A BIOMASS ESTIMATE OVER THE HARVARD FOREST USING FIELD MEASUREMENTS WITH RADAR AND LIDAR DATA

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ABSTRACT

The National Research Council's decadal survey recommended DESDynI as one of the high priority missions for NASA. The mission envisions an InSAR/Lidar instrument for observing ecosystem structures on global scales with high spatial resolutions. Consistent and highly resolved global maps of biomass and carbon stocks require highly accurate observations of vegetation, in fact it is expected that such accuracies would require a combination of the high vertical precision of Lidar observations and the large spatial extent of SAR/InSAR measurements. Here we analyze radar backscatter data along with biomass estimates from a field campaign conducted in the Harvard forest in Massachusetts, USA.

1. INTRODUCTION

The DESDynI project aims to estimate forest biomass to within 20% accuracy. The two instruments on its platform are expected to be a radar and a lidar. Radar backscatter has in the past been directly related to above ground biomass, however at high biomass levels it has been observed that radar backscatter saturates. Heights and structure information provided by lidars and interferometers can also be used to estimate biomass. Here, however, we concenterate on the performance of radar backscatter as an estimator for above ground biomass especially at high biomass levels (between 100 and 300 tons per hectare) that are prevalent in the north-eastern United States.

2. FIELD CAMPAIGN

The Harvard Forest near Petersham, MA is a ecological research facility that has been managed by the Harvard University since 1907. It is spread over 3000 acres and is split mainly in three tracts; Prospect Hill, Tom Swamp and Slab City (see Figure 1). The forest type is Transition Hardwoods-White Pine-Hemlock, with dominant species of Red Oak, Red Maple, White Birch, White Pine and Eastern Hemlock. Most of the forest is artificially planted over reclaimed agricultural land. Different plantations of a certain species are maintained

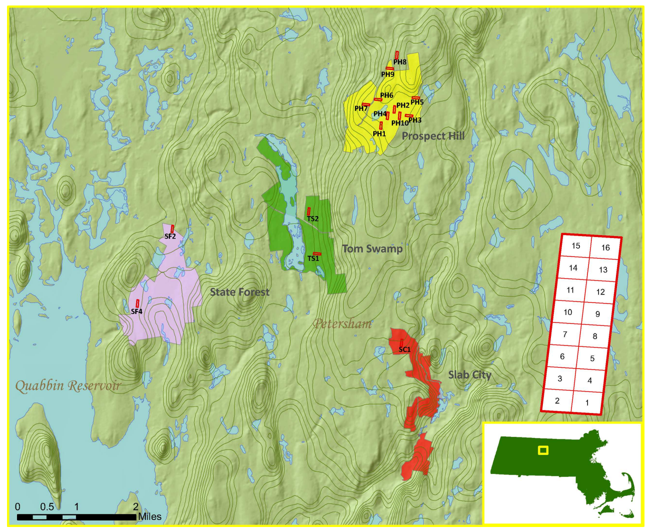

Fig. 1. *Harvard Forest Tracts and survey plots. The inset enlarges plot PH1 with the sixteen 25m by 25m subplots.*

throughout the forest. During July of 2009 tree diameter and species information was surveyed from 15 hectares in the Harvard Forest. The study area was divided into fifteen one hectare plots, with a plot measuring 200×50m. Each plot was was further divided into 16 subplots measuring 25×25m. The orientation of a plot was chosen to be either 5 degrees for vertical plots, or 95 degrees for horizontal plots. These plots were set in the three Harvard Forest tracts of Prospect Hill, Tom Swamp and Slab City. Of the 15 plots, 10 were in Prospect Hill (titled PH01 to PH10), two in Tom Swamp (TS01, TS02) and one in Slab City (SC01). The remaining two plots were set in the nearby State Forest (SF02 and SF04). Figure 1 shows the fifteen survey plot locations and the three Harvard forest tracts those plots were set in. The inset in Figure 1 shows a plot with its sixteen subplot boundaries and the number scheme that was used to identify each subplot. The choice of location of these plots was guided by species diversity, topography, accessibility and radar, lidar coverage. The diameter at breast height (dbh), species information and subplot location of every tree with a dbh larger than 10cm within the fifteen hectares of surveyed area were cataloged. For a subset of the the trees surveyed, tree height was also measured. Estimates of per-tree biomass were obtained using regression curves summarized by Jenkins et. al. [1]. Figure

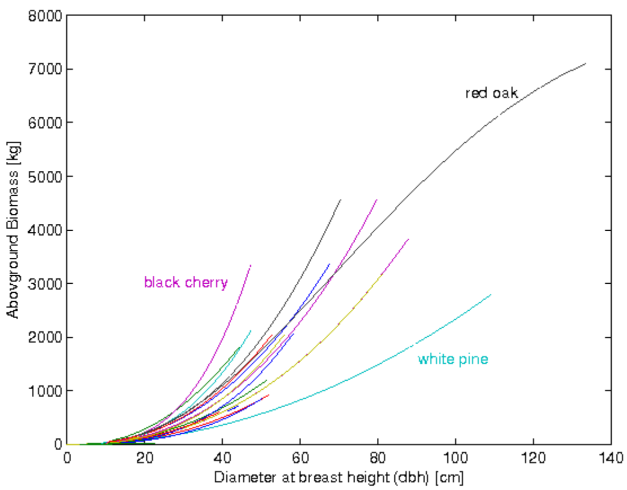

Fig. 2. *Biomass curves derived from diameter data for each of the twenty three species cataloged during the field campaign.*

2 shows the total above ground biomass (in kilograms) broken down for each species encountered in the forest against the range of measured diameter values. A total of 10552 trees were measured during the course of the campaign.

3. REMOTE SENSING DATA SOURCES

In addition to the ground survey data from three separate remote sensing instruments has also been collected for analysis. JAXA's PALSAR (Phase Array L-band Synthetic Aperture Radar), a spaceborne instrument has been operational since February 2006 and has collected data over the Harvard forest region on a regular basis. A few key parameters of ALOS/PALSAR are listed in table 3. Some 100 PALSAR scenes covering the Harvard forest and the surrounding regions have been processed, these scenes consist of 20 high resolution single polarized (FBS, HH) images, 48 wide swath dual-polarized (HH, HV) and 30 fully polarimetric images. PALSAR has a 46 day repeat period which produces a variety of baselines for repeat-orbit interferometry. PALSAR data has been processed interferometrically, but most of the pairs suffer from significant temporal decorrelation. NASA JPL's UAVSAR (uninhabited aerial vehicle synthetic aperture radar) is an L-band SAR capable of collecting fully polarimetric high resolution data from an airborne platform. Table 2 lists some key radar parameters of the UAVSAR. It was flown over the Harvard forest during August of 2009. The flightlines

Table 1. ALOS/PALSAR instrument parameters

Parameter	Value
Center Frequency	1270 MHz
Modes	FBS, FBD, PLR
Bandwidth	28, 14, 14 MHz
Polarization	HH, (HH, HV), (HH, HV, VH, VV)
Look Angles	9.9° - 50.8°
Resolution(m)	4.6×3.5, 9.3×3.5, 9.3×3.5

Table 2. UAVSAR instrument parameters

Parameter	Value
Frequency	1.26GHz
Bandwidth	80MHz
Polarization	HH, HV, VH, VV
Look Angles	25° - 65°
Resolution	1.6m $\times$ 0.66m

were designed to be in a race-track configuration, at headings of 5 and 185 degrees, so that the left looking antenna could image the same area from two different aspect angles. The datatakes for UAVSAR occurred on five days (Aug 6th, 8th, 13th, 16th and 17th) each from an altitude of 12.5km and a 40 degree look angle to the center of swath. UAVSAR was flown such that data could be collected from multiple baselines and multiple look angles. Interferometric data collected from this campaign includes baselines ranging from 0 to 110m over the five days. In addition to the two radars, airborne lidar data has also been collected. This data comes from the laser vegetation imaging sensor (LVIS), an airborne scanning laser altimeter developed and operated by the NASA Goddard spaceflight center. The instrument is a nadir looking profiler that samples full waveforms from an altitude of 10km. It can cover a swath of up to a kilometer by scanning the laser up to 7° off-nadir with a 25m wide footprint. For each location the laser echoes are sampled and processed to produce either full waveform data or moments that include ground height, canopy top and quartiles of the lidar energy returns. LVIS was deployed over the Harvard forest and surrounding region in 2003 and again in August, 2009 in conjunction with the UAVSAR data collection and the field campaign. Data from the 2009 overflights are being processed and are expected to be available soon.

4. ANALYSIS

Even though interferometric data from PALSAR is available and height information can possibly be estimated from a few scenes that are not drastically affected by temporal decorrelation, we focus on the relationship between radar backscatter and biomass in this text. Primarily we will analyze the UAVSAR and PALSAR cross-pol backscatter data.

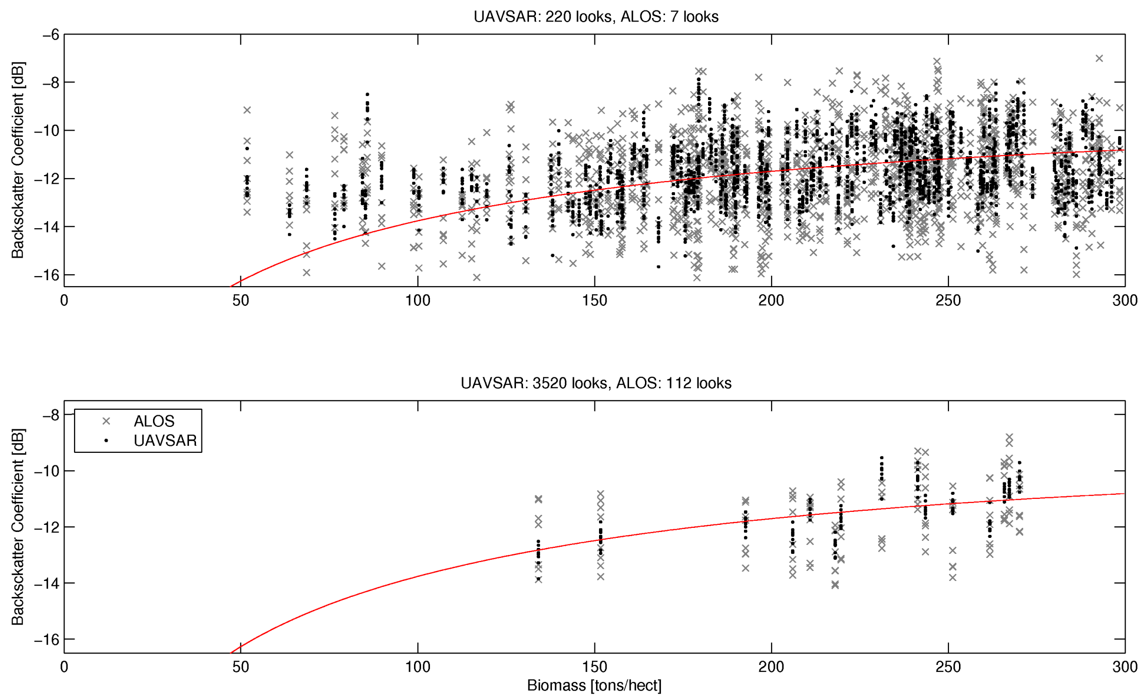

Fig. 3. *Variation in ALOS and UAVSAR cross-pol backscatter for several datatakes. The ALOS data (FBD, HV), spans a period of over two years (2006 to 2008) with datatakes between July and October, whereas the UAVSAR data spans a period of eight days in August of 2009.*

The backscatter coefficient used in this analysis is given by

$$\gamma_0 = \frac{\sigma^0}{\cos(\theta_i)} \quad (1)$$

where θ_i is the local incidence angle and σ^0 is the backscatter coefficient that has been corrected for pixel area variations [2]. The incidence angle and pixel area correction factor are both estimated using radar geometry and the SRTM derived 30m DEM for PALSAR and UAVSAR. The UAVSAR ground projected data is distributed by JPL with the co-registered and oversampled DEM, whereas for PALSAR the DEM was co-registered using the GAMMA SAR processor. Of the many scenes available for the three PALSAR modes, FBD cross-polarized (HV) data acquired over a time span of two years between 2006 and 2008 were chosen for analysis. These scenes were processed from the level 1.0 data distributed by JAXA, to ground projected γ_0 values. Choice of scenes was further restricted to data takes between the months of July and October in order to avoid effects of seasonal variations in backscatter. This left a total of eight scenes. With a native resolution of approximately 9×3m for the FBD mode, roughly 7 independent looks can be achieved for a ground projected area of approximately the same size as the surveyed subplots. On the hectare level this translates to approximately 112 independent looks.

Ten UAVSAR cross-pol (HV) scenes with the a 5 degree heading were chosen for the analysis presented here. These scenes were collected over three days in August, the 6th, 8th and 16th. The nominal resolution of UAVSAR is 1.6×0.66m, which translates to approximately 220 looks for every surveyed subplot. For a hectare a total of 3520 independent UAVSAR pixels are available for averaging.

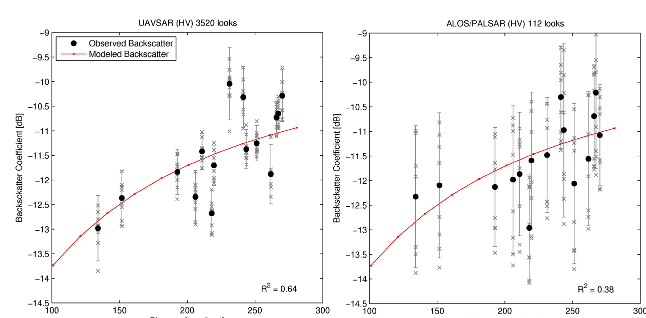

Fig. 4. *ALOS/PALSAR and UAVSAR cross-pol (HV) backscatter modeled as functions of hectare level biomass estimates. The model and UAVSAR data with 3520 looks are in relatively good agreement with an R^2 value of 0.64.*

Figure 3 shows the backscatter values from the two instruments plotted against the surveyed biomass for those pixels. The top plane shows variation in backscatter for the eight PALSAR and the ten UAVSAR scenes for each of the 240 subplots, whereas the bottom plane shows radar data for the fifteen hectare level biomass estimates aggregated from the 240 subplots. The variation seen in both backscatter values is a result of speckle, temporal variations, geolocation errors and random gain variations, among others. The observed variation is expected to decrease with the increased number of looks. This is evident in Figure 3 with reduction in variation for hectare level backscatter values compared to the subplot level backscatter of approximately a dB. The variation in biomass values also decreases considerably at hectare levels, which is to be expected as well. At a certain number of looks the variation in backscatter values ought to have reduced enough such that the underlying variations in forest biomass can be observed. At subplot levels, this seems not to be the case, however at the hectare level variation due to forest attributes seems to be reflected in UAVSAR data. Figure 4 shows data from the two radars plotted against hectare level biomass estimates. Modeled backscatter derived from biomass are also plotted. The model is of the form

$$\gamma_0\,(b) = A\left(1 - e^{(-Bb)}\right) + Cb^{\alpha}e^{(-Bb)} \tag{2}$$

where, b is above ground biomass and the fit coefficients A, B and C are derived using the hectare level UAVSAR data. The clearly visible difference in variation between the two datasets is a result of both the number of looks and the large time span between the PALSAR data takes. Consequently, with such a large number of looks, the UAVSAR data fits the modeled backscatter fairly well. Not only that, the outliers in the data can be explained. The points well above the empirical curve and on the higher side of the biomass scale, are tall coniferous trees (Red Pines, and Hemlocks). These trees seem to have a significantly higher backscatter values but their biomass values are not proportionately higher. The backscatter values that are below the empirical curve are all from stands of deciduous forests. These stands (mostly Red and White Oaks) consists of trees that are smaller than the pines but have high biomass values. PALSAR data in the mean seems to follow similar trends but the differences in backscatter values between the plots are not statistically significant, so it is more difficult to assume that the instrument errors are not dominant. This leads us to believe that the minimum number of looks required to reduce the variation in observed backscatter to levels such that variations of the observed phenomenon are dominant lie somewhere between 220 and 3520 looks, assuming that the temporal variations in backscatter also decrease as a function of looks in the same manner as speckle.

In addition to the backscatter values from UAVSAR and ALOS/PALSAR, lidar heights from the LVIS field campaign of 2003 are also available. Figure 5 shows biomass values estimated from the averaged LVIS rh50 metric and subplot level biomass estimates from field data. The fit does not seem to be as good as some published results, however we notice that in some plots the field measured heights and LVIS heights seem to differ quite significantly. This could be attributed to the six years difference between the two measurements. LVIS data from the 2009 campaign will most likely yield better results from this height to biomass allometry.

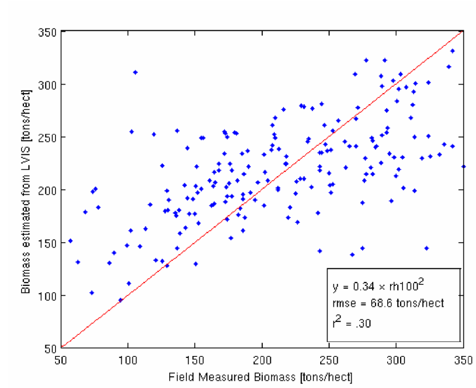

Fig. 5. *Biomass estimated from lidar (LVIS) derived heights plotted against field measured biomass*

5. CONCLUSIONS

A large set of UAVSAR and ALOS/PALSAR cross-pol backscatter data was analyzed with extensive field measured biomass over the Harvard Forest in Massachusetts. The field measured biomass ranges from 130 to 270 tons per hectare. At such high biomass levels, radar backscatter is expected to have saturated. In order to invert backscatter for biomass high precision backscatter measurements are necessary. It is observed that significant precision can be achieved by averaging 3520 independent pixels (equivalently one hectare of UAVSAR looks). This however is not a minimum value, and work is underway to ascertain a minimum number of looks needed to estimate biomass from radar backscatter that would be representative of at least the Harvard Forest, and hopefully the North Eastern US.

6. REFERENCES

[1] Jennifer C. Jenkins et. al., "Comprehensive database of diameter-based biomass regressions for North American tree species," *Gen. Tech. Rep. NE-319, U.S. Department of Agriculture, Forest Service, Northeastern Research Station*, 2004.

[2] L.M.H. Ulander, "Radiometric slope correction of synthetic-aperture radar images," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 34, no. 5, pp. 1115 –1122, sep 1996.