SIR-C/X-SAR Mapping Snow in Alpine Region

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ABSTRACT

This paper demonstrates the capability of SIR-C/X-SAR in mapping seasonal snow cover in an alpine region. The polarization properties at each frequency, the ratios from different frequencies and the synthesized polarization measurements are little affected by topography. Through evaluated angular dependence and separabilities of each target within the scenes, we can determine the optimal measurement set for classification performance. In contrast to a single-polarization SAR, SIR-C/X-SAR has capability to map both dry and wet snow covers and suitable for large scale snow mapping.

INTRODUCTION

For climatological and hydrological investigations, the area of seasonal snow cover is an important parameter. Visible and near-infrared sensors have been used extensively to measure the extent of snow cover, but are hampered by cloud cover, which can be pervasive in some regions. In particular, snow cover must be measured on a timely basis to be useful for operational hydrology, and the opportunities for obtaining suitable data from these sensors can be infrequent.

Active microwave sensors are highly sensitive to the most snowpack parameters interested by hydrologists. They are not affected by weather and have a spatial resolution compatible with the topographic variation in alpine regions. The major problem we are facing in using SAR to map snow covered areas in alpine region is the effects of topography. Due to small incidence angle of ERS-1, layover causes significant loss of information in mountain areas. The study [1] has shown that layover region in a single ERS-1 SAR image of the Oetztal Alp is on the average about 30 percent of the area in map projection. A similar results was shown by [2]. In order to reduce the loss of information due to layover, the scenes from both ascending and descending orbits had to be used [1][2]. In addition to the effects of topography, the penetration depth of C-band radar signal can reach tens of meters when snow is dry. This is because ice is almost transparent to radar signal at 5.3 GHz. The major scattering source is from the snow-ground interface. It is difficult to discriminate dry snow cover with bare ground by using single polarization SAR measurements alone.

A single-polarization SAR imager provides high-resolution images but with only one fixed polarization state. With only one intensity measurement per pixel, we have to rely mainly on radiometric properties to distinguish snow covered area from other targets, such as bare ground or vegetation. Wet snow in alpine regions can be mapped with conventional SAR imagery [1][3]. The methods require a compatible digital elevation model (DEM) for correction of the topographic effects, and that the DEM and SAR data need to be co-registered. Accurate estimation of local illumination angle in a region of high relief is often difficult because of the poor quality of most digital elevation data. Moreover, good DEMs are not available for many of the world’s alpine regions. Therefore, we wish to find a general technique for large scale snow mapping that does not require detailed topographic information.

SIR-C/X-SAR, an spaceborne imaging radar with multi-frequency (L-band at 1.25 GHz, C-band at 5.3 GHz, and X-band at 9.6 GHz) and multi-polarization (polarimetric capability at L- and C-band, VV polarization at X-band) capability, provides much more information per pixel than single-polarization SAR data[4][5]. In this study, we demonstrate the capability of SIR-C/X-SAR on mapping snow cover at one of our test site - Mammoth Mt., California.

BASIC CONSIDERATIONS AND POST-PROCESSING IMAGE DATA

Since the radiometric quality of SAR images in an alpine region is dependent on flight and imaging parameters (e.g. flight altitude, radar elevation angle) and the topography of the imaged area, the representation of the target materials is likely to be inaccurate. This variation in radar backscatter that is unrelated to the surface cover type is particularly evident for high relief surfaces where a large variation of slope and aspect creates a great variation of local incidence angles and illuminated areas.

The study [6] indicates that the topographic effects on radiometric properties measured from spaceborne SAR can be
explained by variation in imaged pixel area and in local incidence angle. When topographic information of the study area is available, both spaceborne and airborne SAR image data can be radiometrically calibrated. The remaining problem for target discrimination is the effect of local incidence angle on the received power. If topographic information is not available, we need to consider the effects of variations in both local incidence angle and imaged pixel area for satellite SAR measurements.

The polarization measurements and ratios of measurements from different frequencies are independent of the estimate of illuminated area because they are all derived from ratio of two measurements. In addition, radar backscatter from a pixel consists of the superposition of a number of waves of a variety of polarizations. The selection of the optimum polarization to enhance the contrast between two types of scatterers is also known as a polarization filter. Using this technique, we can generate a ratio image from two synthesized polarization images. One maximizes the ratio of signal power scattered by one type of target to that scattered by another type of target, and the other minimizes the ratio of signals from these two targets. In this way, we can obtain a measurement with a maximum contrast between two targets and with a reduced topographic effect caused by the pixel size variation. Therefore, it is possible to map snow covered areas in alpine regions by using ratios from polarization properties, frequencies, and synthesized measurements without requiring topographic information.

Figure 1 shows the C-band $\sigma^v_\pi$ image on left and the depolarization factor image $\sigma^v_\pi / \sigma^v_\nu$ on right. In $\sigma^v_\nu$ image, we can see a great variation of the backscattering which are not related to the target’s backscattering properties and mainly affected by the topographic feature. This variation in radar backscatter that is unrelated to the surface cover is a problem in high-relief regions. However, the topographic effects have been greatly reduced as we see in the depolarization factor $\sigma^v_\pi / \sigma^v_\nu$ image. Along with some other selected measurements, we can map snow cover without requiring topographic information. The task is to select the measurements that are less sensitive to the variation in incidence angle and best discriminate between snow with other surfaces.

**MAPPING SNOW COVER**

SIR-C/X-SAR imagery acquired from the first mission on its 40th orbit, April 11, 1994 over the Mammoth Mountain area in the Sierra Nevada, California is used to demonstrate the capability of SIR-C/X-SAR on mapping snow covers. The time of the Shuttle pass over Mammoth Mt. was at 3:12 p.m. for data-take 40.4. Snowpack had been melting for several hours. It was a wet snow condition. The radar was looking at $227^\circ$ from north. The image center was located at latitude 37.7° and longitude −119.1°. The processed scene covered about 50.6 km x 11.5 km.

A supervised classification with regression tree technique was used to map snow covers. The representative Stokes matrix for each targets were obtained by averaging the total number of pixels in the training sites. The selection of the training sites is based on a TM imagery with cloud free, which was obtained on April 14, 1994. It provides the spatial distribution of the targets within each scene. In order to determine the best data sets for classification, we first evaluated the angular dependence the measurements of the polarization properties at each frequency, the ratios of different frequencies, and the enhancement images to select the measurements that have less angular dependence. Then, we evaluated the separabilities of the measurements for different target-pairs from training sites to determine the best combinations of measurements for classification. Finally, a statistical analysis was applied to the selected measurements from the training sites to determine the structure of classification tree and cherished at each node.

As an example, we map wet snow cover using data-take 40.4. Three major targets within the processed scene (1) wet snow, (2) vegetation, and (3) bare surface were selected for classification task. In these three targets, vegetation is quit easy to separate with wet snow and bare ground due to greater depolarization signal. Wet snow can be distinguished from bare rock due to the differences between their dielectric and surface roughness properties. Three polarization measurements were selected to classify the targets in the study area. The C-band depolarization factor $\sigma^v_\pi / \sigma^v_\nu$ and the degree of polarization of the vertically incident wave are good discriminators between snow-cover and vegetation and between snow and rough bare surfaces. They provide the best discrimination between all class-pairs. However, they can not separate snow with smooth sand surface. The ratio of the normalized cross-product of HH scattering matrix's element between L-band and C-band is a good discriminator between wet-snow and smooth sand surface.

In order to verify the classification result, we classified TM image using regression tree technique and coregistered TM classification result to SIR-C/X-SAR classification result by using the Space Shuttle ephemeris data, a digital elevation model with 30 m horizontal resolution, and ground control points. Figure 2 shows the SIR-C/X-SAR classification result on left and the TM classification result on right. In both images, white regions indicate snow cover, grey color represents vegetation, and black is for bare surface.

**CONCLUSIONS**

This paper demonstrated the capability of SIR-C/X-SAR on mapping snow in an alpine region. For large scale snow mapping, the major problem is topographic effect since accurate high resolution DEM data are not available for most
of world. Mapping snow in remote alpine regions by a conventional single polarization SAR imagery requires the topographic information in order to remove the topographic effects on the radiometric properties measured from SAR imagery. SIR-C/X-SAR has capability of mapping wet snow covers without requiring any topographic information by appropriate selection of the measurements of the polarization properties, ratios backscattering coefficient at different frequencies, and synthesized images.

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REFERENCES


Figure 1 SIR-C’s C-band \( \sigma^o_v \) image on left and the depolarization factor \( \sigma^o_v / \sigma^o_w \) image on right. The radar was looking from left to right at 227°.

Figure 2. Classified images of the study area. SIR-C/X-SAR result on left and TM result on right.