Forest Vertical Structure from Multibaseline Interferometric Radar for Studying Growth and Productivity

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ABSTRACT

This paper describes the first quantitative attempt to estimate the vertical profile characteristics of forests from multibaseline interferometric radar (INSAR) data. In order to calculate the accuracy with which vertical characteristics can be estimated with INSAR, a simple, two-layer (sucanopy and canopy) forest is assumed to be observed by 4 baselines, most of which can be realized by current airborne systems. Calculations suggest that the height of the subcanopy layer, the total height of the forest, and the altitude of the underlying surface can be estimated with accuracies of 2-4 meters, with multiple baselines at C-band (wave length= 0.056 cm). Extinction coefficients of each layer can be estimated with accuracies of 0.1 db/m. The estimation of height and extinction parameters from INSAR data is nonlinear, and accuracies therefore may depend heavily on the actual characteristics of the observed forest. This paper also discusses the application of vertical profile information estimated from INSAR to the identification of old-growth forests and their characteristics of growth and productivity. Because old-growth forests are characterized by layered vertical structures, the subanopy and canopy characteristics discussed in this paper may enable identification and monitoring of old-growth stands, which in turn would facilitate ecosystem management and assessment of primary production on a global scale.

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1. INTRODUCTION

For INSAR data taken over forests, the amplitude and phase of the complex cross-correlation depend on the vertical profiles of scatterer density and scattering amplitude. As shown in the next section, the cross-correlation can be expressed as an integral of functions of time profiles. Changing the INSAR baseline changes this integral. This paper begins to answer the following question: What is the accuracy of physical structure and scattering parameters estimated from a set of multibaseline INSAR measurements? A simple two-layer forest is treated in which the 6 estimated parameters (as shown in the next section) are 1) height-to-base-of-canopy ($\mathbf{h_{tbc}}$), 2) total forest height ($\mathbf{h_v}$), 3) subcanopy extinction coefficient ($\sigma_{\mathbf{sc}}$), 4) *canopy extinction coefficient* ($\sigma_{\mathbf{c}}$), 5) *underlying surface topography* ($\mathbf{z_0}$), and 6) the *canopy to subcanopy ratio of the product of the scatterer density and the squared backscattering amplitude* (R). Expressions for the cross-correlation as a function of baseline and the 6 parameters are given in the next section. A simulation using 4 baselines, which can effectively be realized with current airborne systems, was performed and the derived parameter accuracies are presented in section 3. Section 4 discusses the application of these results to the identification and monitoring of old-growth forests.

2. THE INSAR CROSS-CORRELATION FOR A TWO-LAYER FOREST

In Appendix C, (C7) of [1], an expression is derived for the INSAR cross-correlation resulting from observations of a forest (volume scattering only) with arbitrary profiles of vertical density and scattering amplitude. The complex cross-correlation $< E(\vec{R_1})E^*(\vec{R_2}) >$ is proportional to:

where N is the number of independent looks. These standard deviations, which represent "speckle noise," i.e. the random distribution of scatterers from look to look, with small corrections for the loss of correlation amplitude due to finite range resolution [1], were used to generate Monte Carlo data, which were then fed to a nonlinear least square estimation procedure to extract distributions of the 6 parameters. Thermal noise, a small correction, was not included. The table below snows the mean ± the standard deviation of the profile parameters for 50 and 100 radar looks, with the truth values for the simulation at the top of each column. For a roughly 5-m square look size, 50 and 100 looks correspond approximately to 35-m and 50-m square resolution, respectively.

From the table, it can be seen that, the height-to-base-of-canopy, the total forest height, and the underlying topography were determined with accuracies of about 2-5 m, and the extinction coefficients of tile two layers were determined at the 0.1-0.2 db/m level. The performance in the table will be tested with TOPSAR data in the coming year. Improvements to the performance calculation include accounting for correlations in speckle noise between baselines, accounting for the ground-trunk interaction and including polarimetry, and improving on the Monte Carlo nonlinear estimation procedure used here.

4. IDENTIFYING AND MONITORING OLD-GROWTH FORESTS WITH INSAR-ESTIMATED VERTICAL PROFILES

The definition of "old growth" is based largely on forest structure rather than tree age: old-growth forests are characterized by a multiple-story canopy that is structurally complex [4]. The estimation of the subcanopy and canopy parameters described in this paper may enable identification of forests with these structures. Identification, classification, and characterization of old-growth forests are particularly important in the Pacific Northwest of the United States. Management activities in the past have emphasized clearcut harvesting, causing severe loss in the amount of old-growth habitat as well as extensive fragmentation of these habitats. These changes have led to significant declines in populations of animal species that depend on habitats characteristic of old growth forests. Negative impacts of past management practices on fisheries and other resources are also becoming increasingly clear.

Beyond basic classification, remote sensing offers the only realistic tool for predicting primary production on a global scale [5]. Measurements of the reflectance of visible and near-infrared radiation have produced predictions of primary productivity and transpiration of vegetation. However, algorithms based on reflected radiation significantly underestimate transpiration and primary production of old-growth stands. This is because the "conversion efficiency," or the amount of biomass growth per unit of absorbed solar energy, decreases as forests age. With the remotely sensed vertical structure information proposed here, it may be possible to adjust algorithms to account for age-related decline.

5. REFERENCES

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Looks	h_{tbc} (m) (15)	h_v (m) (25)	σ_{sc} (db/m) (0.1)	σ_c (db/m) (0.3)	z_0 (m) (0)	R (2)
50	16.9± 3.4	25.7±4.4	0.11±0.09	0.294-0.16	-0.8±4.2	3.331.8
100	16.2± 2.3	25.5± 3.2	0.12±0.08	0.32±0.12	-0.63.3.0	2.3±1.1

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