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A study of forest biomass estimates from lidar in the northern temperate forests of New England ☆

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ABSTRACT

Quantification of global carbon storage, carbon flux and disturbance in forested regions is of critical importance to refining our understanding of ecosystem processes, climate modeling and climate change. Remote sensing instruments, such as lidar and radar provide a means of obtaining highly accurate and well resolved biomass estimates over global scales. This has sparked interest in mission concepts such as DESDynI. One of the core objectives of the proposed DESDynI mission was global carbon accounting and monitoring through a combination of lidar and radar measurements. In this article, the relationship between field biomass and lidar metrics is analyzed using data from coordinated field measurements and lidar overflights at the Harvard and Howland Forests in North-Eastern United States to assess the performance of a potential biomass mapping instrument. Results show that the performance of lidar estimates of biomass vary significantly between the two sites even though they belong to the same northern temperate forest ecoregion. An attempt is made to isolate the reasons behind the dissimilarities. While RMS errors as low as 30 tons/ha can be seen, these are limited to biomass ranges of up to 300 tons/ha.

1. Introduction

Global carbon accounting is fundamentally important for improving current climate models, developing a better understanding of ecosystem processes and quantifying climate change. With recent advances in remote sensing techniques such as radar and lidar, global accounting of carbon storage, flux and land-use change is becoming a distinct possibility. To that end, the NRC Decadal Survey (Anthes, 2007) recommended a DESDynI-like (Hall et al., 2011) instrument as one of the high priority missions for NASA, a critical component of which is the development of well resolved global biomass maps. The traditional methods of estimating forest biomass through surveys, however accurate, are impossibly difficult over large spatial scales. Global biomass maps must rely on remote sensing measurements, particularly on a combination of lidar and polarimetric radar (Hall et al., 2011). Remote sensing instruments, in general, do not measure forest biomass directly and instead rely on measurements of forest structure, canopy cover, and density among others as proxies for estimating forest biomass. Profiling lidars, optical instruments capable of illuminating forests with light pulses and detecting the reflected light are commonly used to determine forest characteristics such as tree heights. Height estimates from lidars with larger footprints (of tens of meters) have been shown to relate well to stand biomass in various forests and ecoregions (Means et al., 1999; Nelson et al., 1984). Structure metrics from full-waveform lidars, instruments that sample the entire reflected waveforms, have been shown to be even better predictors of forest biomass (Drake et al., 2002a; Hyde et al., 2005; Lefsky et al., 1999, 2005a). Even though the accuracy of these estimates are generally much poorer than the biomass estimates obtained using individual tree diameters, the ability of lidars to cover large regions make them extremely useful instruments for generating large-scale biomass estimates. In this article, we explore the various lidar-biomass relationships for the northern temperate forests alone, using lidar and ground validation data in the Harvard and Howland Forests.

2. Survey sites and field data

In a coordinated effort during the summer of 2009 ground validation data was collected in conjunction with remote sensing measurements from radar and lidar over many field sites in the North-Eastern United States. Sites, such as the Harvard Forest in Massachusetts, the Howland and Penobscott Forests in Maine and the Bartlett and Hubbard Brook Forests in New Hampshire have been used for studies in forest ecology for many years. They have served as a backdrop for field campaigns in support of the proposed DESDynI mission, as numerous one-hectare plots measuring 200 m by 50 m were surveyed throughout these forests. The larger of the plots measuring a hectare,

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referred to in this article as *hectares* were divided into sixteen 25 m by 25 m *subplots* that served as the basic survey unit, in which species information and diameters (at breast height:dbh) of all trees larger than 10 cm were cataloged. While such plots were laid out and surveyed in other forests, this article focuses on only the Harvard and Howland Forests. Field data from these two forests, the biomass estimates derived from this data, the allometric equations used to estimate biomass and the accuracy of those estimates are all discussed in more detail in (Ahmed et al., 2012).

3. Lidar data over the Harvard Forest

The laser vegetation imaging sensor (LVIS) is an airborne scanning laser altimeter developed by the NASA Goddard Spaceflight Center (GSFC) (Blair et al., July 1999). The instrument is a nadir looking profiler that is capable of sampling full waveform returns. It can cover large swaths by scanning the laser up to 7° off-nadir with a footprint that varies between 20 and 80 m. For each location the laser echoes are sampled and processed to generate geolocated full waveform data or moments that include ground height, canopy top and quartiles of the lidar energy returns.

Fig. 1 shows the LVIS nadir track over the Harvard Forest and surrounding region for a deployment in August 2009 in conjunction with the field data collection. Full waveform data from this LVIS deployment has been processed at the Goddard Spaceflight Center.

3.1. LVIS shot selection methodology

The LVIS data is distributed in two forms: (i) the full waveform data, and (ii) estimated RH metrics (quartiles of the return waveform) for every laser shot. Each shot (identified by its corresponding shot number) is associated with a latitude, longitude and height triplet with the first and last sample of the waveform. The choice of which LVIS shot should belong to a particular subplot or plot was based on the percentage area of overlap between the two, defined as the area of intersection as a percentage of the total area of the LVIS footprint. The center of the 25 m diameter LVIS footprint was chosen as the latitude, longitude pair associated with the ground return. Most subplots contain data from more than one shot with at least 5% overlap, with a mean overlap of 74% seen over all subplots.

3.2. LIVS RH metrics and field biomass

Most studies have reported strong relationships between lidar RH metrics and field biomass. It is expected that some ecological process controls the structure of forests as they grow and add to their biomass, in the hope that a measure of structure will somehow reflect biomass. Such a process is not perfectly understood and as a result the relationships between lidar metrics and biomass are inconsistent; varying over different biomes and study sites with factors such as species, age and climate (to name a few) affecting the outcome of such relationships.

The relationship between the four RH metrics and biomass at the Harvard Forest is shown in Fig. 2 at both the subplot and one-hectare levels. For these scatter plots only the shots with at least 5% overlap were selected.

Regression statistics for a linear fit between lidar RH metrics and field biomass are summarized for subplot and hectare scales in Table 1. The RMSE (the root mean square error), in units of tons per hectare, is comparable to the standard deviation of the ground biomass, which is 66.85 tons/ha for subplot level estimates and 40.95 tons/ha for hectare level estimates.

Fig. 3 shows the relationship between subplot and one hectare level biomass estimates and LVIS RH metrics for an overlap of at least 75% or more. As expected the number of subplots that satisfy the 75% overlap criterion are fewer than those that satisfied the 5% overlap, therefore there are fewer number of samples displayed in Fig. 3a (97 subplots) compared to the number of samples shown in Fig. 2a (208 subplots).

Table 2 summarizes regression statistics for linear fits between biomass and LVIS shots with overlap of 75% or more. The R^2 statistic for subplot level estimates reduces significantly whereas that of the hectare level estimates increases slightly. There could be two reasons for the higher correlations seen at hectare scales, one that the LVIS

Fig. 1. The LVIS nadir track is highlighted by green lines while boundaries of the Harvard Forest are shown by the yellow lines. As the LVIS instrument flies along this track its beam scans up to 7° off either side to make a detailed height map of the area.