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RELATING MULTIFREQUENCY RADAR BACKSCATTERING TO FOREST BIOMASS: MODELING AND AIRSAR MEASUREMENT

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1. INTRODUCTION

During the last several years, significant efforts in microwave remote sensing have been devoted to relating forest parameters to radar backscattering coefficients (e.g., Le Toan et al., 1991; Kasischke, et al., 1991). These and other studies showed that in most cases, the longer wavelength (i.e. P band) and cross-polarization (HV) backscattering had higher sensitivity and better correlation to forest biomass.

This research examines this relationship in a northern forest area through both backscatter modeling and SAR data analysis. The field measurements (Ranson and Smith, 1990) were used to estimate stand biomass from forest weight tables. The backscatter model described by Sun et al. (1991) was modified to simulate the backscattering coefficients with respect to stand biomass. The average number of trees per square meter or radar resolution cell, and the average tree height or diameter breast height (dbh) in the forest stand are the driving parameters of the model. The rest of parameters such as the dielectric constants of tree components and soils, roughness of the soil surface, orientation and size distributions of leaves and branches, remain unchanged in the simulations.

2. MODEL DESCRIPTION

2.1. Tree crown scattering

Tree crowns were modeled as ellipsoids consisting of a mixture of leaves and branches (scattering elements) with various sizes and orientations. The scattering can be characterized by the complex scattering matrix **S**. The Stokes matrix **L** derived from the complex scattering matrix **S** was averaged over all orientations and sizes of the scattering elements.

The extinction coefficient matrix $\boldsymbol{\kappa}$ is expressed in terms of the forward scattering amplitude, and was averaged over orientation and size distributions of scatterers in the same way as the Stokes matrix. Having multiplied by the number of scatterers per cubic meter in the tree crown, the Stokes and Extinction matrices then can be used in the radiative transfer equation to calculate the backscattering and attenuation from a tree crown layer.

Table 1 and 2 show some calculated results using input data from a hemlock forest stand (Chauhan et al., 1991). The first element of Stokes matrix ($L(1,1) = S_{vv}S_{vv}^*$) was used to compare the backscattering strength between leaves and branches, and between branches with various sizes. The first element of extinction matrix ($\kappa(1,1) = 2\mathrm{Re}(i\lambda S_{vv}^f)$) was used to compare attenuation from various components within the tree crown.

Table 1 shows that a) attenuation by leaves is higher than branches in all bands; b) backscattering by branches is higher than leaves except at C band; c) backscattering by leaves at P (and L) band is negligible; and d) to account for scattering and attenuation both leaves and branches must be considered in the model.

Table 2 shows that backscattering of branches at C band is mostly contributed by secondary branches, i.e. AA, BB and CC; at L band by A, B, and C branches, and at P band by the large primary branches, i.e. B, C and D branches.

Table 1. Backscattering and attenuation of leaves and branches. 196000 needles and 105.3 branches per m^3 were assumed.

Type	C Band		L Band		P Band	
	L_{11}	κ_{11}	L_{11}	κ_{11}	L_{11}	κ_{11}
Leaves	2.39e-3	0.6384	1.02e-5	0.13348	2.31e-7	0.07630
Branches	1.47e-3	0.1158	1.0e-3	0.06862	5.57e-4	0.003876

Table 2. Branch physical parameters and their relative volume backscattering (vv) strength. Percentages reflect branch size probabilities.

Type	Diameter (cm)	length (cm)	Proba-bility	Relative σ (%) C Band	L Band	P Band
AA	0.2	15	0.86684	13.66	0.26	0.0
BB	0.4	30	0.10312	43.49	1.26	0.09
CC	0.6	40	0.01605	14.88	1.47	0.11
DD	0.8	75	0.00619	8.01	3.88	0.38
A	1.1	90	0.00481	5.15	14.05	1.3
B	2.4	165	0.00154	4.65	35.64	18.90
C	3.0	260	0.00119	7.44	37.42	54.81
D	3.5	350	0.00025	2.72	6.03	24.57

2.2. Model simulation

The following major backscattering components were considered by the model: 1) direct backscattering from tree crowns; 2) direct backscattering from ground surface attenuated by tree canopy; 3) crown-ground double-bounce scattering; 4) trunk-ground double-bounce scattering; and 5) direct backscattering from trunks.

In the model the ground surface was characterized as very rough - with the standard deviation of the surface height (rms height) of 24.3 cm, and correlation length of 1.0 meter. A geometrical optics model was used to calculate both the backscattering and the scattering in the specular direction. Because of the high attenuation from the tree canopy and the roughness of the surface, the components 3 and 4 were very low, even in P band. The dominant component is the direct backscattering from the tree crown, with some contribution from component 2 at HH and VV polarizations, especially in low biomass and long wavelength cases. The HV backscattering was solely from tree crown scattering. A random leaning angle (normal distribution with mean of zero and standard deviation of 5 degrees) was assigned to each tree, but the contribution to HV backscattering from the direct trunk backscattering was not significant.

Figure 1 shows some simulation results. As mentioned earlier, the number of trees per pixel and average height or dbh are inputs to backscatter model. Thus, both the backscattering coefficients and the total biomass of this pixel can be calculated. The lines in these figures show the simulations results. Biomass of several stands were calculated from available ground truth and are plotted in the figures along with backscattering coefficients extracted from JPL AIRSAR data of June 9, 1991.

3. CONCLUSIONS

Generally, the simulations give satisfactory results, except that the backscattering from L band is about 2 dB higher than the JPL SAR data. The possible coupling between branch sizes and L band wavelength may be the cause of this problem. The eight distinct categories of branches are far from representing reality.

Also shown in the figure are the ratios of P/C and L/C. In another study (Ranson and Sun, 1992), it was found that the ratio of HV backscattering from a longer wavelength (P or L) to that from a shorter wavelength (C) was a better combination for mapping forest biomass. This ratio enhanced the correlation of the image signature to the standing biomass and compensated for a major part of the variations in backscattering attributed to radar incidence angle.

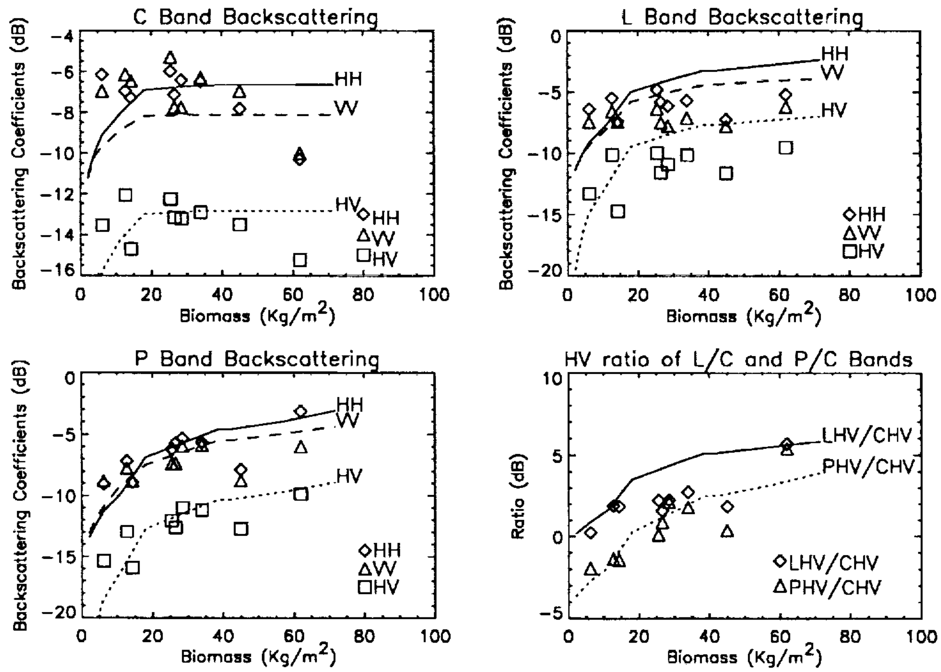

Figure 1. The relationships between backscattering and forest biomass: lines indicate modeling results, and symbols indicate JPL AIRSAR data.

4. REFERENCES

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