Carbon Cycle Science
Abstracts of selected proposals.
(NNH07ZDA001N-CARBON)

The National Aeronautics and Space Administration (NASA) solicited proposals for new and successor Carbon Cycle Science investigations within the NASA Earth Science Program and the U.S. Department of Agriculture (USDA) Cooperative State Research, Education, and Extension Services (CSREES) National Research Initiative Competitive Grants Program (NRI). NASA and USDA-CSREES sought proposals to improve understanding of changes in the distribution and cycling of carbon among the active land, ocean, and atmospheric reservoirs. Of special interest were the factors that affect changes in the sources and sinks for atmospheric carbon dioxide (CO2) and methane (CH4) and carbon management to slow increases of these greenhouse gases.

NASA and USDA-CSREES carbon cycle research contributes toward the goals of the U.S. Climate Change Science Program (http://www.usgcrp.gov/) and the U.S. Ocean Action Plan (http://ocean.ceq.gov/actionplan.pdf) by providing critical scientific information about the movement of carbon in the environment and potential near- and long-term changes in the carbon cycle, including the role of and implications for societal actions. U.S. carbon cycle research addresses two broad questions:

• How large and variable are the dynamic reservoirs and fluxes of carbon within the Earth system and how might carbon cycling change and be managed in future years, decades, and centuries?
• What are our options for managing carbon sources and sinks to achieve an appropriate balance of risk, cost, and benefit to society?

In this solicitation, NASA requested proposals to use satellite observations effectively to address these questions within four research themes:
1. Global carbon cycle modeling and analysis;
2. Regional studies that provide critical understanding of and offer to reduce major uncertainties about the global carbon cycle;
3. Studies of the carbon cycle implications of ocean acidification; and
4. Decision-support systems for carbon management.
The USDA-CSREES requested proposals to conduct regional carbon studies in North America under research themes 2 and 4.

A total of 113 proposals were received, and 35 have been selected for funding. The total funding to be provided for these investigations is approximately $25.9 million over three years. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided. Co-investigators are not listed here.

Richard Birdsey - USDA Forest Service (NASA funded)
Integrating Landscape-scale Forest Measurements with Remote Sensing and Ecosystem Models to Improve Carbon Management Decisions

Managing forests to increase carbon stocks and reduce emissions requires knowledge of how management practices and natural disturbances affect carbon pools over time, and cost-effective techniques for monitoring and reporting. This study improves upon the methodology to collect and integrate the multi-tier monitoring data from the North American Carbon Program (NACP) with management decisions by systematically scaling up intensive forest carbon measurements to land management areas (or landscapes), and reconciling these estimates with ecosystem models and decision-support systems that are driven by remote sensing and national inventories. Monitoring systems for carbon stocks and fluxes in the NACP include a multi-tier hierarchy of observation methods: flux towers, landscape biometrics, inventories, and remote sensing. We propose to use spatial analysis techniques and an ecosystem process model (PnET-CN) to scale up and map observations from flux towers, landscape biometrics, and inventories to areas of approximately 2500 km2 around flux tower sites. The NASA-CASA model is used to derive estimates for the same areas from remote sensing observations by the MODIS sensor, and biophysical maps. We compare and reconcile the top-down and bottom-up approaches, then use the mapped estimates of productivity and biomass that embed consequences of land disturbances and forest age structure as input to decision-support tools. Key information for the decision-support tools includes (1) estimates of carbon stocks and quantified impacts of management activity; (2) estimates of net ecosystem production (NEP) and changes in carbon pools; and (3) estimates of forest/atmosphere carbon fluxes and relevant effects from various environmental controls. With a network of sites that represent different managed forests of the U.S., we envision a set of "benchmark" estimates that can efficiently and reliably document the expected effects of management decisions on the most important carbon pools, and separate these effects from natural factors such as climate variability. This work is relevant to land managers and climate change policy because it supports a need to estimate and report carbon stocks and changes in carbon stocks to state, regional, national, and private greenhouse gas registries. This work also develops large-scale ground truth sites for future NASA missions described in the "Decadal Survey". This is a successor proposal to advance the results of a project selected under the 2004 NASA Research Announcement for carbon cycle science titled "Linking Landscape-scale Carbon Monitoring with Forest Management" and builds upon a foundation of work begun in 2001 by the U.S. Forest Service to implement a forest carbon monitoring and observation system at intermediate or "Tier 3" sites as described in the North American Carbon Program (NACP) science plan.

Kenneth Davis - The Pennsylvania State University (NASA funded)
Probabilistic Carbon Flux Upscaling Across a Northern Forest Ecoregion

We propose to create a Diagnostic Regional NEE Estimator (DiRNEEE) based on model-data synthesis of flux tower, satellite reflectance, meteorology, and biometric data. Our primary goals are to reduce uncertainty in regional flux estimates by improving current

modeling methods, to quantify the source, magnitude, and statistical distribution of uncertainty in local to regional carbon flux estimates, and provide a general framework for accomplishing this globally. DirNEEE will be developed using data from an ending NASA project in the intensively studied ChEAS region, a component of the current NACP-MCI. The results will be compared to at least two predictive terrestrial carbon cycle models (BIOME-BGC, and ORCHIDEE) to evaluate modeled regional carbon fluxes. The product will represent a major advance in space-based diagnosis of forest carbon fluxes and uncertainties.

We will assimilate flux tower observations into the C-flux models for the humid continental, northern mixed forest ecoregion, that lies in the temperate/boreal transition zone, a data rich area important to global carbon cycles due to productivity, carbon storage, and expected change. Uniquely valuable data sets include a long time series from numerous flux towers (12-18), a dense network of meteorological stations, nested networks of dense (180 plots) to broad (1600 plots) forest inventory measurements, and unique remote sensing data sets (< .4 m LiDAR, and spectral data spanning 0.6 to 2.4m Quickbird to 1km MODIS), will guide development of the DiRNEEE.

The project is thus highly responsive to the Carbon Cycle NRA as a regional study that provides critical understanding of and offer to reduce major uncertainties about the global carbon cycle, includes, a focus on observations from space, both current observations (MODIS) and possible future technology (e.g. spaceborne LiDAR), and it, coordinates with observational and experimental facilities such as AmeriFlux, and utilizes a study, established by NACP field campaigns.

Nancy French - Michigan Tech University (NASA funded)
Development of decision products for spatial quantification of carbon emissions from wildfire for North America

A major goal of the North American Carbon Program is to resolve uncertainties in understanding and managing the carbon cycle of North America. As carbon modeling tools become more comprehensive and spatially oriented, accurate datasets to spatially quantify carbon emissions from fire are needed. Under the proposed project, Dr. Nancy French, of the Michigan Technological University, Michigan Tech Research Institute (MTRI), will extend her current NASA-NIP funded research to team with specialists at the USDA Forest Service Pacific Northwest Research Center's Fire and Environmental Research Applications (FERA) lab. The team proposes to provide information for mapping fire-derived carbon emissions by adapting existing Forest Service fire information products and tools using NASA data and products. The goal of the proposed project is: To develop a prototype information system with the help of user input for disseminating improved products for modeling and estimating fire emissions across North America. The project has two components:

- Develop new and accurate user-friendly products for estimating fire emissions at regional scales that are consistent across international borders based on NASA-derived datasets and models and the adaptation of FERA information products and models.

- Provide an effective process for accessing and using new products and emissions models through an on-line information system (Internet Mapping Service, IMS).

The USFS has developed the FCCS, to describe fire fuels across North America, and Consume 3.0, a model for estimating fuel consumption and emissions. Developed primarily for applications of fire effects, these tools hold potential for quantifying carbon emissions to better understand the implications of fire to carbon cycling and carbon management. The proposed project will build on PI French's current NASA NIP to use remote sensing for quantifying the variability in fuel consumption and develop FERA tools for use in quantifying regional to continental-scale fire emissions. Carbon assessment tools developed through the North American Carbon Program, such as Carbon Tracker, will provide a context for development of datasets and methods for production of user-accessible information products.

Marjorie Friedrichs - Virginia Institute of Marine Science (NASA funded)
U.S. Eastern Continential Shelf Carbon Cycling (USECoS): modeling, data assimilation and analysis

Although the oceans play a major role in the uptake of fossil fuel CO2 from the atmosphere, there is much debate about the contribution from continental shelves, since many key shelf fluxes are not yet well quantified: the exchange of carbon across the landocean and shelf-slope interfaces, air-sea exchange of CO2, burial, and biological processes including productivity. Our goal is to quantify these carbon fluxes along the eastern U.S. coast using models quantitatively verified by comparison to observations, and to establish a framework for predicting how these fluxes may be modified as a result of climate and land use change. Our research questions build on those addressed with previous NASA funding for the USECoS (U.S. Eastern Continental Shelf Carbon Cycling) project. We have developed a coupled biogeochemical ocean circulation model configured for this study region and have extensively evaluated this model with both in situ and remotely-sensed data. Results indicate that to further reduce uncertainties in the shelf component of the global carbon cycle, future efforts must be directed towards 1) increasing the resolution of the physical model via nesting and 2) making refinements to the biogeochemical model and quantitatively evaluating these via the assimilation of biogeochemical data (in situ and remotely-sensed). These model improvements are essential for better understanding and reducing estimates of uncertainties in current and future carbon transformations and cycling in continental shelf systems. Our approach and science questions are particularly germane to the carbon cycle science goals of the NASA Earth Science Research Program as well as the U.S. Climate Change Research Program and the North American Carbon Program. Our interdisciplinary research team consists of scientists who have expertise in the physics and biogeochemistry of the U.S. eastern continental shelf, remote-sensing data analysis and data assimilative numerical models.

Anatoly Gitelson - University of Nebraska-Lincoln (NASA funded)
A Satellite-Based Quantification of Carbon Exchange of the Dominant Ecosystems (Maize-Soybean) in the NACP Mid-Continent Intensive (MCI) Region

There is a growing interest in quantifying the carbon dioxide exchange of key ecosystems at a variety of spatial and temporal scales. Tower eddy covariance flux systems, traditionally employed for measuring carbon dioxide (CO2) fluxes, have spatially-limited footprints; therefore, up-scaling beyond these footprints is crucial for regional carbon budget assessments. Remote sensing techniques have been increasingly used for such up-scaling.

Our overall goal is to develop a prototype Landsat-based Crop Carbon CO2 Exchange Product that will accurately estimate gross primary production (GPP) of croplands, would be easy to implement, and considerably decrease uncertainties in such estimations. We will focus on maize and soybean cropping systems that dominate agricultural land use in the north-central USA and play an important role in the annual CO2 exchange in this region. Our recent studies, which used the tower eddy covariance CO2 flux data at three AmeriFlux sites in Nebraska together with (a) in situ radiometric data, (b) hyperspectral imaging AISA-Eagle onboard of aircraft, and (c) Landsat-7 ETM+ imagery, have shown great potential to accurately estimate CO2 exchange in rainfed and irrigated maize and soybean using solely satellite-based observations. Based on these results, we propose to develop and calibrate algorithms for GPP retrieval from Landsat data at the AmeriFlux sites at Mead (NE) and validate them at AmeriFlux sites in Iowa, Illinois, and Minnesota. We will also develop and validate relationships between ecosystem respiration and key controlling variables at these sites in the four states mentioned above. This information will be useful in estimating annual carbon exchange in maize-soybean ecosystems using Landsat observations.

Our proposed effort addresses one of the main topics of this Carbon Cycle solicitation: “Regional studies that provide critical understanding of and offer to reduce major uncertainties about the global carbon cycle”. This project will allow us, perhaps for the first time, to use Landsat remote sensing, with its fine resolution (30x30m/pixal), to study the seasonal and inter-annual CO2 exchange in croplands and potentially increase our predictive capability with respect to CO2 exchange in this key ecosystem. The proposed work will provide a methodology to help obtain the "bottom up" flux estimates, and thus contribute directly to the second objective of the NACP Mid-Continent Intensive (MCI) Campaign.

Scott Goetz - Woods Hole Research Center (NASA funded)
Quantifying Changes in Northern High Latitude Ecosystems and Associated Feedbacks to the Climate System

Temperature increases in the northern high latitudes over the past few decades have led to a wide variety of ecosystem changes, including modification of plant productivity, ecosystem respiration, and fire and insect disturbance. These, in turn, feedback to the

physical climate system through changes in albedo and associated surface energy fluxes, with global implications.

We propose to better quantify these coupled changes by focusing on the use of satellite remote sensing, integrated with biophysical models and field measurements, to: (i) compare and contrast boreal forest ecosystem properties and processes across climate and environmental gradients, (ii) quantify how fire disturbances influence carbon and energy dynamics across these gradients through time, (iii) capture synoptic scale vegetation responses to recent climate change across the circumpolar northern high latitudes, considering both undisturbed and recently disturbed areas, (iv) address uncertainties in carbon cycle components associated with modeling and monitoring changes in net ecosystem carbon exchange.

Each of the PIs has experience working in high latitude boreal and arctic ecosystems, and each brings unique skills to the project. We will make use of long-term field measurements in interior Alaska and the Russian Far East (Chirskii region), augmented with additional observations, building upon our past work at these sites. We will also make use of a wide range of NASA satellite data products, augmented with additional observations and derived products as needed. Select international collaborators will aid access to field sites, data sets, and local expertise. M.Mack will focus on field measurements characterizing how plant functional types modulate local climate processes, and how plant composition controls the response of ecosystem processes to disturbances such as fire. S.Goetz will focus on linking the field measurements with the remote sensing observations and extending these across multiple satellite sensors and spatial scales. J.Randerson will focus on the role of fire disturbance on changes in albedo, energy and carbon budgets using biophysical models.

Our primary objectives are to reduce carbon cycle uncertainties and improve understanding of ecosystem responses to environmental change, using both observations and models at multiple temporal and spatial scales. As such, the proposed work will contribute to research priorities identified as part of the North America Carbon Program, the Northern Eurasia Earth Science Partnership Initiative, and the International Polar Year activities.

Samuel Goward - University of Maryland (NASA funded)
Role of North America Forest Disturbance and Regrowth In NACP: Integrated Analyzes Of Landsat and U.S. Forest Service FIA Data - Phase 2

Information on forest disturbance and regrowth is essential for understanding North American carbon dynamics, and the future of the current "carbon sink". Moderate-resolution (Landsat-type) satellite data provide the only means of constructing spatially-explicit, temporally-detailed disturbance records. This proposal seeks to continue our team's ongoing research to generate a comprehensive record of North American disturbance and regrowth from the Landsat archive. The work relies on the use of dense (annual or biennial) time series of Landsat imagery ("data cubes"), which may be analyzed at the 30m pixel-level, using time series methodologies. Our previous work

focused on obtaining a valid statistical sample of disturbance rates using 23 Landsat data cubes spread across US Forests. We also demonstrated techniques to obtain changes in aboveground live biomass associated with disturbance and regrowth by integrating Landsat reflectance trajectories with US Forest Service Forest Inventory and Analysis Program (FIA) plot-level biomass data. This proposal has six major objectives: These include: (1) Reduce error in nationwide estimates of forest disturbance and regrowth, (2) Convert data cube reflectance to data cube biomass, (3) Develop nationwide maps of forest biomass dynamics, (4) Partner with Canada and Mexico, (5) Develop formal collaborative relationships with other NACP-funded scientists, and (6) Quantify the forest component of woody encroachment nationally. Collectively, these activities will expand and refine our knowledge of North American forest dynamics, and thus significantly reduce uncertainties in carbon flux estimates.

Stith Gower - University of Wisconsin (USDA-CSREES NRI funded)
Coupling Biological and Industrial Forest Ecosystem Carbon Cycle Models to Enhance Carbon Management: A Decision Support Tool

Forests cover a vast area of the Mid-continental intensive (MCI) study area. These forest ecosystems contain a large amount of carbon (C) and are a major source for wood and paper fiber in the United States. The industrial forest carbon cycle, associated with the manufacturing, transportation, and disposal of these products, releases large amounts of C and is a net C source (White et al. 2005, Gower et al. 2006, Ahl et al. 2007). We have recently coupled a forest ecosystem process model (BIOME-BGC) and wood and paper products life cycle models to simulate the net system C production (net biological C sequestration - net industrial C emissions) for the Chequamegon-Nicolet National Forest in Wisconsin. The overall objective of this study is to expand this novel approach to all forest ecosystems in the MCI region. Specifically, we propose to develop a FORest Carbon Analysis and Synthesis (FORCAS) center that will ingest NASA ESE products (e.g. MODIS vegetation cover, LAI, and fire products, etc.) and provide the following products (i) carbon content and fluxes for forests, including forested wetlands, (ii) estimates of net C balance and their major sources for wood and paper products using region-specific greenhouse gas life cycle inventory data, (iii) Develop a web-based decision support tool that estimates (a) net system C balance for forests subject to different forest management, forest product substitution, and other sector (i.e. energy, transportation, and waste management) management opportunities, and (b) matrix tables that quantify the effects of the above-mentioned management decisions on key environmental burdens. (iv) in collaboration with Tris West, use a coupled biogeochemical ecosystem and life cycle models for forest and agroecosystems to examine the bioenergy potential for the MCI region, and associated trade-offs of agriculture versus wood crop systems. It is long-overdue to adopt a “systems” approach to C management because there are opportunities to increase C sequestration of the biological system and reduce C emissions of the industrial system; the two systems are tightly coupled and should not be managed independently.

Watson Gregg - NASA Goddard Space Flight Center (NASA funded)
Reducing Error in Global Ocean Chlorophyll Estimates

Chlorophyll is the most systematically and widely observed carbon-related variable in the oceans. In situ archives date to 1955. Satellite estimates are available on a global basis continuously since 1996. This data treasure provides a unique and irreplaceable indicator of how climate change may affect ocean carbon and vice versa. However, both in situ and satellite and data sets are flawed: in situ because of poor spatial coverage, and satellite because of accuracy and occasional sampling issues.

We intend to investigate issues related to ocean chlorophyll errors, quantify them to the extent possible, and propose solutions when possible. We will bring to bear in situ comparisons, analysis methodologies, and data assimilation techniques. We intend to investigate errors on multiple spatial and temporal scales (regionally, globally, seasonally, and interannually). First we will assess the satellite and in situ chlorophyll error and its variability. Distributions of the error will be provided using the conditional relaxation analysis method, involving in situ and satellite data. This will reveal areas and times when corrections are needed for the satellite data. We will then proceed to estimate sampling errors from satellite. Finally, a full global ocean chlorophyll assimilation system will be applied using various fields, including in situ, analysis of satellite and in situ data, and satellite data to observe overall improvement and continued regions/times where problems exist. An in situ sampling program will be proposed that will minimize the residual errors, after utilizing all available tools, i.e., satellite data, available in situ data, analysis of satellite and in situ, and data assimilation. The result of these analyses can yield information on optimization of future satellite missions, balancing sampling, reducing persistent errors locations and times, with costs.

Guido Grosse - University of Alaska Fairbanks (NASA funded)
Assessing the spatial and temporal dynamics of thermokarst and related carbon cycling in Siberia and Alaska (grants.gov)

Thermokarst depressions and thermokarst lakes (TKLs) dominate large areas of the arctic land surface and may expand as permafrost continues to warm and thaw, releasing large quantities of methane (CH4) and carbon dioxide (CO2) to the atmosphere. We propose to define the relationship of TKLs to global climate change by developing remote sensing methods to quantify thermokarst and greenhouse gas (GHG) emissions from TKLs in regions (>106 km2) of organicrich, icy permafrost and ice-poor permafrost in Siberia and Alaska. We will use fine and broad scale remote sensing, numerical modeling and field validation to determine the role of thermokarst as both a source (GHG release) and sink (peat accumulation) for carbon (C), thereby improving understanding of the behavior of a major C pool ('icy permafrost') previously poorly considered in global C cycle sciences. Specifically, we will use remote-sensing based land cover classification and change detection to derive information about thermokarst distribution, initiation, and related changes in land surface properties to improve C-cycle and ecosystem models for Northern Hemisphere permafrost regions. We will test new satellite-based techniques: InSAR will be tested for quantifying thermokarst related ground settlement, and SAR

data will be used for upscaling field-measurements of CH4 bubbling from lakes to regional estimates of lake CH4 emissions through the establishment of a Pan-Arctic Lake-Ice Methane Monitoring Network (PALIMMN) and detection of possible gas hydrate release through TKLs. Employing sophisticated 2-D and 3-D numerical permafrost models that are driven by remotely sensed spatial data, information derived from multi-temporal satellite data (50 years), radiocarbon dated TKL sediment records (up to ~15,000 years old), and available and predicted climatic data, we will provide scenarios for up to 200 years into the future of the spatial and temporal dynamics of thermokarst and its related GHG emissions as permafrost warms and thaws under global warming.

Niall Hanan - Colorado State University (NASA funded)
African Carbon Exchange II: a systems approach for diagnosis and prediction of carbon, vegetation and disturbance dynamics in the natural and anthropogenic grasslands, savannas and forests of Africa

Africa has a large and growing role in the global carbon cycle, with important climate change implications. However, sparse observations in and around Africa makes it one of the weakest links in our understanding. Recent work by this team suggests Africa has a near zero decade-scale carbon balance, but that climate fluctuations induce sizeable variability in ecosystem productivity and savanna fires, greatly enhancing the inter-annual variability in global atmospheric [CO2]. With increasing populations and economic development Africa is poised for agricultural intensification and conversion to cropland and managed rangeland this century. Furthermore, complex interactions among climate change and ecosystem processes (primary production, tree-grass interactions, grazers, browsers, fire and nitrogen) challenge our ability to predict future carbon stocks in Africa and other tropical regions. Perhaps more important, future provision of vital ecosystem services to Africa's people remains difficult to predict.

We propose an integrated approach to modeling carbon dynamics that builds on our understanding of African ecology and assimilates data from field measurements, remote sensing and atmospheric measurements. Our modeling system will be unique in allowing dynamic simulation of major disturbance factors for prediction of ecosystem processes and vegetation structure, or their proscription using measurements from field data and remote sensing. This data assimilation and diagnosis process will be used to optimize model parameters and validate simulations using data on vegetation structure, productivity and fire frequency. We will validate regional simulations via atmospheric inversions using calibrated [CO2] and 13C measurements.

The integrated modeling system will provide a tool for carbon cycle diagnosis in tropical systems using remotely sensed and other datasets. However, the modeling system in prognostic mode will provide dynamic simulation of climate change and disturbance impacts and enable prediction of ecosystem dynamics, long-term carbon balance, and future productivity and sustainability in Africa's crucial grassland, savanna and forest ecosystems.

Taka Ito - Colorado State University (NASA funded)
High-resolution modeling of the Southern Ocean carbon cycle based on ECCO state estimates

This project will develop a new, high-resolution ocean carbon cycle model of the Southern Ocean designed to improve the realism and quantification of the regional ocean carbon cycle. This project's objective is to better understand and quantify the role of ocean eddies in the carbon fluxes in the Southern Ocean. The Southern Ocean is the major region of the oceanic uptake of anthropogenic CO2, however it is the region where ocean carbon cycle models show the largest disagreement due to the poor representation of physical circulation at the scale of ocean fronts and eddies.

We will improve the realism of the regional carbon fluxes by explicitly resolving the ocean eddy transport. The model employs circulation fields that are determined by the Southern Ocean State Estimation (SOSE) in the Estimate of Climate and Circulation of the Ocean, phase 2 (ECCO-2). Because the circulation field is pre-computed and is assimilated with a suite of satellite and in-situ observation, the modeled transport is realistic and computationally efficient, allowing biogeochemical and ecological parameterizations to be implemented at eddy-permitting spatial resolution. This study will include model development and model-data comparison components. We use the model to simulate regional carbon sources and sinks, and critically evaluate the simulated ecosystem and biogeochemical properties using satellite and in-situ observations. Simulated chlorophyll, primary production, radiocarbon and surface ocean pCO2 fields will be compared against observational data. We will also compare these properties between the high-resolution and the coarse-resolution models to evaluate the significance of resolving the small-scale circulations. Model-data and model-model comparison of multiple biogeochemical parameters will elucidate the causes of uncertainties in the regional carbon fluxes and guide our understanding in the controlling mechanisms.

The unique feature of this new modeling framework is the application of the high-resolution ocean data assimilation products to the ecosystem and carbon cycle simulation, providing the realistic, high-resolution carbon cycle simulations, supporting the objective of NASA Carbon Cycle Science to improve our understanding and reducing the uncertainties of the regional carbon cycle aided by the observations from space.

Xin Jin - UCLA (NASA funded)
The Impacts of the Offshore Transport of Carbon and Nutrients from the Continental Margins on the Carbon Cycle and Air-Sea CO2 Balance of the Pacific Ocean

The continental margins supply organic carbon (OC) and nutrients to the open ocean, which can lead to downstream productivity and respiration changes that influence the air-sea CO2 balance of the open ocean substantially. However, very little is known about this potentially important interaction of the coastal and open oceans. We therefore hypothesize that continental margins have a substantial impact on the open ocean air-sea

CO2 balance by providing OC and nutrients to the open ocean. In order to investigate this hypothesis we propose to address the following questions: (1) How well can we represent the offshore transport of OC and nutrients in our model? (2) What are the roles of the offshore transport of OC and nutrients on open ocean air-sea CO2 flux, respectively? (3) What are the magnitudes of the air-sea CO2 flux due to the offshore transport? We will address these questions using a modeling strategy combined with data analyses, taking advantage of the substantial number of satellite data sets available for the continental margins, and using state-of-the-art coupled high resolution physical/biogeochemical/ecological models configured for the Pacific Ocean and the U.S. West Coast (USWC). We will use satellite data to estimate offshore transport of OC and nutrients. We will use ROMS model at eddy-resolving configuration (5 km) to simulate complex biological and physical processes in USWC. We will use ROMS model at eddy-permitting configuration (50 km) to simulate the response of the offshore transport in the Pacific Ocean. Our research is firmly based on the observations and newly developed model skills and will substantially reduce the uncertainties. The expected results will directly support NASA's objectives in advancing understanding of the global carbon cycle and to quantify changes in atmospheric CO2 as well as terrestrial and aquatic carbon storage in response to human activities and natural events.

Eric Kasischke - University of Maryland (NASA and the USDA-CSREES NRI funded)

Assessing the Impacts of Fire and Insect Disturbance on the Terrestrial Carbon Budgets of Forested Areas in Canada, Alaska, and the Western United States

The overall goal of the proposed research is to analyze the impacts of disturbances from insects and fire on the terrestrial carbon budget for the forested ecoregions of Canada, Alaska and the western U.S. This goal addresses Theme 2 - Regional Scale Studies of the Carbon Cycle Science task of NASA ROSES NNH07ZDA001N, and specifically focuses on carbon cycling in high northern latitude regions. The following objectives will be addressed: (1) Develop a consistent bottom-up methodology to estimate carbon consumed during fires; (2) modify a process-based dynamic vegetation/biogeochemistry model to more accurately depict fuel consumption during fires, mortality from fires and insect disturbance, effects of climate and insects on net primary production, and forest succession as a function of disturbance type and severity; and (3) assess the effects of fire/insect disturbance on terrestrial carbon cycling in the boreal and western temperate forests of North American using different modeling approaches. These objectives will be met through using satellite-derived information on the spatial and temporal characteristics of disturbance and recovery after disturbance as inputs for the Terrestrial Ecosystem Model (TEM). We will use satellite information products to map vegetation/fuel types, burned area, seasonality of fires, estimating fire severity, and mapping patterns of vegetation recovery after disturbance. We will update TEM to more accurately depict fuel consumptions in the forest types found in the study region, to account for tree mortality and variations in NPP induced by fire and insects, and to reflect variations in post-fire successions that are caused by disturbance severity. We will then use TEM to assess the impacts of disturbance in forests on terrestrial cycling. We will compare the carbon estimates generated by TEM to MODIS NPP estimates (MOD17A3) and those

from the Canadian Forest Service (CFS) CBM-CFS3 model to better understand uncertainties of the different modeling approaches. Our project will include collaborations with CFS scientists working on modeling of the carbon cycle, as well as scientists from the USGS and USFS who have expertise and field observations of fuel consumption during fires. The project will aid in the implementation of the Joint North American Carbon Program through the continuation of existing joint research activities between U.S. and Canadian scientists, and reduce terrestrial carbon cycle uncertainties in a significant region of the Northern Hemisphere.

Stephan Kawa - NASA Goddard Space Flight Center (NASA funded)
Modeling the Global Atmospheric Carbon Cycle in Preparation for OCO Data

We propose to build on process-level understanding and global simulation capability developed in previous work to synthesize an improved modeling/data analysis procedure capable of incorporating OCO and other relevant data to more precisely characterize the atmospheric carbon budget. Recent progress in simulating atmospheric CO2 using models driven by analyzed meteorology from the NASA GEOS-4 data assimilation demonstrates considerable skill in reproducing observed variability on time scales from hourly to interannual. The ability to meaningfully compare simulated CO2 with real-time, local observations allows us to better exploit the information content of more extensive and intensive observations including those from the Orbiting Carbon Observatory (OCO) scheduled for launch in 2008. These observations comprise a wealth of information on the distribution and sensitivity of carbon cycle processes over a wide range of time and spatial scales. Better understanding of these processes and their representation in numerical models is key to resolving long-standing uncertainties in the CO2 budget and confidently projecting interactions of the carbon cycle with climate change. Our goal is to utilize OCO and other data constraints to reduce uncertainty in the atmospheric carbon budget and its dependence on changing weather and climate.

Specific tasks include: 1) Continue to evaluate and quantify uncertainty in atmospheric transport and its impact on top-down inference of carbon source/sink distributions including evaluation of the transport characteristics of GEOS-5. 2) Integrate, evaluate, and refine terrestrial biogeochemical process models constrained by global satellite observations including simulation of COS as an indicator of vegetation processes. 3) Prepare for OCO by testing inverse models and pseudo-data consistent with expected OCO instrument sampling, and, when available, use OCO data to infer CO2 sources and sinks. The results will be improved models and process understanding directly relevant to the objectives of NASA Earth Science and Carbon Cycle Research.

Michael Keller - University of New Hampshire (NASA funded)
A Historical Reconstruction of Vegetation Change and a Carbon Budget for the Brazilian Cerrado Using Multiple Satellite Sensors and Historical Aerial Photography

The Cerrado region of Brazil is covering 2 million square kilometers accounts for 9% of the global area of tropical savannas. The Cerrado has suffered a high rate of land use conversion, although it has been neglected in regional carbon budgets. Preliminary calculations indicate that the Cerrado could account for an annual release of carbon (~0.1 Pg per year) to the atmosphere 50% as large as the annual net deforestation flux from the Brazilian Amazon. We propose to estimate the vegetation carbon of the Cerrado for two time periods: prior to large scale conversion (~1964) and the present (2000 to 2008). The 1964 estimates will depend upon a random sample of aerial photography combined with a biophysical stratification of the Cerrado produced with a regression tree. The quantification of biomass from aerial photographs or high resolution images will depend upon measured biophysical properties in the images (e.g. tree stem frequency and canopy size frequency distributions) compared to ground based biomass distributions. Biometric data for both above- and below-ground biomass will be gathered from publications, databases, and limited field work. For 2000 to 2008, we will estimate total biomass carbon and inter-annual changes in Cerrado biomass carbon stocks using moderate resolution imagery (MODIS + MISR) in an artificial neural network model trained with biophysical properties derived from the analysis of high resolution satellite imagery (IKONOS, Quickbird). Current (2000 to 2008) biomass distributions will be checked against an independent estimate derived from calibrated GLAS lidar data. We will calculate changes in the Cerrado carbon content between 1964 and the present. Uncertainties in both biometry and image analyses will be propagated through all biomass carbon estimates. Explicit uncertainty estimates for all portions of the biomass carbon estimates will be calculated use k-fold cross validation and more traditional in-sample statistics.

Josef Kellndorfer - The Woods Hole Research Center (USDA-CSREES NRI funded)
Towards Spatially Explicit Quantification of Carbon Flux (2000-2007) in Northeastern U.S. Forests Linking Remote Sensing with Forest Inventory Data

The overall goal of the proposed research is to generate a high-resolution regional dataset of changes (2000-2007) in land cover and carbon stocks in the forests of the ten Northeastern U.S. states participating in the Regional Greenhouse Gas Initiative (RGGI). The project builds on ongoing work by the proposal team to establish a spatially explicit high-resolution baseline dataset of vegetation canopy height, aboveground live dry biomass and carbon stocks for U.S. forests. This “National Biomass and Carbon Dataset” (NBCD2000) is a NACP core project (PI Kellndorfer). The new work, proposed here, will assess the feasibility and limitations of measuring spatially explicit changes in carbon stocks by comparing the NBCD2000 data set with new estimates of carbon stocks from high-resolution Advanced Land Observing Satellite/Phased Array L-band Synthetic Aperture Radar (ALOS/PALSAR) data obtained in 2007 and calibrated with forest survey data from the USDA Forest Service Forest Inventory and Analysis (FIA) program.

Four specific objectives are proposed to achieve this goal:

(1) Generate an ALOS/PALSAR mosaic for the RGGI region for the year 2007.

(2) Use FIA data together with the ALOS/PALSAR mosaic for forest cover classification at three levels. Level 1 classes are forest/non-forest, level 2 forest classes are coniferous, deciduous, woody wetlands, and mixed forest, level 3 classes are FIA forest type classes grouped by structurally similar forest types.

(3) Use FIA data together with the ALOS/PALSAR mosaic to estimate vegetation height and aboveground live dry biomass and generate the RGGI Biomass and Carbon Dataset 2007 (RBCD2007). Estimation is limited to forest areas and informed by level 2 and 3 forest cover classes. We will also determine the saturation levels for biomass and vegetation height estimation which are largely driven by the ALOS/PALSAR saturation levels.

(4) Quantify spatially explicit changes in vegetation height, biomass and carbon stocks for the RGGI region by comparing the 2007 estimates (from 3) with the NBCD2000 baseline.

Results from objectives 2, 3, and 4 will be validated using independent ground survey and high-resolution remote sensing imagery. Errors will also be estimated from cross-validation of ALOS/PALSAR-derived 2007 land cover classification, NBCD2000, and RBCD2007, and 2001 land cover from the National Land Cover Database.

The proposed work addresses both of the Carbon Cycle Research Themes within the NASA Earth Science Program. First, the work will determine the magnitude and variability of terrestrial carbon stocks and fluxes within the northeastern U.S.; and, second, it will provide information for making decisions about which options for managing carbon sources and sinks are observable and quantifiable with remote sensing data. By quantifying the changes in aboveground carbon stocks in forests of the northeastern U.S., the work is expected to advance two of the research themes of this NRA: (2) Regional studies that provide critical understanding of and reduce uncertainty in the terrestrial carbon budget; and (4) decision-support for carbon management in North America, specifically the lands that will be managed under the northeastern states participating in RGGI. The proposal team will not work directly with RGGI but will provide information useful for future decision making.
The results obtained from working with the ALOS/PALSAR data will also have an impact on NASA's plan for a U.S. DESDynI mission, the goals of which include measurement of vegetation structure and biomass.

Finally, the work has the potential to influence the forest inventory-based monitoring strategy of the U.S. Forest Service. The work will demonstrate how wall-to-wall spatial data provided by satellites have the potential to strengthen the extrapolation algorithms

currently used by the Forest Service to assign areas to samples of forest types and volumes.

Johannes Lehmann - Cornell University (USDA-CSREES NRI funded)
Black carbon stocks in soil of the United States

We propose to quantify the black C stocks in soils throughout the United States. The significance of this proposal lies in the fact that black C stocks have not been estimated, although recent data suggest that black C is a quantitatively important component of total organic C in soils. If the stock of black C in some soils is larger than previously assumed it will (1) change estimates of regional and national cycling of non-black C, and (2) change estimates of the long-term sink and source of atmospheric CO2. We propose to generate estimates of black C stocks in soils of the United States by combining (1) a large-scale inventory of black C stocks, (2) detailed studies of the vertical and horizontal distribution of black C in profiles and across landscapes, and (3) comparisons between natural ecosystems and human-impacted environments. We will make use of the archived soil samples collected by the International Soil Reference and Information Centre (ISRIC) - World Soil Information Database. Also, soil samples will be collected from NSF supported Long Term Ecological Research (LTER) sites from a wide variety of land use, climate, vegetation types and soils across the United States. All samples will be analyzed using a novel mid-infrared (MIR) spectroscopy technique that has been calibrated for black C by UV oxidation followed by nuclear magnetic resonance (NMR) spectroscopy. This method captures the widest range of black C materials of any method. The MIR results will be permanently archived in databases that are accessible to the global research community in preparation for future efforts to build a national black C model. Our results are expected to provide early estimates of biomass-derived black C stocks in US soils and likely alter national and global predictions of total C cycling.

Dennis Lettenmaier - University of Washington (NASA funded)
Diagnosis and prognosis or changes in lake and wetland extent on the regional carbon balance of northern Eurasia

Northern Eurasian lakes and wetlands are the source of over ten percent of global methane emissions, but the uncertainty may be as large as a factor of three, and the sensitivity of these fluxes to rapid ongoing warming in the region is not well known. We propose to assess the effects of changes in lake and wetland extent and accompanying thermal variations associated with ongoing climate change, as well as permafrost degradation, on Northern Eurasia's net CO2 and methane emissions, both retrospectively (last half-century) and over the next century. The large uncertainties in estimates of CO2 and methane emissions in the region are mostly attributable to the sparseness of ground observations. We will, therefore, focus on development and extension of CO2 and methane emissions models coupled with representations of key hydrological and thermal drivers, which will be tested at limited existing in situ observation sites, and driven with remote sensing data that will help to characterize the key driving properties, such as

extent of inundation. We will then use remote sensing data of lake and wetland extent and their temporal variations to help constrain model estimates of regional scale fluxes.
A major thrust of our work will be to create a time series of satellite imagery that will provide accurate estimates of the temporal evolution of the extents and net methane and CO2 emissions of lakes and wetlands. For the measurement of lake and wetland spatial extent, our strategy will be to use high-resolution, long-repeat-cycle SAR imagery to calibrate a low-resolution, fast-repeat cycle time series from AMSR-E and MODIS. The high-resolution element of our strategy will be ALOS/PALSAR-derived classification of lake and wetland extent acquired in 2006-2007 and future years over focused study regions and comparison with JERS -derived products acquired in 1998 or earlier over the same region. The lower-resolution time series component will be based on analysis of wetland dynamics derived from AMSR-E from 2002 onwards.
We will extend information extracted from remote sensing data through use of our large-scale, process-based Variable Infiltration Capacity (VIC) model, which we will continue to enhance to represent methane and CO2 fluxes from lakes as well as wetlands over a region where in situ data are sparse. The enhanced VIC framework will allow estimation of the spatial distribution of water table position and the dynamics of lakes and seasonally-inundated wetlands. Using this modeling framework, we will reconstruct the evolution of the region's lake and wetland extent over the last halfcentury, and perform multimodel ensemble simulations using statistically downscaled IPCC AR4 model output for the next century. Finally, we will identify the major uncertainties in the carbon budgets of Northern Eurasia's lakes and wetlands, and determine where future remote sensing (and/or ground data collection) efforts might be focused to most effectively reduce these uncertainties.
This work addresses NASA's Strategic Goal 3A.3, which is to quantify global land cover change and terrestrial and marine productivity, and improve carbon cycle and ecosystem models. More specifically, this proposal contributes directly to the goals and objectives of The Northern Eurasia Earth Science Partnership Initiative (NEESPI).

Charles McClain - NASA Goddard Space Flight Center (NASA funded)
Physical-Biogeochemical Interactions that Alter the Uptake of CO2 in the North Atlantic Sub-Polar Region

The sub-polar North Atlantic Ocean is one of the largest sinks of CO2 in the global ocean. The uptake of CO2 is driven by both the solubility pump coupled to the meridional overturning circulation and the biological pump associated with the dramatic spring bloom. The region is also characterized by high seasonal calcite concentrations associated with coccolithophore blooms which are a primary component of the carbonate pump. In this study, we will examine the SeaWiFS and MODIS ocean biology time series of chlorophyll-a, primary production, particulate organic carbon and calcite in conjunction with analyses of atmospheric forcing, ocean dynamics and circulation to investigate trends in CO2 fluxes and export production.

Dennis McGillicuddy - Woods Hole Oceanographic Institution (NASA funded)
Carbon cycling in the North Atlantic from regional to basin scales: satellite data, in situ observations, and numerical models

Geochemical estimates of new production surpass the apparent rate of nutrient supply by vertical mixing by a factor of two or more in subtropical oceans, which constitute some of the largest biomes on earth. Two possible mechanisms to supply the "missing" nutrient locally include nitrogen fixation by cyanobacteria, and intermittent upwelling by mesoscale eddies and submesoscale processes. Growing evidence suggests that such episodic processes can have a large impact on mean biogeochemical cycles, so they must be included in our conceptual models and resolved in our numerical models. The overall goal of the proposed research is to investigate the role of mesoscale dynamics and upper ocean processes on biogeochemical fluxes in the open ocean. The general approach is to use a three-dimensional coupled physical and biogeochemical model together with in situ observations and a full complement of remotely sensed information (altimetry, ocean color, scatterometry and AVHRR) to study the biological and chemical ramifications of spatially and temporally intermittent physical processes.

Herein we propose a combination of retrospective data analysis and numerical modeling. Our data analysis will focus on illuminating linkages between eddy-driven physical disturbances, changes in phytoplankton species composition, and carbon export from the euphotic zone. In particular, recent observations have shown that, although plankton blooms occur in both cyclones and mode-water eddies, the biological responses differ. Mode-water eddies can generate extraordinary diatom biomass and primary production at depth, relative to the time-series near Bermuda. These blooms are sustained by eddy-wind interactions, which amplify the eddy-induced upwelling. In contrast, eddy-wind interactions dampen eddy-induced upwelling in cyclones. Carbon export inferred from oxygen anomalies in eddy cores is 1-3 times annual new production for the region. In addition, new observations of the colonial diazotroph Trichodesmium have revealed distinct mesoscale variability in the distribution of this organism and unexpectedly high abundance at depth, which could have a significant impact on basin-scale nitrogen and carbon budgets.

Up to now, basin-scale eddy resolving models have not included the eddy-wind interaction process described above. This effect can be implemented in a straightforward manner by including the surface ocean velocity in the computation of surface wind stress in our existing 0.1 degree resolution nutrient-transport model of the North Atlantic (based on the Los Alamos POP model). Capturing the detailed biogeochemical responses to cyclones and mode-water eddies will require us to adopt more sophisticated biological models that explicitly represent functional groups of phytoplankton such as picoplankton and diatoms. These simulations will be used to diagnose the effects of mesoscale processes on water column biogeochemistry.

We propose to incorporate the 24-component biogeochemical/ecosystem model of Moore et al. (2004) into our eddy-resolving model of the North Atlantic. We will evaluate the

mean state predicted by the model and compare it with both remotely sensed and in situ measurements. Diagnosis of mesoscale physical-biological-biogeochemical coupling will be undertaken, both through phenomenological assessment as well as detailed term-by-term analysis of simulated fluxes. Understanding gleaned from this study will help quantify a major uncertainty in the ocean carbon cycle, and provide the conceptual basis for parameterization of these effects in global climate models.

This proposal includes a high-end computing request of 582,000 CPU-hours and 21 TB storage.

Anna Michalak - University of Michigan (NASA funded)
Mapping Global CO2: Development and Application of Geostatistical Algorithms for Gap Filling and Uncertainty Assessment for the Orbiting Carbon Observatory

This project will directly address the ROSES A.3 Carbon Cycle Science program's call for "proposals to prepare the scientific community for analysis of OCO data," by producing the first full coverage maps of column integrated CO2 dry air mole fraction (XCO2) using the first year of data available from OCO. The proposed approach will develop a new geostatistical spatial and temporal gap-filling algorithm for OCO XCO2 data. In contrast to other more ad-hoc gap-filling strategies, the geostatistical approach uses quantitative estimates of the spatial and temporal scales of variability observed in the retrieved soundings, and produces rigorous assessments of the uncertainties associated with the gap-filled fields, which include the effects of measurement errors, uncertainty due to scaling from the OCO footprint to the gap-filled resolution, and interpolation errors. Such careful uncertainty quantification is critical to the broad scientific applicability of the developed product. This approach is strongly data-driven, and the final product will not rely on atmospheric transport models and estimates of surface fluxes of carbon dioxide. The four specific objectives are to (1) initially quantify the expected spatial and temporal correlation structure of XCO2 using existing data and models, (2) develop preliminary gap filling algorithms and test them by deriving full coverage maps based on subsampled model data, (3) use initial data from OCO to apply the developed algorithm and update the spatial covariance estimates, and (4) use OCO data and the OCO-derived covariance estimates to obtain gap-filled maps of XCO2 at regional and global scales. The resulting full-coverage maps of XCO2 will (a) provide an opportunity for immediate and valuable use of OCO data, (b) serve as an early detection system for anomalies or unexpected features in the XCO2 distribution, and (c) provide independent validation datasets for carbon dioxide flux estimates and atmospheric transport models.

Charles Miller - JPL (NASA funded)
Improving Carbon Source/Sink Estimates Using Atmospheric CO2 Vertical Profile Constraints

Understanding changes in atmospheric carbon dioxide (CO2) concentrations, their global sources and sinks, and the carbon cycle dynamics and processes that control their

variability has emerged as one of the principal challenges of 21st century Earth system science. Satellite observations atmospheric CO2 are poised to revolutionize our understanding of global carbon cycle science by providing unprecedented spatiotemporal resolution and coverage. Major advances are expected with the launch of the Orbiting Carbon Observatory (OCO) in late 2008.

We propose to implement a state of the art retrieval algorithm on the COLUMBIA supercomputer to generate atmospheric CO2 vertical profile data products from simultaneous retrievals of OCO and AIRS satellite observations. This unique data set will significantly improve the estimation of atmospheric carbon sources and sinks by providing observational constraints on vertical as well as horizontal and temporal distributions of atmospheric CO2 in data assimilation and data fusion approaches: accurate vertical transport is essential within the source/sink inversion to avoid systematic flux errors of up to 2 GtC/yr since convection over land is strongly correlated in time with photosynthesis, the dominant surface sink for CO2. We will also quantify the accuracy of simulated CO2 vertical profiles from the Caltech 2D chemical transport model (CTM) and selected 3D CTMs by comparison against aircraft and AIRS CO2 data. We will leverage these analyses to develop and implement improved atmospheric transport schemes.

Our innovative approach is tailored specifically to the use of OCO data for the improved estimation of atmospheric carbon sources and sinks. It exploits the complementary CO2 vertical distribution information from AIRS spectra, merging the two independent space-based observations into a more valuable product. Our research will also provide a framework with which to evaluate the potential impact of higher resolution vertical profile data that will become available in the post-2010 timeframe from active CO2 remote sensing systems. Additionally, we will establish the ability to process XCO2 retrievals from OCO observations on NASA's largest supercomputer, offering the potential for community access to significantly larger volumes of XCO2 data than are planned for delivery by the OCO project.

Our scientific activities target the main Carbon Cycle Science goals within NASA's Earth Science Research Program:
* Improve understanding of the global carbon cycle
* Quantify changes in atmospheric CO2 concentrations
Our studies complement work planned by the OCO Science Team and are independent investigations. The research described here is not planned or funded as part of the OCO project and is not needed for OCO to succeed in achieving its Level 1 Science Requirements.

Mahta Moghaddam - University of Michigan (NASA funded)
Mapping Wetlands Dynamics for Reducing Uncertainties in the Boreal North American Carbon Budget

This proposal addresses the focus area of “Regional Studies to Reduce Major Global Carbon Cycle Uncertainties” within the current Carbon Cycle Science opportunity. We

will develop current and retrospective wetlands maps of the North American boreal region, characterizing wetland spatio-temporal dynamics, and hence provide a major carbon modeling input data source to reduce the uncertainty of carbon exchange estimates. As such, the products, algorithms, and analyses produced here will directly benefit objectives of the NASA Earth Science Research Strategy, the US Climate Change Science Program, the North American Carbon Program (NACP), and the International Polar Year (IPY). Satellite remote sensing data are the only practical way to monitor wetland status in a timely and cost-effective fashion over this large remote area. Establishment of a high-resolution (100m) baseline of current wetland extent and distribution in this region is an essential requisite for estimating sources, sinks, and net fluxes of carbon dioxide and methane. It is also the first step in creating habitat classifications that will provide a baseline against which to compare future changes brought about by climate change. As part of a previous Carbon Cycle Science project, we have developed a robust algorithm for mapping boreal wetlands using L-band satellite radar imagery, and in particular have used the method to produce a complete vegetated wetlands map of Alaska using the JERS radar data. In this work, we plan to apply this algorithm and enhance it as needed to achieve the following primary objectives:

1. Produce a retrospective static map of Canadian wetlands from the 1990s JERS-era radar mosaic data set at 100-m resolution
2. Develop the 2007 static map of wetlands in the targeted boreal North America coverage area of ALOS PALSAR radar, at 100-m resolution
3. Develop the 2007-era (PALSAR) multitemporal wetlands extent and soil wetness regime maps for selected sites in Alaska and Canada at 100-m resolution
4. Assess the impact of these long- and short-term wetlands change products in reducing the carbon cycle uncertainties in the North American boreal region by integrating the results in a carbon modeling framework for examination of carbon fluxes and permafrost soil processes

For the JERS-era temporally static wetlands map of Canada, we will also investigate possible improvements in wetlands mapping accuracy when near-contemporaneous Landsat TM data are used in conjunction with the L-band radar imagery. The work towards achieving these objectives will be carried out using the collective experience of the team and in collaboration with CCRS investigators involved with the major Canadian-led IPY project CiCAT, and investigators at the European Commission and JAXA leading the Kyoto and Carbon Initiative of ALOS/PALSAR.

John Morse - Texas A&M University (NASA funded)
Ocean Acidification of the Greater Caribbean Region 1999 - 2009

Among the potentially greatest environmental impacts of the release of fossil fuel CO2 to the atmosphere is the "acidification" of the world's oceans. The negative affects on calcifying organisms, such as coral reefs, is of particular concern. In order to better understand this process and make predictions for the future, it is necessary to document the on-going changes in the carbonate chemistry of the upper ocean. Although empirical relationships of global surface water total alkalinity (TA) with salinity and temperature were recently derived using JGOFS/WOCE survey data, currently insufficient coverage

of the Western Atlantic and Caribbean Sea prevent derivation of similar relationships for this region. This is a non-trivial omission as these waters house the vast majority of Atlantic coral reef ecosystems which may be impacted by ocean acidification. The central objectives of this research are to 1) conduct a comprehensive CO2 partial pressure (pCO2,sw) and TA survey of Greater Caribbean Region (GCR) surface waters; 2) derive a regionally specific algorithm for application to coupled satellite and modeled data sets to generate GCR seasonal fields of sea surface TA.; 3) couple sea surface pCO2 - TA algorithms to generate GCR seasonal fields of sea surface pH and aragonite saturation state; and 4) estimate changes in GCR sea surface pH and aragonite saturation between 1999-2009. A unique aspect of the proposed research will be the use of the Explorer of the Seas and the Natural Gas carrier from Methanol Holdings Ltd., on a total of 9 cruises, without the need for the usual major costs of ship operations for such a large regional field program.

Ross Nelson - NASA Goddard Space Flight Center (NASA funded)
Using the ICESAT-GLAS LiDAR to Estimate the Amount, Spatial Distribution, and Statistical Uncertainty of Aboveground Carbon Stocks of the North American Boreal Forest

The boreal forest is the largest forest biome on the North American continent and contains the greatest amount of carbon stocks. We will use a hierarchical sampling approach involving ground plots, the airborne PALS lidar, and the spaceborne ICESat-GLAS lidar to develop estimates of aboveground biomass and carbon stocks in the boreal forest of North America. We will combine the GLAS data with Landsat-derived forest cover maps and Shuttle Radar Topographic Mission (SRTM) topographic information to tabulate and map the spatial distribution of aboveground biomass and C stocks in the boreal forest of North America for (a) the major ecozones and cover types; (b) the grid cells of the North American boreal forest typically used for nested inverse modeling, (c) the major watersheds in the boreal forest biome, and (d) the major political units within the North American boreal forest. We will also evaluate the statistical uncertainty of our estimates by evaluating different techniques for assessing variance for the type of transect sampling done using spaceborne lidars. The basic approach involves developing relationships between aboveground biomass measured on ground plots with the structural variables measured by the airborne lidar. We will also fly the airborne lidar along 12 to 14 selected GLAS orbits distributed across the North American boreal forest to develop the relationships between PALS biomass and GLAS structural variables. Finally, we will quality filter the 11 million GLAS pulses collected so far over the North American boreal forest and then combine them with our land cover maps and SRTM slope information to scale our estimates to the entire biome. The research proposed here will make a significant contribution to answering the first broad question in the NASA Carbon Cycle Science Research Themes: “How large and variable are the dynamics reservoirs of carbon within the Earth system?”.

Stephen Ogle - Colorado State University (NASA funded)
Resolving Net CO2 Exchange in the Mid-Continent Region of North America by Comparing and Reconciling Results from Inverse Modeling and Inventory-Based Approaches

Exchange of CO2 between terrestrial ecosystems and the atmosphere has been a major uncertainty in the global carbon budget, largely due to inconsistencies between estimates using inverse modeling approaches compared to inventory methods. Inventory approaches use spatially disaggregated information on land use activity, climate, soils, energy use, product transport and flux measurements to model the net change in carbon pools and CO2 emissions. In contrast, inverse modeling approaches estimate CO2 fluxes based on change in concentration measurements in the atmosphere. Our objective is to compile, diagnose and reconcile estimates of CO2 exchange from the two approaches, and then evaluate the change in estimated fluxes and uncertainties compared to the original inventory. The study will be a quantitative synthesis of results from ongoing projects funded through the carbon cycle science programs, and will focus on the Mid-Continent Region of North America. Differences between the atmospheric inversions and inventories will be analyzed in the diagnosis step using graphical tools and standard time series techniques to investigate spatial patterns and temporal autocorrelations. The estimates will be reconciled with the development of a state-space model, providing spatially and temporally explicit predictions of the best estimate of CO2 fluxes, by optimally combining data from the original atmospheric inversions and inventories. Remote sensing products derived from NASA satellite imagery will be central to the diagnosis and reconciliation of estimates from the two approaches. We anticipate that the proposed study will reduce uncertainties for regional scale carbon cycle monitoring, provide a better understanding of fluxes in the largely agricultural, Mid-Continent region, and generate a more robust method for reporting of greenhouse gas emissions and developing climate change policy.

Scott Ollinger - University of New Hampshire (NASA funded)
Exploring Relationships among Carbon Cycling, Vegetation Nitrogen Status and Surface Albedo across North American Ecosystems to Improve Land Surface Models

In the study of terrestrial carbon cycling, developing methods by which leaf, plant and stand level processes can be related to landscapes, regions and continents represents an important challenge and is a core component of the North American Carbon Program. The ability to seamlessly transfer information across a continuum of spatial scales from field studies to Earth observing satellites would greatly improve our understanding of how vegetation, the carbon cycle and the Earth's climate interact and change over time in response to human activities and natural forcings.

Here, we plan to expand the integration of hyperspectral remote sensing and AmeriFlux research activities conducted under a previous NASA Carbon Cycle Science grant to a broader range of ecosystems (focusing largely on northern latitude systems) and to address linkages between canopy %N and a wider suite of physiological model parameters related to carbon assimilation. Results thus far indicate a significant positive

correlation between canopy %N and canopy Amax (the maximum rate of net photosynthesis) in U.S. forest ecosystems. Work proposed here will extend this approach to address photosynthesis parameters other than (but physiologically related to) Amax (i.e., the Vcmax and Jmax parameters of the Farquhar et al. 1980 model), making our results useful to a wider range of carbon cycle and land surface models.

Further, a consistent and significant pattern in our data suggests that canopy %N is also related to the albedo of vegetation surfaces. We seek the opportunity to extend and clarify the degree to which this pattern applies across North American ecosystems. If these patterns are confirmed and can be shown to exist more broadly, our results would demonstrate an important, but previously unrecognized, feedback in the Earth's climate system involving the nitrogen cycle as a moderator of carbon assimilation and surface energy exchange under changing environmental conditions.

Mary Jane Perry - University of Maine (NASA funded)
Reducing Uncertainty in the Marine Carbon Cycle by Coupling Satellite and In-water Robotic Measurements

This proposal addresses theme #2 in the Carbon Solicitation for "regional studies that provide critical understanding of and offer to reduce major uncertainties about the global carbon cycle". We propose a coupled "satellite - robotic underwater glider" study of the spring bloom in the Gulf of Maine. Our goal through underwater measurements is to improve accuracy in quantification of key biogeochemical stocks and input variables for satellite-based productivity models in mid-latitude coastal ecosystems and provide objective estimates of both their precision and the sensitivity of that precision to subsurface processes. Key estimates from in-water measurements are of high-frequency variation aliased by satellites, small-scale horizontal variations below satellite pixel resolution and depth variations impossible to resolve from the net water-leaving radiance. We target those areas where current productivity models show greatest disagreement, i.e., areas of high productivity and waters colder than 10ºC. The expected outcomes of this study are a reduction in uncertainty in productivity estimates on the local level and a demonstration of how the coupled use of satellites and in-water robotic gliders can be best used to reduce specific components of uncertainty.

Four major challenges to accurate space-based assessment of marine productivity that can be addressed today with existing underwater glider technology are:

1) verification of derived products within different bio-optical regimes;
2) determination of key biogeochemical stocks in the entire euphotic zone;
3) actual measurement of "input" variables for productivity models;
4) continuity of stock measurements during periods of cloudiness.

We propose a two-year field campaign to study the spring bloom in the Gulf of Maine, from mid-March to mid-May. Satellite ocean color and sea-surface temperature will be collected and analyzed for water-leaving radiance, standard pigment products, optical backscattering coefficients, colored dissolved and particulate detrital concentrations, and sea-surface temperature. Two-optically instrumented gliders will be deployed within a defined box to measure chlorophyll and colored dissolved material fluorescence, optical

backscattering coefficients, spectral upwelling and downwelling (ir)radiance, as well as temperature, salinity, and oxygen. Stratification indices will be determined during the evolution of the bloom. Additional optical and chemical measurements (i.e., particulate and dissolved organic carbon, pigments, CDOM and particulate detrital absorption) will be measured on the glider deployment/retrieval cruises to validate the optical proxies for carbon-cycle components.

Christopher Potter - NASA Ames Research Center (NASA funded)
Modeling the Terrestrial Carbon Cycle with Land Cover Disturbance Based on Satellite Remote Sensing

This proposal will bring together investigators with backgrounds in simulation modeling and remote sensing of terrestrial ecosystem carbon fluxes (sources and sinks of CO2) with global circulation model (GCM) scientists. Our project team has a wealth of experience in both high-resolution (1-km or finer) satellite observation studies of land cover dynamics and atmospheric CO2 forcing of global climate. The main objective of the project will be to augment the capacity of advanced carbon-climate models with additions of new scenario-based algorithms for land cover disturbances and terrestrial ecosystem carbon fluxes based on high-resolution analyses of NASA satellite data sets that span the past 25-30 years of climate variations. We will analyze both pre-MODIS (e.g., AVHRR) and MODIS land cover and greenness index alterations and anomalies in relation to large-scale climate events such as cycles of the El Nino Southern Oscillation (ENSO) and the Arctic Oscillation (AO). Statistical representations of vegetation greenness dynamics associated with GCM predicted climate events will be constructed from the satellite greenness record for each 2x2 degree land cover area of the Earth. The ecosystem model NASA-CASA will be run to predict CO2 sources and sinks at high spatial resolution within all 2x2 degree GCM cells over the period 1980-present. Spatially aggregated versions (to the GCM grid resolution) of these ecosystem model predictions of land cover change and surface carbon fluxes will include ecosystem disturbance regimes from time series (re)analysis of the AVHRR and MODIS satellite land products. This will result for the first time in coupling of climate-driven land cover alternations and associated terrestrial CO2 fluxes, nested within GCM simulations of atmospheric greenhouse gas forcing on century-long time scales. We will perform two GCM scenario experiments: one with no disturbance and another simulation with disturbance-model parameters set for maximum disturbances. The difference between these simulations would integrate over time the accumulated effect of an extreme (maximum possible) disturbance scenario. The main goal of these coupled simulations will be to bracket the uncertainty in projections of climate change and CO2 levels in the atmosphere in year 2100 due to the uncertainty in naturally occurring disturbances. Our study will directly address NASA Strategic Plan Sub-goal 3A for deployment of the National Polar-Orbiting Operational Environmental Satellite System Preparatory Project (NPP), Global Precipitation Measurement (GPM), Orbiting Carbon Observatory (OCO), and Landsat Continuity missions. Predictions from the newly coupled Integrated Climate Carbon Model (INCCA) - Disturbance model will help interpret observations made by these future Earth observing satellite sensors.

Joseph Salisbury - University of New Hampshire (NASA funded)
Lagrangian Tracking of Satellite Products with a Numerical Model: A New Method for Diagnosing Net Community Production and Carbon Export in the Ocean

Net community production (NCP), defined as gross primary productivity minus net community respiration, is an important measure of the biological pump as it provides information on the status of net carbon sequestration and the availability of carbon for export and trophic exchange. We propose to estimate NCP by tracking the localized, depth-integrated particulate organic carbon (POC) stock that has been produced or respired in situ. We will use the velocity fields from ocean circulation models to advect Lagrangian particles and consequently trace water parcels. This, in turn, allows monitoring and tracking the temporal evolution of satellite retrievals (e.g. POC) in the moving frame of water parcels. Depth-integrated POC will be derived from NASA MODIS data and several different empirical and semi-analytical models. Changes in the local POC stock will be related to corresponding changes in biologically mediated dissolved inorganic carbon (DIC) and pCO2. Data from NASA's SeaWinds sensor will be used to resolve air-sea carbon exchange necessary in accounting for DIC measured in situ. This will enable estimating the biologically mediated DIC and will serve as validation for the satellite-based estimates. Our methodology will be applied globally, extending outward from continental shelves, which will form the focal point for this study. A synoptic picture of ocean basin-wide NCP and POC export from continental shelves will be constructed to gain an understanding of the role of continental shelves in the global carbon cycle. In this proposal, we demonstrate the described methodology for a single region, the Gulf of Maine; from here it will be extended to other data rich regions around the globe. Our work will be thoroughly validated using the UNH Coastal Observatory and Analysis database, the Gulf of Maine Ocean Observing System buoy array and later from coastal ocean observing systems around the world.

Compton Tucker - NASA Goddard Space Flight Center (NASA funded)
Identifying and Understanding 25 Years of North American Carbon Cycle Disturbances

Problem Statement: We propose to use satellite data and simulation modeling to investigate large areas within North America that have experienced major gross primary production reductions from 1982 to 2007 and beyond.

Analysis Method:
We propose to use 8-km grid cell size inter-calibrated advanced very high resolution radiometer (AVHRR) normalized difference vegetation index (NDVI) data to identify large regions (>100,000 km2) in North America that have experienced marked systematic reductions in NDVI for any times between 1982 and 2007;

Use Landsat data, hyper-spatial commercial satellite data, aerial photography, climatological data, logging records, fire records, etc. to determine the causes of the NDVI natural and anthropogenic disturbances and map their associated land-cover/land-

use change at Landsat 30 m resolution. Specifically we propose to determine if the large-scale NDVI anomalies identified above are due to land use/land cover change and/or to climate; and

Use the information gained from the first two points above to drive simulation models of the carbon cycle to determine the carbon implications of the areas identified. These simulations will investigate the carbon balance for all of North America and improve disturbance implications in the calculation of net ecosystem production (NEP) across North America

Significance: Previous work we performed in 2005 to 2007 identified increases in NEP following a variety of disturbances including: fire, logging, insect outbreaks, agriculture expansion, and climatic influences (principally extension of the growing season due to increased temperature) over the 1982-2005 time periods. We propose to extend this work by investigating negative trends in NDVI (decreases in gross primary production) and incorporate this information with previous work in which we have parameterized disturbance dynamics. Our CASA simulations utilize NDVI to calculate NPP biomass allocated to terrestrial pools on a bimonthly time step, deliver biomass to detritus/soil pools, and respire carbon through heterotrophic decomposition. Our multi-spectral multi-spatial understanding of disturbance, integrated in simulation modeling, will result in an improved carbon balance understanding for North America.

Relevance to NASA: Our proposal addresses several key questions about the role of land use and land cover change and climate in the North American carbon cycle. Furthermore, our proposed work extensively uses satellite data to obtain key information that we link with numerical models to simulate the carbon cycle consequences of land use and land cover change and climate in the North American carbon cycle.

Xiujun Wang - University of Maryland (NASA funded)
Reducing the Global Carbon Cycle Uncertainties: Understanding the Tropical Ocean-Atmosphere CO2 fluxes

The tropical oceans play a very important role in the global carbon cycle and climate because they are the dominant natural oceanic source of CO2 to the atmosphere. Global carbon cycle modeling studies indicate that the tropical oceans contribute the largest fraction of the interannual variability of the global ocean-atmosphere CO2 flux. However, there are considerable discrepancies among different approaches (e.g., observations, ocean carbon models and inverse models), and large uncertainties in the estimates of the CO2 fluxes at basin scales. Here, we propose a combined study employing satellite data and validated regional biogeochemical models to address a number of key issues leading to a better understanding of the large-scale temporal and spatial variability of carbon fluxes in the tropical oceans, aiming to reduce major uncertainties in the global carbon cycle. In particular, we seek to answer: what are the impacts of climate induced biogeochemical changes on the carbon fluxes between the upper ocean and deep ocean, and between the tropical oceans and the atmosphere?

The proposed activity builds on our existing NASA funded research “Seasonal to Decadal Variations of the Oceanic pCO2 and Air-Sea Flux of CO2 in the Equatorial Pacific (CARBON/04-0000-0070)”. Our team has a long history of modeling the tropical ocean circulation and dynamics, and more recently the tropical ecosystem and biogeochemistry. In particular, we have developed and tested a basin scale ocean-ecosystem model for all the tropical oceans (i.e., the Indian Ocean, and the tropical Pacific and Atlantic Oceans). We have implemented a carbon chemistry model into the ocean-ecosystem models, tested and validated for the tropical Pacific Ocean. Recently, we have developed a chlorophyll dynamic model that deals with phytoplankton acclimation to changes in irradiance, nutrient concentration and temperature, which has been validated in the tropical Pacific. We will expand this advanced ecosystem-carbon model to the entire tropical oceans to quantify spatial patterns and variability of carbon fluxes between the ocean and atmosphere.
There have been extensive and growing databases of remotely sensed and in situ biogeochemical measurements, including chlorophyll and particulate organic carbon (POC). We will use these data for model validations and improvements. The major objectives of the proposed studies are to determine the size and variability of the CO2 source of the tropical oceans at decadal and longer time scales. We will undertake a series of studies to investigate: (1) impacts of iron-silica interaction and co-limitation on the spatial and temporal variability of the sea surface pCO2, and sea-air CO2 fluxes, (2) the impacts of C:N and C:Chl ratio variability on the tropical oceanic carbon cycle, including primary productivity and export production, (3) how past and present climate variability and change regulate the spatial and temporal variability of the sea surface pCO2, and sea-air CO2 fluxes in each ocean basin, (4) impact of physical-biological feedback on the ocean carbon cycle, and (5) the uncertainties in estimates of the tropical oceanic CO2 source, resulting from different wind products and gas exchange formulations.

Paul Wennberg - California Institute of Technology (NASA funded)
The Total Carbon Column Observing Network (TCCON): Ground-based Observations in Support of the Orbiting Carbon Observatory

The Total Carbon Column Observing Network (TCCON - www.tccon.caltech.edu) is a group of ground-based solar spectrometers that provide measurements of the atmospheric mass of CO2. The establishment of this network has been made possible with support from the Terrestrial Ecology program at NASA. In addition to providing validation for existing and future space-based measurements of CO2 columns (from, for example SCIAMACHY, OCO, and GOSAT), these observations provide a means to evaluate the information content of the column measurements. In our previous effort, we have shown that these observations allow improved estimates of the flux of carbon between the surface and the atmosphere to be obtained. The network currently has five stations operating with several new observation sites expected to come on-line this year. We plan to propose to use follow-on support to expand the network to provide better global coverage (adding, for example, a station in the Canadian arctic) and to improve and extend our retrievals to include CH4, CO, N2O and other gases. We will use the observations and those provided by NOAA's Global Monitoring Division in situ network to provide estimates of the strengths of the CO2, CH4, and CO fluxes globally.

Toby Westberry – Oregon State University (NASA funded)
Ecosystem Carbon Dynamics in High-latitude Seasonal Seas of the Subarctic North Pacific and North Atlantic

High-latitude seasonal seas are among the most temporally varying ocean regions, and they play a predominant role in global ocean carbon cycling. However, the seasonal dynamics of these regions can differ dramatically from one basin to the next. For example, seasonal patterns in chlorophyll (Chl) concentrations for the subarctic North Atlantic and North Pacific are markedly different and have a long history of documentation. The N. Pacific exhibits very constant and low Chl throughout the year, while the N. Atlantic exemplifies a productive spring bloom system. A number of hypotheses to explain this discrepancy have been proposed involving both top-down and bottom-up controls. The result has been a framework for relating phytoplankton-grazer coupling to ecosystem biogeochemical function, particularly export production. Understanding the controls on this coupling is critical for quantifying the role of high latitude oceans in carbon cycling and climate change.

Using new satellite information on phytoplankton biomass and physiology, we have discovered something rather unexpected in the N. Atlantic and N. Pacific: the two basins appear to have similar sized spring/summer “blooms” when assessed by satellite-derived phytoplankton carbon biomass (phytoC). If this preliminary finding is verified, it suggests that we need to re-evaluate controls on phytoplankton growth and loss terms, and the resulting regional carbon export. Differences between our new results and historical ones can be traced to the independent behavior of phytoC and Chl. In the N. Pacific, we find that spring/summer increases in phytoC are accompanied by substantial decreases in cellular Chl:C that effectively mask the bloom in terms of Chl. In the N. Atlantic, on the other hand, phytoC and Chl:C increase in parallel, giving rise to the classical spring bloom.

While our revised view of N. Pacific phytoplankton dynamics is intriguing and supported by parallel modeling studies, verification of our results and additional analyses are needed. The objectives of the project proposed here are to (1) collect necessary field measurements to test new satellite products upon which our preliminary analysis is based, (2) conduct a detailed error analysis of the bio-optical models employed to generate the new products, (3) investigate the implications of our findings on hypothesized control mechanisms for the two basins, and (4) assess the impact of our results on carbon export. The field component of this project involves 3 multidisciplinary research cruises during the first two years, with ship time coming at no expense to the project. These studies will also include deployment of new ARGO-like floats equipped with bio-optical sensors to provide multi-year match-up data with satellite products. In addition to supporting the research goals of this project, our field measurement suite will significantly enhance available high latitude data for subsequent studies by the ocean color community.