Forest Biomass Based on Leaf Area Densities from Multialtitude AIRSAR Interferometry and AVIRIS Spectroscopy

Robert N. Treuhaft, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA tel: 818-354-6216 email: Robert.Treuhaft@jpl.nasa.gov
Gregory P. Asner, Carnegie Institution, Stanford University, Stanford, CA
tel: 650-325-1521 ext. 245 email: greg@globalecology.stanford.edu
Beverly E. Law, Oregon State University, Corvallis, OR
tel: 541-737-6111 email: bev.law@orst.edu

Abstract: The first remotely sensed leaf area densities (LAD) estimated from multialtitude C-band interferometric AIRSAR and hyperspectral AVIRIS data bear on biomass determination and ecosystem function. The parameter estimation scenario used for analysis illustrates the need for improved AIRSAR calibration. LAD profiles estimated from 1998 and 2000 AIRSAR data over Central Oregon compare with each other and with field measurements within expected errors. Forest structure measurements from interferometry open a new window on biomass sensitivity.

I. Introduction

Forest leaf area density (LAD) is the one-sided leaf area per unit volume as a function of height above the ground. By flying multiple AIRSAR altitudes (8 km, 4 km, and 2 km in 1998 and 8 km, 5.6 km, and 2 km in 2000), relative density profiles were estimated from interferometry for 100 m x 100 m stands in the Metolius River basin in Central Oregon. Leaf area indices (LAI, the one-sided leaf area per unit area) determined from AVIRIS data normalized the AIRSAR relative density, which yielded LAD. Physical models were used to estimate both the relative density profiles from AIRSAR and the LAI from AVIRIS with quantitative parameter estimation. The numerical integrity of both data sets is essential for the accuracy of model-based parameter estimation, and the algorithms developed reveal the need for improved AIRSAR interferometric calibration. The polarimetric horizontal-to-vertical power ratio was also included in the analysis, but only weakly constrained LAD, which resulted primarily from the multialtitude TOPSAR. The data acquisition, analysis of both data types, and LAD results are described in Treuhaft et al., 2002. Model-based analysis of interferometric and polarimetric synthetic aperture radar data for vegetation structure is described in Treuhaft and Siqueira, 2000. Hyperspectral optical modeling is described in Asner and Wessman, 1997. Field estimates of LAD through canopy measurements and modeling are described in Law et al. 2001a&b. LAD profiles derived from AIRSAR and AVIRIS are consistent over time and with field data.

II. Parameter Estimation Scenario

A parameter estimation scenario relates AIRSAR and AVIRIS observations to LAD and other parameters. Denoting the AIRSAR-determined Gaussian center and standard deviation of the relative (unnormalized) LAD as z_0 and σ_G, respectively, and noting that AVIRIS data determine the LAI, the parameter estimation scenario used for LAD estimation was

$$\begin{pmatrix} \text{Interferometric Phase}_1 \\ \text{Interferometric Coherence}_1 \\ . \\ . \\ . \\ \text{Interferometric Phase}_Q \\ \text{Interferometric Coherence}_Q \\ \text{Polarimetric Power Ratio} \\ \text{-------------------------} \\ \text{Hyperspectral channel}_1 \\ . \\ . \\ . \\ \text{Hyperspectral channel}_R \end{pmatrix} = \mathbf{M} \begin{pmatrix} \text{LAD(z)} \\ \text{Other Parameters} \end{pmatrix} = \mathbf{M} \begin{pmatrix} z_0 \\ \sigma_G \\ \text{LAI} \\ \text{Other Parameters} \end{pmatrix} \quad (1)$$

where the “other parameters” are introduced because they are required by the model, and **M** is the physical model relating the radar data to the relative-profile parameters and the hyperspectral data to LAI. The physical explanations of how the data relate to the parameters in (1) are given in Treuhaft et al., 2002.

It was discovered from the AIRSAR data that offsets between the phases of different altitudes had to be estimated, included in the “other parameters”. Because there are overall phase offsets in the nonstandard interferometric phase AIRSAR product, differences between a stand of interest and a clearcut area had to be used. It was found that these differences between altitudes did not agree. For example the ping pong (dual transmit mode) phase of 8-km baseline in the 1998 data did not agree with the single-transmit phase in the 4 km data, as it should have. There are several possible contributing factors to the discrepancy, but a phase screen correction for each altitude would help enormously. If multialtitude data are to be generally useful without a lot of user calibration, phase offsets and slopes should be removed at the processing stage. The errors in vegetation profiles were larger because these extra instrumental parameters had to be estimated. Also, the coherence (normalized interferometric amplitude) loss due to finite range resolution [Treuhaft et al., 1996] was removed by using the clearcut correlation amplitude. This step, too, could be avoided if the chirp characteristics and loss of correlation due to finite range resolution were well understood and removed. The correlation loss due to thermal noise was removed from the interferometric coherences by using the “zero-baseline” correlation amplitudes, i.e. transmit 1, receive 2 correlated with transmit 2, receive 1.

III. LAD Results

Figure 1a shows the LAD of a ponderosa pine stand estimated from the remote sensing data taken in 1998 and from field data [Law et al., 2001]. The dotted line is derived from parameters one standard deviation away from those determined as the best estimate by the radar and hyperspectral data. The stand consists of a mix of mature and large old trees, where the mature trees exist at higher density, and are the first successful cohort following exclusion of fire about 100 years ago. Figure 1b shows LAD for the same stand, estimated from the same AVIRIS data but the radar data were flown along

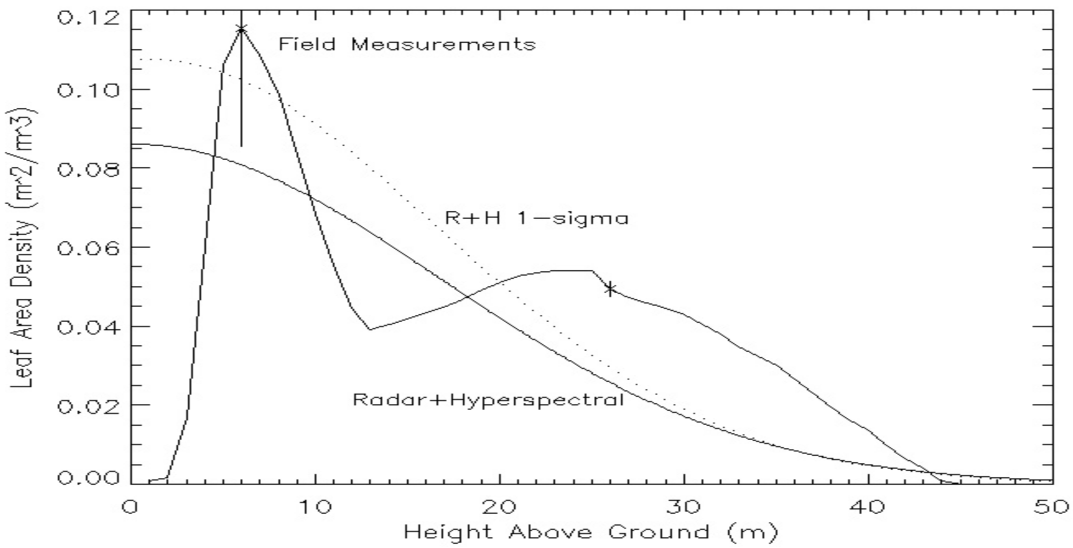

Figure 1a: Leaf area density of stand 1, estimated from radar data taken in April 1998 and hyperspectral data, and field measurements.

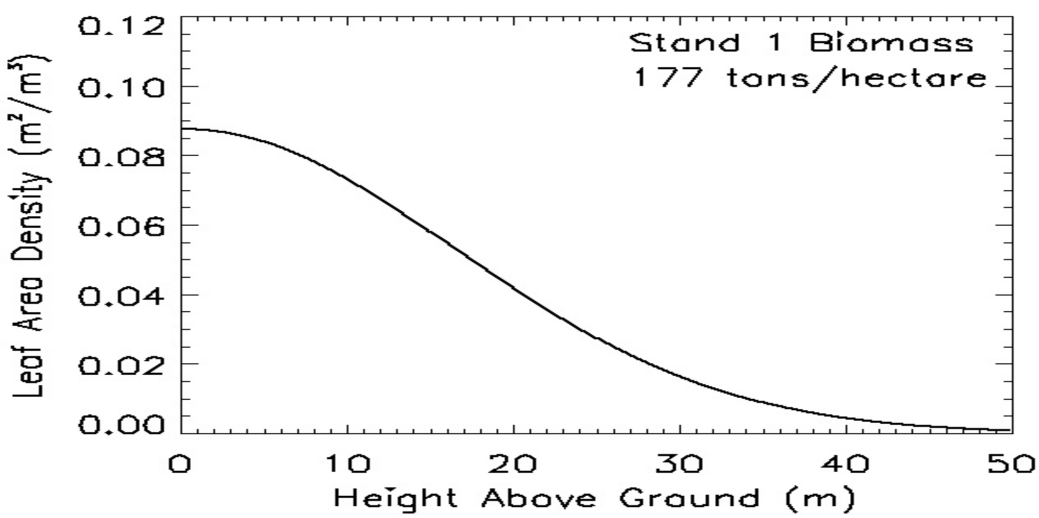

Figure 1b: Stand 1 LAD estimated from different AIRSAR data taken in July 2000, with different flight lines and altitudes.

different lines, along different altitudes in 2000. The agreement is within one standard error. Part of this error is due to forcing LAD to be Gaussian. This was necessary to reduce the number of parameters (1). In the future, eliminating the need instrumental phase-offset parameters will allow for more complex LAD estimates. Figure 2a shows the 1998 LAD for another stand that is composed of fairly uniform (300 year-old) old

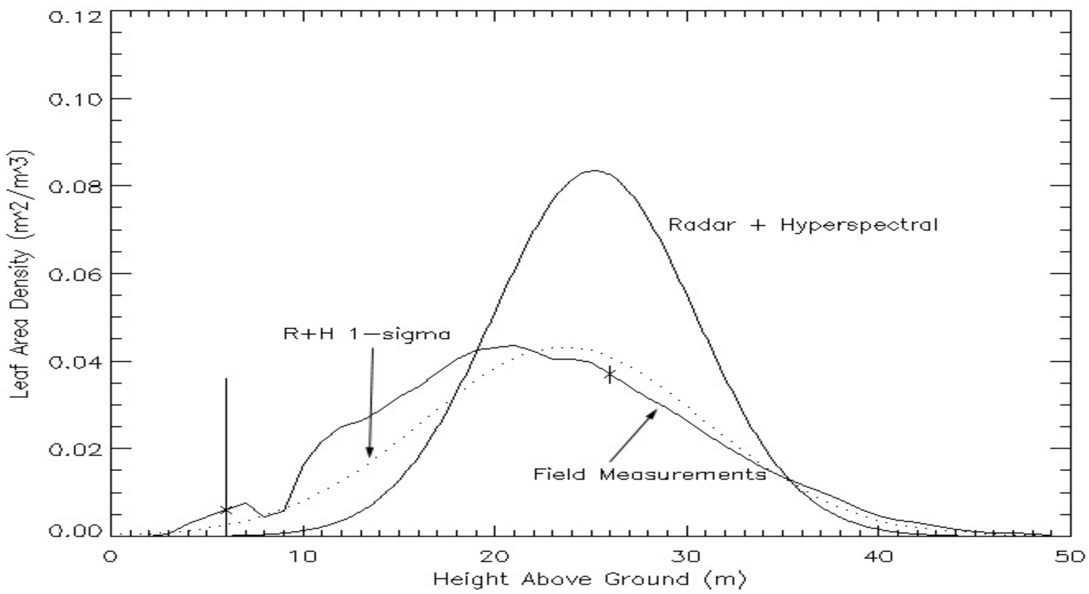

Figure 2a: Leaf area density of a uniform, old-growth stand about 40 m tall, from AVIRIS and 1998 AIRSAR data, along with 1-sigma estimate, and field-measured LAD.

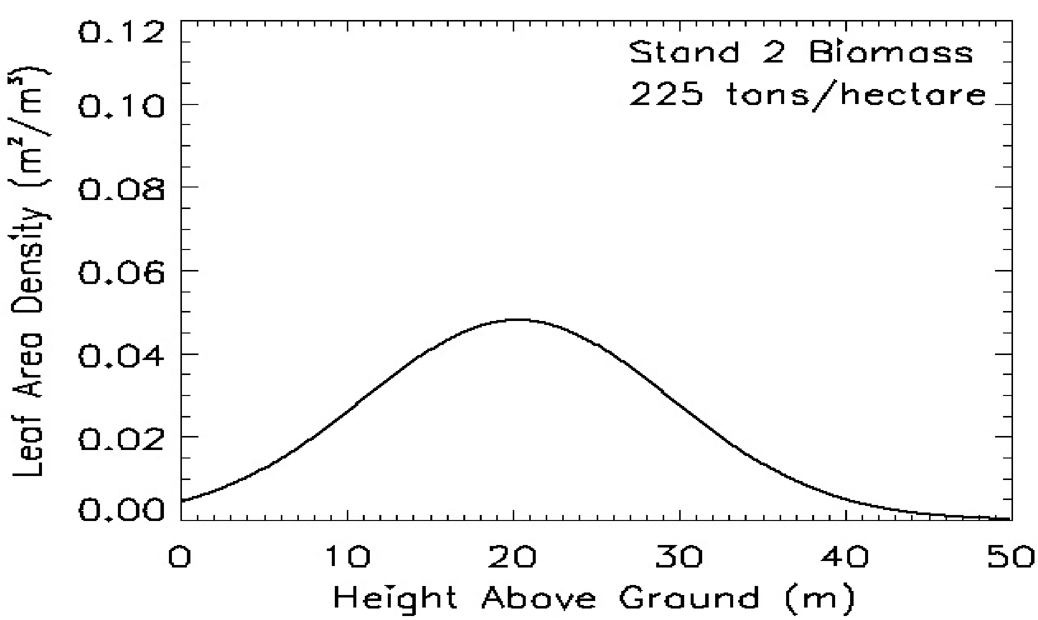

Figure 2b: Leaf area density for the same stand as Figure 2a, but determined from 2000 AIRSAR data.

growth ponderosa pine, along with field measurements, and figure 2b shows the same stand for 2000 data. Note that the LAD for the 2000 data is in good agreement with that from the 1998 data, within one standard error.

IV. Biomass Sensitivity

The biomasses of 20 stands were measured in the field in Central Oregon, and are shown for stands 1 and 2 in Figures 1b and 2b. Total vertical-polarization power at C-band would exhibit saturation characteristics making distinguishing between stands 1 and 2 difficult. Yet the leaf area densities of these two stands show statistically significant differences. LAD profiles have been estimated for 11 stands for which we have biomass measurements. The LADs and biomasses suggest an algorithm under construction for relating structure to biomass. This algorithm will be reported within the next few months.

V. Summary

Leaf area densities estimated from multialtitude, C-band interferometric AIRSAR and AVIRIS data using quantitative parameter estimation based on physical models agree well between observation epochs (1998 and 2000) and with field-measured LAD. Extra parameters characterizing AIRSAR phase inconsistencies between altitudes could be avoided with interferometric phase calibrations at multiple altitudes, improving the accuracy of LAD determination. LADs of stands in the Metolius River basin in Central Oregon, with biomasses well into the C-band "saturation" regime exhibit statistically significant differences in LAD as determined from interferometric AIRSAR and AVIRIS. Interferometric radar combined with hyperspectral optical and perhaps other data, such as lidar, potentially open new windows of sensitivity for the remote sensing of biomass. An algorithm to relate the remotely-sensed LADs to biomass is under development.

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