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POLARIZATION SIGNATURES OF FROZEN AND THAWED FORESTS OF VARYING BIOMASS

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Abstract

During the two different overflights (by the JPL radar polarimeter) of the Bonanza Creek Experimental Forest, the environmental conditions changed significantly with temperatures ranging from unseasonably warm (1 to 9°C) to well below freezing (-8 to -15°C) and the moisture content of the snow and trees changed from a liquid to frozen state. Preliminary investigations have focused on the characterization of the radiometric as well as polarimetric signatures of the data. Significant changes (up to 6dB in certain forest stands) were observed in the L-band radar cross-sections. Features extracted from the Stokes matrices of the same stands from the thawed and frozen days also suggest the relative contribution of the different scattering mechanisms to the radar return. Comparison of the diffuse component and variance of the H-V phase (white spruce, for example) indicate a relatively higher contribution from diffuse scatterers on the thawed day than on the frozen day. These results indicate that the contributions of scattering from the crown is responsible for this appreciable increase in backscatter. Some of these preliminary L-band and P-band observations will be presented here.

Keywords: *Polarimetry, H-V phase difference, Fractional Polarization*

1. Introduction

In March 1988, the NASA/JPL Airborne Synthetic Aperture Radar (SAR) acquired a series of SAR datasets over the Bonanza Creek Experimental Forest near Fairbanks, Alaska. The P-, L- and C-band polarimetric dataset consists of data collected on five different days over a period of two weeks. During that period, the environmental conditions changed significantly with temperatures ranging from unseasonably warm (1 to 9°C) to well below freezing (-8 to -15°C) and the moisture content of the snow and trees changed from a liquid to frozen state. This significant change in environmental conditions during the two data acquisition flights (March 13 and 19) over the Bonanza Creek Experimental Forest offered an excellent opportunity for comparison of polarimetric characteristics of forest stands in their frozen and thawed states. The synthesized total power (L-band) images for both days are shown in Fig. 1. Calibration of the L-band dataset was performed at JPL using in-scene corner reflectors (in an adjacent scene - Fairbanks) which were deployed during the March campaign. Dramatic changes in the scattering signature have been observed in a preliminary paper by Cimino et. al [1]. The purpose of this paper is to present a subset of the quantitative polarimetric measurements based on radiometrically and polarimetrically calibrated data. These data were calibrated using procedures developed at JPL. The measurements and observations presented herein have been compared with model results. The calibration and modelling efforts are present in companion papers by Holt and Freeman [2] and Dobson et. al[3], respectively.

2. Data Calibration

C-Band. The calibration of the C-band data is in progress and the results will not be presented here.

L-Band. The calibration procedure for this polarimetric radar dataset was reported in a paper by Holt and Freeman [3]. Briefly, the procedure first removes crosstalk between the radar channels, the relative amplitude balance between the channels and then it adjusts the absolute gain of the radar data. The relative and absolute calibration of this data is accomplished by the exploiting the scattering properties of distributed targets and the known radar cross-sections of corner reflectors in radar data.

P-Band. This data was phase calibrated without invoking the above procedure. A target with known H-V phase difference was selected as the reference and the data compensated based this expected value. In this case, the bog area above the forested area near the Tanana River was selected as the reference. As a check, the phase difference at

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a clear-cut area was measured and the observed value was close the expected value, i.e. zero. After calibration, the data were stored in the compressed Stokes matrix format [4] and all measurements were derived from these 4-look Stokes matrices.

3. Site Selection for Comparison

A total of 15 single species stands were selected for comparison. Included were 8 white spruce stands, 5 balsam popular stands and 2 black spruce stands. Most of the stands are on the flat areas along the Tanana River to avoid the effects of topography on local incidence angle. The window size selected for sampling the polarization measurements were 25x25 pixels. More detailed descriptions of the stand characteristics can be found in [1].

4. L- and P-band Observations - Frozen and Thawed Forest Stands

Fig. 2 shows the differences in L-band backscatter (dB) between the warm day (3/13) and the cold day (3/19). Only the copolarized backscatter coefficients are shown here. On the warm day, the backscatter was higher in all three types of forest stands selected. On March 19 when both the snow and the trees were frozen, the backscatter decreased significantly. Effectively, there was a large decrease in the dielectric constants due to the change from thaw to freeze. Also, note that the decrease in the HH-response ($\sim$ 3dB) is much less than the VV-response ($\sim$ 5dB). For a closer examination of the polarimetric dataset, two measurements were extracted from the Stokes matrices of these forest stands: Fractional Polarization (FP) and H-V phase difference distribution, or Polarimetric Phase Distribution (PPD). Fig. 3 and Fig. 4 show the changes in the FP and the mean and variance of the H-V phase difference distribution extracted from the same stands for the warm and cold days. The fractional polarization, F, is defined as [5, 6]:

$$F = \frac{P_{max} - P_{min}}{P_{max} + P_{min}}$$

where P_{min} and P_{max} are the minimum and maximum powers over both the co-polarization and cross-polarization signatures. When $F = 1$, the average return is completely polarized and variations in antenna polarization (receive and transmit) will cause relatively large variation in the average backscattered power. When $F = 0$, the average return is completely unpolarized, and variation in antenna polarization will not change the average backscatter power. In general, the larger the FP, the greater the amount of polarized power the average return. The FP increased appreciably on the cold day, largest change was observed in the Balsam Poplar stands. As mentioned, this is related to a large variability in the observed scattering properties, suggesting that the scattering from the branches is important on the warm day.

Whereas the fractional polarization gives an indication of the contribution of the unpolarized component (component with randomly varying polarization) in the spatially averaged return, the PPD tells us whether there is deviation of the mean phase difference from zero as well as the magnitude of the variance. A non-zero phase difference in the observed mean of the PPD, as pointed out by Ulaby et. al[7], would be a consequence of: 1) bistatic reflection by the trunks; 2) delay between the H-pol and V-pol waves as they travel through the canopy; and 3) phase difference caused by scattering in the target. The variance of the PPD of a target is more related to the spatial distribution and distribution in orientation of the scatterers with respect to the transmitted polarization. A large variance also indicates a large unpolarized component in the return signal [8]. There is no significant difference in the means of the distributions between the data from the two days. However there are observable decreases in the variance of the PPD for all the stands in the frozen state, again suggesting a higher variability in the scattering properties on the thawed day. Thus, there is an inverse relationship between this parameter and the FP parameter discussed above. An increase in the variance in the PPD generally reflects a decrease in the FP of the average spatial return from the same target. This result again suggest the scattering from the branches is important during the warm day.

The L- and P-band data on March 13 were classified (using a method described by van Zyl [8]) into three scattering classes: single-bounce; double-bounce and diffuse. The results indicate greater penetration with P-band as the relative percentage of double bounce scattering is much greater in P-band than L-band data. Also, the mean of the P-band PPD showed significant deviation from zero again indicating the importance of scattering mechanisms mentioned above. The FP is also higher in the P-band data indicating a lower unpolarized component in the average return. P-band was not available for the March 19 data acquisition flight. Comparison of the classification maps from the 13th and 19th indicate a predominance of diffuse scatterers on the 13th and a predominance of single bounce on the 19th. This again indicates that the scattering from the crown is important on the 13th whereas the single-bounce volume scattering from the forest is important on the 19th.

Summarizing, in L-band the major component in the higher backscatter in the warm day is due to scattering from the crown. The contribution of the expected double-bounce scattering is low on both days due to the high extinction through the trunk layer on the warm day and low dielectric constants and density of trunks and branches on the cold day.

5. Summary

A subset of the measurements obtained from the polarimetric SAR data from the two days were presented in this paper. This dataset illustrated the changes in the observed scattering signatures of different forest stands in their thawed and frozen state. The dramatic differences observed were the changes in backscatter (up to 6dB), the difference in the changes in the HH and VV σ_0, the changes in the fractional polarization and the changes in the variances of the H-V phase difference distributions. The means of the H-V phase distributions remain relatively unchanged for the two days. Extensive ground measurements were also collected during these days, further work is required not only to use these measurements to drive modeling efforts but also to correlate these ground measurments with statistical characteristics of the polarimetric data.

6. Acknowledgments

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7. References

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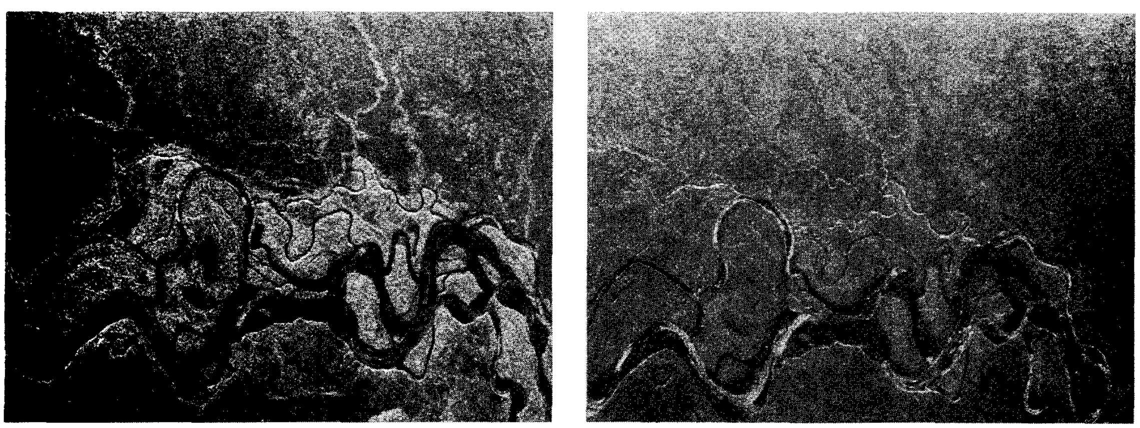

Figure 1. L-band total power images from 3/13 and 3/19.

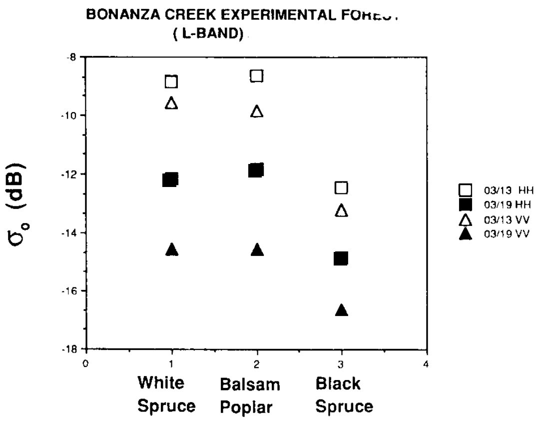

Figure 2. Changes in L-band Backscatter.

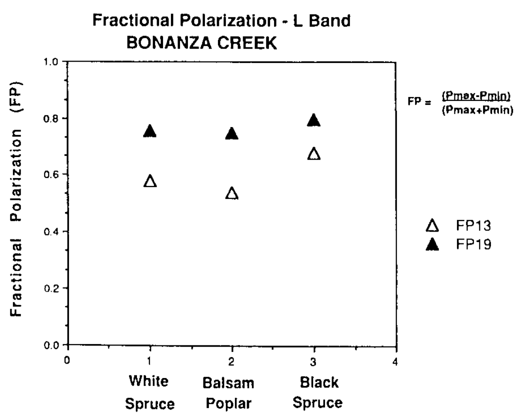

Figure 3. Changes in Fractional Polarization (L-band).

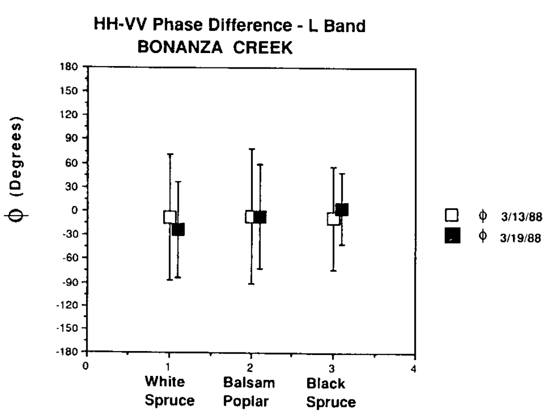

Figure 4. Changes in H-V Phase Difference Distribution - Mean and Variance (L-band).

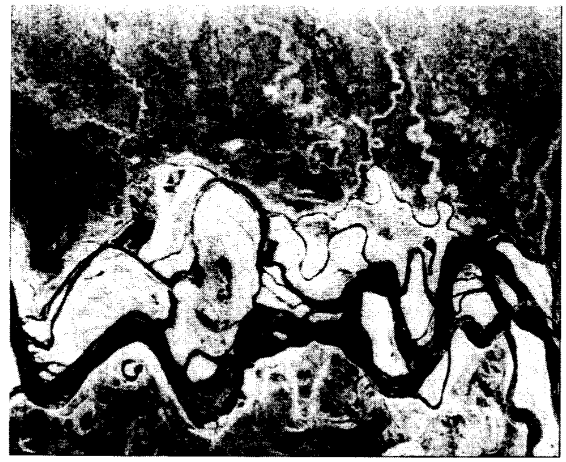

Figure 5. P-band total power images from 3/13.

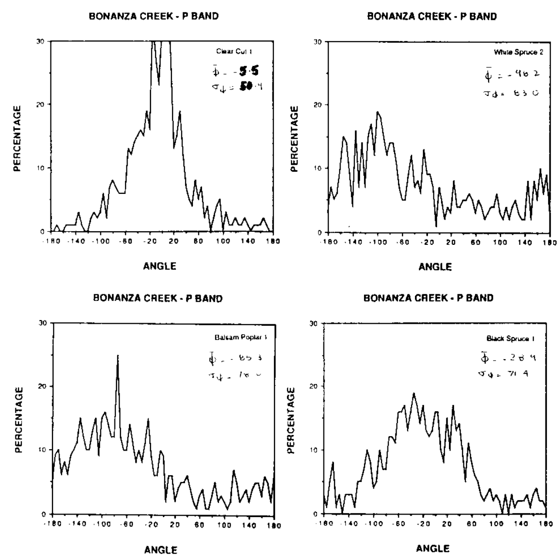

Figure 6. H-V Phase distribution plots for selected stands from 3/13