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A SNOW WETNESS RETRIEVAL ALGORITHM FOR SAR

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The objectives of this study are (1) to evaluate the backscattering signals response to snow wetness and (2) to develop an algorithm for snow wetness measurement using C-band polarimetric SAR. In hydrological investigations, modeling and forecasting of snowmelt runoff requires information about snowpack properties and their spatial variability. In particular, timely measurement of snow parameters is needed for operational hydrology. The liquid water content of snowpack is one of the important parameters. Active microwave sensors are highly sensitive to liquid water in the snowpack because of the large dielectric contrast between ice and water in the microwave spectrum. They are not affected by weather and have a spatial resolution compatible with the topographic variation in alpine regions. However, a quantitative algorithm for retrieval snow wetness has not been developed.

The data, from a polarimetric SAR overflight by the NASA/JPL DC-8 over the glaciers in the Öztal Alps, Austria, were analyzed. In order to utilize the polarimetric SAR data for quantitatively measuring snow wetness purpose, we must consider the accuracy of the radar measurements. For radiometric calibration, and as geometric reference points, trihedral conner reflectors with leg lengths of 0.65, 1.25 and 1.8 meters were deployed on the glaciers. Using topographic information, SAR data can be calibrated (van Zyl and Shi, 1992) so that it contains the more accurate information of the polarization signatures response to snow physical parameters. With the generated incidence angle and radar antenna angle map, the topographic effect on SAR image data is minimized so that a direct comparison in the model simulations and inversion snow wetness become possible.

Backscattering measurements by SAR from wet snow covered terrain are affected by two sets of parameters (Shi and Dozier, 1992a): (1) sensor parameters which include the frequency, polarization, and viewing geometry, and (2) snowpack parameters which include snow density, liquid water content, particle sizes and shapes of ice and water, type of the correlation function and its parameters of surface roughness.

In addition to snowpack physical parameters, the surface roughness and incidence angle have a great impact on the relationship between the backscattering coefficients and snow wetness. A negative correlation between the backscattering coefficients and snow wetness was found by the truck-mounted Microwave Active Spectrometer at frequency 8.6 GHz for incidence angles greater than 5° (Stiles and Ulaby, 1980). However, positive correlation was found in this study when comparing AIRSAR measurements of low and high snow wetness samples. The observed backscattering coefficients for VV and HH polarizations at identical incidence angles were about 5 dB higher from high liquid water content snow samples than from low liquid water content snow samples. A 3 dB difference was found in HV polarization.

Both measurements and model predictions show that the scattering mechanisms of wet snow are characterized as (1) for low liquid water content snow, surface scattering is dominant at small incidence angles and volume scattering dominates at large incidence angles. (2) for high liquid water content snow with a relatively rough surface, surface scattering dominates at all incidence angles.

The actual relationship between the co-polarization signals and snow wetness is controlled by the scattering mechanisms. When the surface is smooth, volume scattering is the dominant scattering source. As snow wetness increases, both the volume scattering albedo and the transmission coefficients greatly decrease. This results in a negative correlation between the backscattering signals and snow wetness. When the surface is not smooth, increasing snow wetness results in greatly increased surface scattering interaction and surface scattering becomes the dominant scattering process. Therefore, a positive correlation between the backscattering signals and snow wetness will be observed.

To develop an algorithm of measuring snow wetness, we need to minimize or combine these factors since the polarimetric SAR only provides a limited number of independent observations. The task is to select appropriate measurements for relating snow wetness to the backscattering measurements.

Based on the identified scattering mechanics of wet snow-covered terrain from the model predictions and measurements of the polarimetric properties (Shi and Dozier, 1992a), we construct the inversion model with two components:

$$\sigma_t^{pp} = \sigma_s^{pp} + \sigma_v^{pp} \tag{1}$$

where pp indicates polarization. σ_t is the total backscattering coefficient. σ_s is the surface backscattering from the air-snow interface and σ_v is the volume backscattering from the snowpack.

Since the relations of the ratios derived by the first-order surface and volume scattering model in co-polarization signals, two ratios of the combined VV and HH polarization signals can be represented as

$$\frac{\sigma_t^{hh}}{\sigma_t^{vv} + \sigma_t^{hh}} = \frac{1}{D_T(\theta_i, \varepsilon_r)(1 - C_{hh}) + C_{hh} D_R(\theta_i, \varepsilon_r) + 1} \tag{2}$$

and

$$\frac{\sigma_t^{vv}}{\sigma_t^{vv} + \sigma_t^{hh}} = \frac{D_T(\theta_i, \varepsilon_r)(1 - C_{hh}) + C_{hh} D_R(\theta_i, \varepsilon_r)}{D_T(\theta_i, \varepsilon_r)(1 - C_{hh}) + C_{hh} D_R(\theta_i, \varepsilon_r) + 1} \tag{3}$$

where D_R and D_T are the surface and volume backscattering ratios of VV and HH polarizations (Shi and Dozier, 1992b), which are only a function of incidence angle and the permittivity of wet snow. The C_{hh} is the surface backscattering contribution in the HH polarization of the total backscattering signal. From the above two measurements, the two unknowns, ε_r and C_{hh}, can be solved. The algorithm derived above does not require any information about the surface roughness and the volume scattering albedo. It only involves the calculation of snowpack permittivity.

To test the algorithm for measuring snow wetness over a large area, a snow map was first obtained by performing the supervised Bayes classification (Shi et al., 1991) and non-snow-covered area was masked. Secondly, the backscattering coefficients of VV and HH polarizations for a given pixel were determined by the median value within a 5 × 5 window to reduce the effect of image speckle. The algorithm was applied after the measurements of $\sigma^{hh}/(\sigma^{vv} + \sigma^{hh})$ and $\sigma^{vv}/(\sigma^{vv} + \sigma^{hh})$ were tested by the physical conditions (Shi and Dozier, 1992b).

Figure shows an image of the inversion-derived snow wetness. The image brightness is proportional to the snow wetness and ranges from 1 to 8 percent by volume. The black region is non-snow-covered area. At the time of the radar survey the snow cover was wet at all elevation zones. The liquid water content of the top snow layer was in the order of 5 to 6 percent by volume at the elevation of 3,000 meters, decreasing to 2 or 3 percent at the highest elevations. The snow densities and depths ranged from 492 to 580 $kg\,m^{-3}$ and from 45 to 114 cm respectively. Using co-registered DEM data, we compared the inversion-derived snow wetness within the elevation zones. The result shows that the algorithm performs well and that the absolute error, generally, is less than 2 percent.

This study shows recent results of our efforts to develop and verify an algorithm for snow wetness retrieval from a polarimetric SAR. Our algorithm is based on the first-order scattering model with consideration of both surface and volume scattering. It operates at C-band and requires only rough information about the ice volume fraction in snowpack. By evaluating the relationship between the backscattering coefficients of both surface and volume scattering for the co-polarization signals, the estimate of snow wetness can be derived from the ratios of the combined co-polarization signals. The inversion algorithm performs well using AIRSAR data and should prove useful for routine and large-area snow wetness measurements.

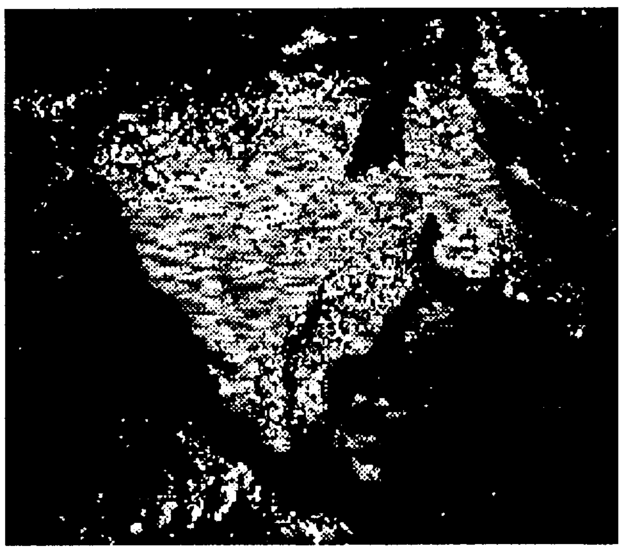

Figure *Inversion-derived snow wetness. The image brightness is proportional to the snow wetness and ranges from 1 to 8 percent by volume. The black region is nonsnow-covered area.*

References

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