with reactive mineral surfaces. This conceptual framework of C stabilization in soils lacks key information about how flow and fate of C are affected by variation in 1) carbon inputs 2) microbial populations and 3) mineral assemblages. It is essential to correctly understand the molecular level mechanisms of C stabilization before estimating large temporal and spatial estimations of changes in terrestrial C storage. Our objective is to examine how different forms of carbon entering the soil environment interact with soil microbial populations and mineral assemblages to stabilize carbon, and to use these data to inform models that can estimate changes in soil C cycling over a large range of temporal scales and climate regimes. This approach supports DOE Carbon Cycle Science objectives to develop, test, and simulate process-level understanding of terrestrial ecosystems and USDA’s objective to improve our understanding of the C cycle such that we may more fully understand the C consequences of land use change.

Our methodology is first to take advantage of a natural ‘climosequence of chronosequences’ along the Pacific from the Channel Islands in southern California to

Santa Cruz in central California and soils near the Mattole River in Northern California. Each location contains soils ranging in age from 6000 to 250,000 years. Climate and soil age are well understood drivers of C storage in soils, but few studies have addressed the interaction of these two drivers simultaneously. Secondly, we will utilize state of the art spectroscopic techniques that will inform a novel terrestrial C model. Methodologies include stable isotope probing (through model compound additions and plant labeling) coupled to confocal micro-Raman spectroscopy (SIP-RAMAN) to quantify the flow of specific forms of labeled C through the microbial community and to evaluate the types of C stabilized into different soil fractions and/or mineral surfaces. Detailed 2-D micro-Raman maps of soil C speciation, 13C incorporation, and mineralogy at the micron scale can also be coupled to fluorescence in-situ hybridization (FISH) probing of bacterial, archeal, and fungal groups. These techniques will be evaluated in comparison with synchrotron-based micro X-ray microscopy and micro-X-ray fluorescence mapping and 13C-PLFA techniques. These data, and other data including radiocarbon content of different soil fractions, will then be used to inform a reactive transport based soil C model (i.e., Crunchflow). Crunchflow is a multiphase reactive transport model that allows for prediction of the transport, reactivity and isotopic fractionation of organic C including organic-mineral interactions. The incorporation of organic C processes into Crunchflow represents a new approach to simulating soil C over long timescales and provides an ideal tool to integrate the molecular, mineralogical, and isotopic aspects of this study.

Paul Wennberg/California Institute of Technology
Quantifying Changes in the Distribution and Cycling of Carbon With Total Column Measurements of CO2 and CH4 (NASA funded)

NASA's Carbon Cycle Program has historically supported the development of the Total Carbon Column Observing Network (TCCON). Here, we propose to continue to support the coordination, maintenance, and analysis of long-term measurements from the network. There are currently 20 operational TCCON sites; 4 additional sites will produce data in the near future. All PIs of existing sites are participants in this proposal.

TCCON is both scientifically and societally important. Data from the network are being used extensively (>50 peer-reviewed publications in the last 3 years) to improve the description of carbon dynamics and to help evaluate products developed from space-based sensors.

The network is highly responsive to the proposal call for Carbon Cycle Science: TCCON observes atmospheric column abundances of CO2, CH4, CO and other species in tropical terrestrial ecosystems (3.1.1, Reunion Island, Ascension Island, Darwin, and the future Manaus station), the arctic and Boreal regions (3.1.2, Eureka, Ny Alesund, Sodankyla, Park Falls, Bialystok, Orleans, Karlsruhe), as well as in urban (3.4, Caltech, Bremen, Wollongong), and background regions (Lauder, Izana).
The proposed work directly addresses the critical need identified in 3.7.2, cross-cutting research activities, to provide a critical and continual evaluation of space-based data for atmospheric CO2 and CH4. TCCON provides the primary validation data for multiple existing and future US and foreign missions. TCCON is a critical source of validation data for GOSAT; for OCO-2 (launch July 2014); OCO-3; for ASCENDS. TCCON has been used in the evaluation of SCIAMACHY and MOPITT data, and is planned for use in GOSAT-2 and S-5P. More than 25 peer-reviewed publications describe validation of such products with TCCON data.

We propose to use TCCON and other data sets to investigate the underlying fluxes of carbon to and from the atmosphere. Through key collaborations with members of the carbon cycle community, we will investigate variability in the flux of CO_2 and CH_4 using observations made from TCCON and associated data sets made by remote sensing from space. We will use both large-scale modeling tools (e.g. global chemical transport models with underlying biochemistry) and tracer-tracer approaches to improve estimation of the underlying fluxes. The focus of these analyses will be on improving the description of large-scale terrestrial carbon dynamics at northern high latitudes.

Proposed Work Plan

1. Continue operations of the Park Falls, Wisconsin TCCON site.
2. Continue coordination of the broader network activities. Continue data evaluation using profiles obtained from AirCore and Aircraft.
3. Assist in the use of TCCON data for evaluation of space-based data for CO_2 and CH_4.
4. Extend the spectral coverage of several TCCON sites to enable retrieval of HCN (biomass burning tracer), ethane (tracer of emissions from fossil fuel extraction), and OCS (tracer of photosynthesis).
5. Investigate use of TCCON and other data sets to improve process-level understanding of carbon flux between the land, ocean, and atmosphere.

a. Long-term records now provide key constraints on interannual variability in CO_2. We will continue to develop new tools and approaches for constraining the large- scale flux patterns and their variability, with a focus on boreal latitudes.

b. The development of highly precise and accurate total and tropospheric CH_4 column measurements enable analysis of the role of chemistry, dynamics, and source variability in determining the temporal and spatial patterns of CH_4. We will undertake a broad investigation of atmospheric methane dynamics to evaluate how the sources and sinks are manifest in the variability of the total column.

Brian Wilsey/Iowa State University
C-Cycling in Native Vs. Non-Native Dominated Systems (USDA funded)

Grassland ecosystems cover roughly 40% of the United States and consist of a mixture of native-dominated rangelands and human derived pasture systems. Grasslands are important to humans as a source of forage for grazing animals, alternative sources of fuel, green space in urban and suburban areas, and as wildlife and pollinator habitat. In many areas, native dominated rangeland has been converted to either cropland or grassland that is dominated by non-native (‘exotic’ or 'introduced' or 'alien' or 'invasive') plant species. Furthermore, these conversions have occurred during a time of changing climate, including altered precipitation. This conversion is hypothesized to have altered C-cycling between exotic-dominated systems and the native systems they replaced. Belowground production often exceeds aboveground production in grassland systems, and a better understanding of how human actions are impacting soil C is necessary. We propose to address a fundamental knowledge gap on how belowground C-cycling is impacted by the replacement of native rangelands with non-native communities under ambient or altered rainfall patterns in a unique long-term experiment. The experiment is in its sixth growing season at the USDA-ARS Grassland, Soil, and Water Research Laboratory (Temple, TX). Highly replicated experimental plots (64 mixtures and 144 monocultures) with identical initial plant densities, functional group proportions, and species diversity were established in 2008 to determine whether ecological differences develop over time between native and exotic plant communities with and without altered precipitation. Either all native species or all exotic species were assigned to 9-species mixtures using a paired species design, and this treatment was crossed with a summer irrigation treatment that alters rainfall patterns (n=16 mixtures in each of the four treatments) using a pool of 36 native and widely distributed non-native species. Treatment differences have stabilized into a high-diversity native system and a low diversity exotic dominated system, which matches the typical situation of fields in the region. There are also differences between native and exotic species in rooting depth, C3-C4 biomass proportions, and aboveground biomass production (peak biomass). We are measuring aboveground net primary productivity by estimating biomass by species in June and October of each year in each mixture and monoculture plot, and this sampling regime will continue for the proposed project. Here, we propose to measure the following C cycling variables: 1) belowground net primary productivity using ingrowth cores, 2) soil bacterial and fungal community structure and enzyme activities, 3) rate of infection by mycorrhizae and total fungal biomass, 4) N mineralization (NH_4^+ and NO_3^-), 5) decomposition of root and shoot litter from plots in mesh bags, and 6) soil C and root biomass in 10-cm depth increments to a 100 cm depth. We will also test whether these conversions have affected the variance in ecosystem process rates, which can be associated with unreliable production of ecosystem services. Variability in C cycling will be quantified with measures of coefficient of variation in productivity over time and with recovery from a major drought. The proposed work directly addresses Theme 3 'Belowground Carbon Processes and Soil Carbon' of the Carbon Cycle Science request for proposals. Results from the study will be useful to modelers and land managers by quantifying the costs and benefits of planting native vs. non-native species under an altered climate. We have an excellent team of investigators assembled to address these issues, including two grassland ecosystem ecologists (Wilsey and Polley), and a microbial ecologist (Hofmockel).

John Worden/Jet Propulsion Laboratory
CH_4 Emissions Estimates From Tropical and Subtropical Fires Using Aura TES CH_4 and Terra MOPITT CO Profiles (NASA funded)

The proposed research will address the following unresolved science questions:
1) How much of the total methane budget is due to tropical and sub-tropical fires?
2) To what extent have tropical and sub-tropical fires affected the recent increase (since 2006) in atmospheric methane?
3) How do methane emissions from tropical and sub-tropical fires vary with precipitation, humidity, and climactic anomalies such as ENSO?

We propose to use NASA Aura TES CH_4 and CO free-tropospheric estimates and Terra MOPITT CO profiles (with sensitivity from the surface to upper-troposphere) to quantify CH_4 emissions from fires and characterize the errors in these estimates due to transport, fuel-type, effect of wetland emissions on the observed air parcels, and the satellite observation uncertainties. We will then evaluate the relationship between these emissions with variations in rainfall and humidity, driven in part by the El Nino Southern Oscillation (ENSO), and how variations in fire emissions affected the recent increase in atmospheric methane since 2006. These results will provide comprehensive top-down tests of modeled methane emissions from fires and will also allow subsequent research efforts to investigate feedbacks between human activities and a warming climate and their effects on tropical and subtropical methane emissions.

Jingfeng Xiao/University of New Hampshire
Exploring the Interactions Between Carbon Cycling, Land Use and Climate Change Within Mixed Agricultural, Forested, Suburban, and Urban Landscapes (NASA funded)

Human activities (e.g., urbanization, land use planning) have led to complex patterns of urban, suburban, agricultural, and forested landscapes. Ecosystems within these landscapes play an important role in climate regulation by acting as regulators of CO_2 and other greenhouse gases and altering surface albedo and other biophysical properties. Although climate change policy initiatives often include incentives for land management activities that can offset warming, most have focused on enhanced carbon storage. Often not considered is the fact that these practices also bear climate consequences through other mechanisms (N_2O and CH_4 emissions, altered albedo, etc). Better understanding of the processes controlling the uptake, storage, and release of greenhouse gas emissions along urban to rural gradients is essential for evaluating how alternative patterns of land use interact with carbon cycling and climate change and how future land use change will influence carbon sequestration potential within these complex landscapes.

The overarching goal of our work is to examine the interactions among carbon cycling, land use, and climate change in a human-dominated, mixed land use region that includes urban, suburban, agriculture, and forest land uses in southern New Hampshire. We plan to combine field measurements of carbon storage and greenhouse gas emissions (CO_2, CH_4, and N_2O), an improved process-based biogeochemical model - DNDC (DeNitrification and DeComposition) designed to predict C fluxes and trace gas emissions, historical and projected land use change data derived from Landsat imagery and cellular automata/agent-based modeling, and high spectral resolution remote sensing data from NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Our specific objectives designed to achieve the overarching goal are to: (1) Measure C pools and greenhouse gas emissions (CO_2, CH_4, and N_2O) in urban, suburban, agricultural, and forested landscapes; (2) Improve and parameterize the DNDC (DeNitrification and DeComposition) model and validate model predictions; (3) Develop historical land use change data for the last three decades from Landsat imagery and projections of future land use change; (4) Generate spatially continuous predictions of C pools and greenhouse gas emissions using Urban-DNDC and assess how land use interacts with C cycling and climate change and how future land use change will influence carbon sequestration potential within these complex landscapes; and (5) Determine the net radiative forcing values (in $w\ m^{-2}$) for the major greenhouse units using CO_2 and climate change scenarios.

Our research is directly responsive to this Carbon Cycle Science program element - Theme 4: Carbon Dynamics within Urban-Suburban-Forested-Agricultural Landscapes, and is highly relevant to the goals and objectives of NASA, USDA, DOE, and NOAA. Our work will reveal how carbon dynamics, non-CO_2 greenhouse gases, surface albedo, land use, and climate change interact with each other. It will also elucidate how future land use change will influence C cycling within complex landscapes. Our results will have implications for crafting effective land management policies that balance C sequestration and climate mitigation with food production, forest resources and many other services that these landscapes provide. Results of this activity will highlight tradeoffs among multiple land management strategies in terms of their net climate effect. Information of this nature is of critical importance for preparing sound land management policies and designing strategies to cope with changes in climate.