NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2014
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The National Aeronautics and Space Administration (NASA) solicited proposals for investigations to advance the development of a carbon monitoring system (CMS). Emphasis is directed towards continued development of CMS pilot studies and acquisition, field sampling, quantification, and development of prototype Monitoring Reporting and Verification (MRV) system capabilities. Data from airborne or spaceborne remote sensing is required as an essential element in all carbon monitoring investigations. Successful applicants will become members of the NASA CMS Science Team (ST). NASA requested proposals for the following types of prototyping, research, and scoping activities for carbon monitoring:

- Studies using commercial off-the-shelf technologies (COTS) to produce and evaluate prototype monitoring, reporting, and verification system approaches and/or calibration and validation data sets for future NASA missions, including, but not limited to, monitoring reporting and verification work in support of REDD, REDD+, or SilvaCarbon projects;
- Studies that address research needs to advance remote sensing-based approaches to monitoring, reporting, and verification (e.g., quantification of forest degradation; independent assessment of the accuracy of airborne remote sensing observations of biomass and carbon stocks; use of airborne flux observations and satellite remote sensing, as alternative methods for quantifying net carbon emissions/storage).
- Studies that advance upon, extend, and/or improve the existing CMS products for biomass and flux resulting from NASA's first phases of CMS pilot studies; such studies may include, for example, product improvements, refined characterization and quantification of errors and uncertainties, and/or preparation and delivery of a mature product for long-term archive at an established NASA DAAC or equivalent data center.

NASA received a total of 71 compliant proposals in response to this NRA and recommended 15 for funding. The total funding to be provided by NASA for these investigations is approximately $14 million over three years. The investigations recommended by NASA are listed below. The Principal Investigator, institution, investigation title, and a project summary are provided. Co-investigators are not listed here.

Arlyn Andrews/National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research, Boulder
Regional Inverse Modeling in North and South America for the NASA Carbon Monitoring System

We propose a single follow-on proposal combining our projects North American Regional-Scale Flux Estimation and Observing System Design for the NASA Carbon Monitoring System (A. Andrews, PI) and In situ CO2-based evaluation of the Carbon Monitoring System flux product (J. Miller, PI) awarded under the 2012 CMS solicitation. Both projects leveraged available in situ measurements of CO2 and used high-resolution regional inverse modeling tools to quantify CO2 fluxes on regional scales and to investigate consistency among in situ and remote sensing datasets. Under the first project, we incorporated remote sensing measurements of CO2 into CarbonTracker-Lagrange, a NOAA-led effort to implement a regional inverse modeling framework for North America that uses footprints from a suite of Lagrangian transport models and a flexible inversion scheme with geostatistical and Bayesian capability. The inversions conducted for this project complement the CMS Flux Pilot estimates, because they are obtained for a regional domain and at higher resolution (1o), using different transport models (i.e. Lagrangian vs. Eulerian), augmented CO2 data sets (in situ and remote sensing), and using explicit matrix inversions rather than a data assimilation approach. Footprints (surface influence functions) for over 3 million ground-based, airborne, and satellite receptors were computed and are being made available to the research community. The second project used in situ atmospheric CO2 data, globally and with a South American focus, to evaluate products from the CMS Flux Pilot project. The South American component of the project focused on comparing CMS modeled CO2 concentrations with observed vertical profiles from aircraft above the Brazilian Amazon, a critically important yet under-sampled region where extensive cloud and aerosol contamination limit the usefulness of satellite data. Here we propose to refine and further develop the Lagrangian inversion framework and to complete the on-going flux inversions for North America and South America, leveraging datasets collected under the North American Carbon Program and through our partnerships with researchers in Brazil and taking into account uncertainties caused by satellite retrieval errors and model inadequacies, such as errors in simulated atmospheric transport and limitations of current inversion approaches. As detailed below, the proposed work will make heavy use of NASA assets, including TCCON and the upcoming OCO-2 XCOÂ¬2 and chlorophyll fluorescence observations along with NASA remote sensing data products describing land cover and vegetation. We will also use and evaluate NASA model products (e.g., MERRA transport fields and the CMS Flux Product), thus strengthening links to NOAA’s CarbonTracker effort and supporting the development of an integrated Carbon Monitoring System. The proposed work will develop strategies for incorporating diverse CO2 observations and quantifying fluxes at scales relevant for Monitoring, Reporting and Verification (MRV) and quantifying uncertainties of CMS products.

David Baker/Colorado State University
A Global High-Resolution Atmospheric Data Assimilation System for Carbon Flux Monitoring and Verification

Measurements of atmospheric CO2 concentration have provided a top-down view of the global carbon cycle, clarifying the impact of the anthropogenic fossil fuel input, and giving a rough latitudinal breakdown of the uptake of the fossil input by the oceans and land biosphere. NASA and other space agencies around the world have invested great effort in designing satellite missions to measure column-integrated CO2 concentrations from space, in hopes of getting enough spatio-temporal coverage to resolve surface CO2 fluxes at regional scales -- it is hoped that the processes driving the uptake and release of CO2 will be easier to identify at these scales, leading to better predictions of CO2 levels and global warming in the future. These CO2 measurements complement direct measurements of plant biomass nicely, since they sense the impact of other land ecosystem processes less easily measured (e.g., carbon stored below the ground in roots and soils, and carbon running off into streams and groundwater), as well as the impact of fossil fuel and biomass burning, and air-sea fluxes. Global flux inversion studies based on atmospheric measurements could thus be used as a check on the more direct measurement of plant biomass. Alternatively, they could be used as a framework for interpreting the biomass measurements in the context of the broader carbon cycle. If the flux estimates from such a system could be made at a spatial resolutions fine enough to parse the results across geopolitical boundaries, with reliable uncertainty estimates, they could be suitable for carbon trading and treaty verification purposes. The density and reliability of current satellite CO2 measurements have limited their usefulness towards this end so far, but the expected explosion of satellite CO2 data in the coming decade or two, including eventually from satellites in geosynchronous and highly-elliptic orbits rapidly scanning the land surface, should make this feasible. If CO2 fluxes must be resolved at scales of 1x1 deg or better to attribute them to individual countries reliably, then there is also a computational challenge to overcome in implementing such an inversion system: atmospheric transport models take roughly an order of magnitude longer to run each time the spatial resolution is doubled; if the resolution of the fluxes is increased from current levels (order 4x4 deg) to 1x1 deg, then the inversions should take roughly a hundred times longer to complete. Running the models at even finer scales is desirable, to come closer to the scales at which the measurements are actually made (e.g. of order 3 km2 for an OCO-2 pixel FOV). Here we propose a new inversion method that will efficiently estimate fluxes at sub-degree resolution, while at the same time producing a high-rank covariance matrix that quantifies flux uncertainty at the same scales. It solves the same Euler-Lagrange equations as the currently-used variational methods do, but does so with a direct matrix inversion rather than with an iterative descent method. The measurements are grouped into blocks, and a basis function is run through the transport model for each block, with the highest spatial resolution being coarsened as mixing spreads out the signal. The variational method is thus effectively parallelized, since the basis functions can be run on separate processors. Once the matrix inversion is done, the resulting covariance matrix may be used as a preconditioner in the standard iterative search to refine the finest scales. The rank of the covariance matrix produced by the method is limited only by the size of the matrix that can be inverted in memory, e.g. O(10,000), as compared with the O(100) matrices currently produced by ensemble Kalman filter and iterative variational methods. We test the accuracy of the uncertainties given by this covariance matrix and use it to compare the ability of different CO2-measuring satellite concepts to constrain country-scale annual mean fluxes.

Kevin Bowman/Jet Propulsion Laboratory
Continuation of the CMS-Flux Pilot Project

Dramatic increases in atmospheric CO2 from preindustrial to present day is the primary driver of climate change. The spatial origin of the CO2 growth rate and its variability is a complex function of anthropogenic, terrestrial, and oceanic processes. The tilt of industrial emissions towards developing countries has increased the uncertainty in fossil fuel emissions. Shifts in the patterns of climate variability, e.g., toward Central Pacific "Modoki" El Ninos, can intensify the magnitude and extend of droughts, e.g., 2005 and 2010 Amazonian droughts, leading to increased fires and reduction of GPP while modulating atmosphere-ocean pCO2 exchange across entire ocean basins. In order to quantify the role of spatio-temporal patterns of anthropogenic and natural carbon fluxes in controlling atmospheric CO2, we will build upon the success of the Carbon Monitoring System Flux Pilot Project (CMS-Flux) initiated in Phase I and continued in Phase II.

We propose to produce observationally-constrained and spatially-explicit "bottom-up" estimates of anthropogenic, oceanic, and terrestrial carbon fluxes using the CMS-Flux system balanced against the observed atmospheric growth rate from 2010-2015. These estimates are a continuation of anthropogenic emissions from the Fossil Fuel Assimilation System (FFDAS), assimilated oceanic pCO2 fluxes from ECCO2-Darwin, and terrestrial ecosystem fluxes from CASA-GFED3 model and the MsTMIP ensemble models. While supported by separately funded NASA activities, these terrestrial ecosystem fluxes will be modified to be consistent with a fully balanced carbon cycle. These carbon fluxes will be subsequently updated by CMS-Flux constrained by GOSAT and OCO-2 xCO2 observations from 2010-2015.

We propose to assimilate ancillary satellite observations of CO and NO2 from MOPITT and OMI into CMS-Flux in order to attribute posterior fluxes to combustion and industrial carbon fluxes, respectively. These estimates exploit the inherent capacity of CMS-Flux to assimilate both passive and chemically active atmospheric constituents within the same framework.

Building upon the analysis in previous CMS-Flux estimates, we will further investigate the correlation of climate variability, especially drought, on regional carbon fluxes and how they modulate the atmospheric CO2 growth rate. Using these estimates of CO and NO2 emissions, we will attribute the variability of those carbon fluxes to combustion processes. Given the breadth of work, we expect the proposal to cost 500K/year.

Temilola Fatoyinbo/Goddard Space Flight Center
Total Carbon Estimation in African Mangroves and Coastal Wetlands in Preparation for REDD and Blue Carbon Credits.

Coastal Blue Carbon ecosystems such as mangroves, salt marshes and seagrass beds have the highest total carbon densities of all ecosystems. Although they only represent 3 % of the total forest area, carbon emissions from mangrove destruction at current rates could be equivalent to 10 % of carbon emissions from deforestation. The high carbon sequestration coupled with the high risk of destruction make mangroves a prime candidate for carbon mitigation initiatives such as the United Nations Collaborative

Programme on Reducing Emissions from Deforestation and Degradation in Developing Countries (UN-REDD and REDD+).

In mangroves especially, the extreme difficulty of the terrain has hindered the establishment of sufficient field plots needed to accurately measure carbon on the scale necessary to relate remotely sensed measurements with field measurements at accuracies of 10% to 20% as required for Monitoring, Reporting and Verification (MRV) activities. Furthermore, there is a large gap in knowledge in African mangrove ecosystems.

We propose to develop a Mangrove Total Carbon Monitoring system in Gabon, Tanzania and Mozambique, three countries that are investing heavily in scientific and logistical aspects of developing MRV systems, through cooperation of the local governments and scientific institutions with international organizations such as the WWF, the UN-REDD programme, USAID, SilvaCarbon and Global Earth Observations-Forest Carbon Tracking (GEO-FCT). In Mozambique and Tanzania, The East Africa Carbon Mangrove Project was recently initiated by the US Forest Service on behalf of USAID to address carbon cycle issues relative to mangroves. The Zambezi River delta in Mozambique has been selected by WWF Mozambique and implemented by the US Forest Service as a baseline study on carbon stocks in mangroves to provide the basis for inclusion of mangroves in the Mozambique national REDD+ strategy. Through its strategic plan, Le Gabon Emergent, the Government of Gabon has committed to pursue sustainable development and a Gabon Forest Carbon Assessment has been initialized across the country. As part of these 3 initiatives there will be airborne lidar data acquired and made available in mangrove sites in all three countries.

We will use a suite of commercial off-the-shelf datasets to estimate forest biomass, extend and cover change over time, including airborne LiDAR, Synthetic Aperture Radar (SAR) and Very High Resolution optical (VHR). Our proposed methodology takes into account that most MRV systems require repeated measurements of carbon stocks and acquiring airborne lidar data on a regular timeframe is costly and impractical. Thus we propose to use commercial spaceborne data from optical sensors as well as Synthetic Aperture Radar (SAR) missions. We will to use the most advanced 3-D remote sensing technology - Polarimetric Interferometric SAR or Pol-InSAR - as an operational technology that can augment, or even replace, costly acquisitions of Lidar data for MRV activities. We propose a 3D mapping methodology to quantitatively characterize forest structure and extent as well as change over time and to inform the field measurements site stratification and location.

Our research strategy consists in using the airborne lidar to upscale field estimates of biomass to a larger scale and enable validation of TanDEM-X derived estimates of canopy height and biomass. We will develop a present day mangrove extent map using Landsat, SAR (ALOS-2) and Very high Resolution commercial optical data then adapt global forest change mapping algorithms to include mangrove forests and develop a timeseries of mangrove change in all three countries from 1990 to the present day.

Finally we will coordinate a Mangrove Carbon Working Group composed of in-country and US experts to coordinate, disseminate and inform field, remote sensing and GIS experts on the use and generation of the data products from this study.

Sangram Ganguly/Ames Research Center
Reducing Uncertainties in Satellite-Derived Forest Aboveground Biomass Estimates Using a High Resolution Forest Cover Map

Several studies to date have provided an extensive knowledge base for estimating forest aboveground biomass (AGB) and recent advances in space-based modeling of the 3-D canopy structure, combined with canopy reflectance measured by passive optical sensors and radar backscatter, are providing improved satellite-derived AGB density mapping for large scale carbon monitoring applications. A key limitation in forest AGB estimation from remote sensing, however, is the large uncertainty in forest cover estimates from the coarse-to-medium resolution satellite-derived land cover maps (present resolution is limited to 30-m of the USGS NLCD Program). As part of our CMS Phase II activities, we have demonstrated the use of Landsat-based estimates of Leaf Area Index and ICESat Geoscience Laser Altimeter System (GLAS) derived canopy heights for estimating AGB at a 30-m spatial resolution, which compare relatively well with inventory based plot level estimates. However, uncertainties in forest cover estimates at the Landsat scale result in high uncertainties for AGB estimation, predominantly in heterogeneous forest and urban landscapes. We have successfully tested an approach using a machine learning algorithm and High-Performance-Computing with NAIP air-borne imagery data for mapping tree cover at 1-m over California and Maryland. In a comparison with high resolution LiDAR data available over selected regions in the two states, we found our results to be promising both in terms of accuracy as well as our ability to scale nationally. In this project, we propose to estimate forest cover for the continental US at spatial resolution of 1-m in support of reducing uncertainties in the AGB estimation. The generated 1-m forest cover map will be aggregated to the Landsat spatial grid to demonstrate differences in AGB estimates (pixel-level AGB density, total AGB at aggregated scales like ecoregions and counties) when using a native 30-m forest cover map versus a 30-m map derived from a higher resolution dataset. The process will also be complemented with a LiDAR derived AGB estimate at the 30-m scale to aid in true validation. The proposed work will substantially contribute to filling the gaps in ongoing NASA CMS research and help quantifying the errors and uncertainties in NASA CMS products.

Jonathan Greenberg/University Of Illinois, Urbana-Champaign
Reducing Uncertainties in Estimating California's Forest Carbon Stocks

We propose to create a prototype Carbon Monitoring System (CMS) for the state of California, with the goal of estimating the mean tree-sequestered above-ground biomass AGB) using various remote sensing techniques for the period of 2005 to 2015 at 30m resolution, and determine the spatially explicit uncertainty in these estimates. One of the key characteristics of this CMS will be a detailed propagation of error analysis for both the field and remote sensing steps. We will investigate and compare state-of-the-art AGB estimation approaches applied to commercial LiDAR and Worldview-2, as well as dense time series of Landsat 4 8 imagery. The CMS will be developed with future-proofing in mind: new techniques, as they become available, will be easily integrated into the system and fused with previous techniques. All models and data products will be released under open content / open source licenses to maximize the utility of the research to the wider community.

Andrew Hudak/USDA Forest Service
Prototyping A Methodology To Develop Regional-Scale Forest Aboveground Biomass Carbon Maps Predicted From Landsat Time Series, Trained From Field and Lidar Data Collections, And Independently Validated With FIA Data

Current Monitoring Reporting and Verification (MRV) needs cannot be met by using only available NASA satellite data products, but must be integrated with commercial off-the-shelf technologies. The exceptional sensitivity of commercial, airborne scanning lidar data to forest canopy structure has made it the best remote sensing technology for predicting vegetation attributes, including biomass. We propose to use multiple, landscape-level lidar datasets, previously acquired in conjunction with project-level field plot datasets for model calibration/validation, to predict aboveground biomass stores across representative vegetation types in the northwestern USA. The predicted biomass maps will serve as training area for upscaling biomass carbon predictions to the regional level, as predicted from Landsat time series imagery processed through LandTrendr. Regional maps will be validated with FIA data summarized at the county level, along with error statistics. Bias between biomass predictions and FIA observations summarized for the representative vegetation types will be quantified, and bias corrections applied, with the goal of maintaining a transparent record of bias corrections at the county level. We envision a lidar and field plot database that can continue to be updated as new project-level forest inventory data are collected. This strategy will actively engage forest managers by utilizing existing data collected by and maintained by land managers of the US Forest Service (USFS) and other public and private stakeholders. Our chosen study region is the northwestern USA, where multiple commercial lidar and field plot datasets exist, LandTrendr data products are farthest along in the production line, and steep environmental gradient provide an exceptional diversity in vegetation types. The cumulative area of LiDAR collections across multiple ownerships in the northwestern USA has reached the point that land managers of the USFS and other stakeholders need to develop a strategy for how to utilize LiDAR for improved regional inventory, and because these inventories are the initial conditions for simulation modeling of future conditions, the strategy will result in more accurate estimates of projected conditions. We have assembled and consistently processed field plot and lidar datasets at >21 landscape-level project areas distributed along a broad climate gradient across the northwestern USA from temperate rainforest to cold desert. We propose to employ imputation as our predictive modeling strategy because it assigns actual ground observations at representative sample locations, to unsampled locations. Further, imputation modeling is firmly ensconced within the forest management community, and has been used for decades to assign stand attributes from reference stands to target stands. Therefore, forest and rangeland managers of the USFS and other major public and private land management stakeholders will have little difficulty buying in to our proposed methodology, and would benefit enormously by making more effective use of available LiDAR and ground inventory data. Fortunately, the USFS has also developed a carbon management capability with greater utility to local forest managers: the carbon accounting tool of the Forest Vegetation Simulator (FVS) (http://www.fs.fed.us/fmsc/fvs/). FVS remains freely available, is now open source (Open-FVS), is approved by the American Carbon Registry to estimate carbon stock changes, and provides the option of climate change projections using Climate-FVS. Our chosen modeling methods and tools lend themselves to transparency and verifiability. Our goal is to develop a prototype CMS that works with acceptable accuracy, objectivity, transparency, and reproducibility in the northwestern USA, it will be ready for replication and application elsewhere in the USA, and globally with ties to SilvaCarbon and REDD+.

George Hurtt/University of Maryland, College Park
High-Resolution Carbon Monitoring and Modeling: Continuing Prototype Development and Deployment

The overall goal of our project is the continuing development of a framework for estimating high-resolution carbon stocks and dynamics and future carbon sequestration potential using remote sensing and ecosystem modeling linked with existing field observation systems such as the USFS Forest Inventory. In particular, we seek to demonstrate an approach that provides the basis for the rapid expansion from Maryland to nearby states, and which additionally enables the monitoring of annualized changes in stocks through time at fine spatial resolution. We believe this build-out is possible today and is a critical step in the development of a national CMS. Specifically we will address the following objectives: (1) Improve our existing methodology for carbon stock estimation and uncertainty based on lessons learned from our Phase 2 study; (2) Provide wall-to-wall, high-resolution estimates of carbon stocks and their uncertainties for the 3-state region of Pennsylvania, Delaware and Maryland; (3) Initialize and run a prognostic ecosystem model for carbon at high-spatial resolution over multiple eastern states; (4) Validate national biomass maps using Forest Inventory and Analysis (FIA) data and high-resolution biomass maps over an expanded domain; (5) Develop and test methods for monitoring changes in carbon stocks through time using repeat lidar data, satellite imagery, forest inventory data, and remote sensing driven mechanistic modeling; (6) Demonstrate MRV efficacy to meet stakeholder needs in our 3-state region, and a vision for future national-scale deployment. Our work has followed a logical expansion of effort, from proof-of concept starting with just two counties in our Phase 1 pilot study, to an entire state (24 counties) in Phase 2. This research has emphatically demonstrated the feasibility of large-scale mapping using airborne lidar. We propose to build on these efforts to encompass another qualitative increase in spatial extent, new MRV-relevant product prototyping, and a vision for future operational deployment of MRV systems that are responsive to local, national and international interests in management and policy.

Daniel Jacob/Harvard University

High-Resolution Constraints on North American and Global Methane Sources Using Satellites

Our proposal will focus on the exploitation of GOSAT and TROPOMI data to better constrain anthropogenic and natural methane emissions at high resolution (0.25x0.33 deg) in North America and globally at (2x2.5 deg). Our work takes advantage of previous integration with CMS-Flux that uses a consistent 4DVAR capability and wetland emissions driven by common biogeochemical models and data. Products generated from this proposal will be used in collaboration with EPA scientists in integrating the information from bottom-up and top-down constraints on emissions. We anticipate a budget request of $300 K per year for three years.

Steven Lohrenz/University Of Massachusetts, Dartmouth
An Integrated Terrestrial-Coastal Ocean Observation and Modeling Framework for Carbon Management Decision Support

The NASA Carbon Monitoring System effort seeks to apply satellite remote sensing resources along with observational and modeling capabilities to improve monitoring of carbon stocks and fluxes, particularly as they contribute to the development of Monitoring, Reporting and Verification (MRV) system capabilities. Our prior NASA-funded research employs a combination of models and remotely-sensed and in situ observations to develop georeferenced products and associated uncertainties for land-ocean exchange of carbon, air-sea exchanges of carbon dioxide, and coastal to open ocean exchanges of carbon. A major aspect of this project has been to establish and populate geospatial portals for sharing and analysis of carbon datasets and products. The primary region of study has been the Mississippi River watershed and northern Gulf of Mexico. The unique nature of our approach, coupling models of terrestrial and ocean ecosystem dynamics and associated carbon processes, allows for assessment of how societal and human-related land use, land use change and forestry (LULUCF) and climate-related change affect terrestrial carbon storage and fluxes, as well as export of materials through watersheds to the coastal margins. Here, we propose to extend the domain of our observational and integrated terrestrial-ocean ecosystem model system to include the southeastern U.S. and South Atlantic Bight. In addition to land-ocean and sea-atmosphere exchanges, we will utilize satellite observations together with the capabilities of the terrestrial ecosystem model to characterize and quantify terrestrial carbon storage and fluxes, including land-atmosphere fluxes of both carbon dioxide and methane. Our approach will include assembling model products along with associated uncertainties and errors in a geospatial framework that will facilitate decision support for carbon and land use management. Objectives of the proposed research include the following: 1) Expand the spatial domain of our observational and integrated modeling approach to include the Mississippi River basin and southeastern U.S., and examine terrestrial carbon storage and fluxes including characterization and quantification of biomass and carbon stocks in and land-atmosphere, land-ocean, and sea-atmosphere fluxes of carbon dioxide and methane; 2) Examine different LULUCF scenarios within the terrestrial domain and different climate scenarios to assess effectiveness of carbon management strategies; 3) Engage with other CMS projects and stakeholders (e.g., USDA, National Climate Assessment, etc.) to identify user needs related to carbon management and MRV activities, modify and expand the scope of information based on user feedback, and explore possible transition of prototype products to fully operational status. The Application Readiness Level of our prior CMS project was rated as ARL-4 (Initial Implementation and Verification in Laboratory Environment), with the potential to advance to ARL-6 (Demonstration in a Relevant Environment). A goal of this proposed research will be to advance this capability to ARL-7 (Application of Prototype in Partner's Operational Decision Making Environment). Our proposed effort will aid in the effective implementation of MRV approaches, which require an understanding of the contributions of individual forest and other ecotypes beyond local to regional and national scale carbon processes. Furthermore, our proposed effort will aid in governance and decision support related to carbon management, including the ability to evaluate different LULUCF scenarios in the context of changing climate conditions. Extended impacts of forest and other land use management strategies on carbon storage and transport, including in soils and into watersheds and coastal margins will be assessed. Finally, this information will be readily accessible as a geo-referenced product to support operational needs of stakeholders.

Douglas Morton/Goddard Space Flight Center
Long-Term Carbon Consequences of Amazon Forest Degradation

Four decades of deforestation, forest degradation, and agricultural use have fundamentally altered remaining forest fragments along the arc of deforestation in southern Amazonia. Forest carbon stocks in these frontier forests remain poorly characterized by existing forest inventory data or moderate resolution (0.25-1 km2) satellite data products. Nonetheless, these frontier landscapes retain clues to historic forest carbon emissions and the legacy of forest degradation from logging and fire. Improving our understanding of the long-term carbon consequences of forest degradation is essential for efforts to Reduce Emissions from Deforestation and Forest Degradation and enhance forest carbon stocks (REDD+). The level of emphasis on forest degradation in monitoring, reporting, and verification (MRV) of REDD+ activities in Amazonia fundamentally depends on the magnitude of net carbon emissions from logging, fire, and forest fragmentation.

We propose to conduct detailed analyses of forest carbon stocks and land cover transitions in three frontier forest regions in the Peruvian and Brazilian Amazon. The proposed study combines contemporary forest inventory data and extensive airborne lidar surveys with time series of Landsat data to evaluate landscape patterns of forest carbon stocks. Our major emphasis is the variety of forest carbon loss trajectories from different intensities and frequencies of forest degradation. We selected three frontier regions to evaluate the mosaic of forest ages and conditions from logging, fire, and forest fragmentation in old (SantarÃ©m, ParÃ¡, Brazil), established (Feliz Natal, Mato Grosso, Brazil), and young frontier forests (Colonel Portillo, Ucayali, Peru). Key research themes include 1) long-term changes in forest structure and carbon stocks from forest degradation; 2) lidar-biomass relationships in degraded forests; and 3) full carbon accounting of forest emissions, including deforestation, degradation, and secondary forest dynamics.

The proposed research addresses the two priority areas in the Carbon Monitoring System (CMS) solicitation (A.7). Specifically, we will use airborne lidar data from commercial off-the-shelf sensors, collected under separate funding from USAID and the US Department of State, to characterize Amazon forest structure and biomass and prototype MRV capabilities for intact and degraded forest types. Improving estimates of carbon losses from forest degradation is a key priority for NASA CMS and SilvaCarbon (Peru is a SilvaCarbon country), and a major impediment to progress on REDD+. Research activities will further develop methodologies to combine field measurements, airborne scanning lidar data, and satellite observations in support of REDD+ MRV. Finally, study results will provide validation datasets for ICESat-2 and proposed lidar missions under NASA's Earth Venture program (EVi-2 and EVs-2).

The proposed effort leverages four sources of existing support. Field measurements and airborne lidar data for study sites in the Brazilian and Peruvian Amazon will be acquired under separate funding from USAID, US Department of State, SilvaCarbon, and the Brazilian Conselho Nacional de Desenvolvimento Cientifico e TecnolÃ´gico (CNPq). PI Morton is an unfunded collaborator on these existing projects, including his recent selection as a CiÃªncia sem Fronteiras (Science Without Borders) Fellow by CNPq for 2014-2017. Additional funding for the proposed research through CMS would leverage these field and lidar data collections to address priority science areas for CMS and enhance the international impact of research activities supported by USAID and SilvaCarbon.

Lesley Ott/Goddard Space Flight Center
GEOS-Carb II: Delivering Carbon Flux and Concentration Products Based on the GEOS Modeling System

This proposal is to extend NASA GSFC's contributions to the Carbon Monitoring System (CMS) from the Flux Pilot Project and CMS Phase One. The proposed work will draw on the capabilities of NASA's Goddard Earth Observing System (GEOS) models to deliver mature flux and concentration data products in support of CMS objectives. The proposed work consists of four main components: (i) production of observationally constrained atmosphere-ocean and atmosphere-land biosphere fluxes and uncertainties for the past decade; (ii) generation of atmospheric forward model ensembles to quantify errors in atmospheric CO2 simulations due to both flux and transport uncertainty; (iii) incorporation of GOSAT, OCO-2, and in situ observations to produce high-resolution global atmospheric CO and CO2 concentration reanalyses; (iv) evaluation of the sensitivity of inversion flux estimates to assumptions of prior flux uncertainty and transport uncertainty using multiple inversion methodologies. A central component of these efforts is the use of meteorological forcing provided by NASA's Modern Era Retrospective-analysis for Research and Applications 2 (MERRA-2) to produce a consistent picture of the interactions between weather, climate, and the carbon cycle. Flux estimates will be improved through improvements in input datasets and process representation and new methods of uncertainty quantification will be employed to deliver reliable flux estimates with associated uncertainties. Land biosphere fluxes from the CASA-GFED model, currently funded separately, will be further updated here to utilize new vegetation fluorescence, MERRA-2 soil moisture, and fire products. The ocean, land, and fossil fuel flux uncertainties will be propagated forward in the GEOS Model, version 5 (GEOS-5) to examine their impact on calculated CO2 mixing ratios and comparisons with observations. An ensemble of GEOS-5 simulations with perturbations to subgrid transport processes will be used to quantify the impact of transport uncertainty. These uncertainty estimates and fluxes will be combined with satellite and in situ CO and CO2 observations to produce realistic trace gas reanalyses for use by the carbon monitoring community. Finally, we will examine the issue of error propagation through multiple inversion modeling frameworks to better understand the constraint placed on carbon flux by existing and future atmospheric CO2 measurements. All products will be hosted on NASA's Global Modeling and Assimilation Office (GMAO) servers with simple download and visualization options provided through GMAO's website.

Wayne Walker/Woods Hole Research Center
Direct Measurement of Aboveground Carbon Dynamics in Support of Large-Area CMS Development

In response to the implications that high uncertainties associated with traditional approaches to forest carbon accounting have, not only for the credibility of REDD+, but also for the advancement of biospheric modeling and carbon cycle science, the main goal of this research is to investigate the potential for annual changes in the aboveground carbon density (ACD) of forests to be estimated directly, consistently, and with measurable accuracy across large areas using an array of existing commercial off-the-shelf and NASA remote sensing assets. The geographic focus is the country of Mexico where members of the proposal team have been working closely with the Mexican government since 2011 to assist in advancing their forest monitoring capacity as part of a USAID-supported project to Reduce Emissions from Deforestation and Forest Degradation in Mexico (USAID/M-REDD). The specific objectives are to:

(1) Quantify the certainty with which extensive field, off-the-shelf airborne LiDAR, and MODIS satellite data can be used synergistically to estimate wall-to-wall changes in ACD at a resolution of 500 m across Mexico over a 15-year period (2001-2015). This objective expands on the work of Baccini et al. (2012) who successfully combined field, ICESat GLAS LiDAR, and MODIS optical data sets for single-epoch mapping of pantropical ACD. Here we replace spaceborne GLAS LiDAR with off-the-shelf airborne LiDAR and combine time-series mapping with change-point analysis to enable annual ACD change estimation,

(2) Quantify the certainty with which extensive field, off-the-shelf airborne LiDAR, and VIIRS satellite data can be used synergistically to estimate wall-to-wall changes in ACD at a resolution of 375 m across Mexico over 5-year period (2012-2016). As NASAâ€™s second-generation moderate-resolution imaging radiometer, VIIRS extends and improves

upon MODIS; yet the performance of VIIRS data for large-area ACD and ACD change mapping, has not been demonstrated,

(3) Quantify the certainty with which extensive field, off-the-shelf airborne LiDAR, and Landsat 5-8 satellite data can be used synergistically to estimate wall-to-wall changes in ACD for the Mexican states of Chihuahua, Oaxaca, Campeche, Yucatan, and Quintana Roo over a 15-year period (2001-2015). While acknowledging the increasing demand for large-area ACD estimates at resolutions ranging from 10s to 100s of meters, we seek to more closely examine Landsat performance, particularly the inverse relationship that appears to exist between resolution and accuracy, and

(4) Conduct an independent accuracy assessment of the ACD change products produced in Objectives 1-3 as well as of derivative estimates of gross emissions. We will leverage permanent plot data from the Mexico National Inventory of Forest and Soil (INFyS), intensive field and micrometeorological measurements from the Mexico network of eddy covariance flux towers (MexFlux), and deforestation data from Hansen et al. (2013), among other data sources.

The ACD change products we propose to produce here represent a fundamentally new way of quantifying carbon fluxes that will significantly reduce uncertainty while leading to a more complete understanding of terrestrial carbon cycling. Unlike conventional approaches, which focus on deforestation leaving degradation unaccounted for, the proposed approach provides for a unique estimates of gross emissions at the pixel level, integrating losses due to deforestation, degradation, and other disturbances with gains due to growth. The work is expected to transform operational carbon accounting and, in doing so, drive the science, and ultimately the policy, forward. Within Mexico itself, the opportunity exists, not only to impact MRV system development at the national level through the involvement of proposal team members in the USAID/M-REDD project, but also at the jurisdictional level through relationships with the GCF and member states Chiapas and Campeche.

Christopher Williams/Clark University
Translating Forest Change to Carbon Emissions/Removals Linking Disturbance Products, Biomass Maps, and Carbon Cycle Modeling in a Comprehensive Carbon Monitoring Framework

Protecting forest carbon storage and uptake is central to national and international polices aimed at mitigating climate change. The success of such policies relies on high quality, accurate reporting (Tier 3) that earns the greatest financial value of carbon credits and hence incentivizes forest conservation and protection. Methods for Tier 3 Measuring, Reporting, and Verification (MRV) to assess carbon stocks and fluxes over time and for large areas (national to sub-national) are still in development. They generally involve some combination of direct remote sensing, ground based inventorying, and computer modeling, but have tended to emphasize assessments of live aboveground carbon stocks with a less clear connection to the real target of MRV which is carbon emissions and removals. Most existing methods are also largely ambiguous as to the mechanisms that underlie carbon accumulation, and many have limited capacity for forecasting carbon dynamics over time. This project's core objective is to build new capacity for a more thorough approach by advancing our existing carbon stock and flux monitoring framework (Williams et al. 2012, 2013) to deliver a new tool for Tier 3 MRV, decision support, and forecasting, all with process-specificity. The proposed methodology begins with extending our existing framework by providing a more detailed family of carbon flux and stock trajectories, and mapping them to a 1x1 km scale for the conterminous US based on new and emerging data products. A number of improvements to the framework are proposed (Tasks 1 to 5), designed to further characterize the attributes of forested pixels beyond the regionally-defined strata used in our prior work (forest type, site productivity, and age) to now also include pre-disturbance biomass, disturbance type, and disturbance severity attributes based on recently developed RS-derived biomass maps (e.g. Kellndorfer et al. 2012, Saatchi et al. 2013), and Landsat-derived disturbance products linked to the NAFD project. Flux and stock trajectories will also be adjusted to account for any growth enhancements we may detect from detailed analysis FIA data (Task 6). Accounting of the fate of harvested wood products will be added (Task 7) to prepare the framework for more complete assessment of the forest sector carbon balance. We will then map carbon fluxes and stocks by assigning values from modeled trajectories to forest attributes defined at a pixel scale (Task 8). The improved framework will be applied for Tier 3 MRV, yielding regional and country-scale annual carbon fluxes and stocks from 1990 to 2011 (Task 9). It will also be applied in a forecasting mode to test carbon implications of likely management and natural disturbance scenarios (Task 10).

Lisamarie Windham-Myers/U.S. Geological Survey
Linking Satellite and Soil Data to Validate Coastal Wetland "Blue Carbon" Inventories: Upscaled Support for Developing MRV and REDD+ Protocols

The NASA Carbon Monitoring System (CMS) is poised to fill a missing gap in blue carbon accounting by providing 1) a national-scale data framework to integrate and extrapolate field measurements that support national GHG inventory requirements, and 2) testing data needs for quantification of stock-based changes in coastal wetland sediments (soil) and vegetation for eventual REDD+ eligibility. We propose to develop a verifiable carbon (C) monitoring protocol appropriate for national policy and market interventions. Our approach is to refine Landsat-based land cover change data from NOAA's Coastal Change Analysis Program, with C-relevant attributes from finer scale NASA-derived spectral and RADAR data, as well as broadly available field-data from partner agencies. Synthesizing previously-collected data for 6 sentinel sites along representative coasts of the U.S., we will refine and validate an IPCC-relevant, temporally-explicit (1992-2011) accounting method for coastal wetland C stocks and annual fluxes. Our approach leverages a recent surge in research on the key processes that regulate soil C accumulation in tidal wetlands, which we propose can be captured at large spatial scales using remotely sensed data and GIS modeling. Net annual C flux into tidal wetland soils is largely a function of vertical accretion due to organic accumulation with sea level rise, or C losses due to oxidation and erosion. Dated soil cores (137Cs, 210Pb) provide quantification of C stocks and long-term rates of net C accretion or loss. The IPCC default value for soil C sequestration in tidal wetlands is 140 g/m2/yr, but rates in U.S.

tidal wetlands range from 20-800 g C /m2/yr. The greatest uncertainty in current â€œblue carbonâ€ inventory approaches arises from categorical upscaling, or distributing point data through the estuarine landscape. Both the updated USFWS National Wetland Inventory (NWI) and NOAA’s Landsat-based C-CAP program provide current and historic national distributions of estuarine intertidal wetlands. As linked with USDA SSURGO dataset, the raster-based Landsat-derived C-CAP land cover maps will be used as the primary spatial dataset for tidal wetland distribution and initial estimates of U.S. coastal wetland GHG annual inventories. Field data provide both a) attributes in a land cover model (tide gauges, elevation) and b) validation datasets (soil cores, biomass, salinity, methane fluxes). While analyses are focused on 6 sites, these field-based data are broadly available across the U.S. through partner agencies such as NOAA, Smithsonian, NSF, EPA, USFWS, and Louisiana’s CRMS databases. One goal will be to determine the price of precision or extent to which finer habitat classifications (hydrology, salinity, sea-level rise) continue to inform C accounting with greater accuracy. Remotely-sensed data products will be derived from ongoing NASA Earth Observations, specifically Landsat, Aquarius, PRISM, ALOS-2, UAVSAR, and HICO. Where available, airborne datasets (AVIRIS, AirSWOT) may illustrate the value of future satellite missions (HyspIRI, SWOT) for wetland C accounting. This project will provide a fundamental data platform to aid the U.S. in quantifying emissions and removals in response to the IPCC Wetlands Supplement (2014) as requested to support the national report in 2017. We recognize that MRV in coastal wetlands will require both remote sensing and field-based data to hindcast and continue monitoring C emissions and removals. Critical products will include network building, data compilation, algorithm development, and MRV error analyses across a series of data-driven scales. Our intensive site validation supports testable indices for accurate C flux accounting, and thus meets several CMS goals such as 1) future application at continental scales, 2) model testing of key drivers of coastal C sequestration and 3) intercomparison and collaboration with associated NASA-supported coastal C cycling research and scenario testing.