FUSION OF AIRSAR AND MEIS DATA FOR ESTIMATING FOREST PARAMETERS

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Abstract - During the SEIDAM Project [1], remotely sensed data from a variety of sensors were acquired over test sites in British Columbia in 1993 and 1994. Included in these data sets are multi-frequency, multi-polarization AIRSAR data, and optical data from the MEIS sensor. Ground plots were used to provide initial calibration data for forest parameters such as the estimation of timber volume from AIRSAR data. The AIRSAR data were fused with geocoded one-meter MEIS data from the Greater Victoria Watershed District test site in order to identify forest cover types and individual trees automatically. The purpose of this data fusion was to create additional calibration sites for volume estimation. This paper reports on progress on using AIRSAR and MEIS data to estimate forest parameters for largely unmanaged forest stands of Douglas Fir in the Greater Victoria Watershed District (GVWD) test site on Vancouver Island, Canada, an area of high relief.

INTRODUCTION

In an era of global concern about the sources and sinks of greenhouse gases, forests are seen as very important biome in the health of the planet. In North America nations have agreed to reduce their greenhouse gases by 6% below 1990 levels. Forests are an important storage site of carbon, and can be, depending upon the successional stage and available nutrients, a sink for greenhouse gases. National forest inventories usually include more than 20 parameters characterizing the forest, such as distribution of forest types, forest age, and forest volume. Therefore, an important need is to be able to estimate or measure the volume of timber in a forest stand.

Traditionally, estimates of volume are done by ground samples in which measurements are made of individual tree diameter, height, and species for a group of trees within a fixed radius. Allometric equations are then used to compute the timber volume of each tree. These equations were derived from previous experiments in which trees were harvested and their volume directly measured either on that site or on similar sites. In conducting a volume experiment, there is a trade off between getting sufficient ground samples and the precision of the volume estimates. Large-scale, destructive harvesting and measurement will give precise volume estimates and tree structure, but is very expensive. Traditional ground sampling will give more samples, but with poorer estimates of individual tree volumes. If the samples are valid for a homogeneous stand, then these samples can be used to calibrate remote sensing techniques.

Investigators have tried optical techniques to estimate timber volume or biomass, as for example in [2], [3], [4], [5], and [6]. In [7] with Thematic Mapper (TM) imagery and airborne Multi-detector Electro-optical Imaging Scanner (MEIS) 3-meter imagery, a regression equation is derived between a normalized difference for TM 4 and 5, ND (4,5), and timber volume for 7-hectare samples. The regression was found to be valid over the range 150 m^3/ha to 300 m^3/ha. At higher timber volumes, Gemmell and Goodenough [7] predicted that Thematic Mapper data could not give accurate volume estimates because of the high crown closures. An alternative approach to using satellite optical sensors is to use synthetic aperture radars. In references [8], [9], and [10], relationships between timber volume and radar backscatter for P-band (68 cm) HV SAR imagery have been developed. In Bhogal et al [8], the number of data points was limited for a high volume site on Vancouver Island, British Columbia where western coastal Douglas Fir dominates. One way to increase the number of estimates for timber volume is to use very high spatial resolution (1 m) airborne imagery and identify individual trees. This identification in turn allows an estimate to made of the stems per hectare in a site.

In the next section we describe the test site used for this experiment, the SAR and MEIS data, and the analytical results obtained.

GVWD TEST SITE CHARACTERISTICS AND DATA

During the SEIDAM (System of Experts for Intelligent Data Management) field programs of 1993 and 1994, NASA acquired multi-frequency and multi-polarization AIRSAR data over the SEIDAM test sites. Data were acquired over two test sites on Vancouver Island, the Greater Victoria Watershed District (GVWD) and Clayoquot Sound.

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The GVWD test site is the primary SEIDAM test site. Over 90 percent of the trees found in this test site are Douglas Fir. The average elevation of GVWD is about 400 meters above sea level, with slopes as great as 45 degrees for some of the plots. Except for the younger stands, the old growth forest in this test site is largely unmanaged, and most of our experimental plots are from unmanaged areas. The GVWD test site contains some of the oldest stands of Douglas Fir in the southern half of Vancouver Island. Studies in the GVWD test site conducted by the Canadian Forest Service have shown that trees having a diameter at breast height (dbh) of over 30 centimeters will seldom grow more than one millimeter per year in dbh [11]. Annual volume increments per hectare in Douglas Fir under the environmental conditions present at the GVWD range from 10 percent of standing volume at age 24 years, to about 5 percent by age 40, declining to zero after maturity is reached. Therefore, the change in biomass at each of the plots was assumed to be negligible over the two years of AIRSAR data acquisition.

AIRSAR AND MEIS DATA PROCESSING

The NASA AIRSAR is a multi-frequency, multi-polarization synthetic aperture radar system. The radar flies on a DC-8 platform and operates in the C-band (5.7 cm wavelength), L-band (25 cm wavelength) and P-band (68 cm wavelength). NASA/JPL supply the data as calibrated compressed Stokes matrix files which can be used to produce data at user-defined polarizations.

The NASA/JPL AIRSAR system acquired data over the SEIDAM test sites on August 14, 1993 and July 27, 1994, at 1900 GMT. In this paper we concentrate on the 1994 data only, as environmental conditions during the 1994 AIRSAR flights were dry. In order to assist with the calibration of AIRSAR data, trihedral corner reflectors were deployed in the GVWD test site in both 1993 and 1994. POLCAL [12] was used to check the radiometric fidelity of the AIRSAR data. Target analysis of the corner reflector signal returns using POLCAL indicated that the AIRSAR HH/VV ratios and HH and VV phase differences were within 5 percent of expected values.

The airborne Multi-detector Electro-optical Imaging Scanner (MEIS) was flown on a Falcon Fan-jet. MEIS is capable of acquiring high (10-100 cm/pixel) spatial resolution multispectral images in eight spectral bands, two of which are typically fore and aft stereo pairs. The simultaneous acquisition of precise navigational information permits the geometric correction of the images using sophisticated post-flight ground processing. In 1993, 1-meter MEIS imagery was acquired over the GVWD SEIDAM test site. This high resolution optical data was geocoded by GeoRef using 20-meter topographic data (TRIM) supplied by a SEIDAM partner, Geographic Data BC of the Province of British Columbia. The geocoded imagery was used to select test plots reflecting a wide range of stand density differences. Stem density computations were also carried out using a technique (TREETOPS) originally developed to detect mature trees and identify their species in high resolution images of 1-3 m/pixel [13]. The technique consists of detecting (with or without prior smoothing), local maxima in an appropriate spectral band (typically the near-infrared). In dense coniferous stands, where individual tree crowns appear separated by areas of shade, the algorithm generally isolates a single pixel per tree, usually corresponding to its well illuminated tree top. The selection of test plots using MEIS data, and the identification of tree stems in the same using the TREETOPS algorithm enabled the computation of biotonnage per hectare using diameter at breast height (dbh) values from the GIS data, as well as allometric equations for Douglas Fir stands as per [11].

Preprocessing of the AIRSAR data consisted of a number of steps. First, digital elevation models (DEM) were created from the 1:20,000 scale topographic data for the GVWD which exists as ungeneralized digital elevation points. The DEM were registered to slant-range AIRSAR data and topographic calibration was carried out using POLCAL. The resulting slant range AIRSAR images were then converted to ground range. Using the test plots extracted previously from the MEIS data, the same locations were identified on the AIRSAR images, and 40 meter by 40 meter areas were averaged to obtain the backscatter representative of each test plot.

RESULTS

The AIRSAR response was extracted from ninety-one plots at all aspects. All plots fell within 35 to 55 degrees incidence angle. Figures 1 through 3 show the behavior of the normalized backscatter coefficient against the Log of biomass per hectare computed from the tree stem density determined from MEIS data for plots having an aspect angle of less than 90 degrees relative to the radar boresight. The plots are shown for P-band HH, VV and HV data respectively. In all three cases, the correlation is poor, yielding a R^2 value of less than 0.5. This is contrary to the results reported by references [9] and [10]. Numerous authors have indicated the effect on backscatter of slope and aspect. We have observed a poor correlation in the relationship between backscatter and biotonnage per hectare for all 91 plots (not shown here).

The equations for a second-order polynomial curve fit to the above data are as follows:

Sigma0-HH = $-18.6 + 10.1\,X - 1.42\,X^2$, $R^2 = 0.355$

Sigma0-VV = $29.4 + 17.8\,X - 3.3\,X^2$, $R^2 = 0.245$

Sigma0-HV = -26.3 + 10.9 X -1.53 X^2, R^2 = 0.469
where X is Log of biotons per hectare.

Although the correlations are small, we make the following observations. The HH and HV polarization curves (Figure 1 and 3) have a higher R^2 value than the VV curve (Figure 2). This is due to HH and HV being less sensitive to ground layer conditions compared with VV. Despite the poor correlation, we have observed that the R^2 value increases by a factor of 2 when the signal has been restricted to aspect angles no greater than 90 degrees relative to the radar look angle. The R-squared values for the data set restricted to aspect angles within 90° of radar look direction and all aspect angles are given in Table 1.

Table 1 : Coefficient of determination for both restricted and unrestricted (91 points) data sets.

Polarization	Aspect ± 90°	All aspects
HH	0.355	0.229
VV	0.245	0.103
HV	0.469	0.197

We believe that the application of radar backscatter for biomass determination must take into account additional factors. Our test site is characterized by high relief, largely unmanaged forest stands, shallow bedrock, edaphic gaps and rock outcrops underneath the forest canopy. The surficial geology will have an effect on the SAR signal return. We intend to fuse surficial geology maps with our AIRSAR and MEIS data as part of our continuing research in computing forest biomass using SAR in this rugged terrain.

We acknowledge support from Natural Resources Canada, National Science and Engineering Research Council (NSERC), Provincial Government of British Columbia, and NASA.

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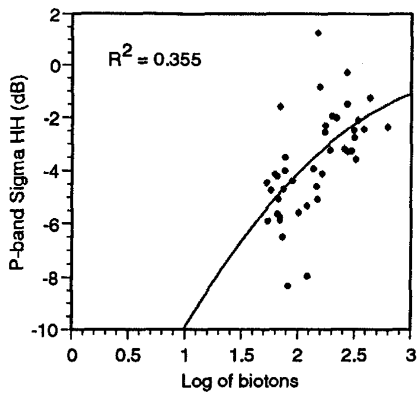

Figure 1: Backscatter (dB) against biomass (tons/hectare) for P-band HH signal.

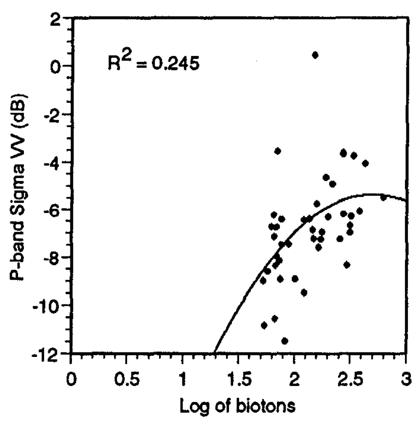

Figure 2: Backscatter (dB) against biomass (tons/hectare) for P-band VV signal.

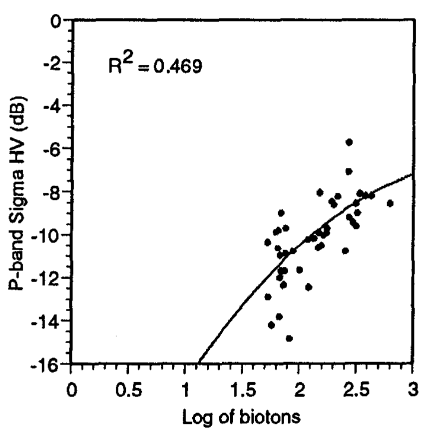

Figure 3: Backscatter (dB) against biomass (tons/hectare) for P-band HV signal