Estimating Forest Biomass in Temperate Forests Using Airborne Multi-frequency Polarimetric SAR Data

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Abstract:

We used multi-sensor, multi-frequency and multi-polarization SAR data for biophysical parameter retrieval in plantation forests of Northern Japan. The statistical relationships with different biophysical parameters are quite robust for certain frequencies-polarization combination. A combination of different frequencies and polarizations facilitate the retrieval of these parameters with R^2 of 0.95 and rms error of 15.19 tons ha^{-1}. Further, a large sample of 186 stand age from coniferous species showed a robust relationship for all the three polarizations of the L-band data up to 40 years of age. L-band data provided very good retrieval accuracy for the dry biomass with the SEE = 22.52 *tons* ha^{-1}.

1. INTRODUCTION

Though, the scientific community is aware of the technical requirements for making full carbon estimation but we are confronted with a number of issues related to accuracy, precision and uncertainties. SAR has been employed since long for biomass monitoring and estimation at different scales across the globe (Dobson et al., 1992, Saatachi et al., 2000). The knowledge of the amount and distribution of aboveground woody biomass is also very important for understanding a number of land surface processes and predicting the biosphere responses to climate change. Remote sensing data from optical, radar, thermal and lidar sensors has a tremendous potential to measure biophysical attributes and land surface properties that could aid in modeling and assessment of the carbon cycle with better accuracies. Radars (Hoekman et al., 2000, Kuplich et al., 2000, Le Toan, 2001), optical sensors (Myneni et al., 2000) and lidars (Jason et al., 2002), have demonstrated their potential for vegetation parameter retrieval. But radars, besides being weather independent, are more sensitive to the biomass stocks and have demonstrated higher saturation and thus shown more potential for biophysical parameter retrieval (Dobson et al., 1995a, Hussin et al., 1991, Kasischke et al., 1994, Schmullius et al., 2001). Despite all these and many more studies, we don't have a robust algorithm that works on an operational basis for biomass estimation (Ulaby, 1998).

2. STUDY AREA AND FIELD MEASUREMENTS

The study area is located near Tomakomai, in the north of Japan. The topography of the area is almost flat and thus ideal for SAR observations. The site is located at 42.41° N Latitude and 141.32° E Longitude. The Tomakomai forests are basically plantations that have been raised in adjacent plots of 500x100 m and could comprise of one or more tree species. The main tree species growing in the area are; fir (*Abies mayriana*), Spruces (*Picea jezoensis* and *Picea glehnii*), Larch (*Larix leptolepsis*) and a few broad tree species like *Birch* etc. The field measurements of geo- and bio-physical parameters like tree height, DBH, stocking density, canopy characteristics, LAI, soil moisture etc. were conducted at 17 sample plots between 5-11 Nov., 2202, coincident with the Pi-SAR over-flight. The sampling plots were laid along a transect that runs parallel to the flight course of the PiSAR and Perpendicular to that of the AirSAR. The 20x20 m size sampling plots were demarcated on the ground for measurement of the biophysical parameters for tree = 10 cm DBH while as 10x10 m sample plots were laid for the measurements of trees that were = 10 cm DBH. Further, the 9 samples of soil moisture were measured in a grid format at a spacing of 10 m and depth resolution of 8 cm within each sample plot. Fish eye camera was used to get the LAI index measurements for each plot. The average estimates of these measured parameters are were used for comparison with s^o. The forest biophysical parameters were estimated using following methods:

The dry trunk biomass (B_{tr}) of each plot was estimated by summation of the individual tree trunk biomass as follows

$$B_{tr} = \sum_{j=1}^{n} Grh_j t \qquad (1)$$

Where, G is the stand basal area, r is the dry density of the wood for each species, h_j is the bole height of each tree in the plot. The basal area (G) for each plot is estimated as follows:

$$G = \frac{pd^2}{4} \qquad (2)$$

Where d is the average stand diameter. Similarly, the wood volume of the trunks (W_{tr}) was estimated using the following equations:

$$W_{tr} = \sum_{j=1}^{n} Gh_j t \qquad (3)$$

The wood density (r), dry weight per unit volume of wood of the each of the tree species growing in the study area was found using oven dry method. The common method of determining the dry density of the wood is as follows:

$$r = \left({}^{w_d}\!\!\diagup_{w_g} \right)\left(1 + {}^{M}\!\!\diagup_{100} \right) \qquad (4)$$

W_d and W_g are the oven dry and green weight of the wood and M is the moisture content in percent.

There is some approximations in estimating the taper factor *(t)* for the tree types found in the area. Most of the values were taken from the structurally similar trees found in the literature (Brown, 1997). Since, we could not gather enough information about the crown parameters, the crown biomass could not be estimated with a reasonable accuracy. Because of strong relationship between crown depth *(CD)* and crown biomass (Kasischke, et al., 1994), it was used as a surrogate to crown biomass and is computed from the difference of the tree height *(ht)* and the bole height *(h)*.

3. SAR DATA

The PiSAR, an airborne polarimetric and interferometric SAR system, has been jointly developed by the National Space Development Agency (NASDA), Japan and the Communication Research Laboratory (CRL), Japan. The SAR system consists of an X-band SAR and an L-band SAR with very high spatial resolution of 1.5 m (X-band) and 3.0 m (L-band). Pi-SAR is capable to make full polarimetric observations and the X-band SAR has two antennas displaced in the cross-track to make interferometric observations. The system has been used to conduct flight experiments for a number of geological, hydrological and vegetation studies in the past (Kobayahi et al., 1997, Mitsuzuka et al., 2000). The L-band incidence angle along the transect varied between 31^o-33^o and for the X-band, the incidence angle varied 25^o-35^o. The data were filtered to reduce the speckle level. This was done by using 5x5 GAMA-MAP filter (Lopes et al., 1993). The filter operation was controlled by checking for the coefficient of variation and the image degradation visually. We also used multi-frequency (C, L and P bands) and multi-polarization (HH, HV and VV) AirSAR data from NASA that had been taken two years back. Being temperate vegetation types, we assume marginal increase in the biomass over the period. The incidence angle of the AirSAR data varies between 47^o-52^o over the study area.

4. DATA ANALYSIS AND DISCUSSION

The SAR data from the PiSAR L-band and AirSAR (C-, L-, and P-bands) were analysed for assessing their potential for biophysical parameter retrieval. The sample point averages of these biophysical parameters were compared with the average backscattering coefficient of the sample. The correlations coefficients of each combination of the frequency for AirSAR are given in the Table 1 while Table 2 gives these relationships for the PiSAR data. In case of AirSAR, the relationships between the biophysical parameters and the backscattering coefficient are quite good for all the linear polarizations of L- and P-bands. Surprisingly the L-band relationships, particularly VV polarization, with most of the biophysical parameters measured, are better than the P-band relationships. But the rms error of the P-band s^o with most of the biophysical parameters is more than the L-band data for HH and VV polarizations. For HV polarizations, the rms error is better for P-band than for the L-band. The dynamic range of the s^o is similar for L- and P-bands for AirSAR data. In case of C-band data, only the HV polarization shows statistically significant relationships with most of the biophysical parameters. The HH polarization gives better results than the VV polarization. The dynamic ranges of the s^o are very small compared to L- and P-bands (Tab. 1). For PiSAR, we used only L-band data for the analysis. The statistical relationships between the biophysical parameters and the PiSAR data are equally good when compared with the AirSAR data. The PiSAR data shows higher dynamic range compared to the AirSAR data for the L-band. The figure 1 shows the L-band SAR relationships for three linear polarizations (HH, HV and VV) against the dry biomass, basal area, wood volume and tree height. The Figure 2 shows the relationships between the PiSAR L-band data and the Stand age, basal area, dry biomass and tree height. Though the statistical relationships in terms of R^2 are similar to AirSAR L-band data but the rms error, another statistic for judging the robustness of the relationships, is more compared to the AirSAR data.

Stepwise linear regression method was used to find the best frequency-polarization combination from both Pi-SAR and AirSAR data for Biophysical parameter estimation. For lack of space, only the results for the dry biomass estimation are discussed here. The results of the regression analysis are shown in the Table 3 for PiSAR and Table 4 for AirSAR. If, all the three L-band channels of the PiSAR are used, the $R^2 = 0.64$ and the rms error is 21.80 tons/ha. For a single channel, the HV gives the best fit and lowest rms error. For AirSAR, the single best channel for dry biomass estimation is P-HV with $R^2 = 0.73$ and an rms error of 21.99 tons/ha. If, we use the six best channels, the R^2 shoots up to 0.95 and the rms error comes down to 15.19 tons/ha. The addition of other three channels does not improve the rms error of the estimation.

5. CONCLUSIONS

The analysis shows a good sensitivity of the L- band SAR for the all the biophysical parameters test in this study. The X-band sensitivity to these parameters is week. The observed results could be explained well by the theoretical results using a radiative transfer based model, the MIMICS (Ulaby et al., 1990). Expectedly, the X-band data was not found suitable for the retrieval of biomass. Even, the X-band sensitivity to the crown depth was found statistically insignificant. This was due to insensitivity of the X-band to the canopy constituents that were larger than the X-band wavelength. Further, the L-band data showed a good sensitivity with the stand age of trees up to 30-40 years depending upon the tree type. These relationships could be used to compute other biophysical parameters, if, and when, the detailed allometric relationships become available.

Because of the strong sensitivity of the L-band data to vegetation parameters, the SAR retrieved biomass estimates show reasonably good agreement with the measured estimates. The usage of all the data from the L- and X-band marginally improved the retrieval results. The results are encouraging and the field campaign and airborne SAR missions are being continued this year to gather more data from as much plots and as many parameters as possible. It is expected that a longer time series of the SAR data supported by complete and statistically adequate information about the different biophysical parameters would lead to the development of a robust algorithm for retrieval of the biophysical parameters. For better retrieval accuracy, the forest structural effects would have to be eliminated by pre-classification of the forests on a landscape scale. With the availability of the ALOS data by the mid of this year (2006), it is hoped that a retrieval algorithm employing fully polarimetric data would be developed and hopefully could be tested for different vegetation types in other climatic zones.

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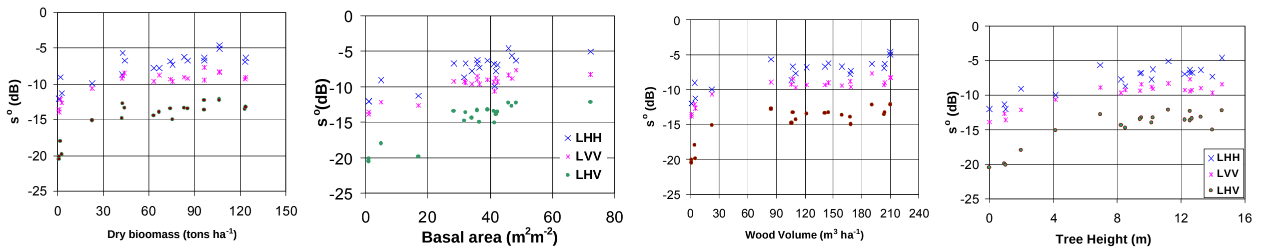

Fig 1: Relationship between the s ° and the biophysical parameters for AirSAR L-band data

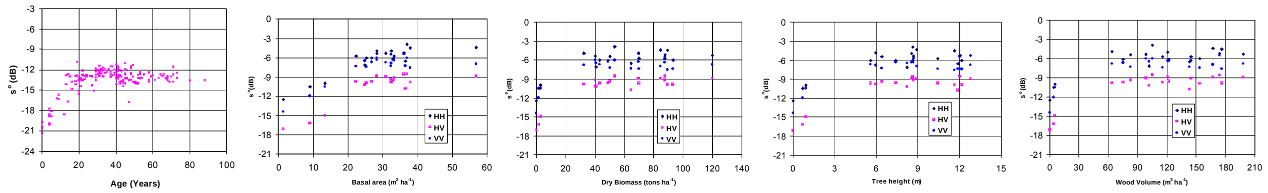

Fig 2: Relationship between the s ° and the biophysical parameters for PiSAR L-band data

Biophysical Parameters	Chh	Chv	Cvv	Lhh	Lhv	Lvv	Phh	Phv	Pvv
Basal area	0.38	0.55	0.27	0.64	0.81	0.78	0.7	0.68	0.73
Dry Biomass	0.59	0.78	0.43	0.78	0.89	0.91	0.77	0.76	0.81
Wood volume	0.57	0.76	0.47	0.8	0.93	0.9	0.76	0.8	0.79
Stand Height	0.55	0.74	0.48	0.75	0.76	0.76	0.62	0.77	0.78
Dynamic Range (dB)	2.83	3.67	4.08	7.44	6.15	8.35	9.61	5.53	6.18

Table1: Statistical relationships between AirSAR data and biophysical parameters

Biophysical Parameter	L-HH	L-HV	L-VH	L-VV
Basal area	0.82	0.77	0.8	0.83
Dry Biomass	0.77	0.76	0.8	0.83
Wood volume	0.74	0.73	0.77	0.82
Stand Height	0.73	0.71	0.75	0.81
Stand Age	0.62	0.64	0.7	0.7
Dynamic Range (dB)	8.57	8.58	9.48	8.96

Table2: Statistical relationships between PiSAR data and biophysical parameters

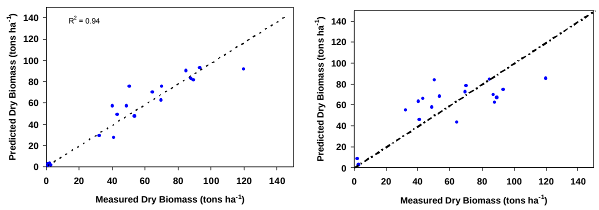

Figure 3: Observed dry biomass versus SAR derived biomass (both AirSAR and PiSAR)

Biophysical Parameter	Data	R-square	rmse (t/ha)
Dry Biomass (t/ha)	HV	0.54	27.62
	HH+HV	0.62	26.08
	HH+HV+VV	0.64	26.05

Table 3: Best data channels for dry biomass retrieval using L-band PiSAR data

Biophysical Parameter	Data	R-square	rmse (t/ha)
Dry Biomass (t/ha)	P-hv	0.73	21.99
	L-hh+P-hv	0.77	21.00
	C-hv+L-hh +P-hv	0.84	17.88
	L(hh+hv+vv)	0.65	24.5
	6 best channels	0.95	15.19

Table 4: Best data channels for dry biomass retrieval using L-band AirSAR data