Carbon Monitoring Pilot Initiative:
Biomass and Carbon Storage

Overview

Carbon storage in vegetation represents an important reservoir within the global carbon cycle, and changes in carbon uptake by and storage within vegetation and their soils can have significant impact on the global carbon balance. Vegetation biomass density (Mg dry weight per hectare) is used to estimate the amount of carbon stored in vegetation and emitted to the atmosphere when ecosystems are disturbed (IPCC, 2006). Emissions from vegetation disturbance and land-use and land-cover change are considered the most uncertain component of the global carbon cycle. The uncertainty is attributed to large errors in the spatial distribution of vegetation biomass as well as discrepancies in estimates of land cover and land use change (Houghton et al., 2009). Apart from its scientific merit in understanding the global carbon cycle, accurate and precise quantification of emissions from land use change has also become a key issue for policy makers in light of recent developments relating to reducing emissions from deforestation and degradation (REDD) in developing nations as a climate mitigation strategy.

NASA's future DESDynl mission will radically improve the current capability by providing direct measurements of biomass from active sensors (Lidar and SAR). The high precision and accuracy of biomass estimation from DESDynl will quantify carbon stock and changes, improve the geographic distribution of carbon sources and sinks, and reduce the uncertainty in global carbon cycle. However, before the launch of DESDynl, distribution of biomass and carbon storage produced from the existing remote sensing and in situ measurements will provide sub-optimum, but necessary information to develop national and international scale REDD policies and Monitoring, Reporting, and Verification (MRV) frameworks (Goetz et al., 2009; Gibbs et al., 2007)
This pilot project is designed to address the urgent need for geospatially explicit, consistent carbon and biomass inventory information to inform national and international policy making by addressing two objectives:

1. To develop prototype data products of national and global biomass (and carbon storage/emissions) that can be assessed with respect to how they meet the nation's needs for Monitoring, Reporting, and Verification (MRV) of carbon inventories.

2. To demonstrate our readiness to produce a consistent global biomass/carbon stock distribution using the existing in situ and satellite observations to meet the MRV requirements.

The pilot project will focus on quantifying the carbon stock estimates in a spatially and globally consistent approach and to perform uncertainty analysis on its magnitude and spatial distribution. The product will enable the estimation of emissions from land cover and land use change by integrating information on the area of change, the corresponding carbon stock of changed land, and the subsequent accumulation of carbon.

The pilot project will benefit from recent advances in NASA's satellite data processing and products from a suite of sensors including MODIS, Landsat, ICESAT GLAS, and SRTM. Currently data from these sensors are available with improved calibration, atmospheric corrections, and spatial orthorectification that will allow an easy access and data mining for national and global applications. In recent years, NASA's MODIS sensor has brought a new dimension to monitoring the dynamics of the biosphere, providing data products related to biophysical factors and creating the ability to forecast the conditions of the biosphere. Infrastructures such as the Terrestrial Observation and Prediction System (TOPS) have been designed to seamlessly integrate data from these sensors with in situ measurements and models to expeditiously produce operational forecasts of ecological conditions. It is only in the light of recent advances in observations and analytical infrastructure that we are able to provide this new information for scientific exploration and policy making.

Work Plan

The pilot project will focus on several products and assessments. These include:

1. Provide a benchmark analysis of the U.S. carbon/biomass stocks and biomass/carbon change at spatially-refined and temporally- constrained resolutions using state-of-the-art remote sensing observations (MODIS, Landsat, ICESAT GLAS, ALOS PALSAR, SRTM).

2. Assess the accuracy and the utility of the above product using the FIA forest inventory plots and address uncertainty in magnitude and spatial scales.

3. Develop the best forest biomass and biomass change spatial products for the U.S. by combining the FIA forest inventory data and satellite observations. Evaluate quality of product and provide uncertainty characterization through a detailed comparison to sites where high-quality forest carbon/biomass data products have been created, especially sites with existing airborne lidar data.

4. Provide a benchmark analysis of global terrestrial biomass/carbon stocks at spatially refined and temporally-constrained resolutions using the best available state-of-the-art global observations – using the same methodologies as for the U.S. (see objective 1 above), but constrained by the types of remote sensing and supporting observations available globally.

5. Compare the various products produced for the U.S. (including the U.S. region extracted from the global product), fully document errors and uncertainties, and evaluate the likely improvements that could be achieved using data from future missions.

Approach:

The overall approach includes three types of data:

Remote sensing data: The project will include data from several relevant satellites obtained over the period of 2005-2010. These include: 1. MODIS 250 m bands and vegetation index processed to remove low quality and cloudy pixels for seasonal (leaf-on and leaf-off) periods. 2. ICESat GLAS laser profiles and vegetation height that can be used to estimate the aboveground biomass from existing allometric equations. 3. U.S. ALOS PALSAR mosaic at 100 m spatial resolution currently being produced by JPL for the periods of 2007-2008. 4. LVIS data, and possibly other biomass data products, acquired at specific sites to develop refined distribution (1.0 ha) of forest biomass for spatial validation of the national products (at least 5 such LVIS data sets are known to be available).

Spatial land products: These data sets include: 1. SRTM and NED (National Elevation Data) data sets to provide both surface topography and vegetation height index at 100 m spatial resolution (Kellndorfer et al., 2004; Yu et al., 2010). 2. The North American Forest Dynamics (NAFD) product from Landsat time series providing the forest disturbance history at 30 m spatial resolution (Huang et al., 2009). The NAFD information can be used to locate areas that have undergone either stand-clearing disturbance (clear cutting, crown fire) or "partial" disturbance (thinning, partial harvest, insect mortality, storm damage). These data can then be used to parameterize models of post-disturbance carbon accumulation and current net ecosystem productivity (NEP) (e.g. Masek et al. 2006). 3. A related project (LEDAPS) has assembled a wall-to-wall map of stand-clearing North American forest disturbance for the epoch 1990-2000 (Masek et al., 2008). An extension of this effort is refining the disturbance history into 5-year mapping epochs (1990-1995; 1995-2000; 2000-2005). 4. The US land cover data (NLCD) at 30 m spatial resolution providing the spatial distribution of forest cover and types.

Forest inventory data: Over the United States, the most recent inventory includes data from early 2000s and 2005s. The inventory data are available at plot level (~ 1.0 ha) and in spatially aggregated products (County scale). The data will be provided in collaboration with the USDA Forest Service scientists. We plan to use the FIA database (FIADB) to have ground measurements of forest biomass and productivity for training and validation of satellite-based estimation of biomass.

Expanded Scope for Local to Regional Scales

NASA has expanded the scope of the terrestrial biomass product to include more analysis at local and regional scales (i.e., project, county, and state level) and a new model-data fusion study to assess changes in carbon stocks over multi-year time scales. NASA Goddard Space Flight Center will lead these efforts, leveraging its considerable expertise in the preparation and analysis of airborne lidar data, advanced time series Landsat data analysis, geospatial data manipulation, and carbon modeling/data fusion.

The domain of the local scale, high-resolution analyses to be conducted using advanced airborne lidar and multi-temporal Landsat data in combination with forest inventory data will be significantly expanded. NASA will demonstrate how well biomass can be quantified with high-quality remotely sensed data taken at fine spatial resolution for selected sites representative of U.S. forest types and conditions. Sites with intensive inventory measurements will be selected so that comparisons with state and national carbon and biomass inventory products can be made. The accuracy of and uncertainties within the national biomass map product will be evaluated using these high-resolution products for validation. Additional work to evaluate geospatial aggregation methodologies will be conducted using these site data, which offer the opportunity to evaluate how well remote sensing products in grid-cell units can be aggregated into the geopolitical products required for inventory reporting (e.g., counties, states as units). This work will expand the number of sites from ~2-4 (focused mainly on validation) to ~6-12 (focused also on a more representative demonstration of accuracies and uncertainties) and will include:

- new preparation of NASA GSFC LVIS airborne lidar data
- obtaining and preparing suitable data from other airborne lidar sensors
- collaboration with the U.S. Forest Service at their intensive inventory sites
- new field work at the selected sites

This work will rely heavily on existing airborne data, but new acquisitions may be attempted, if needed and if feasible within the short duration the pilot activity.

The terrestrial biomass pilot activity will utilize the data assembled for the local-regional scale biomass product in combination with a forest growth and demographics model to estimate changes in carbon stocks over multi-year time periods. Recent research has shown that spatially explicit data on disturbance, age, and regrowth spectral trajectories derived using a data fusion involving Landsat and airborne lidar data not only improves initialization of the Ecosystem Demography (ED) model but substantially improves overall model performance by providing information on successional state and age to tightly constrain downstream estimates of changes in carbon stocks. These studies have demonstrated how the simplest lidar canopy structure metric, mean canopy height, may be used to initialize various ED model states, and greatly improve model projections.

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Table 1. Summary of national and global scale products developed from the pilot project.

Product Region	Biomass	Biomass Change
Global Benchmark Product over all vegetated ecosystems: • 500-1000 m resolution • 2005-2010 epoch	**Data**: MODIS, GLAS, QSCAT, SRTM **Methods:** - Convert GLAS waveforms to biomass; - Use GLAS biomass to train fusion models using RS data - Validate and perform uncertainty analysis using global inventory plots	**Data:** MODIS forest change, global biomass, MODIS fire history **Methods:** - IPCC-style calculation using (cleared area) * (biomass) - Assess stock change uncertainty using various estimations of forest clearing from MODIS - Compare with IPCC/FAO products - For biomass accumulation, compile inventory data on biomass change; extrapolate globally using MODIS, SRTM, QSCAT, land cover and soil map
United States (benchmark) • 100-250 m resolution • 2005-2010 epoch	**Data:** MODIS, PALSAR, GLAS, SRTM, FIA **Methods:** -Convert GLAS waveforms to biomass; - Use GLAS biomass to train fusion models using RS data - Use FIA data for validation & error analysis	**Data:** LEDAPS 5-year disturbance, MODIS, PALSAR, FIA, MTBS fire history, US biomass **Methods:** - Similar to above for clearing/stock losses - Use LEDAPS "age" + FIA age/biomass data to calculate carbon accumulation -Use all input data to train on FIA productivity
United States (best - 5 subregions) • 100-250 m resolution • 2005-2010 epoch	**Data:** MODIS, PALSAR, SRTM, LVIS, FIA **Methods:** - use FIA as training target; DESDynI-like input data in fusion model (PALSAR SRTM) - Assess spatial uncertainty using LVIS data	**Data:** NAFD annual disturbance, best biomass, MTBS fire history, MODIS, PALSAR, LVIS **Methods:** - Similar to above for clearing/stock losses + PALSAR disturbance maps - Use ED model to generate height/biomass/age curves; compare to observed LVIS data + PALSAR and NAFD disturbance history