NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH16ZDA001N-CARBON
A.5 Carbon Cycle Science

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), the U.S. Department of Energy (DOE) Terrestrial Ecosystem Science Program, and the Ocean Acidification (OA) Program within NOAA. Proposals were requested for research and/or applied science investigations aimed at addressing five specific research themes. The five research themes solicited and the agencies participating in each them were:

1. Carbon research in critical regions, specifically: tropical terrestrial ecosystems, Arctic-boreal terrestrial ecosystems, North American continental margins (NASA, DOE, USDA-NIFA);
2. Blue Carbon and Carbon in Associated Ecosystems (USDA-NIFA, NASA);
3. Carbon dynamics across managed landscapes, specifically: urban-rural, forested-agricultural and terrestrial-aquatic (USDA-NIFA, NASA);
4. The impact of rising CO_2 on ocean ecology (NASA, NOAA); and
5. Carbon cycle science synthesis research (NASA, USDA)

NASA received a total of 135 compliant proposals in response to this NRA, of which 28 were selected by the four agencies. Of the 28 selected, NASA recommended 20 for funding, including two co-funded with the USDA-NIFA. For the two proposals co-funded by NASA and USDA-NIFA, the agencies will make two distinct awards (one from each agency) for each selection. Eight proposals were identified as 'selectable' and these were referred to the USDA, DOE, or NOAA for funding consideration by that agency. The total funding to be provided by NASA for the selected investigations is approximately $21.5 million over three years. The investigations recommended by NASA are listed below and include the Principal Investigator, institution, project title, agency providing the funding, and a project summary; co-investigators are not listed here. NASA will post the selections made by the other participating agencies after they have completed their required processes for award confirmation.

William Balch/Bigelow Laboratory for Ocean Sciences
GNATS: An Experimental Observatory Documenting the Gulf of Maine Carbon Cycle
16-CARBON16-0104

Carbon cycling within coastal continental margins is fundamentally important to the global carbon cycle. Coastal oceans contribute about 1/3 of the total marine productivity across the globe (or ~ 16 Pg (1Pg =1E15g)). They receive ~1Pg from terrestrial discharge via rivers. They contribute about half of the total global ocean new production (3.6Pg). These are big numbers—yet we still do not know whether coastal margins are net sources or sinks for carbon. There are four components of the carbon cycle—particulate organic carbon (POC), particulate inorganic carbon (PIC), dissolved organic carbon (DOC), and dissolved inorganic carbon (DIC). The first three carbon fractions (POC, PIC, and DOC) can be estimated using optical proxies while the fourth (DIC, associated with ocean acidification) is best measured chemically. There are few coastal time series that assess all of these components. This proposal is a successor proposal for the Gulf of Maine North Atlantic Time Series (GNATS), an 18-year transect time series across the Gulf of Maine (GoM) using ferries, small research vessels, and gliders to measure all four parts of the carbon cycle. During several anomalously wet years, GNATS documented some fundamental shifts in the GoM such as significant drops in primary production (associated with POC and PIC production) and the appearance of unexpected highly scattering particles <0.2um diameter (hence DOC), well out to sea. We have also observed winter DIC concentrations across the GoM, low enough that the entire GoM can show low aragonite saturation values < 1.6—levels that are known to be inhibitory to calcification by certain marine organisms. Here we are proposing to (a) continue the GNATS for three years with eight cruises per year (six aboard a commercial ferry and two aboard a small research vessel) focusing on the four parts of the GoM carbon cycle, (b) further validate satellite ocean-color sensors for radiance and other products in this complex optical environment, (c) make GNATS into an experimental observatory by testing a range of hypotheses on changing productivity and the source of submicron scattering particles, (d) construct carbon cycle models of the GoM based on biogeochemical fluxes and allometric scaling—performing model intercomparison and hypothesis testing using the models, and (e) continue a collaboration in which we are deploying an above-water LIDAR (light detection and ranging) from the GNATS, assessing the LIDAR's ability to profile optical properties deeper than one optical depth. We include previous results demonstrating that we can track water masses using temperature and salinity, then document co-varying changes in POC (based on an optical proxy to particle backscattering), oxygen, and chlorophyll in these water masses; these allow the estimation of net primary production (NPP) and net community production. We also show how allometric scaling models can contribute to these estimations. We are requesting funds to upgrade one of our Slocum gliders to carry a SUNA nitrate sensor that will allow us to more accurately estimate nitrate depletion and NPP. These glider results will allow us to better discern and quantify whether the GoM is a net source or sink for carbon. Along with a whole host of environmental variables, GNATS provides critical insights about the major processes affecting all aspects of the carbon cycle in this

temperate coastal region: changes in productivity, hydrography, phytoplankton functional groups, land–sea carbon transport caused by major riverine flood events and droughts, plus potential changes due to ocean acidification. Such results will provide insights to other temperate coastal zones around the globe. Simply put, a sustained, combined measurement and modeling approach, such as the kind we are proposing here, is the optimal way for NASA to predict changes to all four parts of the marine carbon cycle as a function of long-term climate change in this complex coastal zone.

Jiquan Chen/Michigan State University
Socioecological Carbon Production in Managed Agricultural-Forest Landscapes
16-CARBON16-0106

Land use, land cover changes, and ecosystem-specific management practices are increasingly recognized for their roles in mediating the climatic effects on ecosystem structure and function. A major challenge is that our understanding and forecasting of ecosystem C fluxes cannot rely solely on conventional biophysical regulations at any scale, from the local ecosystem to the globe. A second challenge is to quantify the magnitude of the C fluxes from managed ecosystems and landscapes over the lifetime of the C cycle, and to deduct the various energy inputs during management. Our overall objective, consequently, is to quantify the landscape-scale C footprint of both managed agricultural-forest landscapes and people, using the Kalamazoo watershed in southwestern Michigan as our testbed. The underlying mechanisms from both human activities and biophysical changes on ecosystem C dynamics at different temporal and spatial scales will be explored by modeling total net ecosystem C production (including physical and social C fluxes), exploring the complex relationships through Bayesian structural equation modeling (SEM), and performing a spatially-explicit LCA on the total C production within the contrasting landscapes and the entire watershed.
We will take a bottom-up approach to quantify landscape C fluxes and a top-down scaling effort to characterize the contributions of climatic change, land use, and site-specific management practices at two spatial scales: landscapes with contrasting structure and composition and the entire Kalamazoo River watershed. Our overarching hypothesis is that social C flux is more responsible than physical C flux for the dynamics, and especially the uncertainty, of the cumulative CO2 equivalent (CO2eq) production of the landscapes. However, their proportions vary significantly among the landscapes and over history because of the great variations in land conversions, land use, site-specific management practices, and climatic changes/extremes. A combination of remote sensing technology, available geospatial data, historical records of management practices, survey of historical practices, a land surface model (Community Land Model, CLM), in situ measurements of C fluxes from seven permanent and two mobile eddy covariance flux towers, historical CO2eq import/export records, biophysical/empirical modeling of key C-cycle process, and LCA will be used to achieve our study objectives.
Through our collaborations with the LTER/GLBRC at KBS, Planetek, the RS&GIS Center, MSU the three research tasks will provide an understanding of the changes and regulations of CO2eq production in the four contrasting landscapes and the entire watershed: (1) model the dynamics of the physical C fluxes of the watershed for 1978–

2018 and of the four contrasting landscapes for 1938–2018; (2) estimate the social C fluxes for the same time period; and (3) diagnose the underlying mechanisms from land use, land cover changes, site-specific management practices, mean climatic change, and climatic extremes on the total CO2eq fluxes at the two spatial and temporal scales through Life Cycle Analysis. The physical C fluxes of the landscapes and watershed will be quantified through the Community Land Model after ecosystem-specific parameterization and independent validation. Back-of-the-envelope calculations will be applied to estimate the social C fluxes with precision land cover, create land ownership maps, and take extensive surveys of land owners for the same time period. We anticipate a reliable forecasting method will be developed through modeling alternative climate and management practices for the future. Our objectives will also be enhanced through the broad engagement of stakeholders and the wide distribution of our data and scientific products. This ambitious study could not be successful without the many relevant projects in the study region, rich historical data, existing infrastructure, as well as a collaborative research team.

Christian Frankenberg/California Institute of Technology
Evaluating Crop Productivity Using Solar Induced Chlorophyll Fluorescence Measured From Ground and Space
16-CARBON16-0119

Remotely sensed Solar Induced Chlorophyll Fluorescence (SIF) can be a very effective proxy for gross primary production in agricultural environments. Agricultural systems exhibit the largest peak carbon fluxes and are playing an increasingly important role in the global carbon cycle. CO2 drawdown in summer can result in boundary layer CO2 concentrations close to pre-industrial levels, potentially limiting growth for C3 crops and natural landscapes. Intensification of agriculture also impacts changes in CO2 seasonal amplitudes as are related to cooling of US Midwest summer temperature extremes (Mueller et al, Nature CC, 2015). In summary, crops, esp. in the Midwest, alter the regional and global carbon cycle as well as latent and sensible heat fluxes, affecting summer temperatures, regional climate and precipitation.

SIF can provide unique insights in the carbon cycle of agricultural systems and forest canopies. For crops, both remote sensing indices for greenness as well as carbon cycle models, that are largely calibrated in forest systems, fail to reproduce the observed large carbon uptake rates. However, SIF clearly identifies the higher carbon fluxes (Guanter et al PNAS, 2014) and carbon use efficiency (Guan et al, GBC, 2015) of crop systems. Initial comparisons with OCO-2 have already shown strong local features of CO2 drawdown associated with high fluorescence values in the Midwest crop areas, strongly contrasting forested systems. Despite this potential, many up-scaling approaches using SIF are still empirical and lack validation and mechanistic understanding. We posit that agricultural systems are an ideal study area to address this as I) traditional vegetation indices fail to reproduce high carbon uptakes, II) canopy structure is well defined and can be treated in 1-Dimensional radiative transfer models, and III) provide a wealth of additional information via harvest statistics.

The goal of this proposal is to provide a solid framework for using SIF to estimate gross and net carbon fluxes in agricultural systems.

We will leverage recent developments for measuring chlorophyll fluorescence and carbon exchange from the leaf to the canopy and landscape scale. This includes a modified Fluorescence and Gas Exchange system (Walz), a set of novel high-resolution ground-based SIF spectrometers (PhotoSpec, UCLA/Caltech/JPL) enabling independent measurements of SIF at 680 and 740nm as well as surface reflectance (300-900nm) with full 2D scanning capabilities, air-borne observation already acquired with the Chlorophyll Fluorescence Imaging Spectrometer (CFIS, JPL) as well as space-based data from OCO-2 and TROPOMI, to be launched in October 2016 (ESUSPI proposal for SIF retrievals is funded).

We will deploy three ground-based PhotoSpec systems at selected Fluxtower sites in different agricultural systems to measure SIF and reflectance (bi-directional) at <10min temporal resolution over the full growing cycle in parallel with direct carbon exchange measurements (NEE, GPP) from the FluxTower at 30min resolution. SIF directionality and impact of spatial averaging, which has thus far been poorly defined, will be assessed using the 2D scanning capability of PhotoSpec. In addition, leaf-level measurements of gas exchange and the full fluorescence spectral shape will be performed at different growing stages. This full set of observations, in conjunction with SIF/GPP modeling (Soil-Canopy Observation of Photosynthesis and Energy, SCOPE), will enable us to derive a robust scaling approach from the leaf to the canopy and landscape scale. Ultimately, we will use satellite data to determine carbon uptake at the county level (bi-weekly) and compare annual totals against available yield statistics. Ground-based measurements in irrigated vs. rainfed will also be used to evaluate the relationship of SIF with latent heat fluxes and the impact of water stress (both in terms of soil moisture as well as atmospheric evaporative demand)."

Niall Hanan/South Dakota State University
Bistability and Feedbacks in Tropical Woodlands and Savannas: Carbon Cycle Implications of Changing Climate and Management
16-CARBON16-0117

We propose to study wood biomass distributions and carbon cycle dynamics under current and future climate and land use in the drought-seasonal savannas and woodlands of Africa. We will focus on the drought seasonal systems of Africa because, (1) they represent a key ‘missing-link’ in our understanding of global biomass distributions, (2) they are one of the major sources of inter-annual variability in terrestrial carbon sources and sinks associated with variability in productivity and fire, (3) the potential amplifying feedbacks and thresholds in savanna systems suggest that gradual global change (atmospheric CO2, rainfall and temperature) may trigger threshold responses in ecosystem processes (with associated rapid changes in carbon source-sink distributions), (4) human management of key processes (fire, herbivory, wood harvest, agricultural practices) can also trigger strongly divergent vegetation structure responses, providing

opportunities for management of carbon sources and sinks, and because (5) methods developed in African seasonal woodlands and savannas will be applicable to the pan tropical drought seasonal systems of South and Central America, South Asia and Australasia.

Goal 1 is to create improved remote sensing products using methods and field data optimized for the assessment of woody vegetation cover and biomass in the tropical woodlands and savannas of Africa. As part of this research we will finalize a tree cover product we have been developing for the African savannas, and propose a novel approach to woody biomass estimation to be developed and tested as part of this research.

Goal 2 is to analyze the current distributions of wood biomass in African savannas to develop an empirical understanding of how carbon is distributed in relation to recent climate, phylogeny, soils and anthropogenic management of fire, grazing and wood harvest.

Goal 3 is to develop empirical projections of likely future distributions of biomass in African drought-deciduous woodlands and savannas based on IPCC climate and land use change scenarios, assuming that future sensitivity of savanna and woodland vegetation to climate and management will be similar to current patterns.

Goal 4 is to resolve the debate over the presence and nature of bistability in drought-seasonal Africa. This will be achieved via a detailed multi-scale investigation using remote sensing data (1-1000 m scales) to explore the mechanisms likely important across scales.

Goal 5 is to integrate data and insight from the earlier analyses to calibrate and validate a dynamic tree-grass vegetation model that we will use for process-based simulations of climate change and management impacts on woody biomass and carbon distributions in Africa during the 21st Century.

Ralph Keeling/University of California, San Diego
Detection, Quantification, and Analysis of Changes in Boreal and Arctic Ecosystems Using Measurements and Models of CO2 and Its Isotopes
16-CARBON16-0034

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 makes 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. This proposal is responsive to the solicited research Theme #1, relating to carbon cycling in Arctic and boreal regions, particularly to changes brought about by warming, CO2 and nitrogen fertilization, and associated changes to hydrology and carbon storage. It is also responsive to the need for “cross-cutting research activities”, e.g. for improving observations by providing an archive of CO2 samples to support development

of novel isotopic applications related to land carbon cycling, and it is responsive to the need for modelling studies in relation to atmospheric transport modelling, ecosystem component modelling, regional and global modelling.

This proposal would provide core support for the measurement activities of the Scripps CO2 program, which sustains measurements from a flask sampling program from an array of ten stations distributed from the Arctic to the Antarctic including the iconic Mauna Loa continuous record. The program complements the larger NOAA ESRL program by providing critical redundancy for state of the art measurements, by ensuring continuity of the longest records of critical importance, and providing interpretive capabilities for understanding the data significance. The program also complements the DOE modelling (ACME) and measurements programs (NGEE-Arctic, FACE, Ameriflux) by providing cross cutting constraints on large-scale carbon cycling and it is highly relevant to the DOE Scientific Focus Area on Biogeochemistryâ€"Climate Feedbacks. By sustaining the longest records of CO2 and isotopes and advancing related interpretive capabilities, the Scripps program is well positioned to make agenda setting discoveries related to carbon cycling and carbon/climate feedbacks.

In addition to supporting the continuation of these observations and their improvement, this proposal will support a collaboration with Drs. Peter Thornton and Lianhong Gu of ORNL which builds on two recent significant discoveries from the program. The first is the evidence of the large increase in the seasonal amplitude at high northern latitudes documented by Graven et al. (2013). The second is emergent evidence for a shift towards higher photosynthetic discrimination both globally and at high northern latitudes. Both discoveries are highly relevant for understanding ongoing changes in arctic and boreal ecosystems. Both potentially provide critical insights into the coupled carbon, nitrogen, and water cycling in the context of ongoing changes. The collaboration will entail combined data synthesis and modelling activities, taking advantage of recent advances in global and plant-level modelling capabilities at ORNL. The collaboration is aimed at answering these key questions:

1) How can the observed seasonal cycles in CO2 concentration be used to constrain the representation of nitrogen cycling within land surface models?

2) How does the formulation of nitrogen cycling in models impact the predicted photosynthetic discrimination on seasonal time scales?

3) What plausible changes in leaf level processes can account for the long-term changes in photosynthetic discrimination suggested by atmospheric data?

Samuel Laney/Woods Hole Oceanographic Institution
Riverine Carbon Contributions to Alaskan Arctic Coastal Margins
16-CARBON16-0028

This research seeks to better quantify the seasonality and variability in the riverine contribution of organic carbon into Arctic Ocean coastal margins. Rivers feeding the coastal Arctic Ocean drain several types of biomes and represent a major source of particulate and dissolved organic carbon (POC and DOC) to Arctic coastal margins. Climate-driven changes to Arctic terrestrial biomes will almost certainly alter the magnitudes and relative contributions of POC and DOC that different rivers transport into their adjacent coastal oceans. Direct assessment of river-specific baselines for this terrestrial carbon input has been challenging because much of this carbon is delivered by the spring freshet that occurs while the coastal ocean is still covered by landfast sea ice. This project will examine the seasonality and magnitude of this carbon transport and its relationship to coastal hydrography and circulation, the spring freshet, seasonal ice dynamics, and remote sensing variables available during the freshet such as sea ice cover and ice morphology.

This research involves a two-year observational study on the Alaskan Beaufort Shelf using bio-optical moorings and direct, through-ice monitoring to assess the magnitude and timing of riverine POC and DOC contribution into the coastal Arctic. Six moorings will be deployed near Prudhoe Bay at the mouths of two rivers that drain terrestrial biomes with different vegetation and precipitation characteristics: the Kuparuk River which drains a primarily tundra biome, and the Sagavanirktok River which drains the coastal plain and the north slope of the Brooks Range. Sensors will measure optical proxies for POC and DOC over two full annual cycles, most critically in the period encompassing the spring freshet when riverine transport of POC and DOC is largest but when these coastal waters remain ice-covered and thus not yet directly observable by remote sensing. Monthly-scale field studies will be conducted in the late spring, immediately prior to the freshet, to deploy sensor clusters through the sea ice to directly measure these optical proxies over the course of the freshet until sea ice cover degrades and coastal waters become visible to remote sensors. These two observational efforts will generate unique and valuable time series of proxies for POC and DOC as well as key environmental parameters related to coastal circulation, sea ice cover, and river discharge dynamics. These will be used in a subsequent analysis to quantify how the spatial and temporal evolution of riverine DOC and POC injection by these two rivers relate to physical factors such as riverine seasonal flow and freshwater runoff, coastal hydrography and circulation, and importantly, seasonal sea ice cover.

By examining two representative rivers that drain different types of terrestrial biomes, this study will provide insight into possible source-river differences in organic carbon transport into these seasonally ice-covered Arctic coastal margins. Having such direct, long-term observations of proxies for the POC and DOC delivered by the spring freshet is essential for reducing uncertainties about key aspects of the organic carbon cycle on the Alaskan Arctic coastal margin:

- What is the timing and magnitude of POC and DOC injection into Arctic coastal margins?

- How can autonomous systems help to assess differences in POC-DOC contributions by rivers that drain such different types of biomes (e.g., tundra vs. alpine)?

- How do ice cover, hydrography, circulation, winds, and freshwater input affect the areal distribution of water column POC and DOC on this shelf, during the freshet?

- How might available remote sensing variables during this time of year be used to better understand similar riverine contributions of POC and DOC more broadly across Arctic coastal margins in the Beaufort Sea and beyond?

Deepak Mishra/University of Georgia, Athens
A Tidal and Species Based MODIS GPP Product for Estimating Marsh Blue Carbon Across the Southeastern United States
16-CARBON16-0070

Coastal marshes are atmospheric carbon sinks, depositing as much as 1713 g C m-2 yr-1 in soils,which has been termed “blue carbon”. However, marshes are threatened by multiple causes,especially sea-level rise. Remote monitoring of landscape Gross Primary Productivity (GPP), a proxy for carbon sequestration potential, helps assess C sinks and facilitate prioritization of restoration and conservation. We propose to create a novel MODIS GPP algorithm for coastal marshes that accounts for the species specific influence of tidal inundation on plant production. We will calibrate our models across four salt and brackish marsh sites across three states (Louisiana, Mississippi, Georgia) and covering three species (Spartina alterniflora, Spartina patens, Juncus roemerianus). Models will be based on a combination of eddy covariance carbon flux data, monitoring of plant level photosynthesis, field and spectral estimates of species composition and plant biophysical variables, as well as accurate measures of marsh surface inundation. The ultimate product will be regional maps of GPP that assists with monitoring coastal marsh blue carbon across the southeastern United States. This work relies on MODIS based remote sensing to scale from carbon flux and field data to regional GPP assessments. These remote sensing GPP models will be based on two approaches: production efficiency models (PEM) which compute GPP from absorbed solar radiation and canopy photosynthesis models (CPM), based on biophysical variables including leaf area index. We will adapt PEM and CPM GPP models to tidal marshes from 500 m tide-indexed MODIS daily surface reflectance data.

As part of this study, we will solve problems that complicate tidal marsh GPP estimates. For example, we will improve marsh surface flooding estimates, generate a plant-centered GPP model that reduces the influence of tidal exchange on carbon accounting,

adapt new spectral biophysical indices that account for the influence of wetland moist soils on reflectance, and use chlorophyll flouremetry to measure plant level productivity during high tides, a time when eddy covariance towers can not estimate carbon flux. We also will map species composition and generate light use efficiency estimates for common coastal marsh species. Consequently, we will be able to generate species invariant and tide robust CPM and PEM plant centered GPP. The crux of this proposal is to combine multiple sources of information to generate our ultimate product, regional maps of MODIS derived plant GPP spanning 2000-2020 and perform a comprehensive phenological analysis.

End-users engagement is also important. We will make end-users, such as coastal managers,aware of the tools we will develop, provide access to tools and instructional documents, and train staff to use the tools to inform decision-making. To ease this task, we will develop a Python plug-in for QGIS, an open source geospatial software and host our source code on GitHub to facilitate future and community model development. Applications of our work include estimating CO2 exchange after natural and anthropogenic disasters, modeling the influence of sea level rise on marsh health, understanding coastal C sources and sinks, and use by government agencies to assess restoration trajectories for conservation and management of critical coastal ecosystems.

J. William Munger/Harvard College
Multi-Scale Data Assimilation and Model Comparison for ABoVE to Identify Processes Controlling CO2 and CH4 Exchange and Influencing Seasonal Transitions in Arctic Tundra Ecosystems
16-CARBON16-0047

Background and Objectives
Transition seasons in Arctic tundra are particularly important for the ecosystem's short- and long-term carbon balance and for the long-term carbon balance. Climate-driven changes in the timing of seasonal transitions can affect whether the annual carbon balance for an ecosystem is positive or negative, but detailed understanding of processes that control arctic carbon cycling during this period lags behind understanding of growing season processes. Year-round eddy flux tower and seasonal aircraft observations of CO2 and CH4 fluxes at far northern tundra sites demonstrate previously unrecognized carbon exchange during transition seasons. Notably, the spring onset of carbon uptake is not accurately predicted using vegetation greenness defined by traditional satellite vegetation indices, and elevated carbon emissions extend well into the cold season when air and surface soil temperatures have fallen below freezing. We propose an in-depth analysis that integrates surface and airborne in situ data for CO2 and CH4 concentrations, remote sensing of vegetation and soils, satellite observations of Solar Induced Fluorescence (SIF) and CO2 and CH4 columns, tower fluxes, and meteorological products into a model-data synthesis framework that will improve our understanding of how the large pool of carbon stored in frozen tundra soils is responding to changing climate conditions. We will examine whether observed changes in transition season carbon exchange at local scales

are occurring throughout the entire region and identify the environmental state variables that can best predict the timing of seasonal transitions across the tundra.

Methodology
We will test empirical functional models and process-based terrestrial ecosystem models against observations by comparing measured atmospheric CO2 and CH4 concentrations to concentrations predicted from applying atmospheric mixing and transport models to predictions of carbon uptake and emission. Using atmospheric data rather than flux measurements at a particular site tests whether the models accurately represent the regional mix of different environmental conditions and vegetation characteristics.

Significance
The proposed work responds to the call for carbon research in the critical arctic ecosystem. Specifically, we will use an array of observational data to challenge and improve ecosystem models at scales from individual landscape patch up to regional scales. By quantitatively assessing model simulations against observations at regional scales we will identify gaps in our understanding of carbon dynamics and climate feedbacks, and contribute to an improved quantitative and predictive understanding of processes that regulate carbon cycling from northern terrestrial ecosystems.

Raymond Najjar/Pennsylvania State University
Response of Carbon Cycling to Climatic and Anthropogenic Perturbations in Two North American Subtropical Estuaries
16-CARBON16-0087

Subtropical estuaries worldwide are facing increasing pressure from human population growth, development, and climate change perturbations, i.e, more extreme storms, warming, sea-level rise, hydrological changes, and changing riverine loads of nutrients, sediments, and organic carbon. We propose to use Tampa Bay and Biscayne Bay as test beds for studying subtropical estuarine carbon cycling at temporal scales ranging from months to decades. In addition, we propose to fill a key data gap by making field measurements of net primary production (NPP), which are very limited in the subtropical estuaries.

The central objective of this proposal is to understand how carbon cycling in Biscayne Bay and Tampa Bay responds to climatic and anthropogenic perturbations. To address our central objective, we will complete five main tasks:

1) Synthesize historical water quality data sets in Biscayne Bay and Tampa Bay.
2) Make in situ measurements of key carbon fluxes, carbon stocks, and optically active materials, to better constrain the carbon cycle in these systems and provide data for remote sensing algorithms.
3) Use data from MODIS and SeaWiFS to develop and apply remote sensing algorithms for primary production and dissolvd organic carbon in the two estuaries, which will extend the spatial and temporal coverage of in situ measurements.

4) Create time-dependent diagnostic mass-balance box models of the fluxes of carbon and related constituents in the two estuaries using the in situ and remote sensing data sets.
5) Analyze the model results to determine the factors affecting the fluxes of carbon and related constituents in the two estuaries, specifically climate and anthropogenic activity.

The derived estimates of biogeochemical fluxes allow us to investigate a number of hypotheses regarding the impacts of climate and anthropogenic activity on biogenic processes that influence carbon and related elements in subtropical estuaries. Specific hypotheses that we will test are the following:

1) H1: Tropical cyclones cause subtropical estuaries to become more autotrophic.
2) H2: The long-term decline in nitrogen loading to Tampa Bay has caused it to become more heterotrophic with time.
3) H3: High streamflow results in low net ecosystem production (NEP) through increases in sediment delivery, which lead to declines in water clarity and NPP.
4) H4: NPP and NEP are correlated with phosphorus in Biscayne Bay and nitrogen in Tampa Bay.
5) H5: Spatial variations in NEP are dictated by the light field, such that turbid waters are more heterotrophic than clearer waters.
6) H6: Denitrification is enhanced when particle flux to the seafloor is high.
7) H7: The biological sink of silicate (Si) is lower than expected based on NPP and the Si:C ratio of diatoms.

This proposal is responsive to the goals of NASA, USDA-NIFA, DOE, and NOAA, who "seek proposals to improve understanding of changes in the distribution and cycling of carbon among the active land, ocean, coastal, and atmospheric reservoirs and how that understanding can be used to establish a scientific foundation for societal responses to global environmental change."•

Christopher Neigh/NASA Goddard Space Flight Center
Disturbance, Growth, and Recovery of Boreal Forests Spanning the Satellite Era: 3D Structure, Site Index, and Ecosystem Carbon Flux with Changing Climate
16-CARBON16-0124

We propose to study the growth, disturbance, and carbon storage of northern hemisphere forests to "improve understanding of…Arctic/Boreal terrestrial ecosystems that may be approaching a potential tipping point with regard to the release of stored carbon". At continental scales, climate change is altering vegetation productivity, dynamics, and carbon (C) sequestration. These shifts are reflected in vegetation canopy structure (cover and height) that vary across the landscape. Now, to understand environmental constraints on canopy structure and to predict impacts of environmental change on vegetation cover, C-stock/flux, we propose to correlate Landsat derived Global Forest Cover and Change (GFCC) estimates to environmental factors and incorporate the relationships into Dynamic Global Vegetation Models (DGVMs). Studies thus far have found large

increases in productivity and C-flux. But turnover rates in models remain a large source of divergence between them. Site Index (SI) is a parameter widely used in forestry to describe the potential height-growth of trees in a particular location or "site." SI knowledge will reduce uncertainty of live C turn over into soil C pools. We will estimate rates of forest-canopy disturbance, growth, and C-flux by pairing sub-meter resolution estimates of canopy height/cover and structure with a ~40 year time-series of biome-wide records of stand disturbance, age, and environmental conditions. We will estimate boreal forest SI to capture spatially explicit patterns of forest growth.

With prior NASA Carbon Cycle Science program support (13-CARBON13_2-0377), we developed samples of canopy-cover and height estimates from airborne LiDAR measurements and sub-meter spaceborne stereo image pairs. We used these datasets to calibrate/validate global 30-m tree cover estimates across the boreal biome. These results improved the accuracy of the NASA/University of Maryland (UMD) GFCC and refined models and estimates of the location of the Taiga Tundra Ecotone (TTE). Our prior study examined ~2,000 WorldView stereo pairs. In this study, we will analyze > 10,000 image pairs. From this sample, we will develop biome-wide estimates of forest stand age from the entire Landsat archive, 1970s until present. This extension of the disturbance record will enable modeling/analysis of forest growth and disturbance across a ~40-year chronosequence—a time span necessary for studying slow-growing boreal forests. We will develop a chronosequence of canopy structure in relation to stand age to understand topographic and climatic effects on canopy structure and growth. 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 sufficiently comprehensive to establish a map of SI for northern forests.

Our objectives are to:

1. Produce a stand-history/forest-age map: using a time-series of forest cover at annual, sub-hectare resolution spanning the entire Landsat archive pan-boreal, from 1972 to present;
2. Model and estimate forest growth potential: using a chronosequence of tree-canopy cover and height from samples of WorldView-1, 2, and 3 stereo imagery to estimate height-growth potential as the forest Site Index (SI); and
3. Estimate pan-boreal forest net C-flux: by incorporating stand age and SI into the process-based Lund-Potsdam-Jena (LPJ) DGVM.

This work addresses NASA’s interest in C dynamics in Arctic-Boreal Terrestrial Ecosystems. Our work will contribute directly to NASA’s interests and can contribute data and science analysis to the proposed Arctic-Boreal Vulnerability Experiment (ABoVE). DGVMs that require SI and forest age structure can use results from this work to reduce the currently large uncertainties in terrestrial C-flux estimates.

Peter Raymond/Yale University
Magnitude and Controls on the Lateral Transport of Carbon via Streams and Rivers
16-CARBON16-0069

Inland waters cover a small area of the planet and thus their impact on global budgets has received limited systematic study. Nevertheless, idiosyncratic approaches, have, in recent years, suggested that inland waters are key "hot spots" that control the processing of carbon at the global scale. The study of the roles of both the ocean and the terrestrial biosphere have made stunning achievements by launching systematic large regional- to-global networks. In contrast, the study of inland waters has lagged, largely due to lack of any centralized coordination and synthesis.

The proposed synthesis activities will launch a systematic program to refine and scale-up inland water fluxes. The proposal will catalyze an international group of scientists with specialties ranging from geomorphology to remote sensing to biogeochemistry. The lead PI, Raymond, led a grass-roots effort to include inland waters in regional and global fluxes as part of the Global Carbon Project's (GCP) REgional Carbon Cycle Assessment and Processes (RECCAP) project. One of the conclusions of the RECCAP work is that sustained, organized study would be highly beneficial moving forward. The proposed work consists of a number of research activities in Years 1 and 2 that have already been defined as major shortcomings coupled with a series of workshops to continue and broaden synthesis activities, with emphasis on engaging scientists in tropical regions that have little data.

Calculating the inland water CO2 flux involves global spatially explicit knowledge of the gas transfer velocity, surface area and CO2 concentration. For surface area we will improve 1) the temporal and spatial resolution of water surface area, which is currently at annual and >1000's km2 scales, 2) Develop spatial maps for streams at high latitudes, which are currently lacking, 3) improve data sets and knowledge of hydraulic coefficients, which are currently derived from the United States only and contain biases due to the use of gaging station data. To improve estimates of dissolved CO2 concentration we propose to 1) create standard operating procedures (SOP's) for the inland water community, 2) begin the creation of a database and 3) facilitate a network for direct CO2 measurements in undersampled tropical regions. For the gas transfer velocity, the aforementioned improvement of hydraulic coefficients is critical for improved estimates.

We are budgeting for one technician and one postdoctoral scientist to lend support to different tasks. For some tasks, work is already underway (e.g., high latitude surface area) and the proposed synthesis activities will link groups working on inland water's with the global inland water carbon community. In other cases (e.g., creation of SOP's) progress will be made at the proposed workshops through discussion and break out groups.

The inland water community has made recent scaling advancements, but the community still suffers from a lack of cohesion that precludes a systematic and sustained approach. A major impact of the proposed work is to create a coordinated network of international scientists, including representation from regions that are generally not included, for scaling inland water fluxes. The proposed work centers exclusively on carbon, which is an element with obvious societal importance due to its radiative heating potential in the atmosphere. The proposed products, however, will be important to any element in aquatic environments that has a gaseous phase, is exported to the ocean, or is buried in inland lakes, reservoirs and wetlands. The initial team has a mixture of established and new career scientists which will be critical for maintaining a network into the future. The group also has budgeted room to grow and will strive to keep a wide range of scientist from both a career and background stand point.

Keith Rodgers/Princeton University
Evaluating Spatiotemporal Scales and Underlying Mechanisms for Emergence of Anthropogenic Trends in the Solubility and Biological Ocean Carbon Pumps
16-CARBON16-0096

An important question for the climate research community pertains to how the oceanâ€™s solubility and biological pumps will be perturbed by anthropogenic climate change. This will have important consequences not only for the coupled carbon-climate system, but also for ocean acidification and ecosystems. However, natural variability in the climate system will complicate the task of detecting anthropogenic changes in the carbon pumps, as measurements collected through the global carbon observing system represent a mixture of anthropogenic signals and natural background climate variability. One promising approach to unraveling the natural and forced trends is through the use of Earth system models (ESMs). Large (≥30 member) ensemble experiments run with ESMs provide a powerful means to identify both the forced (signal) and natural variability (noise) components of the Earth system evolution. By ensemble here, we refer to a suite of simulations with the same model with identical boundary conditions, but different initial conditions, so that modes of natural variability are randomized amongst the ensemble members for the duration of the simulation. From a modeling perspective, emergence of an anthropogenic signal occurs if/when the magnitude of the anthropogenic trend is sufficiently larger than the natural climate variability.
Preliminary results with a large ensemble of simulations with GFDL's ESM2M indicate that anthropogenic changes in the solubility carbon pump emerge significantly earlier than the biological carbon pump during the course of the 21st century. However, the timing and spatial structures of emergence of anthropogenic signals in the ocean carbon pump, in particular the biological carbon pump, are likely to be highly dependent on the particular ESM evaluated. ESMs diverge widely in their representation of the amplitude of the response of the biological pump. Therefore we propose to consider systematically the emergence characteristics of the solubility and biological carbon pumps for four Earth system models. Each of these ESMs have large ensemble experiments, allowing for the clean separation of anthropogenic and natural forcings, providing a means of evaluating both model uncertainty and random uncertainty in state-of-the-art ESM components of

the global carbon cycle. Particular emphasis will be placed on identifying mechanistic controls on the separation between the solubility and carbon pump emergence timescales, and how these vary among models and compare to observations. Additionally, we will use a multi-model suite of ESMs to evaluate climate-carbon feedbacks on the ocean carbon pumps, but consider both seasonal and mechanistic dependence of the climate-carbon feedback parameter. Finally, we will address model biases in the representation of natural variability through a novel suite of data-override experiments with GFDL-ESM2M that utilize remotely sensed products to constrain simulated recent and future decadal variability.
The relevance to NASA's Carbon Cycle Science synthesis goals will be derived from (1) the proposal leading to improved understanding, through model-to-model and model-to-measurement comparisons of the causes and impact of rising CO2 on ocean ecology, namely impacts and feedbacks on the ocean's biological pump, and (2) the project helping to set priorities for optimization of the remote sensing contributions to optimization of the observing system, so as to better capture both the natural variability of the carbon cycle and its anthropogenic transients. Central to the proposed work will be a framework for quantifying uncertainty and contributing to quantification of errors in trend detection with remote sensing.

Brendan Rogers/Woods Hole Research Center Inc.
Understanding the Causes and Implications of Enhanced Seasonal CO2 Exchange in Boreal and Arctic Ecosystems
16-CARBON16-0048

The amplitude of atmospheric seasonal CO2 cycles in high latitude environments has increased by 30-50% over the last 50 years. Roughly two-thirds of this increase is attributed to greater seasonal CO2 exchange in arctic tundra and boreal forests. Several plausible mechanisms have been highlighted but the overall contributions remain unknown, despite the implications for arctic and boreal carbon cycling and climate feedbacks.

From a broad perspective, the increasing amplitude can only be due to either increased net CO2 uptake in the growing season and/or increased efflux in the dormant season. A number of studies have identified this, but the contribution from each process remains uncertain. However, even a complete understanding at this level is not sufficient for diagnosing system changes and predictive modeling, as a variety of ecosystem processes and responses to global change could be responsible.

The proposed project works to fill this knowledge gap by presenting bottom-up estimates of ecosystem drivers leading to this amplitude trend. Estimates will be evaluated in the context of multiple top-down constraints. Because any one research tool is inherently limited, the project will utilize several tools and approaches to address multiple lines of inquiry within a hypothesis-driven framework. These include (i) large-scale and long-term remote sensing data sets, (ii) benchmarking, development, and experiments with a land surface model, (iii) multi-model intercomparisons, (iv)

atmospheric transport modeling, and (v) meta-analysis of in situ flux observations. Research tasks are linked through a set of complementary and tractable hypotheses.

Our primary goal will be to attribute the causes of the observed increased CO2 exchange in high latitudes. This will improve our collective understanding and ability to project high-latitude carbon dynamics. However, our proposed research will also advance several related topics of broad interest to the community. These include how vegetation properties have changed in tundra and boreal forests and how much change stems from disturbance; how climate and other factors have enhanced productivity; and how increased temperature, substrate quantity, vegetation cover, and snow dynamics have influenced dormant season respiration.

Our project addresses several high-level research questions and priorities for DOE, NASA, and the US Carbon Cycle Science Program as they relate to element 3.1.2 of the Carbon Cycle Science solicitation. Among others, these include (i) How do natural processes and human actions affect the carbon on land and in the atmosphere?, (ii) How are ecosystems impacted by increasing greenhouse gas concentrations and the associated changes in climate?, (iii) What is the direction and strength of Arctic/boreal climate feedbacks?, and (iv) How can we best represent mechanistic carbon feedbacks in Earth system models? Because of the strong links with process-level understanding, Earth system models, and climate feedbacks, we are recommending our proposal be reviewed by DOE. However, there are strong ties to NASA priorities and we propose to incorporate existing and novel remote-sensing based data sets into several project components; thus co-review with NASA would be appropriate.

Sassan Saatchi/Jet Propulsion Laboratory
Impacts of Droughts on Carbon Stocks and Fluxes of Amazonian Forest Ecosystems
16-CARBON16-0130

Climate change is projected to alter both the climate mean condition and variability, leading to more intense climate extremes such as severe droughts. Recent Amazonian mega droughts from a combination of intensified El Nino and Atlantic Multi-decadal Oscillations (AMO) have drawn attention to the vulnerability of tropical forests to extreme water stress as their ecological processes are more sensitive to climate extremes than changes in mean states of climate. With potential changes of the ecosystem function, such as slowing down of the forest productivity and changes in tree demography and composition, extreme climate variability may cause major impacts on the ecosystem level carbon cycling, limiting the large carbon uptake of tropical forests. Ground measurements and satellite observations of the 2005 and 2010 mega-droughts in Amazonia have already shown anomalously extensive fires during the drought years and increasing tree mortality for a period after the droughts.
In this proposal, we use a combination of satellite observations on hydro-ecological variables combined with ecosystem modeling over Amazonia to quantify the impacts and legacy of droughts on the carbon stocks and fluxes of forests of Amazonia over a period of more than 15 years. The proposed research will focus on the magnitude and extent of

the impacts of droughts on the carbon assimilation and dynamics of these forests by addressing the following questions:

1. How fast and to what degree do Amazon forests respond to and recover from extreme water stress?
2. What is the magnitude of the effects of recent drought and their legacy on the carbon stocks and fluxes of the Amazon forests?
3. To what extent does variation in forest structure and environment (climate & edaphic) impact the sensitivity and the ecological resilience of the Amazonian forests to climate variability and change?

Our research project is designed to quantify the impacts of the climate change and variability on the short and long-term carbon sequestration capacity of tropical systems. The results of the proposed work will improve our understanding of the response of tropical ecosystems to recent pervasive droughts and predict the function of the ecosystem when exposed to more frequent and extensive droughts in near future.

Scott Saleska/ University of Arizona
Testing Satellite-based Scaling of Tropical Forest Photosynthesis with a New Network of Cameras and Fluorescence Spectrometers in Amazonia
16-CARBON16-0032

We propose a study focused on using satellite remote sensing to address the basic question: What controls the response of photosynthesis in Amazonian forests to seasonal and interannual variations in climate? This question, despite its apparent simplicity, remains difficult for modern earth system models to answer, and is also the subject of continuing controversy in the remote-sensing literature. In the modeling arena, cutting-edge earth system models (ESMs) show significant divergence in their seasonal patterns of photosynthesis from observed whole-system photosynthetic fluxes at sites in the central Amazon. At the same time, satellite-based remote sensing studies continue a long-standing debate about whether forest photosynthetic seasonality derived from MODIS Vegetation Indices is an artifact of sun-sensor geometry or of actual vegetation dynamics.

We propose to use a new network of tower-mounted sophisticated cameras (including traditional 3-band phenocams, newly developed 4-band dynamic-range cameras and two hyperspectral imaging systems paired with new chlorophyll fluorescence spectrometers) to provide novel and rigorous tests of a range of satellite-based approaches, including traditional MODIS studies and newer solar-induced chlorophyll fluorescence products from GOSAT and OCO-2. We will combine these observations with sophisticated 3-D canopy radiative transfer modeling of canopy photosynthesis, reflectance, and fluorescence to represent the mechanisms of phenology and photosynthetic seasonality detectable by satellites. The overall objective of the project is to guide improvements in our understanding of tropical forest photosynthesis by collecting and integrating a suite of observations and modeling to (1) test hypothesized ecological mechanisms driving photosynthetic seasonality, (2) scale from leaves to canopy with hyperspectral cameras

that can also test sun-sensor geometry (BRDF) effects, and (3) use tested modeling products to discern Amazon forest responses to the large-scale 2015/2016 El Nino drought event.

The project will provide an extensive suite of new and unique datasets that enable us to fill, through advanced modeling techniques and analysis, critical knowledge gaps in current understanding of what controls the response of canopy photosynthesis and related functions in Amazonian forests to seasonal variation in climate. Four major types of datasets and data products will be delivered: (1) time-series observations of leaf-to-crown scale forest reflectance properties and atmospheric radiation from two innovative, ground-based imaging sensors (respectively, the Hyperspectral Vegetation Imaging System and the High Dynamic Range All-Sky Imaging System), (2) associated hyperspectral reflectance (400-1000nm) images of the canopy surface and visible interior, collected at multiple view angles to enable rigorous tests of canopy sun-angle effects; (3) associated canopy-scale solar-induced fluorescence observations to compare to new satellite fluorescence observations such as from GOSAT and OCO-2, and (4) results from state-of-the-art modeling of 3-dimensional canopy processes for radiative transfer and photosynthesis that integrate and link our observations from leaves to landscapes observable from space to tropical forest processes. These data products and the improved knowledge we achieve with them will contribute to testing and improving the treatment of tropical forest processes in ESMs, and hence, to improved predictions of forest response to long-term climate change.

Jorge Sarmiento/Princeton University
Determination of the Relationship Between Primary Production and Net Community Production in the Southern Ocean Through the Use Profiling Floats, Satellite Data, and Ecosystem Models
16-CARBON16-0100

Challenge: The export of organic carbon in the Southern Ocean exerts a major control over the nutrient supply to the global upper ocean, driving up to 75% of the biological production north of 30°S. This exported carbon is the residual component of organic material produced via photosynthesis which is transferred and respired across different trophic levels of the ecosystem, and is defined as net community production (NCP). Satellites provide the most synoptic estimate of NCP by combining ocean color data of chlorophyll and primary production with estimates of the ratio of export or new production to primary production. However, satellite estimates show significant discrepancies with in situ calculations of NCP. In situ annual NCP rates show relatively little variation in the ocean, with 2-3 mol C m-2 yr-1 measured in various ocean locations. In contrast, satellite estimates of productivity and subsequent export show differences between the sub-tropics and sub-polar gyres of two fold. The discrepancy between in situ and satellite estimates is due to uncertainty in the retrieval of biological quantities from ocean color data, as well as important gaps in our understanding of the link between primary production and export. The export ratio and resulting NCP are important constraints on global earth system models and their ability to reproduce the

observed ocean nutrient and carbon cycle is directly related to these processes. Reconciling satellite and in situ estimates of carbon export and understanding the ecological processes that drive NCP in the Southern Ocean will allow us to better constrain and inform models that aim to project the future carbon cycle.

Opportunity: The SOCCOM project has deployed more than 50 floats as of June 2016, representing the first large-scale array of contemporaneous oxygen, nitrate, pH, backscatter, and fluorescence measurements with the goal of quantifying biogeochemical processes in the Southern Ocean through a mixture of unprecedented year-round measurements, data-assimilating and earth system models. These data and model products, combined with novel satellite tools and improved prognostic ecosystem models, present an opportunity to estimate in situ NCP and link satellite-derived primary production to the fraction of exported carbon both observationally and mechanistically, thereby advancing our ability to utilize satellite data to determine carbon export.

Goal: In this proposal we seek to use float measurements of biogeochemical tracers to produce mass-balance estimates of NCP paired with satellite-derived primary production to determine export ratios for the Southern Ocean and compare these against traditional algorithms. We will then use a regional biogeochemical model to simulate the observed in situ NCP patterns and understand the ecosystem processes driving them. Our goal is to address the following overarching question: What are the ecosystem controls on the relationship between primary production and export production in the Southern Ocean?

Relevance: The essence of this proposal is to improve the utility of satellite observations for understanding biological carbon export through the synthesis of satellite products, in situ observational data, and an ecosystem model. In this way, this proposal directly responds to program A.5 Carbon Cycle Science, 3.6 Cross-cutting research Topics, under both 3.6.3.1 Improved Observations and 3.6.3.2 Modeling, as we seek to address the limitations on “scientific understanding of the carbon cycle” due to the “amount and quality of relevant observations.” Through this proposal we also address Theme 1 of the A.5 Carbon Cycle Science call, Carbon Research in Critical Regions, due to the critical role of the Southern Ocean in the exchange of carbon between the ocean and atmosphere and in acting as the largest repository of unutilized surface macronutrients in the ocean.

Conghe Song/University of North Carolina, Chapel Hill
Impacts of Land-Use/Land-Cover and Climate Changes on the Gross and Net Primary Productivity in the Southeastern USA
16-CARBON16-0046

The southeastern US is characterized by generally abundant in precipitation and high radiation inputs; therefore the gross and net primary productivity (GPP and NPP, respectively) of the region are high, making it a major carbon sink in the conterminous US. NPP is also the basis for food and fiber provision and sustaining vital ecosystem services. Over the last two centuries, this region has experienced a remarkable disturbance history characterized by widespread clearcutting and then reforestation under

active land management that includes a focus on intensive forest management. More recently, the combination of human population growth, rapid expansion of urban areas, and forest management practice has resulted significant LULC changes in many areas of the southeast, but especially in the piedmont regions and along some coastal areas. Regional carbon cycling is undoubtedly linked to this management history, yet the mechanisms by which historical and future land management decisions determine the magnitude and variability of the regional carbon sink have not been elucidated. Moving forward, the ability of the southeastern landscape to requester carbon could be substantially altered by climate changes. For example, the region recently experienced unprecedented droughts in 2001 and 2007, and a severe ice storm in 2002, all of which substantially reduced the primary productivity in the region. According to the most recent IPCC report, we can expect more frequent and severe extreme weather in the future, which could promote large inter-annual variation in ecosystem productivity, and alter disturbance regimes that could have long lasting impacts on the primary productivity and carbon sequestration; however, our current understanding of such impacts on GPP and NPP are poorly. To better quantify and understand these impacts, we will use the rich remote sensing data available for this region, that include historical air photos, long time series of Landsat imagery, recently collected LiDAR, MODIS as well as Sentinel-2 from ESA. The remotely sensed data will be used synergistically to reconstruct the LULC change through time, including changes in LULC categories as well as species composition as a result of forest succession. The LULC history reconstructed from remote sensing will be used as input to an ecosystem productivity model to disaggregate the impacts of climate and LULC changes on primary productivity, respectively. We will use US Forest Service's Forest Inventory Analysis, AmeriFlux data as well as the high quality stream flow data from USGS for model calibration and evaluation. We intend to address the following questions: (1) what are the historical trends in the patterns of LULC, and species composition in US Southeast since the 1950s? (2) How have the changes in forest extent and composition altered gross and net primary productivity? (3) How, and to what extent, does the combination of the historical trends in climate and LCLU impact the vulnerability of carbon storage in the southeast in the past and in the future? Answers to these questions are critical for sustainable development planning in this region, given the high ecological and economic importance of southeastern U.S. forest ecosystems.

Paul Wennberg/California Institute of Technology
Changes in the Carbon Cycle Observed in Greenhouse Gas Total Columns-TCCON
16-CARBON16-0122

NASA's Carbon Cycle Science Investigation Program has historically supported the development and operations of the Total Carbon Column Observing Network (TCCON). Here, we propose to continue the coordination, maintenance, improvement and analysis of long-term measurements from the TCCON. There are currently more than 20 operational TCCON sites. All PIs of the operational TCCON sites are participants in this proposal.

TCCON is both scientifically and societally important. Data from the network are being used extensively to improve the description of carbon dynamics and to help evaluate products developed from space-based sensors from the US, ESA, and JAXA.

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 (launch 2018); and for the future ASCENDS mission. TCCON has been used in the evaluation of SCIAMACHY and MOPITT data, and is planned for use in GOSAT-2 and TropOMI aboard S-5P.

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 CO2 and CH4 using observations made from TCCON and associated data sets made by remote sensing from space.

Xuesong Zhang/University of Maryland, College Park
Integrating Field Experiments, Remote Sensing, and Process-based Modeling Toward Improved Understanding and Quantification of Watershed Scale Carbon
16-CARBON16-0065

Recent estimates indicate that agricultural technologies and practices hold the potential to mitigate 0.3-4.6 Pg CO2eq yr-1 emissions at the global scale, therefore have been recognized as an important measure to limit global temperature to 2 Celsius degree above pre-industrial levels. However, most of these estimates are based on measurements and/or modeling of the terrestrial carbon (C) balance without explicit accounting of consequences for C cycling in downstream aquatic ecosystems. The lack of clear understanding and reliable quantification of the linkages between interconnected terrestrial and aquatic ecosystems represents a significant uncertainty in assessment of C flows and stocks as influenced by human activities and under various climate change scenarios. Therefore, our goal is to develop and test an integrated data-model approach to advance the representation of C cycling at the watershed scale that encompasses interconnected upland, wetland and riverine ecosystems.

To achieve this goal, we will use the Choptank River Watershed (CRW) as the testbed and pursue tasks in the following three aspects: [1] enhance the widely used Soil and Water Assessment Tool (SWAT) model with new capability of representing C cycling Across upland, wetland and riverine Landscapes at the Watershed scale (referred to as SWAT-CALW), by incorporating wetland-DNDC, WetQual, and revised Dissolved Organic Carbon (DOC) algorithms into SWAT; [2] leverage a wide array of field measurements of terrestrial and aquatic ecosystems as supported by USDA's Conservation Effects Assessment Project (CEAP) and Long-term Agricultural Research (LTAR) and numerous NASA remote sensing products, as well as expand wetland and

stream hydrology & biogeochemistry field experiments in the CRW to parameterize, drive and constrain SWAT-CALW; and [3] apply SWAT-CALW to understand compelling scientific questions, such as What is the magnitude and spatial distribution of C transported between terrestrial and aquatic ecosystems? How do the linkages between landscapes influence C cycling at the watershed scale? To what extent is terrestrial based C accounting different from coupled terrestrial-aquatic C balance? How do human activities and climate change (e.g. conservation and temperature increase) influence coupled C cycling at the watershed scale?

The outcome of this research will directly contribute to the NASAs objective to quantify, understand, and predict changes in Earths ecosystems and biogeochemical cycles. The proposed research also addresses the overarching scientific questions outlined in A U.S. Carbon Cycle Science Plan: how do natural processes and human actions affect C cycle on land and how are ecosystems and natural sources impacted by changes in climate and C management decisions? Our research activities are closely aligned with USDA-NIFAs strategic sub-goal 1.2: Advance the development & of science for agricultural, forest, and range systems & to mitigate climate impacts, as well as USDA Strategic Plan for 2010-2015s Goal 2, Objective 2.2, particularly the strategy to develop models, national observing and monitoring systems, decision support tools and new technology and adaptation strategies for communities, agriculture producer, and natural resource managers.

The open-source SWAT-CALW model developed here will be shared with the public through the SWAT website. The methods developed here on how to integrate NASA remote sensing data into SWAT-CALW will also be shared, facilitating sustained use of NASA remote sensing data to support societal benefits. Particularly, we will seek opportunities to disseminate the scientific knowledge and analytic tools resulting from the proposed research via long-term research/community programs (such as NACP, CEAP and LTAR, and US FWS's National Wetland Inventory).

Richard Zimmerman/Old Dominion University Research Foundation
Quantification of Blue Carbon Burial in Seagrass Ecosystems and the Impact of Projected Climate Change
16-CARBON16-0029

Vegetated coastal ecosystems cover only 0.2% of the ocean, yet they are disproportionally important in sequestering organic carbon relative to other ecosystems, and may account for 50% of all the carbon buried in marine sediments. Although less abundant than saltmarshes or mangrove ecosystems, seagrass meadows represent important sites of organic carbon accumulation that may account for 15% of that buried carbon. Besides burying carbon in anoxic sediments, seagrass meadows promote carbon storage in ocean waters by raising seawater alkalinity through carbonate dissolution and pyrite precipitation that is not captured in most Blue Carbon estimates. There is a large uncertainty in global Blue Carbon burial due to poorly constrained estimates of global seagrass coverage, regional disparities in situ data availability, and significant differences

in the nature of seagrass ecosystem function derived from functional and morphological differences among species.

The proposed study will develop software tools for extracting seagrass distribution and biomass from appropriately resolved multispectral imagery that ultimately can be scaled up to provide global coverage when combined with information on submarine bathymetry and water quality. We will provide test case verification of our approach by quantifying abundances and mapping distributions of seagrasses in the Chesapeake Bay and Eastern Gulf of Mexico (EGOM), two regions of the coastal United States encompassing important seagrass resources that are currently threatened by changes in water quality, climate warming and sea level rise, and with which we have extensive local experience. We will exploit archived remote sensing imagery available from the USGS LandSat-8 and the Digital Globe (DG) WorldView-2, WorldView-3 satellites, and determine temporal changes in seagrass resources as permitted from the archived data. Remotely sensed estimates of above-ground biomass will be determined using algorithms developed by the PIs that have previously been successful in turbid coastal regions. A new genetic algorithm will be explored that can improve classification and threshold determination. The above ground biomass retrievals will be used to estimate potential Blue Carbon deposits consisting of below-ground seagrass biomass, buried leaf litter and allochthonous detrital carbon (terrestrial and marine) for each site. Remotely sensed seagrass distributions will be linked to a predictive bio-optical model we call GrassLight that will be used to explore the differential effects of water quality, ambient temperature and CO2 availability on seagrass abundance and distribution, and ultimate impacts on Blue Carbon reserves.

Advances in understanding the optics of shallow water environments, submerged vegetation canopies and seagrass physiology, combined with improved spatial resolution of radiometrically calibrated remote sensing platforms, now enable seagrass ecosystems to be monitored from orbiting platforms such as LandSat-8, WorldView-2, and WorldView-3 in addition to hyperspectral systems. Extensive meadows covering very large regions (e.g. Bahamas Banks) can even be quantified with MODIS. In anticipation of future NASA missions offering increased spatial and spectral resolution over current orbiting systems, we will develop procedures to quantify seagrass assets and monitor changes from existing archived data that can provide a bridge to new orbiting platforms as they become available. The algorithms and models developed here will quantify status for a key coastal marine habitat in the US and provide a pathway to utilize future higher resolution datasets providing increased spatial and spectral resolution to observe coastal environments (HyspIRI, and future high-resolution sensors) across the globe.