Briefing Packet

NASA CMS Science Team Meeting
Nov 12-14, 2014
At Bethesda, MD

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Timeline

2014

- **2014 CMS Progress Report:** NASA Carbon Monitoring System: Prototype Monitoring, Reporting, and Verification, Progress Report and Future Plans, October 2014.
- Proposal Selections Announced for NASA ROSES-2014: Carbon Monitoring System: Continuing Prototype Product Development, Research, and Scoping. (July 24)
- NASA Carbon Monitoring System Phase 1 Report, [PDF 4M] May 16, 2014
- Meeting: NASA Carbon Monitoring System Science Team Meeting and Applications Workshop (Nov 12-14)

2013

- Meeting: CMS Science Team, NASA JPL, Pasadena, CA (Nov 5–7)
- Peer-Reviewed Proposal Selections Announced for NASA ROSES-2013 Carbon Monitoring System: Continuing Prototype Product Development, Research, and Scoping Solicitation. (August 15)
- Research Amendment to NASA ROSES-2013: The proposal due date is 60 days from release of this announcement, rather than the standard 90 days, because of the FY 2013 appropriations committee requirement that for this activity "funds shall be competitively awarded within 120 days of enactment of this act." (Apr 29)
- Research Announcement: NASA releases ROSES-2013 Carbon Monitoring System: Continuing Prototype Product Development, Research, and Scoping Solicitation (Feb 14)

2012

- CMS Workshop: NASA GSFC, Greenbelt, MD (Nov 7–9)
- Proposals Selected for NASA ROSES-2011 Carbon Monitoring System Program Solicitation. Peer-ReviewedProposal Selections. (Aug 2)
- Progress Report for the CMS System Design Study. (PDF) (Jan 12)
- Briefing: Characterizing Flux Uncertainty Resources for the Future, Washington D.C. By Invitation Only (Jan 11)

2011

- CMS Community Forum: A Community Forum was held at the NASA Carbon Cycle and Ecosystem Joint Science Workshop, Hilton Mark Center, Alexandria, VA (Oct 5)
- Meeting: CMS Science Definition Team Meeting with Biomass and Flux Product Teams, Marriott Greenbelt, Greenbelt, MD (Sep 21–22)
- Meeting: CMS Flux Team Meeting, JPL/Caltech, Pasadena, CA (Jul 12–13)
- Meeting: CMS Biomass Team Meeting, NASA GSFC, Greenbelt, MD (Jun 22–23)

- Meeting: CMS Flux Team Meeting, Pasadena, CA. (Mar 27–28)
- Meeting: CMS Science Definition Team Scoping Efforts, NASA GSFC, Greenbelt, MD (Mar 23–24)
- SDT Selection: CMS Science Definition Team. (Mar 10)
- Research Announcement: NASA releases ROSES-2011 Carbon Monitoring System Program Solicitation. (Feb 18)

2010

- Report: CMS Scoping Study Workshop Final Report
- Workshop: The First Carbon Monitoring System Scoping Study Workshop held in Boulder, CO. (Jul 13–14)
- Scoping Efforts Planning Session: CMS Scoping Efforts began with a planning session held at the NASA Terrestrial Ecology Science Team Meeting in La Jolla, CA. (Mar 15–17)
- Research Announcement: NASA releases ROSES-2010 Science Definition Team for Carbon Monitoring System. (Feb 10)
- Congressional Appropriation: The Fiscal Year 2010 Congressional Appropriation required NASA to initiate work towards a Carbon Monitoring System (CMS). Some specific direction has been provided, including that NASA replicate state and national carbon and biomass inventory processes as well as carry out pilot initiatives for the development of a Carbon Monitoring System. These include Science Definition Team, Biomass Pilot, Flux Pilot, Ocean Pilot, and Scoping Efforts.

2012 Selections Abstracts

Andrews-02 (2012)

Project Title: North American Regional-Scale Flux Estimation and Observing System Design for the NASA Carbon Monitoring System

Science Team: Arlyn Andrews, NOAA ESRL, Arlyn.Andrews@noaa.gov (Project Lead)
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Abstract: We propose to apply a high-resolution regional inverse modeling framework to quantify CO2 fluxes that are optimally consistent with surface, aircraft, and satellite data, both current and planned. We will develop objective metrics for weighting the data and use a Lagrangian atmospheric transport model to compute a library of footprints corresponding to the various sources of CO2 observations. We will investigate consistency among the available datasets, taking into account uncertainties caused by satellite retrieval errors and model inadequacies, such as errors in simulated atmospheric transport and structural and numerical limitations of current inversion approaches (particularly when applied to the large volume of satellite data). This work fosters collaboration between Federal agencies, academia, and private industry engaged in greenhouse gas research and monitoring and leverages multiple NASA- and USGCRP-funded efforts to obtain measurements of atmospheric CO2 and develop regional-scale inverse modeling tools for quantifying carbon dioxide fluxes and their uncertainties. The proposed work will inform the development of the NASA Carbon Monitoring System (CMS) Flux Product, in particular regarding strategies for incorporating diverse CO2 observations and quantifying fluxes at policy-relevant scales. The proposed data products will be directly useful for evaluating the current CMS Flux Product.

Keywords: Atmospheric Transport
Land-Atmosphere Flux

Balch-03 (2012)

Project Title: Coccolithophores of the Beaufort and Chukchi Seas: Harbingers of a polar biogeochemical province in transition?

Science Team: William (Barney) Balch, Bigelow Laboratory for Ocean Sciences, bbalch@bigelow.org (Project Lead)

Abstract: I propose a series of biological and bio-optical observations to address the role of calcifiers in the Arctic Ocean (AO). The biogeochemical province that includes the Chukchi and Beaufort Seas is expected to undergo fundamental changes as the ice cap melts, affecting both the biota (increased abundance of coccolithophores) and the biooptical properties of the water mass (due to increased abundance of highly-scattering calcium carbonate coccoliths). I am proposing a series of measurements to be done on the two NASA cruises to the Chukchi and Beaufort Seas, falling into “discrete” and “underway” sampling. The discrete measurements will determine: calcification rate (using the 14C micro-diffusion method which also estimates total primary productivity), concentrations of the two major sea water ballast minerals (particulate inorganic carbon (PIC) plus biogenic silica (BSi)) and coccolithophore/phytoplankton abundance (using polarized microscopy plus a Flow-cam). Automated underway measurements will be made for: inherent optical properties (spectral absorption and attenuation [dissolved and particulate], backscattering, acid-labile backscattering, chlorophyll fluorescence, all sampled from the ship’s seawater system) plus apparent optical properties (spectral upwelling radiance, sky radiance and downwelling irradiance as measured from bowmounted radiometers). The latter measurements will provide critical matchups for satellite measurements, as well as radiometry for use in real time estimates of chlorophyll and PIC when clouds obscure the satellite view. In the latter two years of the project, the ship data will be used for regional calibration and validation of PIC and calcification algorithms so that we can use the historical data base of satellite ocean color to examine for long-term changes in coccolithophore abundance in the AO. This work will provide fundamental, new knowledge on the standing stocks and production rates of calcium carbonate by coccolithophores, in the Chukchi and Beaufort Seas. These proposed measurements will be the first-ever, direct 14C measurements of coccolithophore calcification in the AO, as opposed to indirect estimates based on carbonate system parameters or ocean color. Why is this important? First, PIC represents the most important ballast material responsible for sinking POC, which drives the biological pump. Indeed, the future of calcification and PIC production represents the future of the ocean’s biological pump. Moreover, even at typical, non-bloom concentrations, coccolith PIC is a significant contributor to the ocean albedo. In summer, they likely have even greater impact in the AO when extensive coccolithophore blooms form. Second, global climate change and ocean acidification are bringing unprecedented changes to the AO by a) melting the seasonal plus permanent sea ice cover, and b) slowly decreasing the pH over the next century. Decreasing sea ice cover will likely bring about a major biological shift in the Boreal Polar biogeochemical province (Longhurst et al., 1995), making it more Sub-Arctic in character. This is hypothesized to be allowing the current invasion of coccolithophores to the AO over the last decade. Less sea ice cover may also allow more air-sea influx of anthropogenic CO2, the cause of ocean acidification; this is expected to have the largest negative impact on calcifiers at high latitudes due to lower calcite and aragonite saturation states there. Our bio-optical measurements will allow critical revisions to PIC and calcification algorithms for the AO, technically impossible to do now due to a paucity of ship data. Armed with these validated algorithms, our proposed retrospective investigation of ocean color imagery for PIC and calcification in the AO will be critical to discern long time-scale changes in AO calcifiers associated with climate change.

Keywords: Ocean Biomass
Ocean-Atmosphere Flux

Behrenfeld-01 (2012)

Project Title: Characterizing the Phytoplankton Component of Oceanic Particle Assemblages

Science Team: Michael Behrenfeld, Oregon State University, mjb@science.oregonstate.edu (Project Lead)

Abstract: This research project is focused on the development of a technique for routinely assessing phytoplankton carbon biomass (Cphyto) in the field. If successful, this investment will create a foundation for (1) evaluating and evolving new satellite Cphyto products, (2) characterizing light- and nutrient-stress effects in the field independently of radiotracer measurements, and (3) distinguishing physiological- and biomass-responses to climate forcings in satellite time-series of ocean color (Fig. 1). The measurement and future validated retrieval of phytoplantkon biomass is essential for understanding global ocean carbon pools and fluxes and for detecting changes in this key carbon stock over time. Throughout the history of satellite ocean color measurements, chlorophyll concentration has functioned as the primary parameter retrieved from space related to the abundance of phytoplankton in the upper ocean. The relationship between phytoplankton biomass and chlorophyll concentration, however, is highly variable due to physiological adjustments in intracellular pigmentation resulting from variations in light and nutrient conditions of the mixed layer. Indeed, phytoplankton Chl:C ratios can vary by nearly 2 orders of magnitude (Geider 1987, Behrenfeld et al. 2005). Recently, an approach has emerged for directly estimating Cphyto from remote sensing retrievals of particle backscattering (Behrenfeld et al. 2005). Multiple studies have attempted to evaluate the scattering-biomass relationship, but true validation of satellite Cphyto products remains impossible due to a near complete lack of field Cphyto estimates. The current proposed study will develop a technique for measuring Cphyto and demonstrate its application in the field. Our approach is multifaceted to improve the probability of success, including both flow-cytometer sample analysis and construction of a new liquid-aperture particle counter/sizer. This work directly addresses the objectives of NASA's Ocean Biology and Biogeochemistry program by providing new scientific evaluation capabilities for novel space-based measurements of global ocean phytoplankton communities that will improve ocean productivity estimates and lead to robust satellite physiological products for comparison with ocean biogeochemical-ecosystem models.

Keywords: Ocean Biomass

Bowman-01 (2012)

Project Title: Continuation of the Carbon Monitoring System Flux Pilot Project

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Abstract: We propose to evolve the Carbon Monitoring System Flux Pilot Project funded under Phase 1 into a framework that integrates observational constraints on all major components of the carbon-cycle-anthropogenic system anthropogenic, terrestrial, oceanic, atmospheric in a top-down CO2 attribution system constrained by atmospheric satellite observations. This expanded framework will enable a deeper understanding of the global carbon cycle and a means of quantifying the effectiveness of climate mitigation policies. This CMS-FPP is motivated by the increase in tropospheric CO2 from anthropogenic emissions, which is the single largest driver of observed and predicted climate change [Forster et al, 2007]. However, roughly half of the CO2 produced from these emissions has been removed by terrestrial and ocean sinks. Consequently, The future trajectory of climate forcing will depend on future emissions and on the capacity of the carbon-cycle to absorb more CO2 [Friedlingstein, 2008]. Recent years have seen an acceleration of fossil fuel emissions and signs of an onset of carbon-cycle feedbacks [Canadell et al, 2007]. Since 2005, fossil fuel emissions have been regionally redistributed towards developing countries, which now make up more than half of CO2 emissions (>4 PgC/yr) [Peters et al, 2012]. While the global carbon budget and its partitioning between anthropogenic, terrestrial, and oceanic fluxes are reasonably understood, the contribution of regional drivers to that budget are not [Canadell et al, 2010]. Consequently, uncertainty in the attribution of CO2 accumulation rate on a year-to-year basis to those drivers limits our capacity to quantify the effectiveness of climate mitigation policies [Le Quere et al, 2009]. In order to reduce uncertainty in CO2 attribution, we will simultaneously improve and augment all major aspects of the current CMS-FPP: new satellites observations, an additional terrestrial eco-system model, a new fossil fuel assimilation system, updated ocean assimilation algorithms, and improved atmospheric inversion algorithms. The CMS-FPP Phase 2 will generate a suite of new and updated products covering 7/2009- 2011 including new global spatially resolved CO2 sources and sinks, new high resolution global fossil fuel emissions, better estimates of oceanic CO2 air-sea exchange, new estimates of global above-ground biomass, and refinements in top-down attribution and uncertainty algorithms. Products generated from bottom-up and top-down estimates will be made publically available through carbon.nasa.gov and linked to cmsflux.jpl.nasa.gov. Through these updates, the CMS-FPP will play a crucial and on-going role in assessing the current capability of space-borne observing systems to improve our knowledge of the integrated carbon-cycle-anthropogenic system and its impact on climate forcing

Keywords: Land-Atmosphere Flux
Ocean-Atmosphere Flux
Global Flux

Cook-B-01 (2012)

Project Title: Improving Forest Biomass Mapping Accuracy with Optical-LiDAR Data and Hierarchical Bayesian Spatial Models

Science Team: Bruce Cook, NASA GSFC, bruce.cook@nasa.gov (Project Lead)
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Abstract: We propose to implement a novel approach for mapping forest biomass and associated errors using the fusion of airborne LiDAR, passive optical and thermal data and a Bayesian hierarchical model that accounts for spatial variances between ground observations and remotely sensed data. This method will be compared with the more traditional approach of using a variety of plot-scale LiDAR metrics in a generalized, multiple linear regression model for relatively large region of interest (e.g., county- or state- scale). Also, we will use fine-resolution LiDAR and passive optical data (<1 m) to delineate individual trees, identify species class, and derive additional tree-level attributes (e.g., crown dimensions, crown area weighted heights, stem density) to improve upon biomass estimates made with aggregated point cloud metrics and inventory data at the plot-level (the traditional approach). These three methods will be evaluated and compared at four study sites in the midAtlantic and New England regions of the eastern US: Howland Forest and Holt Research Forest, ME; Harvard Forest, MA; and the Smithsonian Environmental Research Center near Edgewater, MD. This study will leverage coincident and co-registered LiDAR, passive optical, and thermal data that were collected at these sites for NASA s local-scale biomass pilot project between 2011 and 2012. Remotely sensed data was collected with Goddard s LiDAR, Hyperspectral, and Thermal (G-LiHT) airborne imager, which PI Cook developed at NASA-GSFC for studying the complex relationship between terrestrial ecosystem form and function. Large-area stem maps (3 to 35 ha per site, in which all stems greater than 1 cm have been measured) exist at each of these study sites, and these data will be used to verify crown delineations and enable the creation of a fineresolution spectral library. Subsets of the stem map areas will be used to simulate inventory plots, which will then be used as inputs for the Bayesian spatial latent factor model. Each of the stem map areas contain a variety of over/understory tree species, variable topography and range of drainage conditions, which will allow us to validate each of the methods over a wide range of forest types between and within each of the four study sites. Benefits of the proposed Bayesian spatial latent factor prediction model are 1) variables are selected using an efficient, dimension reduction technique; 2) spatial dependencies are incorporated into the model to and improve inference; 3) data compression is used to reduce the computational burden; and 4) sources of uncertainty are acknowledged and propagated through to prediction. Benefits of using data fusion for biomass mapping is that LiDAR and passive optical data provide unique information on the 3- dimensional structure and species composition of the forest, respectively. This synergy has been the focus of recent research, and has spawned the development of multi-instrument airborne systems such at the Carnegie Airborne Observatory (CAO), NASA s G-LiHT, and National Ecological Observatory Network (NEON) system that will begin systematic data collections in 2012. New algorithms and model variables for mapping forest biomass, such as the Bayesian latent spatial factor model and individual tree attributes we propose in this study, are needed to take full advantage of the synergy offered by these new, complementary datasets.

Keywords: Land Biomass

Dubayah-03 (2012)

Project Title: High Resolution Carbon Monitoring and Modeling: A CMS Phase 2 Study

Science Team: Ralph Dubayah, University of Maryland, dubayah@umd.edu (Project Lead)
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Abstract: The overall goal of our proposed research is the continuing prototype development of a framework for estimating local-scale carbon stocks and future carbon sequestration potential for the State of Maryland using remote sensing and ecosystem modeling. Specifically, we will address the following objectives: (1) Improve our existing methodology for carbon stock estimation and uncertainty and assess its efficacy across an expanded range of environmental and forest conditions; (2) Provide local-scale estimates of carbon stocks and their uncertainties for the entire state of Maryland representing Eastern U.S. forest types; (3) Initialize and run a prognostic ecosystem model to estimate carbon stocks and their changes, and to estimate carbon sequestration potential; (4) Provide detailed validation of national biomass maps using FIA data and localscale biomass maps.(5) Demonstrate new data acquisition technology (single photon counting) for lowcost, rapid carbon assessments. Our proposed work will greatly expand our coverage from 2 to 24 Maryland counties and extends from the tidewater forests of the Chesapeake Bay through the coastal plains and uplands, to the mountainous forests of Western Maryland and the Appalachians. This gradient in land use, topographic, edaphic, and climatic conditions enables an appropriate expansion of methods, models, data, and assessments consistent with the goals of the second phase of CMS. Our objectives build from our Phase 1 work and lead to a clear set of tasks for the proposed effort. These are divided into seven categories of activities traceable to this framework: (1) Remote sensing data acquisition and processing; (2) Field data collection and analysis; (3) Algorithm development and image processing; (4) Statistical and machine learning model development; (5) County biomass and uncertainty map generation, and end-to-end error analysis; (6) Prognostic ecosystem modeling, and; (7) national biomass map validations. An additional element of our proposed work is a coordinated outreach effort to county and state agencies to inform and promote their activities in CMS and includes a transfer of technology to the State of Vermont. To promote this outreach we will also implement a new, web-based data visualization, query and delivery system, Grid^Intel Online (GIO) that allows any user to call up lidar data, associated imagery, biomass and error estimates for arbitrary map areas. Deliverables for this project expand upon those from Phase 1. In addition to the developed framework the project will produce the following CMS products: (1) tiled and mosaicked canopy height and forest/non-forest maps at 2 m and 30 m resolution for Maryland; (2) AGBM maps at 30 m resolution with associated uncertainty maps; (3) EDmodel based carbon and carbon-flux maps at 90 m resolution; (4) ED-model maps of carbon sequestration potential; (5) web-based data visualization and query system; (6) map of canopy structure and biomass derived from wall-to-wall single photon lidar for Alleghany county; (7) assessment of main sources of error and proposed strategies for reducing errors in future deployment of an operational CMS.

Keywords: Land Biomass
Decision Support

French-04 (2012)

Project Title: Development of Regional Fire Emissions Products for NASA's Carbon Monitoring System using the Wildland Fire Emissions Information System

Science Team: Michael Billmire, Michgan Tech Research Institute, mgbillmi@mtu.edu
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Abstract: Current work under the NASA-CMS Flux Pilot project includes measures of biomass burning emissions for the quantification of carbon flux from land to the atmosphere. Fire is recognized as an important mechanism for this exchange. Measures of biomass burning emissions are included in this pilot project, but the estimates would greatly benefit from further refinement, and some idea of the uncertainty in biomass burning emissions is needed. There is a growing community of international, federal, and state-level parties that desire and in some cases require refinements in methods to quantify emissions from wildland and prescribed fire (biomass burning). To meet these requirements, these parties are developing a suite of methods to address their needs. We propose to use tools developed from collaborations with the US Forest Service and US Environmental Protection Agency, as well as recent research carried out for NASA, to refine the fire emissions module of the CASA-GFED model currently used by CMS. For the proposed project, to be conducted in Phase II of the CMS, we are proposing to assist the NASA-Goddard CASA-GFED team in improving the GFED approach currently used in the CMS Phase I Flux Pilot project. We will use the Wildland Fire Emissions Information System (WFEIS), an approach developed under NASA s Carbon Cycle Science program in collaboration with others in the fire emissions community, to adjust GFED estimates over North America. WFEIS operates at a 1-km spatial grid scale, while GFED operates at a 0.5 deg grid scale. The two approaches use the same general construct, however they use different data sources for the model parameters and make different assumptions when applying the general model. WFEIS uses a ground-based method to map biomass (fuel loading) and a more direct method to estimate combustion completeness (fuel consumption) than GFED. WFEIS was developed as a regional to landscape-scale method, making it an appropriate tool to refine the GFED estimates of emissions for areas where the two methods can be implemented. The proposed activity includes: 1) improvements in quantifying mapped fuels (biomass) for the US and combustion in deep organic soils of Alaska; 2) development of an uncertainty measurement methodology for emissions estimation; 3) production of 1-kmscale fire emissions estimates for the US; 4) a comparison of these products to CASAGFED emissions estimates; and 5) refinements of GFED parameters based on the results found with WFEIS. Specific outputs from this activity will provide important information for improving our understanding of carbon emissions from wildland fire.

Keywords: Land Biomass
Land-Atmosphere Flux
Decision Support

Healey-01 (2012)

Project Title: A Global Forest Biomass Inventory Based upon GLAS Lidar Data

Science Team: Sean Healey, USDA Forest Service, seanhealey@fs.fed.us (Project Lead)

Abstract: The United Nations Food and Agriculture Organization (FAO) compiles and monitors national-level biomass estimates across the world s forests through the Global Forest Resources Assessment (FRA). FRA reports represent the current state of knowledge regarding key forest parameters as expressed by national forest agencies and ministries worldwide. Data collected in the FRA is important to UN initiatives such as REDD (Reducing Emissions from Deforestation and Degradation), which depend upon accurate, precise, and consistent national-level reporting of forest carbon storage. The proposed work would establish a satellite-based NASA CMS global inventory of aboveground tree biomass (a primary component of overall biomass) as an official component of FAO s FRA 2015. Methods for this inventory were developed during the CMS pilot phase though a partnership between members of the CMS national biomass pilot team and representatives of the national forest inventory (FIA: US Forest Service s Forest Inventory and Analysis unit) on the CMS Science Definition Team. Discrete full waveform lidar footprints from the GLAS (Geoscience Laser Altimeter System aboard ICESat) are strongly correlated with aboveground tree biomass, and are here used in a survey/sample context as the basis for the CMS/FAO global biomass inventory. Based upon CMS pilot results, this approach is likely to provide an improvement in the precision of biomass estimates for countries without established national forest inventories, and its global consistency should enhance inter-comparability of biomass stocks across all nations. This inventory would be based upon model-based estimation, an approach which provides clear estimates of biomass and related uncertainty, accounting for both the variance of the sample and variance introduced by modeling biomass at each GLAS shot. FAO will coordinate global compilation of the ground data needed from national forestry agencies for calibration of models to be used in this inventory. A series of approximately 10 regional workshops will be held for national forest inventory representatives from around the world in 2013. At each workshop, time will be dedicated to engage participating countries in the needed data sharing. Almost all costs associated with this effort (including travel and lodging for many participants) will be borne by FAO. In addition to providing country- and global-level forest biomass estimates, this project will publish relationships between GLAS heights and field-measured biomass, which may be of use to other CMS efforts using GLAS data to calibrate wall-to-wall maps. Lastly, there is a forward-looking element which involves forecasting the precision of this inventory approach using lidar data from the ICESat-2 satellite (launch: 2016). Collection of ground data by this project will be coordinated with the ICESat-2 Science Team, which is programming overflights of GLAS shots by MABEL (an ICESat-2 simulation platform) and airborne lidar. Taken together, the components of the proposed project will: 1) develop a global CMS aboveground forest biomass product; 2) establish it as a critical monitoring asset within the FAO FRA monitoring process; and 3) assess its sustainability in view of upcoming NASA missions. The proposed work includes a good deal of in-kind salary contribution from the Forest Service, and there is a 55/45 balance of funding to non-federal/federal entities. Sean Healey, FIA s remote sensing representative to FAO and a member of the CMS Science Definition Team, is nominated for membership on the CMS Science Team.

Keywords: Land Biomass
MRV

Houghton-02 (2012)

Project Title: Spatially Explicit Sources and Sinks of Carbon from Deforestation, Reforestation, Growth and Degradation in the Tropics: Development of a Method and a 10 Year Data Set 2000-2010

Science Team: Richard (Skee) Houghton, The Woods Hole Research Center, rhoughton@whrc.org (Project Lead)

Abstract: Neither of the pilot studies in NASA s Phase 1 of the CMS has explicitly considered changes in terrestrial carbon storage that result from land use and land-cover change (LULCC). The biomass pilot study could be extended to estimate changes in aboveground carbon density, but modeling and ancillary data will be needed to account for changes in soils, downed wood, and wood products. The flux pilot study has, so far, concentrated on short-term fluxes of carbon (i.e., photosynthesis, respiration, etc.) and has paid less attention to the longer-term, structural changes that result from disturbance and recovery. Yet it is these changes in biomass and soil carbon that define the net contribution of LULCC to the global carbon budget. We propose (1) to develop and demonstrate a method for monitoring changes in carbon density in forests and (2) to produce a map of gross and net fluxes of carbon associated with deforestation, reforestation, growth and degradation for the entire tropics. We will focus on the changes in carbon density that result from disturbance and recovery. We propose to use multi-scale changes in forest cover (gains and losses) combined with lidar-based estimates of aboveground carbon density to inform a carbon-tracking model that will calculate losses and gains of carbon at a spatial resolution of 250m across the tropics and at a resolution of 30m for two regions within southeast Asia and the Congo Basin. As a part of this research, we will determine the propagation of error for each method (change in land cover, change in carbon density), including allometry error and modeling error. The analysis of error will help define how small a disturbance (in area and in carbon density) can be observed. And, using a carbon tracking model, we will investigate the effect of this minimum detection on carbon emissions. The work proposed here will complement the current pilot studies and will track changes in terrestrial carbon density, in particular the changes that result from disturbance and recovery of forests. The model will use a combination of MODIS, Landsat, and GLAS data to determine annual changes in carbon density in aboveground living and dead biomass, belowground biomass, litter, coarse woody debris, and wood products. The work will focus on identifying, characterizing, and measuring disturbances (and recovery) and on calculating the resulting fluxes of carbon. The products of this work will be (1) a methodological approach incorporating satellite data, a carbon-tracking model, and error analyses, and (2) multi-scale gridded data sets showing the distribution of carbon sources and sinks attributable to forest disturbance and recovery. The method will not be limited to the data inputs used here. Rather the model will be flexible enough to accommodate other data sets as they evolve. The products will include the data sets used to calculate carbon sources and sinks (rates and intensities of disturbance and aboveground carbon densities), the errors in each data set and the propagation of error through the calculation of net carbon flux. The work is relevant to societal needs in two ways: first, carbon emissions from LULCC are an important but poorly constrained component in the global carbon balance; this work will demonstrate the capacity of satellite-based measurements to reduce the error of that flux. Second, project-level and national-level emissions are the basis for evaluating emission reduction strategies, arguably the most effective mechanism for reducing emissions of carbon from developing countries.

Keywords: Land Biomass
MRV

Huntzinger-01 (2012)

Project Title: Reduction in Bottom-Up Land Surface CO2 Flux Uncertainty in NASA's Carbon Monitoring System Flux Project through Systematic Multi-Model Evaluation and Infrastructure Development

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Abstract: This study will generate improved global estimates of land-atmosphere carbon exchange by combining and enhancing the technical infrastructure and observational constraints within the NASA Carbon Monitoring System (CMS) Flux Project with new "bottom-up" a priori surface flux estimates. These new surface flux products will be derived from a community of models that represent our best process-based understanding of how carbon is exchanged between the land and the atmosphere. We will leverage and build off of an existing NASA funded grant: The Multi-Scale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP). MsTMIP is a coordinated, large-scale intercomparison effort that combines common forcing data and a detailed simulation protocol in order to improve the diagnosis and attribution of carbon sources and sinks across both global and regional scales. What MsTMIP does that other intercomparisons have failed to do, is create a framework that isolates, interprets, and helps inform understanding of how differences in process parameterizations among current "bottom-up" models impact their flux estimations. As a result, the MsTMIP framework allows for the isolation and quantification of the intermodel variance in estimates of land-atmosphere carbon exchange due to model structure, or variations in the types of processes consider in the model and how these process are represented. This inter-model variance provides a robust assessment of uncertainty in land surface priors due to varying model physics, a component currently missing from the CMS-Flux system. CMS-Flux has the ability to produce ensembles of atmospheric CO2 distributions using perturbations to transport and surface fluxes. These ensembles can help build understanding of the relationship between surface flux and atmospheric CO2 concentrations, particularly if the consistency (or inconsistency) between surface flux representations and atmospheric CO2 measurements can be linked back to representation of processes within the models. However, to do so effectively CMS-Flux needs to include a priori flux estimates that are more representative of our current understanding of landatmosphere sources and sinks than what is currently in the system. In other words, the a priori flux estimates need to be informed by the range of models used by the scientific community given that there is no consensus on the "best" model overall. CMS-Flux is currently limited with respect to the land surface bottom-up priors because: 1) it uses only two closely related land surface models, and as a result has a restricted representation of the "true" uncertainty in the land surface bottom-up fluxes; 2) the uncertainty in the bottom-up fluxes themselves is not quantified in the system; and, 3) the atmospheric inversion system is disconnected from the TBMs in that one unified system cannot currently be run. This proposed effort improves the current CMS-Flux product with four key advances. First, we propose to leverage the existing NASA funded MsTMIP activity to generate new a priori "bottom-up" land-surface flux products for the CMS-Flux system. Second, we will quantify uncertainties in a priori flux estimates. Third, we will develop the technical infrastructure of CMS-Flux to handle multiple land-surface models as priors. Four, we will combine the new a priori input products with the enhanced CMS infrastructure to test the influence of prior flux estimates (and their associated uncertainty) on posterior flux estimations from the inversion. Finally, the new infrastructure will also be used to compare existing terrestrial biospheric model estimates to the atmospheric CO2 constraints within CMS-Flux, providing another means of evaluating understanding of the processes controlling land-atmosphere carbon exchange. Combined, this proposed activity will expand the operational-use of CMS-Flux and allow for more robust posterior flux estimates and their associated uncertainties.

Keywords: Land-Atmosphere Flux

Jacob-01 (2012)

Project Title: Use of GOSAT, TES, and Suborbital Observations to Constrain North American Methane Emissions in the Carbon Monitoring System

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Abstract: We propose to contribute to the NASA Carbon Monitoring System (CMS) with a fourdimensional variational (4D-var) inverse modeling capability for methane emissions in North America integrating satellite (GOSAT, TES), aircraft (CalNex, HIPPO, NOAA/CCGG), and surface-based (TCCON, NOAA/CCGG) observations. Our work will build on the existing CMS capability at JPL for carbon flux inversions using the adjoint of the global GEOS-Chem chemical transport model (CTM). Here we will apply the adjoint of the nested version of GEOS-Chem with 1/2o × 2/3o (~50 × 50 km2) horizontal resolution over North America and adjacent oceans. The nested model will enable fine-scale constraints on methane sources through the 4D-var inversion. We will focus on 2009 2011 when data from both GOSAT and TES are available together with aircraft campaign data over the US from CalNex (May July 2010) and HIPPO (June September 2011). Combined use of GOSAT and TES data will enable us to separate boundary layer and free tropospheric contributions to the methane column through the inversion. The satellite data will be ingested in the 4D-var inverse model while the suborbital data will be used for independent analysis of the optimized methane fluxes. We will conduct a targeted analysis of the CalNex period to constrain methane sources in California by applying both Lagrangian (STILT) and Eulerian (GEOS-Chem) inverse modeling approaches to the aircraft and satellite data, testing the effect of different meteorological data sets and of different a priori constraints. This analysis will provide a unique opportunity to assess inverse modeling uncertainties related to resolution, data type (satellite or aircraft), meteorological model, and inversion procedure. We will use results from our continental-scale inversion of methane fluxes to better understand and quantify the major sources contributing to methane emissions in North America, and to provide guidance to the US EPA for improving its national emission inventories. The inverse modeling capability for methane will be implemented into the existing CMS Flux Pilot Project at JPL for consistent inversion of CO2 and methane fluxes over North America using the same 4D-var system. This will provide a powerful facility to monitor the fluxes of the two most important anthropogenic greenhouse gases. Our work will be directly responsive to major climate policy initiatives in the US targeting methane emissions including the Global Climate Change and Clean Air Initiative of the US State Department and the Global Methane Initiative of the U.S. EPA. P.I. Daniel Jacob and CoI Steve Wofsy will join the CMS Science Team as part of this project.

Keywords: Atmospheric Transport
Land-Atmosphere Flux
Decision Support

Kasischke-03 (2012)

Project Title: The Forest Disturbance Carbon Tracking System A CMS Phase 2 Study

Science Team: Eric Kasischke, University of Maryland, ekasisch@umd.edu (Project Lead)

Abstract: Forest disturbances are a key process that drives significant variations in the terrestrial carbon budget for North America. While many NASA funded projects for the North American Carbon Program, as well as others funded by U.S. land management agencies, were focused on developing approaches to map forest disturbances, and assess the impacts of these disturbances on carbon cycling. However, efforts have not progressed enough to integrate the results from these efforts in order to provide a forest disturbance product that is useful for assessing the impacts of disturbances. The goal for this proposed Carbon Monitoring System (CMS) pilot project is to (1) develop a new regional carbon monitoring product that utilizes satellite remote sensing data to map forest disturbed area on an annual basis at medium resolution; and (2) to use this product as a basis for assessing the impacts of disturbance on forest carbon stocks for specific ecoregions of the United States. The development of the Forest Disturbance Carbon Tracking System (FDCTS) will provide an approach based on using a number of information products derived from remotely sensed data to address the following objectives: (a) Integrate a number of forest disturbance products in systematic fashion to create a map of the spatial and temporal extent of different forest disturbance events and episodes; and (b) Assess the impacts of these disturbances on key forest characteristics that control changes to carbon cycling (tree mortality, damage to branches and foliage, loss of live biomass, harvest removals, and combustion) for specific forest types in two North American forest ecoregions in order to produce a data product that depicts changes to forest carbon stocks on an annual basis for the ecoregions being studied. This CMS pilot project would focus on forest disturbances in two Level II U.S. ecoregions where disturbances have been dominant drivers of the terrestrial carbon cycle over the past decade: (a) the Western Cordillera ecoregion which has experienced major outbreaks of pine bark beetles as well as wildfire; and (b) the Alaska Boreal Interior ecoregion where burning of deep organic layers during fires represents the major impact on forest carbon cycles. As part of this pilot project, for each ecoregion, we would develop disturbance maps and forest impact products for the 2000s on an annual basis. The outputs from thithis CMS pilot project would be medium resolution (30 m) maps of all forest disturbances in the study ecoregions, which also contains data layers on pre-disturbance forest and carbon pool characteristics, the impacts of forest disturbances on carbon pools, and the amount of carbon remaining after the disturbances for specific pools. Within the climate change area, reliable and up-to-date information is needed on the terrestrial sources and sinks for a number of carbon-based greenhouse gases. The results from this pilot project will demonstrate a new approach for integrating multiple data sources to generate a product that quantifies the impacts of forest disturbance on the primary forest carbon pools. This new data product would not only provide the basis for providing inputs into models that quantify the impacts of disturbances on carbon cycling, but also to validate such models. The pilot project not only represents the first step towards creating national and continental-scale forest disturbance products, but also would provide the foundation for developing a system that would be able to quantify the impacts of forest disturbances on an annual basis going back thirty years to the mid-1980s (based on exploiting the Landsat TM/ETM+ data archive). Such an analysis would not only provide scientists, managers, and policy makers with clearer information on the integrated impacts of past disturbances, but the approach could be used to provide improved information on the impacts of forest disturbance on an annual basis.

Keywords: Land Biomass
Decision Support

Kennedy-01 (2012)

Project Title: Integrating and Expanding a Regional Carbon Monitoring System into the NASA CMS

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Abstract: A key challenge in a carbon monitoring system is scaling thematically rich but highly localized information to the broad spatial scales needed for carbon accounting and management. This is particularly true for wooded ecosystems, where carbon storage potential is high, but actual carbon status is highly determined by local-scale environmental and forest management conditions. Through a USDA-NIFA funded project entitled Integrated, observation-based carbon monitoring for wooded lands of Washington, Oregon and California , our team is developing a system to integrate Landsat satellite imagery, maps of environmental characteristics, Forest Inventory and Analysis (FIA) plot data, small-footprint lidar data, and aerial photos to characterize key carbon dynamics in forested ecosystems across all ownerships in the states of Washington, Oregon, and California from 1985 to 2010. Key characteristics of our system include: ' Operational scaling of local-scale dynamics to all forests in Washington, Oregon, and California ' Yearly mapping of forest biomass and change in biomass from 1990 to 2010 ' Explicit characterization of cause of change ' Integration of USDA Forest Service Forest Inventory and Analysis (FIA) plot data ' Linkage of small-footprint lidar data with regional scale biomass maps ' Explicit quantification of methodological uncertainties for all estimates Because our approach addresses key challenges faced by the current NASA Carbon Monitoring System (CMS), we believe it has the potential to complement and aid NASA s mandate for operational carbon monitoring. To help reach that potential, we propose three activities. -- 1. We will utilize the products from our own carbon monitoring program in forests of Washington, Oregon, and California to evaluate, understand, and improve performance of the NASA CMS products, and compare a variety of national-scale products both to each other and to FIA plot estimates. -- 2. We will work with collaborators within the USDA FIA to extend our approaches to a different forest system, linking explicitly with the local-scale NASA CMS efforts in eastern forests. -- 3. Finally, we will bring our data, methods, and lessons-learned to NASA CMS Science Definition Team, and work closely with other SDT members to link our approaches into those analytical and modeling frameworks to further the overarching goals of the CMS. The following characteristics of our project are relevant to NASA s need to evaluate and improve its CMS: - Evaluating the utility and characterizing uncertainties in CMS products - Understanding scaling issues needed to link local to national scale products - Developing and demonstrating feasibility of alternative approaches to monitoring - Illustrating capabilities of satellite-based monitoring for science and management

Keywords: Land Biomass
Decision Support

Lohrenz-04 (2012)

Project Title: Development of Observational Products and Coupled Models of Land-Ocean-Atmospheric Fluxes in the Mississippi River Watershed and Gulf of Mexico in Support of Carbon Monitoring

Science Team: Steven (Steve) Lohrenz, University of Massachusetts Dartmouth, slohrenz@umassd.edu (Project Lead)

Abstract: Information about carbon fluxes in continental margins and linkages to terrestrial carbon cycles is key focus of NASA s Earth Science Research Program and a central aspect of NASA s Carbon Monitoring System. The uncertainties in coastal carbon fluxes are such that the net uptake of carbon in the coastal margins remains a poorly constrained term in global budgets. In particular, our ability to estimate current air-sea CO2 fluxes in continental margins is limited, and there is even less capability for predicting changes in the CO2 uptake capacity in coastal waters. The need to improve the understanding of coastal carbon dynamics and precision of estimates of coastal carbon fluxes has implications for attribution of land sources and sinks because atmospheric inversions are sensitive to uncertainties in coastal boundaries. Moreover, characterization of trends in carbon inventories reveal an increasing fraction of fossil fuel carbon is remaining in the atmosphere due to reductions in the efficiencies of ocean sinks and other sink processes not considered in current models. The proposed research will employ 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. Such information is critically needed to better constrain the contribution of coastal margins to carbon sources and sinks and improve capabilities to attribute sources and sinks to different regions as well as reducing uncertainties in estimates. The proposed effort will use a combination of observations and coupled terrestrial and ocean models to examine carbon processes and fluxes from the watershed to the continental margin. A major aspect of this proposed project will be to establish and populate geospatial portals for sharing and analysis of carbon datasets and products. The primary region of study will be the Mississippi River watershed and northern Gulf of Mexico. However, the model domain will also include the continental margins of Florida and the South Atlantic Bight. The region of study provides an excellent setting to carry out this work as there are a large number of supporting datasets and on-going programs that will complement this work. The proposed work is closely aligned with objectives of the NASA Carbon Monitoring System scoping effort and of the North American Carbon Program and will support National Climate Assessment activities. The effort will also contribute to NASA Coastal Carbon Synthesis effort and international efforts to develop a North American carbon budget (CarboNA). The unique nature of our approach, coupling models of terrestrial and ocean ecosystem dynamics and associated carbon processes, will allow for assessment of how societal and human-related LCLUC, as well as climate change, affects terrestrial carbon sources and sinks, export of materials to coastal margins, and associated carbon processes in the continental margins. Results would also benefit efforts to describe and predict how land cover and land use changes impact coastal water quality, including possible effects of coastal eutrophication, hypoxia, and ocean acidification.

Keywords: Land-Atmosphere Flux
Ocean-Atmosphere Flux
Land-Ocean Flux
Decision Support

Miller-J-01 (2012)

Project Title: In Situ CO2-Based Evaluation of the Carbon Monitoring System Flux Product

Science Team: John Miller, NOAA Earth System Research Laboratory, John.B.Miller@noaa.gov (Project Lead)

Abstract: The fundamental objective of the NASA Carbon Monitoring System (CMS) flux product is to derive surface CO2 fluxes using satellite-based column CO2 mole fractions. Although the CMS flux product has an existing evaluation strategy, it is limited in scope and has acknowledged shortcomings, especially with regard to tropical carbon fluxes. Here, we propose to use the large number of high-accuracy, high-precision, globally distributed in situ tropospheric CO2 observations (including a unique set of tropical observations) to assess the realism of the optimized CMS fluxes and their stated uncertainties. First, CO2 observations will be compared directly with a posteriori CMS-modeled CO2 mole fractions. To first-order, near surface CO2 surpluses in the modeled CO2 mole fractions can be interpreted as excess positive surface flux, and vice versa. Second, CMS fluxes will be compared to fluxes derived from independent flux optimization systems (using in situ CO2 data). This more direct flux evaluation will be conducted globally using the CarbonTracker data assimilation system. Moreover, CarbonTracker will be run using multiple transport models to help assess the role of transport errors in the mismatch between simulation and observation. Additionally, in tropical South America we will use a state of the art regional flux inversion system to create a second set of fluxes, taking advantage of a two-year data set of fortnightly measurements in Brazil at four vertical profile sites and two additional surface sites. Tropical South America is of particular interest in global satellite-based inversions because of its disproportionate importance for the global carbon cycle combined with the anticipated seasonal biases in tropical satellite-based column CO2 arising from frequent cloud cover and high aerosol loadings. Working with the CMS flux product team, we will use the in situ CO2-based flux evaluations to diagnose shortcomings in the existing CMS flux optimization approach, transport parameterization and input GOSAT/ACOS CO2 columns. Finally, while we do expect OCO-2 to ultimately have better coverage than GOSAT over tropical South America, we still anticipate significant seasonal biases in sensitivity to Amazonian surface fluxes. To address this issue, and guard against biases in eventual CO2 flux optimization, we will produce an in situ CO2-optimized flux map for use as a prior in future CMS flux products. For any top-down CO2 flux estimation system, evaluation and uncertainty characterization is as important as the flux calculation itself, and the research proposed here will leverage the highest precision measurements in the global carbon cycle to assess the quality of the CMS flux product.

Keywords: Atmospheric Transport
Land-Atmosphere Flux

Pawson-01 (2012)

Project Title: GEOS-CARB: A Framework for Monitoring Carbon Concentrations and Fluxes

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Abstract: This proposal is for a continuation of NASA GSFC s activities related to the Carbon Monitoring System, Flux Pilot Study (CMS FPP). The work will enhance and develop the capabilities of NASA s Goddard Earth Observing System (GEOS) set of models and assimilation components to further develop a core capability for CMS-related carbon cycle science and monitoring. The work consists of three components: (i) continuation of past work to compute atmosphere-ocean and atmosphere-land biosphere fluxes, as well as their evaluation using forward modeling in GEOS-5; (ii) enhancements of GEOS-5 for carbon monitoring, including a model study of the intermingling of uncertainties in anthropogenic and land-biospheric carbon emissions, and development of an enhanced assimilation capability to include multiple space-borne CO2 estimates (from AIRS and ACOS-GOSAT); (iii) a focused activity that examines aspects related to top-down (inverse) estimates of carbon fluxes. The latter effort will include a controlled comparison of three inverse estimates, including the one from CMS FPP, that use the same input data but use different methods. It also includes the implementation and application of a Lagrangian particle dispersion model to compute global footprints of GOSAT observations. Further, substantial new developments will be implemented into an existing variation inversion system. The work proposed in GEOS-CARB will implement and adapt various modeling and analysis tools, linking them closely with GEOS-5 systems available in the Global Modeling and Assimilation Office, in order to better exploit NASA s carbon-relevant observations for monitoring and understanding the global carbon cycle. The development work will leave NASA with enhanced modeling and analysis tools for carbon-cycle monitoring using space-based observations. These tools will be used to address some of the research questions that have arisen in the course of CMS FPP, with a strong emphasis on characterizing uncertainty in CO2 flux computations.

Keywords: Land-Atmosphere Flux
Ocean-Atmosphere Flux
Global Flux

Saatchi-02 (2012)

Project Title: Prototyping MRV Systems Based on Systematic and Spatial Estimates of Carbon Stock and Stock Changes of Forestlands

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Abstract: Under phase I of the Carbon Monitoring System (CMS) Biomass Pilot Project, we developed a map of aboveground carbon stocks at 100-m spatial resolution using a combination of remote sensing products combined with ground inventory data. In phase II, we propose to build upon phase I by developing similar spatial products for carbon stocks in all pools (belowground biomass, dead wood, forest floor, soil organic carbon) for three points in time so that net annual carbon stock changes (fluxes) over time may be estimated spatially over US forestlands. Additionally, we propose to test a methodology for separating net flux into its component parts of gross emissions and gross removals to enable a better understanding of how forests should be managed to decrease emissions and increase removals. We will use remote sensing products to quantify areas of forest disturbance and change and develop a fully spatial framework for estimating GHG dynamics (i.e., gross emissions and removals). Our proposed methodology will follow the IPCC Good Practice Guidelines for national GHG accounting from the forest/land-use sector. The expected spatial framework will enable future integration of the proposed activities and products with the CMS Flux Pilot Project. It will also demonstrate a method by which spatial data and models can be integrated with ground data to prototype IPCC recommended Monitoring, Reporting and Verification (MRV) systems for reducing emissions from deforestation and forest degradation and increasing removals from enhancement of forest carbon stocks.

Keywords: Land Biomass
Land-Atmosphere Flux
MRV

Shuchman-01 (2012)

Project Title: Development of New Regional Carbon Monitoring Products for the Great Lakes Using Satellite Remote Sensing Data

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Abstract: The Great Lakes represent approximately 20% of Earth's surface freshwater and are the largest surface area of freshwater on the planet. Understanding the magnitude of the contribution that the Great Lakes make to Earth's carbon budget is important to regional, national, and international carbon monitoring efforts. Quantifying the annual carbon fixation for each of the five Great Lakes as well as determining which of the Lakes are carbon sinks versus sources will be a significant contribution to the overall understanding of the Earth's carbon budget. Despite the large number of in situ based productivity measurements made at selected locations and limited times during the year in the Great Lakes, a strong case can be made that accurate annual lake-wide estimates of primary production do not exist for any of the Great Lakes. Thus, a new approach using satellite data is needed to provide truly lake-wide primary production in these important large ecosystems. This proposed satellite based program will result in new regional carbon monitoring products that will characterize each Laurentian Great Lake's annual carbon fixation and additionally address whether each Great Lake is a net source or sink of carbon. This will be accomplished through characterization of phytoplankton primary production (PP) using a new Great Lakes Primary Productivity Model (GLPPM). The GLPPM utilizes NASA OceanColor satellite imagery (MODIS, VIIRS). Additionally, aggregating annual PP for all five lakes will give insight into whether the Great Lakes are as a whole is a source or sink of carbon and to determine the significance of the Great Lakes to Earth's total carbon budget. Individual Great Lakes annual carbon production information will also be invaluable input into high resolution regional carbon models. A key element to the success of this program includes additional field measurements in Lakes Superior, Michigan, Huron and Great Lakes embayments. These in situ observations will be used to better quantify carbon fixation rates that are key to producing accurate carbon estimation products. Additionally the field data will aid in the product accuracy assessment. In summary, monthly and annual carbon production products for each of the five Great Lakes generated under this program will be provided to stakeholders via an active data sharing program within NOAA/Great Lakes Environmental Research Lab (GLERL) and the Great Lakes Observing System (GLOS). A key to providing this valuable data for decision makers, scientists, the public, and other stakeholders will be rigorous error quantification and accuracy assessment.

Keywords: Lake Biomass
Ocean Biomass
Ocean-Atmosphere Flux

Verdy-01 (2012)

Project Title: Towards a 4D-Var Approach for Estimation of Air-Sea Carbon Dioxide Fluxes

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Abstract: The challenge- Any Carbon Monitoring System (CMS) must account for fluxes of carbon between the atmosphere and the oceans, the world s largest reservoir of carbon dioxide (CO2). Currently, air-sea CO2 flux estimates are produced by sophisticated physical-biogeochemical models. However, these models still fail to represent significant patterns in the observed fluxes, and these discrepancies are thought to be largely due to errors in the simulation of biogeochemical processes. Our goal- This proposal capitalizes on two recent developments in oceanography to lay the groundwork for a global ocean CMS with improved biogeochemistry. Satellite measurements of the surface ocean and sensor-based measurements of the interior ocean are rapidly increasing the temporal and spatial coverage of biogeochemical data. Simultaneously, the development of four-dimensional variational assimilation (4D-Var) modeling has combined the forward modeling and traditional static inversion approaches to overcome the primary limitations of both: forward models estimate what could have happened in the ocean rather than what actually happened, and inversions cannot yield predictions. The 4D-Var approach automates the process of adjusting initial conditions and model parameters to produce an optimal fit of the model to physical constraints and all available observations. Our vision is of a state-of-the-art global physical-biogeochemical ocean model that incorporates data from the growing global network of satellites, sensors, and shipboard measurements to improve its estimates of air-sea CO2 fluxes. Our contribution- We will provide the missing components for 4D-Var physical-biogeochemical assimilation. As we build toward our goal of a global model-observation synthesis, each step of the proposed research will generate independently valuable scientific products: 1. We will test the efficacy of extending the 4D-Var approach to biogeochemistry by using it to optimize both the idealized biogeochemical and physical state of an eddy-resolving model of the California Current Ecosystem (CCE) for 2007-2011. The model will be optimized by adjusting the initial conditions, boundary conditions, external forcing, and parameter values to reduce the misfit between the model and the dense and diverse observations (including in situ measurements of carbon, oxygen, phosphate, pH, and alkalinity) available of the CCE during this time period. 2. We will further develop the biogeochemical component of the model to allow assimilation of satellite-based chlorophyll estimates and to improve the representation of other constraints, and optimize this new implementation of the physical-biogeochemical model to improve our estimate of air-sea CO2 fluxes in the CCE. 3. We will extend the data-processing of hydrographic observations to produce a self-consistent dataset of the quality, richness of properties, and temporal extent that will be required to constrain a global 4D-Var biogeochemical model. GLODAPv2 (GLobal Ocean Data Analysis Project version 2) will be a calibrated unification of existing biogeochemical data products and new data over the period 1972-2011. As more observations become available, state estimation is undoubtedly the way forward for addressing the objectives of NASA's CMS by bringing together observations and modeling tools to generate accurate high-resolution and time-varying maps of air-sea CO2 fluxes. Together, the development of 4D-Var methods and the observational dataset will enable global model-observation syntheses of the ocean carbon cycle over climate-relevant time scales.

Keywords: Ocean-Atmosphere Flux

West-03 (2012)

Project Title: Estimating Global Inventory-Based Net Carbon Exchange from Agricultural Lands for Use in the NASA Flux Pilot Study

Science Team: Tristram (Tris) West, Joint Global Change Research Institute, tristram.west@pnnl.gov (Project Lead)

Abstract: Inventory-based estimates of C flux have been developed for US agriculture (West et al. 2011), US forests (Zheng et al. 2011 and McKinley et al. 2011), and for North American agriculture and forest lands (Hayes et al. 2012). These estimates combine C uptake, harvest and removal, and C release to generate regional C flux estimates. These estimates differ from carbon biomass or stock estimates which often only represent the net C uptake component of the flux. The inventory-based C flux method of estimation has evolved over the past 5 years, as noted by the recent aforementioned citations, and has been used successfully as input to biogeochemical models, atmospheric transport models, and economic models. Estimates have also been used as independent data sets for comparison with other methods (King et al. 2012). The usefulness of this new method is evident. What is needed now is an expansion of the method for global use. The purpose of this proposed research is to develop a global C budget for agricultural carbon uptake and release, as was done for the US by West et al. (2011). A global US C budget, together with satellite remote sensing of land cover, will provide a gridded global C flux for agricultural lands. This product can be used as input to the NASA Flux Pilot Study and by models currently engaged in the Study. The proposed method combines aforementioned methods of spatially explicit C uptake and release with a NASA-generated global data set on human consumption of agricultural commodities (Imhoff et al. 2004, 2006) for use in the CASA model (Potter et al. 1993, Williams et al. 2012) and other Pilot Study models. Datasets generated will also be commensurate with those used in the DOE Integrated Assessment (IA) program, which allows for future economic projections of land use and human population to be linked with carbon fluxes generated with NASA models.

Keywords: Land Biomass
Land-Atmosphere Flux
Decision Support

2013 Selections Abstracts

Brown-01 (2013)

Project Title: Applications of the NASA Carbon Monitoring System: Engagement, Use, and Evaluation

Science Team: Molly Brown, NASA GSFC, molly.brown@nasa.gov (Project Lead)
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Abstract: This proposal provides a scope of work for studying and engaging with the user community for the NASA Carbon Monitoring System (CMS) pilot projects. Under the CMS initiative, NASA will be developing end-to-end expertise on regional, national and international carbon monitoring products based on satellite remote sensing. In this proposal, we focus on understanding and engaging the science and user community of these products to enable improved characterization of CMS products, preparation for eventual data delivery, and evaluate the CMS products that have been developed. The focus of this activity is to evaluate current and planned NASA CMS products with regard to their use in specific decision making contexts. This effort is aligned with the mission of the Carbon Cycle Science program to leverage NASA investments to discover and demonstrate applications that inform resource management, policy development, and decision making within operational agencies responsible for resource management and policy decisions that affect carbon emissions, sequestration, and fluxes among terrestrial, aquatic, and atmospheric environments. Our proposed research is highly relevant to the following activities listed as a priority for this NRA: Studies of stakeholder interests and requirements that offer to 1) understand and engage the user community for carbon monitoring products and/or 2) evaluate current and planned NASA CMS products with regard to their value for decision making by these users. The effort is designed to identify and engage with the user community for carbon monitoring products and to ensure that every scientist working within CMS has exposure to these users. Determining the requirements of the broader decision making community is a critical element of an effective applications program. We will work to find policy and practical users of CMS products for the atmosphere, ocean, and land. We will express the needs of the community to the CMS SDT and the broader CMS science community to help guide product development. Thus, we will develop a path that illustrates the connection between the user needs, the CMS product and the decision and policy frameworks that link the science to society. In order to foster this interplay between science capabilities and user needs via CMS product development and product application in decision-making environments, we have three broad objectives: 1) Develop communication strategies that link directly to the goals, objectives and accomplishments of the NASA CMS program and build a broad support system for CMS science PIs through transparent and inclusive processes involving scientists and end users; 2) Identify group(s) of institutions and organizations who become 'early adopters' of NASA CMS products. Selected early adopters will have an immediate use for the CMS product(s) and have clearly identified requirements for existing and planned NASA CMS scientific output; and 3) Evaluate the current and planned NASA CMS products, and determine the degree to which this proposed CMS Applications program has met success criteria.

Keywords: Land Biomass
Land-Atmosphere Flux
Decision Support

Cochrane-01 (2013)

Project Title: Filling a Critical Gap in Indonesia's National Carbon Monitoring, Reporting, and Verification Capabilities for Supporting REDD+ Activities: Incorporating, Quantifying and Locating Fire Emissions from Within Tropical Peat-swamp Forests

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Abstract: Because of episodic uncontrolled fires within drained peat-swamp forests, Indonesia is ranked the 4th largest CO2 emitter over the last half century. The former 1 million hectare Mega Rice Project (MRP), designed to convert extensive peat lands into farm lands, is a major emissions source. Deep organic soils storing vast amounts of carbon are now being lost to decomposition and combustion. The 120,000 ha Kalimantan Forests and Climate Partnership (KFCP) Reduced Emissions from Deforestation and forest Degradation (REDD+) project is within the former MRP. In collaboration with the Indonesian government's Forestry Research and Development Agency (FORDA), we will develop a prototype peat-fire emissions module for KFCP to incorporate into the Indonesian National Carbon Accounting System (INCAS). This capacity will enable annual quantification of fire-related emissions. Our research project will utilize Landsat and MODIS data and products to quantify land cover changes, burned area and estimate the timing of fire activity. We will incorporate TRMM data for relating precipitation history to the timing of observed water table changes that impact peat-fire activity at KFCP. We will integrate satellite data with existing aerial KFCP Lidar (2007 & 2010), and propose a repeat Lidar collection during the study to provide quantified temporal topographic change maps to validate our modeled results of fire-related peat consumption. This project will leverage the extensive and ongoing data collection efforts for hydrology, fuels, land uses and fire occurrence at KFCP, with our initial field work and laboratory testing of regional peat combustion and emission characteristics to provide guided field testing of background and fire-related carbon emission rates and types (e.g. methane, CO2, CO, particulates, other) during El Nino and non-El Nino years as available. Through groundbreaking emissions field sampling of in-situ smoldering surface, shallow (<20 cm) and deep (>20 cm) peat fires, with on-site gas chromatography for quantifying reactive species, whole air sampling for precise lab measurements of non-reactive gases, and simultaneous filter sampling of particulates, we will create comprehensive and pertinent emissions factors (EFs) that will be critically important for assessing the health impacts and total global warming potential (GWP) of these emissions. In our interdisciplinary research, we will investigate the chains of social and bio-physical events leading to these deep-peat fires, integrating fire scene analyses with social data to describe when, where, how, and under what conditions fires within KFCP have occurred, so that more effective mitigation strategies can be developed in the future. Accurate accounting of peat-fire carbon emissions requires understanding how their presence, depth of burning, and spread rates relate to the interplay of climate, weather, land use, land cover, drainage status, disturbance history, fire type, peat depth and composition. Modeling this phenomenon requires defining 1) the annual surface area burned, 2) the available fuel fraction (burnable) at each location through time, and 3) the amount of fuel consumed per unit area. We will implement a modeling approach that initially uses existing data on the peat hydrology, climate, land cover, burned area, timing of ignitions and fuel loads to stochastically provide peat fire probability and parameterize depth and area burned from the 2007 Lidar data. This initial model will be used to project the expected area, type, and depth of burning from 2007-2011 and then checked against the 2011 Lidar data set to refine calibration of the modeled parameters. The third modeling phase will provide Monte Carlo estimates of type, depth and area of burning, with emissions quantitatively weighted by appropriate EFs derived for surface, shallow and deep peat smoke amounts that will be validated using the proposed third Lidar data collection

Keywords: Land Biomass
Land-Atmosphere Flux
MRV

Cohen-02 (2013)

Project Title: An Historically Consistent and Broadly Applicable MRV System Based on Lidar Sampling and Landsat Time-series (Tested in the US, and applied to the US NGHGI reporting system)

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Abstract: We focus our attention on the development of a Monitoring, Reporting, and Verification (MRV) accounting system that could be used by developing countries within the context of the United Nations (UN) REDD Programme. Because one system will not fit all needs, we consider different biomass estimation frameworks and different components for inclusion in the system. Design-based inference is commonly applied to a sample field plot network, as it is for the US National Greenhouse Gas Inventory (NGHGI) baseline reporting to the UN Framework Convention on Climate Change (UNFCCC). But field plot networks are expensive to install and maintain. Sampling with lidar strips, supported by a smaller set of plots may be an attractive alternative that is highly relevant to many REDD countries, as is the use of Landsat for disturbance monitoring. Biomass estimation uncertainties associated with use of these different datasets in a design-based inference framework will be examined. We will also develop and test estimators that rely primarily on Landsat data within a model-based inference framework. The contributions from Landsat are the current (e.g., 2013) spectral response and metrics that describe disturbance history derived from a time series leading up to the current date. In this context, either plot data or lidar data can be used to parameterize the model and we will contrast the uncertainty effects of these datasets. A key advantage of the model-based framework is that it can be extended back in time (e.g., to 1990) using a consistent approach. The main feature of the model-based approach is that it relies directly on disturbance history as an indicator of biomass density. Using Landsat spectral data from a given date (e.g., 2000) and disturbance history metrics derived from a time series leading up to that date (e.g., 1984-2000), the statistical model developed for the current period (e.g., 2013) can be applied historically. This is critical because REDD requires a way to estimate biomass historically, back to a baseline year of 1990. For the approach to take maximum advantage of disturbance history metrics to predict biomass density, a sufficient time series length is critical. This requires that we reach back into the MSS archive to develop the disturbance history metrics for the approach to be fully effective in estimating biomass for the 1990 baseline. The US, while not a REDD country, is a party to the UNFCCC and has a need for similar NGHGI baseline information. The various components of our MRV system will be tested in the US, where the best data are available for parsing the uncertainty contributions of the several system components we will test. In doing so, we will develop and test an historical biomass mapping approach that, if implemented, would provide REDD countries a practical set of workflows for integrated monitoring of current and historic baseline carbon stocks and trends, with an understanding of the uncertainties associated with different components of the alternative workflows. Additionally, with the improvements expected from including Landsat-derived disturbance history into the methods used for the US NGHGI, this research would provide NASA and CMS with a collaborative roll in the process of reporting US forest carbon estimates to the UNFCCC.

Keywords: Land Biomass
MRV

Collatz-02 (2013)

Project Title: Improving and extending CMS land surface carbon flux products including estimates of uncertainties in fluxes and biomass

Science Team: George (Jim) Collatz, NASA GSFC, jim.collatz@nasa.gov (Project Lead)

Abstract: This proposal addresses the Studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them; component of CMS call for proposals. Our team was originally funded in Phase I of the CMS project to provide land surface carbon fluxes (NPP/GPP, RH/RE, Fire from CASA-GFED3) for the period 2009-2010. We produced these products, evaluated them against other models and contributed to the interpretation of modeled atmospheric CO2 distributions produced by GSFC's GEOS-5 transport model and the source/sink distributions produced by JPL's atmospheric inverse model. Our data products are available on the CMS website. For Phase II, we did not seek funding support but contributed to the Pawson and Bowman projects as collaborators providing fluxes for 2011 and further evaluation of those. Our data products are well suited for use by other CMS projects because they are highly constrained by satellite observations and have a long history of evaluation by the atmospheric CO2 modeling community. There is the need for continued updates of these key land data products and for estimates of uncertainties which were not previously supplied. For this proposed work we plan to produce land carbon fluxes for 2012 from CASA-GFED3 by the end of this calendar year. In subsequent years of the proposal we will introduce the new updated version of the model (CASA-GFED4) with improved physiological and fire parameterizations, improved burned area estimates including representation of smaller fires, and finer spatial resolution (1/4 degree) extending the time series into the future with a latency of ~5 months. We have begun preliminary uncertainty analyses of the CASA-GFED3 fluxes by first testing the sensitivity of the modeled fluxes to characteristic model parameters. From the sensitivity analyses we are selecting a number of key parameters and using published and expert opinion estimates of uncertainties in these parameters to estimate flux uncertainties using a Monte Carlo method. We will estimate uncertainties in the individual fluxes (NPP, RH, fires, NBP, GPP, RE) at monthly time steps for the entire period of the data set. Quantified flux uncertainties are critically needed by the CMS atmospheric modeling groups for their estimates of overall uncertainties in surface carbon sources and sinks. Our simulations also produce global biomass estimates at the model's native resolution with uncertainties. We plan to evaluate these estimates against others including the CMS Biomass products.

Keywords: Land-Atmosphere Flux

Dubayah-04 (2013)

Project Title: Development of a Prototype MRV System to Support Carbon Ecomarket Infrastructure in Sonoma County

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Abstract: National and international programs have an increasing need for precise and accurate estimates of forest carbon and structure to support greenhouse gas reduction plans, climate initiatives, and other international climate treaty frameworks such as REDD++. Central to these activities is the development of MRV (measurement, reporting and verification) systems that provide an accounting of forest carbon emission and sequestration at high spatial resolution with appropriate temporal frequencies. Such systems can be used to support and sustain the development of an 'ecomarket' infrastructure centered on carbon, along with other ecosystem services, such as biodiversity, water resources, and the like. Central to ecomarkets is the creation of financial incentives that reward the preservation and enhancement of ecosystem services through time, as enabled from robust MRV systems. NASA has recognized the urgent need for the development of MRV through its initiation of the Carbon Monitoring System (CMS) program. The University of Maryland, working with NASA centers, the USFS, and commercial entities has led research efforts in Phase I and Phase II that have laid the basic groundwork for MRV. Our Phase II project uses existing, wall-to-wall airborne lidar coverage and in-situ field data collection to produce high-resolution maps of carbon stocks for all of Maryland. These same data are also used to drive a prognostic ecosystem model to predict carbon fluxes and carbon sequestration potential. This work has demonstrated the feasibility of large-scale mapping using airborne lidar, an important first step, and suggests logical follow-on activities that should be undertaken towards the realization of operational MRV systems that are responsive to local, national and international interests in management and policy. The overall goal of this project is the continuing development of a prototype MRV system based on commercial off-the-shelf (COTS) remote sensing and analysis capabilities to support ecomarket infrastructure in Sonoma County, California. Building on our East Coast county-level work as part of CMS I and CMS II, we seek to address the following questions: - What accuracies are achievable using predominantly COTS-based approaches to high-resolution MRV for forest carbon? - What is the 'price-of-precision' for MRV systems and how does this vary as a function of sample design, ground data, remote sensing data acquisition and analysis costs? - How can stakeholder needs and requirements be integrated during the creation and implementation of MRV systems to provide effective decision support and compliance capabilities, and with better-informed policy decisions? Can a cloud-based architecture be used to facilitate the initiation and use of MRV systems to enable their implementation domestically and abroad? We have identified five objectives to answer our research questions: (1) Integration of Sonoma County stakeholder needs and requirements into the MRV system design. (2) High-resolution wall-to-wall estimation of carbon stocks and their uncertainties for Sonoma County and mapping of sequestration potential under various development scenarios using the Ecosystem Demography model. (3) Development of the key components of an end-to-end MRV system that includes data acquisition, warehousing, baseline quantification, data accessibility, accounting, reporting and stakeholder communication. (4) Analysis of the 'price-of-precision' through a cost-benefit analysis of data resolution relative to accuracy achievable at particular spatial scales e.g. United Nations Framework Conference on Climate Change (UNFCCC) Tier 1 vs. Tier 3. (5) Demonstration of a functional prototype MRV platform with visualization, and analytical capabilities for addressing Sonoma County initiatives. Our basic approach to high-resolution carbon stock mapping has been established in our CMS Phase 1 (two Maryland counties) and Phase 2 (23 Maryland counties) efforts.

Keywords: Land Biomass
MRV

Dubey-01 (2013)

Project Title: Off-the-shelf Commercial Compact Solar FTS for CO_2 and CH_4 Observations for MRV

Science Team: Manvendra Dubey, Los Alamos National Laboratory, dubey@lanl.gov (Project Lead)

Abstract: Monitoring, reporting and verification (MRV) of natural sources and sinks and anthropogenic emission of carbon dioxide (CO_2) and methane (CH_4) are crucial to predict climate change and develop transparent accounting policies to contain climate forcing. Remote sensing technologies are beginning to monitor CO_2 and CH_4 from ground and space using high-resolution solar spectroscopy enabling direct MRV. However, the current ground based coverage is very sparse due the need for large and expensive high-resolution spectrometers that limits our MRV abilities, both regionally and globally. There are striking monitoring gaps in Asia (China and India), South America and Africa where the CO_2 emissions are growing and there is a large uncertainty in fluxes from land use change and biomass burning. Our project will evaluate the precision, accuracy and stability of new off-the-shelf commercial, compact, affordable and easy to use low-resolution spectrometers by comparing with the much larger high-resolution spectrometers used to monitor CO_2 and CH_4. While initial results are promising our study will encompass real world conditions and challenges. If we are successful the new off-the-shelf spectrometers will dramatically expand the coverage of regional column CO_2 and CH_4 observations, particularly in gap regions in the developing world. This will enable transparent and reliable MRV that would put carbon cycle science and carbon trading and put climate treaty verification on a firm foundation.

Keywords: Land-Atmosphere Flux
MRV

Duren-01 (2013)

Project Title: Understanding user needs for carbon monitoring information

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Abstract: The objectives of the proposed work are to: 1) engage the user community and identify needs for policy-relevant carbon monitoring information, 2) evaluate current and planned NASA Carbon Monitoring System data products with regard to their value for decision making, and 3) explore alternative methods for visualizing and communicating carbon monitoring information and associated uncertainties to decision makers and other stakeholders. We will establish a framework that facilitates frequent and sustained engagement of carbon policy and management stakeholders to define requirements for CMS data products. Our team will work with the CMS science team to acquire prototype data products and help stakeholders evaluate the utility and relevance for policy planning and decision support. We will develop a Carbon Caculator and Data Portal that integrates multiple CMS products to enable those evaluation efforts. Where necessary we will explore new approaches for presenting the results of CMS data products and their uncertainties to decision-makers, again with the intent of helping to inform future CMS requirements and improve relevance of the ultimate data products. Our team combines experts in carbon management and policy from a representative cross-section of stakeholders in the US government (including the State Department's Bureau of Oceans and International Environment and Scientific Affairs (OES), the Environmental Protection Agency (EPA), and the White House Council on Environmental Quality (CEQ) with other experts working at the interface of science and policy for carbon monitoring (co-investigators from JPL, RFF, ASU, and USFS). The team will meet regularly and share information through a flexible web portal that leverages emerging tools for visualizing data. We will apply the above process to study a range of representative policy scenarios. Examples of topics that may be explored include but are not limited to: policies and management efforts focused on: 1) Land Use, Land Use Change, and Forestry (LULUCF) fluxes for the United States and/or selected developing countries (e.g., Indonesia), 2) Forest carbon stocks and disturbances for the US and/or tropical countries or sub-national projects therein, 3) methane (CH4) emissions from major shale gas basins in the US, and 4) fossil fuel CO2 and CH4 emissions from cities and industrialized states and provinces (including potential linked sub-national carbon emissions trading systems).

Keywords: Land Biomass
Land-Atmosphere Flux
Decision Support

Graven-01 (2013)

Project Title: Quantifying fossil and biospheric CO_2 fluxes in California using ground-based and satellite observations

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Abstract: This proposal develops a prototype system that combines commercial ground-based measurement techniques with satellite data to address Monitoring, Reporting and Verification (MRV) of regional CO2 fluxes from fossil fuel emissions and biospheric exchange. The system will be centered on the State of California, where it will be responsive to the State's policy measure to reduce greenhouse gas emissions, California's Global Warming Solutions Act (AB-32) which includes a cap-and-trade program, and where a relatively dense measurement network for atmospheric CO2 concentration is already in place. We will use this existing network to conduct field sampling for the measurement of radiocarbon content (D14C) in atmospheric CO2 that will enable us to identify fossil-derived and biospheric-derived CO2 [Turnbull et al. 2006; Graven et al. 2009] at 9 sites across the state. The D14C-based observations of fossil-derived and biospheric-derived CO2, along with measurements of total CO2 concentration from ground-based and satellite platforms, will be analyzed in an atmospheric inversion framework that we will develop from a similar framework currently being used to estimate emissions of CH4 in California [Jeong et al. 2012; Fischer et al. 2012]. Unique contributions of the proposed work involve the integration of D14C data into an inversion framework to optimize fossil fuel emissions explicitly, and the integration of satellite-derived total column CO2 with ground-based data. The proposed work will also provide evaluation of the natural sink or source of CO2 in California's terrestrial biosphere and evaluation of the biospheric models, CASA-GFED and NASA-CASA, across the widely varying biome types and land uses present in California. These models incorporate satellite retrievals of vegetation index and land cover and are currently used in the NASA Carbon Monitoring System Flux Product. Data products resulting from the proposed work include optimized CO2 flux distributions and totals, including uncertainty, for the State of California for both fossil fuel emissions and biospheric exchange, providing an atmospheric observation-based MRV product that can be used to support California's AB-32 policy. The prototype system we develop could be replicated in other regions, providing similar MRV applications to other greenhouse gas emission policies.

Keywords: Land-Atmosphere Flux
MRV

Hagen-01 (2013)

Project Title: Operational multi-sensor design for national scale forest carbon monitoring to support REDD+ MRV systems

Science Team: (Steve) Hagen, Applied Geosolutions, shagen@appliedgeosolutions.com (Project Lead)

Abstract: Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have been requested to establish robust and transparent national forest monitoring systems (NFMS) that use a combination of remote sensing and ground-based forest carbon inventory approaches to estimate anthropogenic forest-related greenhouse gas emissions and removals, reducing uncertainties as far as possible. A country's NFMS should also be used for data collection to inform the assessment of national or subnational forest reference emission levels and/or forest reference levels (RELs/RLs). In this way, the NFMS forms the link between historical assessments and current/future assessments, enabling consistency in the data and information to support the implementation of REDD+ activities in countries. The creation of a reliable, transparent, and comprehensive NFMS is currently limited by a dearth of relevant data that are accurate, low-cost, and spatially resolved at subnational scales. We propose to develop, evaluate, and validate several critical components of a NFMS in Kalimantan, Indonesia, focusing on the use of LiDAR and radar imagery for improved carbon stock and forest degradation information. Our goal will be to evaluate sensor and platform tradeoffs systematically against in situ investments, as well as provide detailed tracking and characterization of uncertainty in a cost-benefit framework. Kalimantan is an ideal area to evaluate the use of remote sensing methods because measuring forest carbon stocks and their human caused changes with a high degree of certainty in areas of dense tropical forests has proven to be difficult. While the proposed NFMS components will be developed at the subnational scale for Kalimantan, we will target these methods for applicability across broader geographies and for implementation at various scales. This proposed research will advance the state of the art of Measuring, Reporting, and Verification (MRV) system methodologies in ways that are both technical and operational. First, because a primary focus of carbon monitoring systems, especially in developing countries, is on cost-effectiveness, our analysis of optimal inputs of information from various satellite, airborne, and in situ measurements will provide valuable practical information that countries can use to consider the tradeoffs. Second, because quantifying and understanding uncertainty is critical both in an Earth science research context and with regard to payment for ecosystem services, our development of reusable methods for tracking and evaluating uncertainty within a carbon monitoring system will provide a framework for stakeholders and researchers to understand and minimize errors across MRV components. Third, because carbon monitoring requires integration of advanced technologies with multidisciplinary scientific methods from forestry, ecology, soil science, remote sensing and biogeochemistry, our team's expertise is particularly well-constructed to address these complex scientific and technical issues.

Keywords: Land Biomass
MRV

Keller-01 (2013)

Project Title: A data assimilation approach to quantify uncertainty for estimates of biomass stocks and changes in Amazon forests

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Abstract: Brazilian tropical forests contain approximately one-third of the global carbon stock in above-ground tropical forest biomass. Deforestation has cleared about 15% of the extensive forest on the Brazilian Amazon frontier. Logging, and understory forest fires may have degraded a similar area of forest. In response to the potential climatic effects of deforestation, policy makers have suggested reductions in emissions through deforestation and forest degradation and enhanced forest carbon stocks (REDD+). Carbon accounting for REDD+ requires knowledge of deforestation, degradation, and associated changes in forest carbon stocks. Degradation is more difficult to detect than deforestation so SilvaCarbon, an US inter-agency effort, has set a priority to better characterize forest degradation effects on carbon loss. We propose to quantify carbon stocks and changes and associated uncertainties in Paragominas, a jurisdiction in the eastern Brazilian Amazon with a high proportion of logged and burned degraded forests where political change has opened the way for REDD+. We will build on a long history of research including our extensive studies of logging damage. In addition, we will use recent forest inventories and airborne lidar supported by USAID and managed by the US Forest Service and the Brazilian Corporation for Agricultural Research (EMBRAPA) under the Sustainable Landscapes Brazil program. Existing data will allow us to start analysis immediately and will also permit REDD+ relevant multi-temporal measurements of change during the brief three-year study period. We plan to supplement the existing data by collection of additional ground-based forest inventory data contemporary with commercial airborne lidar (supported by USAID) and Landsat remote sensing data that will incorporate a novel use of time series data to estimate the structural properties of degraded forests using bidirectional reflectance information. We identify two objectives for forest carbon accounting at the jurisdictional level: - Quantify spatially explicit above-ground carbon stocks and the changes in carbon stocks; - Quantify spatially explicit uncertainties in above-ground carbon stocks and changes in carbon stocks We will meet these objectives by employing innovative data assimilation methods. Our approach employs a hierarchical Bayesian modeling (HBM) framework where the assimilation of information from multiple sources is accomplished using a change of support (COS) technique. The COS problem formulation allows data from several spatial resolutions to be assimilated into an intermediate resolution. This approach provides a mechanism to assimilate information from multiple sources to produce spatially-explicit maps of carbon stocks and changes with corresponding spatially explicit maps of uncertainty. Importantly, this approach also provides a mechanism that can be used to assess the value of information from specific data products. Hence future data collection can be optimized in the context of the reduction of uncertainty. The spatially explicit quantification of uncertainties naturally provides insights into effective sampling designs. Members of the team used this statistical approach previously as part of prototyping efforts for the National Ecological Observatory Network. The proposed work will add a new research dimension to the Sustainable Landscapes Brazil program, a direct outcome of the US-Brazil Memorandum of Understanding on climate change. Through that program, we have already successfully acquired airborne remote sensing data in Brazil and all requirements for international data collection have already been met. Because the proposed research is closely linked to an active program of international cooperation and capacity building, we will be in a unique position to transfer the results of our research to practitioners in the Brazilian government and in Brazilian civil society.

Keywords: Land Biomass
MRV

Kellndorfer-03 (2013)

Project Title: Time Series Fusion of Optical and Radar Imagery for Improved Monitoring of Activity Data, and Uncertainty Analysis of Emission Factors for Estimation of Forest Carbon Flux

Science Team: Josef Kellndorfer, Woods Hole Research Center, josefk@whrc.org (Project Lead)
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Abstract: We propose to support the development and improvement of national MRV systems for REDD+ through two objectives. First, we will develop, test, and share with the public domain robust and transparent methods for mapping activity data (e.g., deforestation, forest degradation). Second, we will conduct an uncertainty analysis of carbon emission estimates from the activity data and from emission factors. We will use novel approaches to time series data mining of optical and radar satellite imagery and conduct the work in three test sites (Colombia, Peru and Mexico) identified as National Demonstrator sites by the Group on Earth Observation's (GEO) Forest Carbon Tracking Task (GEO-FCT). The test sites include a variety of ecosystems, biomass regimes, and cloud-cover conditions, and they exhibit a range of drivers of deforestation and land conversion methods, including selective logging, burning, clearing for permanent conversion, and forest regrowth. A large amount of data from optical and radar satellites has already been collected for these GEO-FCT verification sites. More specifically, we will develop an algorithm from optical and radar time series fusion to produce an accurate assessment of annual changes in areas experiencing deforestation, forest degradation, and forest regrowth (i.e., activity data). The work will include an approach for distinguishing between natural disturbances and permanent anthropogenic change. We will assess the uncertainty and accuracy of the activity data estimated with this algorithm. To assess the uncertainty of carbon emission estimates, we propose to compile a database of country specific emission factors, stratified by land-cover categories (from the first objective), and linked with carbon density estimates from forest inventory and existing biomass maps. The database will contain uncertainty estimates. To provide guidance for national MRV implementation, we will also explore the impact of uncertainties in activity data and emissions factors on carbon fluxes estimated using a bookkeeping model. The proposed work is relevant to the specific objectives of this NASA Carbon Monitoring System solicitation, including rigorous exploitation of NASA and international partner satellite remote sensing resources and computational capabilities. The Subsidiary Body of Scientific and Technological Advice (SBSTA) of the UNFCCC agreed in June 2013 that continuous improvement of data and methods is vital for developing MRV systems for REDD+. In particular, SBSTA identified the need to reduce uncertainties in emissions accounting and to develop methodologically consistent ways to harness new observational data, whether field or remote sensing, that can be used to report against reference levels of deforestation and forest degradation, as well as associated reference emission levels (SBSTA, 2013). To develop methodologically consistent, transparent, yet flexible accounting methods, as required in the international framework of the UNFCCC, as well as numerous bi- and multi-lateral agreements, the Group on Earth Observation (GEO) has established a Forest Carbon Tracking Task (GEO- FCT). PI Kellndorfer and Co-I's Woodcock and Olofsson are among those chosen by GEO to formulate and support the implementation of a Global Forest Observing Initiative (http://geo- fct.org). Support of this proposal would allow them to carry out that work.

Keywords: Land Biomass
Land-Atmosphere Flux
MRV

Lauvaux-01 (2013)

Project Title: Quantification of the sensitivity of NASA CMS Flux inversions to uncertainty in atmospheric transport

Science Team: Thomas Lauvaux, Pennsylvania State University, tul5@meteo.psu.edu (Project Lead)

Abstract: Uncertainty in atmospheric transport and a lack of atmospheric carbon dioxide (CO2) observations are the two major sources of uncertainty in inverse estimates of CO2 sources and sinks. Space-based measurements of atmospheric CO2 will greatly increase the density of atmospheric measurements. Atmospheric transport, however, remains a major challenge. We propose to improve our understanding of the uncertainties associated with atmospheric transport in the NASA Carbon Monitoring System Flux estimation and attribution pilot project (CMS Flux). This project will focus on uncertainties at the regional to continental scale, focusing in particular on North America for calendar year 2010. The results should be applicable to any mid-latitude continental region. We will: 1) assess the transport error in the global NASA CMS-Flux system and the mesoscale WRF-LPDM using meteorological data and CO2 profiles from airborne measurements over North America; 2) represent transport error with a physics-based ensemble of atmospheric transport configurations; and 3) estimate the contribution of transport uncertainty over North America to North American and global flux uncertainty. This proposal will address the request in the NASA CMS announcement of opportunity for, 'Studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them.' We will evaluate the impact of atmospheric transport on the CMS Flux pilot products by embedding the Penn State regional atmospheric inversion system, which utilizes the mesoscale Weather Research and Forecast model (WRF), within the CMS Flux system, by simulating atmospheric CO2 and solving for continental fluxes with both systems, and by evaluating transport uncertainty by comparing the CMS Flux system output to meteorological observations and aircraft CO2 profile data. The first objective will be met by simulating the atmospheric distribution of CO2 across North America with both WRF and Geos-Chem (the CMS Flux atmospheric transport scheme). Both simulations will use the same lateral boundary conditions and surface fluxes. Meteorological observations will be used to quantify the atmospheric transport uncertainty in CMS Flux. Aircraft CO2 profiles will be used to quantify the model-data mismatch error used in CMS Flux inversions. The second objective will be met by running a physics-based ensemble of WRF simulations conditioned to match the range of transport errors found in the CMS Flux system by comparison to meteorological observations. This ensemble will be sampled to simulated GOSAT and OCO-2 observational patterns. This produces a set of column CO2 pseudo-data with a distribution similar to the CMS Flux transport error. The third objective will be addressed by using this ensemble of simulated satellite observations to infer an ensemble of fluxes using the CMS Flux system. The differences among the inferred fluxes should be a realistic representation of atmospheric transport error in the CMS Flux biogenic flux product.

Keywords: Atmospheric Transport
Land-Atmosphere Flux

Nehrkorn-01 (2013)

Project Title: Prototype Monitoring, Reporting and Verification System for the Regional Scale: The Boston-DC Corridor

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Abstract: The world's population growth is increasingly concentrated in urban areas and this trend is expected to continue in the future. Urbanization has a profound impact on carbon dynamics, leading to increases in anthropogenic carbon dioxide (CO2) emissions and decreases in biogenic fluxes from these areas. The latter are a key component of a carbon monitoring system (CMS), while spatially and temporally resolved estimates of anthropogenic fluxes are central to meeting greenhouse gas emissions reductions goals. We intend to design a measurement network and develop an accompanying atmospheric modeling framework for downscaling the current NASA CMS flux products to the regional and local scales pertinent to Monitoring, Reporting, and Verification (MRV). Our proposed research will focus on the Boston-DC megalopolis corridor, where about 17% of the U.S. population lives on less than 2% of the nation's land area, making it a key source of US anthropogenic CO2 emissions. Simultaneously, these urban areas are interspersed with vegetation that imposes a strong biogenic signal on the atmospheric CO2 mixing ratios. The proposed research will proceed along three main lines: 1) High-resolution transport modeling (WRF-STILT) customized and verified for the region, 2) High-resolution CO2 flux model incorporating anthropogenic emissions estimates and the CASA model (including its 0.5-deg resolution variant that provides the foundational biosphere model for the current CMS Flux Product and nested higher resolution runs to represent the scale sensitivity within heterogeneous urban areas), and 3) Inverse CO2 flux estimates corresponding to in-situ and remote CO2 observations in and around Boston, New York City, and Washington DC. As part of the proposed work, we will quantify errors in the WRF-STILT simulations of the planetary boundary layer (PBL), relying for this purpose on remotely sensed PBL measurements by the Sigma Space Corporation's Micro Pulse LiDAR (MPL). The PBL height is a key parameter entering inverse flux estimates, as it determines the mixing region and varies inversely to the trace gas concentrations. A key result of the proposed research will be the quantification of observing requirements for flux uncertainty reduction to levels needed for MRV. Our proposal addresses two stated goals of the NNH13ZDA001N-CMS solicitation: 'studies using commercial off-the-shelf technologies to produce and evaluate prototype MRV system approaches' and 'studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them.' The proposed work will leverage and extend the current CMS projects led by Drs. Arlyn Andrews and Steven Pawson, with which the lead proposing team at Atmospheric and Environmental Research (AER) is intimately involved, and the CMS pilot surface carbon fluxes modeling analysis.

Keywords: Atmospheric Transport
Land-Atmosphere Flux
MRV

Nelson-03 (2013)

Project Title: A Joint USFS-NASA Pilot Project to Estimate Forest Carbon Stocks in Interior Alaska by Integrating Field, Airborne and Satellite Data

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Abstract: Monitoring U.S. forest carbon stocks is critical for natural resource management and national greenhouse gas reporting activities. The USFS Forest Inventory and Analysis (FIA) program 'the largest network of permanent forest inventory plots in the world' covers most U.S. forestlands. However, more than 450,000 km2 of forests in interior Alaska (15% of US forestland) are not included in the FIA program, as these remote regions are difficult and expensive to monitor with standard field methods. Recent and projected future impacts from climate change on forest carbon stocks, composition, and extent have elevated the need to develop new approaches for forest monitoring in Alaska. In particular, airborne remote sensing offers unique advantages for monitoring remote forested regions. In many respects, the methods, logistics, and timeliness of carbon monitoring in Alaska are analogous to ongoing efforts to develop carbon monitoring systems for remote tropical forest regions to Reduce Emissions from Deforestation and forest Degradation and enhancing forest carbon stocks (REDD+). Here, we propose to develop the first regional estimates of forest carbon stocks for the Tanana Inventory Unit of interior Alaska (146,000 km2). The proposed research leverages a sizable investment ($800k) by the USFS FIA Program in 2014 for new forest inventory plots and airborne data collection with Goddard's LiDAR, Hyperspectral, and Thermal Airborne Imager (G-LiHT; http://gliht.gsfc.nasa.gov). G LiHT is a well-calibrated airborne remote sensing package that is assembled from commercial off-the-shelf (COTS) instruments and a proven track record of timely, free, and open access to both low-and high-level products. The USFS project, a pilot study for LiDAR-assisted forest inventory in interior Alaska, does not provide support for research collaboration between NASA and USFS scientists, data analysis, or methods development. In this project, we will expand the Tanana research activity to 1) collaborate on the experimental design for optimal integration of field and LiDAR data for forest carbon monitoring; 2) compare established model-based and model-assisted methods for estimating forest carbon stocks using both plot and LiDAR information; 3) enhance the inventory activity using individual tree, species composition, and vegetation cover information from the combination of G-LiHT hyperspectral, thermal, and LiDAR sensors; and 4) characterize the impacts of recent fires and risk of future fire-driven carbon losses using the systematic sample of G-LiHT flight lines over ~2.5% of the Tanana region (3800 km2); and 5) develop new, spatially explicit estimates of carbon stocks and uncertainties using Bayesian statistical methods. The main outcomes from this work will be estimates of forest carbon stocks and associated uncertainties for the Tanana Inventory Unit. These estimates provide critical and timely information for resource management, and baseline conditions for the spatial distribution of forest cover and carbon stocks in a region that is rapidly changing from climate warming.

Keywords: Land Biomass
MRV

Stehman-01 (2013)

Project Title: Developing Statistically Rigorous Sampling Design and Analysis Methods to Reduce and Quantify Uncertainties Associated with Carbon Monitoring Systems

Science Team: Stephen (Steve) Stehman, SUNY College of Environ Sci & Forestry, svstehma@syr.edu (Project Lead)

Abstract: The research described in this proposal will develop statistically rigorous sampling design and analysis protocols that will reduce uncertainty of key estimates of target parameters of a carbon monitoring system (CMS) and lead to better quantification of uncertainty. The IPCC Good Practice Guidance emphasizes the importance of land area to estimates of carbon stocks and emissions and removals of greenhouse gases associated with land use, land-use change and forestry activities. Effective regional, national and global carbon monitoring systems can exploit satellite remote sensing in a variety of ways to substantially reduce the uncertainty of area estimates and to reduce costs associated with field sampling. A central theme of the proposed research is to develop and evaluate methods for advantageously combining remote sensing and ground data obtained from multiple sources to obtain more accurate (i.e., unbiased) and more precise estimates of land area and other key parameters of a CMS. Sampling is a key component of a CMS because much of the information needed for monitoring can only be collected in a cost-effective way via a sample. The proposed research is heavily focused on sampling methods. The outcome of the research will be recommendations for choosing a sampling design and estimation protocol that effectively combines information from multiple data sources emphasizing airborne and satellite remote sensing and field plot data. The specific objectives addressed include: 1) identify effective sampling designs and estimators that take advantage of remote sensing information to reduce costs and uncertainty associated with sample-based estimates; 2) compare different sample-based estimators proposed for a commonly used design in monitoring (two-stage cluster sampling) and provide a recommendation for which estimator(s) most effectively use remote sensing information to reduce uncertainty; 3) develop methods for quantifying measurement error (in particular, reference data error associated with assessing accuracy of land cover and land change maps) and for estimating land cover or land change area taking into account this measurement error; 4) develop rigorous sampling design and estimation protocols for incorporating community based monitoring and volunteered geographic information into land change monitoring protocols; and 5) investigate approaches for combining information from two probability samples to improve precision of estimates. Two obvious desirable goals for designing a CMS are to reduce uncertainties and lower costs. This research will achieve both of these benefits because the results of the research will guide selection of a cost effective sampling design and use of statistical estimators that take advantage of combining airborne and satellite remote sensing to reduce variability of key sample-based estimates required of the CMS. The proposed work not only contributes to a more efficient and effective CMS but also contributes to the wider NASA mission of validating land cover and land change products.

Keywords: Land Biomass
MRV

Vargas-01 (2013)

Project Title: A framework for carbon monitoring and upscaling in forests across Mexico to support implementation of REDD+

Science Team: Richard Birdsey, USDA Forest Service, rbirdsey@fs.fed.us
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Rodrigo Vargas, University of Delaware, rvargas@udel.edu (Project Lead)

Abstract: Rationale: Mexico is a mega-diverse country where nearly 40% of its territory is covered by forests. The long-term impacts of land use and anthropogenic changes have fragmented and fundamentally transformed Mexican landscapes. Therefore, forests in Mexico are determined by climate gradients and land history creating a heterogeneous landscape. The most important land use change types having caused severe ecological degradation include: deforestation, high impact livestock grazing, and soil tillage. Furthermore, Mexico has shown an average rate of deforestation of nearly 550,000 ha year for the period 1993-2007 with a slight increase in natural forest regeneration, particularly in southern Mexico. It is estimated that gross primary productivity (GPP) of the conterminous USA is ~7 PgC, but Mexico's ecosystems uptake ~2.6 PgC yr-1 with only 1/3 of the USA land mass. During the last decade the scientific capacity of Mexican scientists has rapidly increased and state-of-the-art measurements on carbon dynamics are now available at representative landscapes, and nationally supported by remote sensing and a national forest inventory. Thus, the time is ripe to test different approaches towards a framework for monitoring, reporting and verification (MRV) to support implementation of REDD+ across a gradient of forests in Mexico. Overall goal: to analyze carbon stocks and dynamics from ecosystem- to the regional-scale as well as characterize and quantify the errors and uncertainties across scales for the MRV to support implementation of REDD+ in Mexican forests. Specific objectives: 1) standardize ongoing methodologies for upscaling forest inventories and carbon dynamics measurements across 6 intensive forest monitoring sites; 2) characterize and quantify the errors and uncertainties in measurements and ecosystem models (BESS, DNDC) and remote sensing approaches (MODIS) for upscaling purposes of carbon dynamics in Mexican Forests; 3) identify hot-spots suitable for REDD+ and assess the potential vulnerability and variability of carbon dynamics at the national scale for the last 13 years. Approach: this proposal builds upon ongoing efforts by the USDA Forest Service (support by USAID and the Commission for Environmental Cooperation) and the University of Delaware to study carbon dynamics in ecosystems across Mexico. This proposal will consolidate collaboration with Mexican scientists across six intensive forest monitoring sites (Tier 3) representing different forest types (evergreen, deciduous, mix, mangrove). Detailed data, including forest inventory, LIDAR, and net ecosystem exchange (NEE; using the eddy covariance technique) is already available at most sites. First, this proposal will standardize/harmonize the available data across sites (forest inventory, eddy covariance). Second, we will validate biomass, NEE, and gross primary productivity (GPP) at the site level based on forest inventories and eddy covariance measurements with ecosystem models (BESS, DNDC), and remote sensing approaches (MODIS). Third, errors and uncertainties will be quantified at the ecosystem-level and at the regional scale for estimation of carbon socks and carbon dynamics across Mexican forests. Finally, we will use 13 years of archived remote sensing information (MODIS 2000-2013) to identify hot-spots, extreme values and trends at the regional scale that will provide insights for establishment for REDD+ initiatives. Significance: This proposal supports NASA carbon cycle research through validation of MODIS products through measurements of forest inventories, and cross-validation with other models. This study will generate harmonized datasets on carbon cycle science in Mexico to make them comparable to datasets available in the United States.

Keywords: Land Biomass
MRV

West-04 (2013)

Project Title: Carbon Monitoring of Agricultural Lands: Developing a Globally Consistent Estimate of Carbon Stocks and Fluxes

Science Team: Tristram (Tris) West, Joint Global Change Research Institute, tristram.west@pnnl.gov (Project Lead)

Abstract: A comprehensive carbon monitoring system will likely include the integration of bottom-up and top-down estimates. Current bottom-up estimates for global agricultural lands often consist of individual inventory-based estimates per country. This results in a global bottom-up estimate that is not consistent in underlying soils or land cover data, methods of estimating carbon stocks and fluxes, or estimates of uncertainty. The proposed research will use off-the-shelf data, models, and remote sensing products to develop a global bottom-up, inventory-based estimate of carbon stocks and fluxes for agricultural lands, including vegetation and soils. The annual estimates will be generated using globally consistent datasets, C estimation methods, and methods for estimating uncertainty. Land area will be defined by a fusion of MODIS land cover data and inventory-based land area data. Methods will coincide with current national and international methods and protocols for compatibility with ongoing efforts in carbon monitoring, reporting, and verification. While these estimates can be used independently for synthesis and assessment reports, they can also be (a) used in conjunction with similar global data on forest carbon stocks and fluxes, thereby generating one comprehensive bottom-up, inventory-based estimates, and (b) used to evaluate the latest state-of-the-art monitoring components generated by NASA in the coming years. A scoping study will also be conducted to determine how the bottom-up, inventory-based estimate can be improved upon or integrated with other satellite-based bottom-up estimates, and how the global agricultural estimate can be integrated with previously conducted estimates on global forest carbon.

Keywords: Land Biomass
Land-Atmosphere Flux
Decision Support

2014 Selections Abstracts

Andrews-03 (2014)

Project Title: Regional Inverse Modeling in North and South America for the NASA Carbon Monitoring System

Science Team: Arlyn Andrews, NOAA ESRL (**Project Lead**)
Anna Michalak, Carnegie Inst. for Science
John Miller, NOAA Earth System Research Laboratory

Abstract: 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.

Baker-01 (2014)

Project Title: A Global High-Resolution Atmospheric Data Assimilation System for Carbon Flux Monitoring and Verification

Science Team: David Baker, CIRA Colorado State Univ. (**Project Lead**)

Abstract: 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.

Bowman-02 (2014)

Project Title: Continuation of the CMS-Flux Pilot Project

Science Team: Kevin Bowman, JPL (**Project Lead**)
Kevin Gurney, Arizona State University
Deborah Huntzinger, Northern Arizona University
Junjie Liu, JPL
Dimitris Menemenlis, JPL

Abstract: 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.

Fatoyinbo-01 (2014)

Project Title: Total Carbon Estimation in African Mangroves and Coastal Wetlands in Preparation for REDD and Blue Carbon Credits

Science Team: Temilola (Lola) Fatoyinbo, NASA GSFC (**Project Lead**)

Abstract: 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.

Ganguly-01 (2014)

Project Title: Reducing Uncertainties in Satellite-Derived Forest Aboveground Biomass Estimates Using a High Resolution Forest Cover Map

Science Team: Sangram Ganguly, NASA ARC BAERI (**Project Lead**)
Cristina Milesi, NASA ARC
Ramakrishna (Rama) Nemani, NASA ARC

Abstract: 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.

Greenberg-01 (2014)

Project Title: Reducing Uncertainties in Estimating California's Forest Carbon Stocks

Science Team: Jonathan Greenberg, University of Illinois (**Project Lead**)

Abstract: 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.

Hudak-01 (2014)

Project Title: 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

Science Team: Andrew (Andy) Hudak, USDA Forest Service (**Project Lead**)

Abstract: 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+.

Hurtt-03 (2014)

Project Title: High-Resolution Carbon Monitoring and Modeling: Continuing Prototype Development and Deployment

Science Team: Ralph Dubayah, University of Maryland
George Hurtt, University of Maryland (**Project Lead**)

Abstract: 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.

Jacob-02 (2014)

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

Science Team: Kevin Bowman, JPL
Daniel Jacob, Harvard University (**Project Lead**)

Abstract: 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.

Lohrenz-05 (2014)

Project Title: An Integrated Terrestrial-Coastal Ocean Observation and Modeling Framework for Carbon Management Decision Support

Science Team: Steven (Steve) Lohrenz, University of Massachusetts Dartmouth (**Project Lead**)
Hanqin Tian, Auburn University

Abstract: 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.

Morton-01 (2014)

Project Title: Long-Term Carbon Consequences of Amazon Forest Degradation

Science Team: Douglas (Doug) Morton, NASA GSFC (**Project Lead**)

Abstract: 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 (Santarém, Pará, 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 Científico e Tecnológico (CNPq). PI Morton is an unfunded collaborator on these existing projects, including his recent selection as a Ciência 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.

Ott-01 (2014)

Project Title: GEOS-Carb II: Delivering Carbon Flux and Concentration Products Based on the GEOS Modeling System

Science Team: George (Jim) Collatz, NASA GSFC
Stephan (Randy) Kawa, NASA GSFC
Lesley Ott, NASA GSFC (**Project Lead**)

Abstract: 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.

Walker-W-01 (2014)

Project Title: Direct Measurement of Aboveground Carbon Dynamics in Support of Large-Area CMS Development

Science Team: Wayne Walker, WHRC (**Project Lead**)

Abstract: 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.

Williams-C-01 (2014)

Project Title: Translating Forest Change to Carbon Emissions/Removals Linking Disturbance Products, Biomass Maps, and Carbon Cycle Modeling in a Comprehensive Carbon Monitoring Framework

Science Team: Christopher Williams, Clark University (**Project Lead**)

Abstract: 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).

Windham-Myers-01 (2014)

Project Title: Linking Satellite and Soil Data to Validate Coastal Wetland 'Blue Carbon' Inventories: Upscaled Support for Developing MRV and REDD+ Protocols

Science Team: Kristin Byrd, USGS
Marc (Mac) Simard, Caltech/Jet Propulsion Laboratory
Lisamarie Windham-Myers, United States Geological Survey (**Project Lead**)

Abstract: 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 blue carbon 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.

CMS Working Group Reports

External Communications Working Group

Participants:
Molly Brown (WG LEAD), David Baker, Kevin Bowman, Holger Brix, Sabrina Delgado Arias, Riley Duren, Vanessa Escobar, Carla Evens, Peter Griffith, Kevin Gurney, Sean Healey, George Hurtt, Daniel Jacob, Christine Kang, Leanne Kendig, Elizabeth Nelson, Ariane Verdy, Tristram West, Seung Hyun Woo

Goals/charge
The external communications working group continues from the CMS Phase 1 and 2a, where the focus of the working group was to create materials for the CMS website and to communicate the products, science, and impact that CMS has had during its existence. Going forward, the working group will focus on finding ways to broaden and strengthen the knowledge of CMS research and engagement with the broader Earth science community through communication products such as articles, websites and meetings. Through this engagement, we seek to ensure that the community understands the nature, quality, and utility of NASA CMS science information and data products, and that CMS scientists are responsive to these needs through ongoing research.

Approach/method
The working group has four primary methods of communication:
Website at http://carbon.nasa.gov
Papers and reports for the external scientific community
Congressional report to respond to funding earmark of CMS program
Policy talks and events meant to bring scientists and decision makers together

Outcomes
The WG is demonstrating the value of CMS products to users from multiple domains. The WG, with the support of the staff of the Carbon Cycle & Ecosystems Office, has provided support for meetings, conducted community briefings, developed publications and methodological summaries, and engaged with regulatory entities to translate the benefits of CMS science for policy. The WG hopes to broaden and update the CMS website to reach out to new communities. The WG has engaged and is continuing to engage a representative cross section of potential stakeholders and have produced meeting reports, published in journals and presented at conferences on the topic of carbon monitoring for decision support. In addition to stakeholders, the WG has actively engaged the CMS science community in order to present each CMS project's details in a uniformly organized, comprehensive manner that can be understood by non-technical decision makers and receive feedback on the WG's efforts to communicate CMS projects to the public through a series of extensive phone interviews with PI's.

Next Steps
The current focus of the WG is to pivot the CMS website from a PI focus to a CMS product focus. This approach will provide viewers to the ability to find products on a particular, thematic carbon source or sink and find data products that address this issue. The main categories in

which all CMS products will be organized for stakeholders' easy inquiry are: carbon stocks, source, sink, flux/movement, ecosystem composition & structure, disturbance, evaluation & user interface, and uncertainties & standard errors. Additional activities include ongoing CMS policy speaker series, papers and reports that seek to engage across the scientific and policy communities.

System Framework Working Group

Members:
Kevin Bowman (WG Lead), Molly Brown, Jim Collatz, Vanessa Escobar, Nancy French, Skee Houghton, George Hurtt, Christine Kang, Eric Kasischke, Robert Key, Meemong Lee, Steve Lohrenz, Steve Pawson

Charge:
To develop framework(s) that integrates Global Surface-Atmosphere Flux, Ocean-Atmosphere-Flux, Land-Atmosphere Flux, Ocean Biomass, Land-Ocean Flux, and Land Biomass into a coherent Carbon Monitoring System that advances CMS and NASA objectives.

Methods:
"Top-down":
- High-level analysis of the carbon cycle including anthropogenic, atmospheric, terrestrial, and oceanic processes.
- Analysis of other international carbon monitoring systems

"Application":
- Analysis of current and potential stakeholder needs.

"Bottom-up":
- Analysis of currently funded projects and their potential interconnections.

Progress:
Initial meeting and discussion of framework ideas.
Development of survey questions.

Next Steps:
- Review of framework survey response questions.
- Review of the Geo Carbon Strategy document
- Review of Mass-balance framework.
- Network analysis of existing projects.

Uncertainty Working Group

Participants

Participants: Riley Duren, Steve Hagen, Steve Lohrenz, Molly Macauley, Dimitris Menemenlis
Compiler of this summary/ Group organizer: Robert Kennedy.

Goal: Build from definitions described in 2013 report to understand how uncertainty estimates can be compared across projects; bring new CMS projects into the same uncertainty framework.

Approach: As in 2013, we included questions in the CMS project survey to help us hone understanding of how and where projects could compare uncertainty envelopes with other projects. Also, questions from2013 about how each project handles uncertainty were to be included in the broader interviews of all CMS projects, and we hope to evaluate those as well for the new 2014 projects.

The uncertainty working group continues from the prior cycle of CMS. For the most recent science team meeting in November 2013, we established a conceptual framework to describe the different approaches taken to quantifying uncertainty among CMS projects, and evaluated how Phase 2 2012 CMS projects fit into that framework. We understand that questions from the 2013 survey will be part of new project surveys, and at the science team meeting breakout, we hope to incorporate those responses from 2013 Phase 2 and 2014 projects into the broader uncertainty framework.

The next critical step is to move beyond documentation toward integration. Ideally, these concepts of uncertainty could allow the larger CMS effort a means to reconcile uncertainty estimates across projects. This work involves significant effort to compare and evaluate patterns of agreement and disagreement in uncertainties and estimates across projects.

As a starting point, we included questions in the 2014 CMS survey to help us move toward that goal. We arranged the questions around these goals:

1. Identify the projects that are already comparing products from different projects, and determine if practices for evaluation of different uncertainty estimates are already emerging.
2. Identify possible linkages between projects where such comparisons might be possible, and begin sketching out the methodological approaches to compare and learn from the integration.

Our goal for the next science team meeting will be to evaluate survey results and begin proposing approaches or models for comparing uncertainty envelopes among projects.

Outcomes:

To date, our working group has communicated largely by email, and then only to agree on wording for our 2014 survey questions.
We are having a conference call on October 22nd to evaluate responses to the survey, and lay our plans for the upcoming science team meeting.

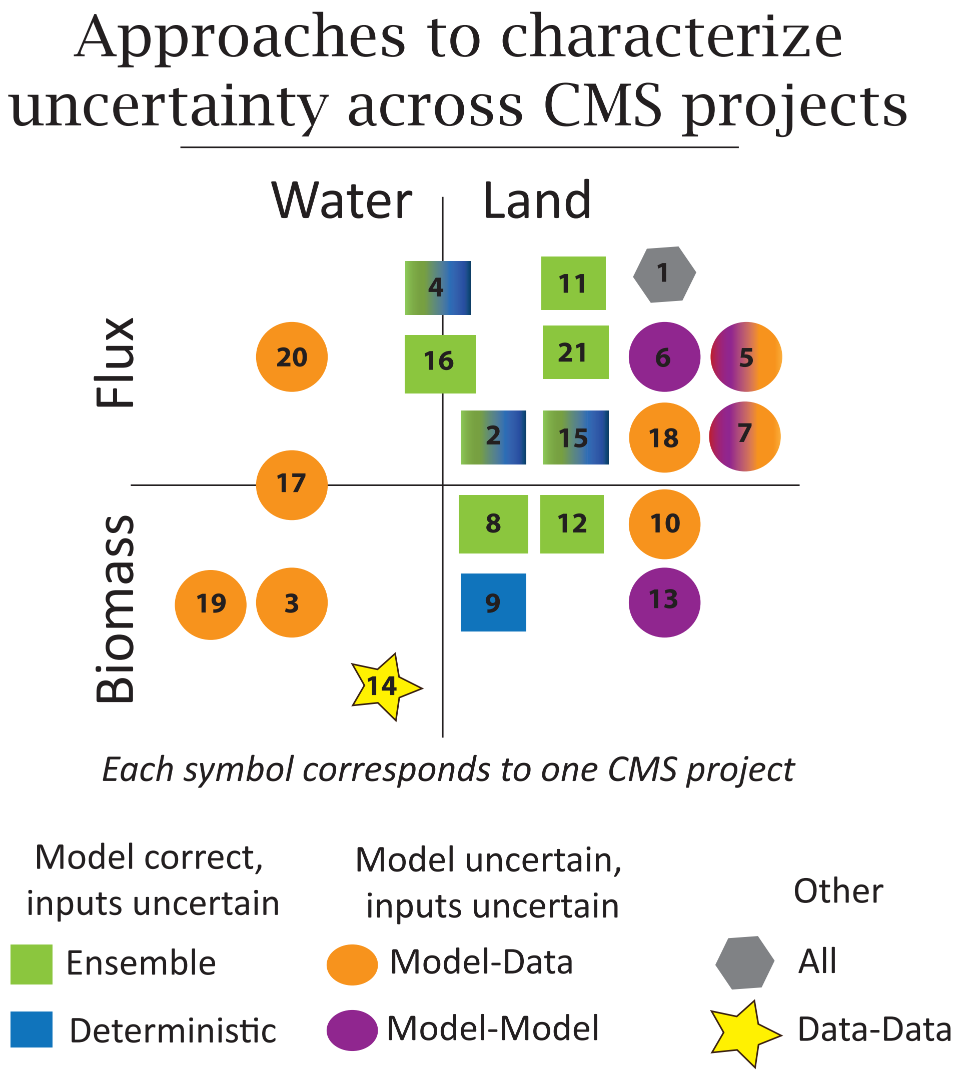

Figure 1. Approaches to characterize uncertainty in NASA CMS Phase II (2012) projects. Numbers correspond to project numbers in Table 2 of the NASA CMS Uncertainty Working Group document.

Algorithm Assessment/Intercomparison Working Group

Coordinator: Sangram Ganguly, NASA ARC BAERI
Members: David Baker, Molly Brown, Jim Collatz, Vanessa Escobar, Nancy French, Daven Henze, Chris Hill, George Hurtt, Christine Kang, Eric Kasischke, Robert Kennedy, Junjie Liu, Steven Pawson, Scott Powell, Rodrigo Vargas, Cristina Milesi
Email List: cms_wg_algorithms@gs618-ccesrvl4.gsfc.nasa.gov

Charge

- Document the range of intercomparison activities within each of the primary domains (biomass, flux, oceans).
- Identify key gaps where further intercomparison efforts are warranted.
- Document effective strategies for intercomparison activities.

Approach

- Solicit CMS team input to survey questions about intercomparison efforts.
- Coordinate with Working Group members to document "best-practices" for intercomparison activities.

Results

- Documentation of current and anticipated intercomparison efforts by primary domain (Biomass, Flux, Oceans) (Table 1).
- Documentation of discussion about effective strategies for biomass/flux map comparisons.
  - Key issues to consider: Differences among maps due to data, methods, and scale.
  - Direct versus Indirect Validation Efforts.
  - Assessment metrics for Algorithm Performance (relative accuracy, bias, etc.)
  - Develop Success Metrics for "similar" end products both spatially and temporally.

Next Steps:

- Incorporate new 2013 & 2014 projects into documentation (some are updated in Table 1).
- Continue to seek project- and domain-level input to finalize table.
- Continue domain-level discussions on effective strategies for intercomparison activities, especially Flux and Oceans.

Table 1. Documentation of current and anticipated intercomparison activities by primary domain (2012, 2013 and 2014 CMS studies only).

PI/CMS Study	Intercomparison Activities
BIOMASS	
Cook: Improving forest biomass mapping accuracy with optical-LIDAR data and hierarchical Bayesian spatial models	• (awaiting feedback)
Dubayah: High Resolution Carbon	• Comparison to national scale maps (NBCD, FIA,

Monitoring and Modeling: A CMS Phase 2 Study	CMS P1) • Comparisons between lidar and FIA biomass maps and ED modeled biomass at local scale
Healey: A global forest biomass inventory based upon GLAS lidar data	• Estimates can be compared with field-based estimates in countries with an established national forest inventory
Houghton: Spatially explicit sources and sinks of carbon from deforestation, reforestation, growth and degradation in the tropics: Development of a method and a 10-year data set 2000-2010	• Previous estimates of tropical emissions from land use and land-cover change
Kasischke: The Forest Disturbance Carbon Tracking System A CMS Phase 2 Study	• Intercomparison of carbon consumed during fires will be carried out between different modeling approaches and fire emissions database
Kennedy: Integrating and Expanding a Regional Carbon Monitoring System into the NASA CMS	• Comparison to national scale maps (NBCD, FIA, CMS P1) • Direct validation at select sites to small-footprint-derived lidar data • Develop success metrics that are spatially explicit as well as aggregate (i.e. overall bias)
Saatchi: Prototyping MRV Systems Based on Systematic and Spatial Estimates of Carbon Stock and Stock Changes of Forestlands	• Comparison to national scale maps (NBCD, FIA)
Hagen: Operational multi-sensor design for national scale forest carbon monitoring to support REDD+ MRV systems	• Indirect and direct validation is performed.
Nelson: A Joint USFS-NASA Pilot Project to Estimate Forest Carbon Stocks in Interior Alaska by Integrating Field, Airborne and Satellite Data	• Will directly compare laser-based estimates with USFS ground-based estimates - biomass to biomass comparison. • Algorithm Performance Metrics and TRL: accuracy and precision as characterized by differences between mean (or total) estimates and the associated standard errors. The TRL will be judged by the USFS. They will implement laser-assisted biomass if we can show them that we can deliver comparable estimates with lower uncertainties at reduced cost.
Ganguly: Reducing Uncertainties in Satellite-Derived Forest Aboveground Biomass Estimates Using a High Resolution Forest Cover Map	• Plan on performing a direct validation with LiDAR and NLCD estimates of tree cover and LiDAR and NLCD-based aboveground biomass estimates. • The performance of our tree cover map will be assessed through error matrix analysis and Receiver Operating Characteristic Curve analysis.

Greenberg: Reducing Uncertainties in Estimating California's Forest Carbon Stocks	• Direct Validation will be performed. • Algorithm performance assessment to be performed.
Hurtt: High-Resolution Carbon Monitoring and Modeling: Continuing Prototype Development and Deployment	• Direct and indirect validation will be performed. Empirical modeled biomass with FIA biomass, process model biomass with empirical model biomass, process model biomass with field plot and FIA plot biomass, empirical and process model biomass change with field plot and FIA change, empirical and process model estimate of biomass change on carbon offset projects with field data from carbon offset projects; validation of national level biomass maps with high res biomass maps over tri-state region MD, DE, PA • Direct measures of biomass and biomass change (not reliant on allometry etc) would provide new level of validation. Direct harvest data? Future links to high resolution inversions?
Walker: Direct Measurement of Aboveground Carbon Dynamics in Support of Large-area CMS Development	• Both indirect and direct validation will be undertaken. Indirect through comparisons with existing information on land cover change as well as carbon density and carbon density change, e.g., Hansen et al./Cartus et al. Direct using CONAFOR field inventory data sets and other sources of ground-based biomass data. • Interested to explore success metrics to the extent that similar end products (e.g., biomass/carbon density change) are available. • Internal to the project there will be comparison of several carbon density change products derived from differing sets of multi-resolution/multi-sensor inputs using standard metrics. Establishing the TRL level is not an explicit goal but is one worth pursuing.
FLUX	
Andrews: North American Regional-Scale Flux Estimation and Observing System Design for the NASA Carbon Monitoring System	• Comparison of best estimate CO2 profiles with ACOS GOSAT data, • Evaluation of posterior fluxes using surface and aircraft data, • Comparison of best estimate fluxes with CMS-FPP and NOAA CarbonTracker fluxes
Bowman: Continuation of the carbon monitoring system flux pilot project	• Surface and aircraft sampling network, TCCON
French: Development of Regional Fire Emissions Products for	• Site (landscape-scales) comparisons with other fire emissions methods including GFED (French et al

NASA's Carbon Monitoring System using the Wildland Fire Emissions Information System	2011) • Indirect and direct validation with GFED and other models (French et al., 2011)
Huntzinger: Reduction in Bottom-Up Land Surface CO2 Flux Uncertainty in NASA's Carbon Monitoring System Flux Project through Systematic Multi-Model Evaluation and Infrastructure Development	• Evaluate the consistency of MsTMIP model estimates with atmospheric CO2 observations, providing an additional benchmark of land-surface model performance. Multiple benchmark datasets.
Jacob: Use of GOSAT, TES, and suborbital observations to constrain North American methane emissions in the Carbon Monitoring System	• Surface and aircraft sampling networks, TCCON; SCIAMACHY
Lohrenz: Development of observational tools and coupled models of land-ocean-atmospheric fluxes and exchanges in the Mississippi River watershed and Gulf of Mexico in support of carbon monitoring	• USGS monitoring data, ship-based observations, NOAA Ocean Acidification monitoring program
Miller: In situ CO2-based evaluation of the Carbon Monitoring System flux product	• Comparison between observed CO2 and a posteriori modeled CO2 from the CMS flux product
Pawson: GEOS-CARB: A Framework for Monitoring Carbon Concentrations and Fluxes	• Sander Houweling is conducting an intercomparison of satellite-based CO2 inversions under the aegis of the Transcom project. • in situ CO2 measurements at surface and from aircraft, land-based column CO2 measurements from TCCON, etc.
Verdy: Towards a 4D-Var Approach for Estimation of Air-Sea Carbon Dioxide Fluxes	• Adjoint model evaluation of the cost function (misfit between observations and model); GLODAPv1, CARINA, PACIFICA • Direct validation: comparison with satellite data and in situ measurements; indirect validation: comparison with climatologies •
West: Estimating Global Inventory-Based Net Carbon Exchange from Agricultural Lands for Use in the NASA Flux Pilot Study	• Inherent intercomparison with inventory and MODIS data
Nehrkorn: Prototyping Monitoring, Reporting and Verification System for the Regional Scale: The Boston-DC	• Comparison with biospheric CO2 flux estimates and uncertainties from CASA models and CMS Flux project •

Corridor	
OCEANS	
Balch: Coccolithophores of the Beaufort and Chukchi Seas: Harbingers of a polar biogeochemical province in transition?	• (awaiting feedback)
Behrenfeld: Characterizing the phytoplankton component of oceanic particle assemblages	• Site specific comparison to local optical measurements
Shuchman: Development of new regional carbon monitoring products for the Great Lakes using satellite remote sensing data	• Direct validation with Lake Michigan and Lake Superior in situ measurements. Need comparisons to in situ measurements in Lake Erie and Lake Ontario. NOAA GLERL in situ monitoring data. • Assessed performance of algorithm with relative accuracy and bias.
Graven: Quantifying fossil and biospheric CO2 fluxes in California using ground-based and satellite observations	• Compare the inversion-based top-down estimates of CO2 fluxes with other top-down and bottom-up estimates in California. Use independent atmospheric data to evaluate the inversion results as well.

Biomass-Flux Working Group

Members: Jim Collatz (WG Lead), Molly Brown, Vanessa Escobar, Nancy French, Skee Houghton, George Hurtt, Christine Kang, Don McKenzie, Crystal Schaaf, Christopher Schwalm, Rodrigo Vargas, Tris West, Lucia Woo, Chris Woodall

Goals/Charge: The Biomass-Flux working group seeks to integrate land-atmosphere carbon fluxes, biomass, and changes in biomass across CMS to improve estimation of all three. The working group will (1) query and identify domains in space and time for which various relevant projects overlap; (2) identify and encourage projects to cross-compare flux and biomass products (3) track and summarize results and outcomes of comparisons. The ultimate goal would be to reconcile measurements of biomass and biomass change with process model biomass/fluxes and atmospheric CO_2 variability.

Methods:

- Identify projects/products that are potentially comparable.
- Identify comparable scales (temporal, spatial) and variables (e.g. above ground biomass, net carbon flux) among products.
- Encourage exchange of products and collaborations among projects that produce comparable biomass, biomass change, and flux products
- These activities will be accomplished through periodic telecons, WG breakout sessions, and CMS projects whose scope may include cross-project comparisons.

Progress:

- Initially the working group was queried for input from their projects specifically related to biomass and flux estimation (4 responses)

Next Steps:

- Identify projects/products that are potentially comparable starting with survey response question.
- Identify spatial, temporal, variable, and format characteristics of products that will facilitate cross-product comparisons. Encourage product developers to produce products useful for cross-comparisons.
- Recruit projects to participate in biomass-flux comparisons

Data/Data Management Working Group

The data working group will adopt protocols and workflows to make CMS data available to scientists and stakeholders over project and archival time frames. The mode of operation will be to communicate and coordinate between both the domain (e.g., atmosphere, land, ocean) and derived (e.g., algorithm, uncertainty) working groups in CMS for appropriate data storage and accessibility to relevant carbon cycle research communities. The data working group cross cuts all CMS working groups and will serve as a model of coordination and communication. Initially, the data working group will respond to several needs and responsibilities:

- Recruitment of CMS science team members with an appropriate cross-cut of scientific expertise and participation on other working groups
- Identification of data and metadata formats needed for both stakeholders and scientists
- Development of a short-term strategy for exposure of data products on the CMS website
- Engage the CMS Science Team regarding their role in archival of final products at one (or more) NASA DAACs (the choice of archive(s) will be made by NASA HQ in consultation with ESDIS)

Measurement, Reporting, and Verification (MRV) Working Group

Members: Rich Birdsey (Chair), Rodrigo Vargas, Grant Domke, Michael Keller, Josef Kellndorfer, Richard Houghton, George Hurtt, Christine Kang, Stephen Hagan, Tom Oda, Steve Stehman, Chris Williams.

Goals/charge: This WG was formed to develop guidance to the NASA CMS program on how to integrate the different program elements, which are represented by many individual projects, into a cohesive program that addresses the most urgent Measurement, Reporting, and Verification (MRV) applications. MRV is a very broad concept guiding the application of monitoring technology to the needs of countries or entities for reporting and verifying greenhouse gas emissions. Credibility, cost-effectiveness, and compatibility are important features of global MRV efforts.

Approach: Initially, the MRV WG will develop a broad-brush review of the CMS projects and their potential contribution to resolving some of the difficult issues that are encountered when designing MRV systems in various contexts around the world. The review includes specific MRV questions included in the project survey, and reading of project summaries. After this review and interactions with others in the CMS community at the 2014 CMS science team meeting, the MRV WG can focus on one or a few of the most useful MRV-related tasks to support CMS.

Progress: Some wide-ranging MRV considerations that need additional focus in CMS have been identified.

1. There is a need for more attention to the "R" of MRV. What are the reporting requirements globally or for different countries or regions? What are the targets for reducing GHGs? How do the reporting requirements affect the selection of appropriate monitoring technologies?
2. There is a need for more attention to the "V" of MRV. This is a very complex topic politically at the national scale, and may not be very practical at the project scale, yet can be essential for assessing progress and assuring compliance. Which of the CMS technologies are appropriate for verification in different contexts?
3. How will analysis and integration of data fit into CMS? To date, most funded projects are focused on specific monitoring technologies, yet MRV requires integration of different monitoring data often by using models or model-data integration. How can CMS evolve to enhance synthesis of data for MRV applications?
4. What are options for applying different combinations of technologies for different countries or at different scales (e.g., projects or nations)? Different combinations are possible to deploy and are not likely to be the same in

different contexts, yet there is a need for consistency in reporting. This could be a good link with the SilvaCarbon program which is working with different tropical countries to support their MRV needs. Are there one or a few case studies to illustrate the use of CMS monitoring technology to different MRV applications?

5. How can the CMS technologies help attribute observed GHG changes to anthropogenic vs. natural causes? This is one of the most important but difficult issues to address in operational MRV systems. The IPCC has not yet been able to provide guidance to countries about how to do this, other than to divide the world's land using a proxy of "managed" and "unmanaged" land.

Atmospheric Validation Working Group

Members (22): Heather Graven, Manvendra Dubey, Arlyn Andrews, David Baker, Kevin Bowman, Martha Butler, Jim Collatz, Ken Davis, Riley Duren, Marc Fischer, George Hurtt, Lucy Hutyra, Daniel Jacob, Christine Kang, Ralph Keeling, Thomas Lauvaux, Chip Miller, Thomas Nehrkorn, Tom Oda, Nick Parazoo, Crystal Schaaf, Steve Wofsy

Goals: The focus of the Atmospheric Validation Working Group is on the integration of atmospheric measurements and modeling to study carbon exchanges using so-called "top-down" approaches. Current projects by the working group members range in scale from individual point sources to state or multi-state regions to hemispheric or global domains. The working group aims to facilitate communication between colleagues, to raise awareness of current work, to advance the state of the art of top-down methodologies, to identify community needs for observations, data synthesis and modeling, and to develop future research directions.

Approach: Monthly telecons with presentations on current CMS projects and related research in atmospheric "top-down" approaches. Started in June 2014 with 10-16 participants joining each call.

Progress:

- Gaining awareness of current methods, activities and challenges, many common to several different projects
- Discussing various types of atmospheric data and their uses and limitations
- Providing more detail about the available CMS products to facilitate their integration in current projects
- Making other available resources known to the community, e.g. library of footprints from WRF-STILT
- Considering role of atmospheric studies to meet MRV needs and potential synergy with MRV working group and CMS Applications Team

Next steps:

- Discuss specific topics in person at Science Team meeting
- Continue monthly telecons
- Identify and initiate tangible outcomes from the working group, potentially including a review paper or white paper

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