ABOVEGROUND FOREST BIOMASS TRENDS FOR THE CONTERMINOUS U.S. INFERRED FROM LANDSAT TIME-SERIES AND FIELD INVENTORY DATA

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We used a sample of Landsat time-series stacks (LTSS) across the conterminous U.S., calibrated with Forest Inventory and Analysis (FIA) plot-level biomass data to estimate 20+ year trends in live, aboveground biomass. To help overcome some of the limitations associated with optical remote sensing of biomass stocks, we employed a pixel-level curve-fitting algorithm to leverage the information contained within the Landsat time-series itself. The sampling framework developed here enabled estimation of live, aboveground biomass flux across 20+ years for eastern and western U.S. forest strata.

The rationale for quantifying the contribution of forest dynamics to carbon accounting is unambiguous, given that U.S. forests offset nearly 13% of total U.S. carbon dioxide emissions in 2007 (U.S. EPA, 2009). Of that 13% offset, aboveground forest biomass dynamics represented the single largest contribution at nearly 50% (U.S. EPA, 2009). This underscores the need to quantify forest biomass dynamics across large areas and long time-frames. Inventory-based (Woodbury et al., 2007) and bookkeeping-based (Houghton et al., 1999) biomass accounting approaches have traditionally been relied upon for large area monitoring, but by their very nature, inventories are potentially constrained by the spatial and temporal frequency of plot samples, as well as the distribution of samples, and, therefore, might not adequately capture forest management, disturbance processes, or areas of marginal forest land (Houghton, 2005). Remote sensing-based approaches have demonstrated good potential for mapping biomass stocks (Kellndorfer et al., 2004; Blackard et al., 2008), but typically lack the historical data required to estimate decadal biomass flux. Archived AVHRR data have been used to estimate biomass flux over several decades (Myneni et al., 2001), but the course spatial resolution of these data might not adequately capture changes in biomass stocks attributable to forest management or disturbance.

Despite known limitations of optical remote sensing data for measuring biomass stocks, the spatial and temporal resolution of the 30+ years of archived Landsat imagery enable consistent measurement of biomass stocks and change across large areas, long time-frames, and at the resolution of land management and disturbance (Cohen and Goward, 2004). Operational and logistical hurdles are rapidly disappearing for large area, long time-frame wall-to-wall Landsat studies. In the meantime, the North American Forest

Dynamics (NAFD) study has implemented a Landsat sampling framework under the auspices of the North American Carbon Program (Goward et al., 2008). The primary goal of the NAFD study is to estimate rates of forest disturbance and regrowth across the conterminous U.S., and eventually North America. In Phase I (Figure 1), we selected 23 LTSS to represent the distribution of forest types across

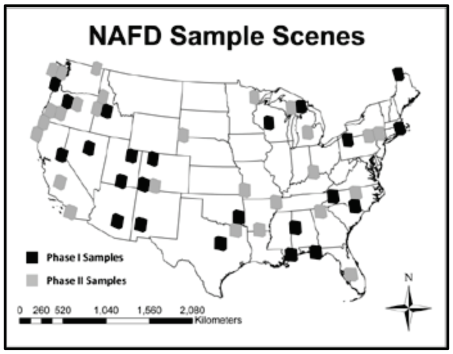

Figure 1. Sample scenes from the NAFD study.

eastern and western U.S. forest strata. For each LTSS we implemented an algorithm called Vegetation Change Tracker (VCT) to map forest disturbance and regrowth at a biennial time step (Huang et al., 2010), and used these results to estimate stratum-level rates of forest disturbance (Figure 2). Phase II of the NAFD study will approximately double the sample size (Figure 1). Another Phase II objective is to convert each LTSS into estimates of live, aboveground biomass, and hence biomass flux across 20+ years.

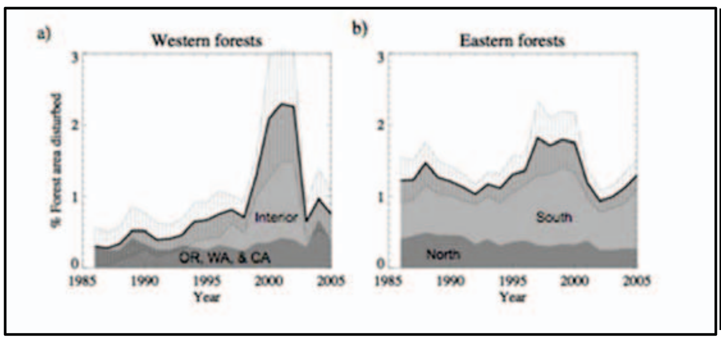

Figure 2. Forest disturbance rates for eastern and western forest strata as quantified by the NAFD study.

For each LTSS we developed an empirical model of live, aboveground forest biomass using FIA plot-level biomass data (Powell et al., in press). We paired FIA biomass observations with contemporaneous Landsat spectral data and biophysical predictor variables, and implemented a Random Forests (RF) regression tree modeling approach. RF is a non-parametric ensemble modeling approach that constructs numerous small regression trees that vote on predictions, and is considered to be robust to over-fitting (Breiman, 2001). The RF model for each LTSS was applied to each image in the radiometrically normalized time-series. Then, a linear segmentation curve-fitting algorithm, called LandTrendr (Kennedy et al., 2007; Kennedy et al., in review) was applied at the pixel-level to minimize exogenous year-to-year variability associated with biomass predictions, sun-angle differences, and vegetation phenology. The result of the curve-fitting procedure was improved estimates of biomass change (Powell et al., in press).

Annual biomass fluxes for eastern and western forest strata were estimated based on the NAFD sampling framework (Figure 3).

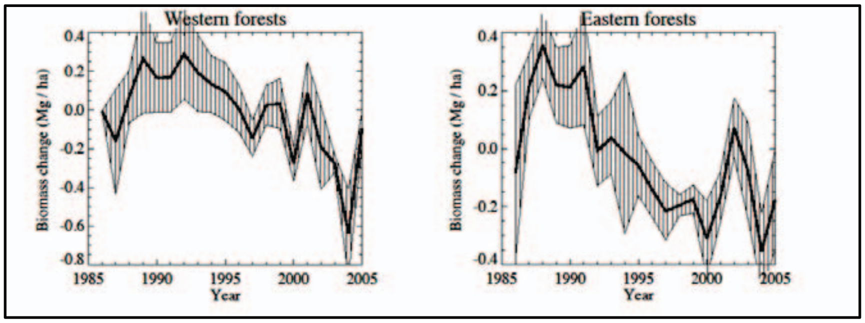

Figure 3. Aboveground biomass flux rates for the western and eastern forest strata.

The results of the stratum-level biomass flux estimates reveal year-to-year variability in the rates of biomass flux for both eastern and western forest strata. Both strata reveal a similar pattern of generally positive flux (sink) in the first half of the time-series followed by generally negative flux (source) in the second-half of the time series. These trends are consistent with the trends in stratum-level forest disturbance rates (Figure 2), which both show an increase in the rate of forest disturbance in the latter half of the time-series. In the western U.S., the increase in forest disturbance rate is largely attributable to increases in fire size and frequency (Westerling et al., 2006). In the eastern U.S., increased rates of forest disturbance, especially in the south, suggest that increased forest management activities are responsible. The positive rates of biomass flux reported here during the first half of each time-series are generally consistent with previous bookkeeping-based approaches (Houghton et al., 1999), but lower than previously reported inventory-based (Woodbury et al., 2007) and remote sensing-based (Myneni et al. 2001) estimates of biomass flux. Previous inventory-based approaches also do not depict the reversal of the biomass flux from positive to negative during the second half of each time-series. Additional research is necessary to determine the extent to which this observed trend is an artifact of sampling, biomass estimation, or some other factor, or in fact a supportable trend based upon increased rates of forest disturbance.

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