Mapping snow with repeat pass synthetic aperture radar

JIANCHENG SHI
Institute For Computational Earth System Science (ICCSS), University of California, Santa Barbara, California 93106, USA
e-mail: shi@iccss.ucsb.edu

SCOTT HENSLEY
Radar Science & Engineering Section, NASA/Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109-8099, USA

JEFF DOZIER
School of Environmental Science and Management, University of California, Santa Barbara, California 93106, USA

Abstract In hydrological investigations, modelling and forecasting of snowmelt runoff requires information about snowpack properties and their spatial variability. This study demonstrates a technique to map snow cover with both backscattering and coherence (with and without snow covered images) measurements. We found the coherence measurements provide a much easier way to map snow-covered area. For validation of this method, we compared the classification result with that derived from TM imagery. An accuracy of better than 86% can be achieved if we consider the classification result from TM imagery as ground truth.

Key words backscattering; interferometric coherence; repeat-pass; SAR; snow mapping

INTRODUCTION

Recently, several methods have been developed to map snow cover in alpine regions: (a) using single pass, single frequency and polarization SAR imagery (Rott et al., 1988; Shi & Dozier, 1993); (b) using single pass but polarization properties (Shi et al., 1994); (c) using single frequency and polarization with repeat passes (Rott & Nagler, 1993); and (d) using single pass but multi-frequency and polarization (Shi & Dozier, 1997). Except for the last technique, all the above methods are restricted to mapping wet snow cover since it is difficult to discriminate dry snow cover from bare ground and short vegetation. In a recent study using SIR-C/X-SAR data to map snow cover (Shi & Dozier, 1997), it was found that wet snow cover had very similar backscattering intensity and polarization characteristics to smooth bare surfaces at C-band and X-band. For instance, the backscattering from wet snow cover is very similar to smooth dry soil, alluvial surfaces, and relatively rough water surfaces. At the large drainage basin or regional scale, where many different targets are within a scene, those techniques might not be reliable. For similar reasons, change detection measurements are more unreliable since similar change in backscattering could be caused by different natural environment changes. In order to develop a large-scale snow mapping technique other measurement are required to discriminate between snow and other targets.
Interferometric radar techniques for topographic mapping of surfaces promise the high-resolution of digital elevation models. But they also permit the inference of changes in the surface over the orbit repeat cycle from the correlation properties of the radar echoes. Measurements of interferometer correlation describe processes occurring on the time scales of the orbit repeat time, and size scales on the order of a radar wavelength, such as vegetation growth, glacier motion, permafrost freezing and thawing, and soil moisture induced effects. The coherence measurement between two repeat-passes, therefore, provides a useful measurement in addition to backscattering intensities in each scene and their changes between two passes, and makes it possible to develop an algorithm for mapping both dry and wet snow cover over large areas.

This study evaluates the usage of the interferometric measurements, mainly the coherence measurements with and without snow covered SAR imagery, for mapping snow covered area. We demonstrate the principle of snow mapping using both back-scattering and coherence measurements with repeat pass SIR-C image data from Mammoth, California, USA.

The Mammoth Mountain SIR-C/X-SAR site, at 37°N 119°W on the eastern slope of the Sierra Nevada, is typical of much of the alpine region of the range. The study site includes a range of climatic zones only a few kilometres apart, from the heat and dryness of the high desert at 1000–2000 m elevation, to the cold and snow of the alpine zone above 3000 m. Each climatic zone has its own assemblage or community of plants and soil types. The tree line is at about 3000 m. Below the tree line, the forest type progresses through high mountain to mixed forest. The short vegetation at the study site varies from sagebrush in Long Valley, patchy grass along the Owens River, to the alpine cold of the Sierra Montane Chaparral. The soils of the study site are young and undeveloped, consisting of pumice ash, glacial till, and lava, with little organic material. At low elevations, most bare surfaces are pumice ash, glacial till, and poorly developed soils, with smooth surface roughness.

**CHARACTERISTICS OF COHERENCE MEASUREMENTS**

We evaluated the coherence measurements between two repeat-pass SIR-C image data from its first mission in April (with snow) and second mission in October (without snow), 1994. This measurement indicates that if the ground is completely undisturbed between viewings, the signals will be highly correlated. Otherwise, decorrelation will occur. Figure 1 shows the coherence measurements of L-band VV polarization as the y-axis and VH polarization ratio of L-band to C-band as the x-axis from five targets: snow – s, lake – w, bare surface – b, short vegetation – v, and forest – f. The reason for selecting the VH polarization ratio of L-band to C-band is that this measurement can be obtained without requiring terrain correction and also provides a good separation between the bare surface, short vegetation, and forest. It can be clearly seen that lake and snow cover have very low coherence between two data-takes with and without snow cover. For the lake, the decorrelation between two data-takes is mainly due to the changes of the lake surface roughness characteristics, because of different wind conditions, such as wind speed and direction. For the dry snow case, the dominant scattering at L-band is from the snow–ground interface. In addition to the change of the
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Fig. 1 The coherence measurements of L-band VV polarization, y-axis and VH polarization ratio of L-band to C-band, x-axis from five targets: snow as shown by character s, lake – w, bare surface – b, short vegetation – v, and forest – f.

dielectric contrast from the air–ground to snow–ground interfaces, existing dry snow cover will result in a large decorrelation. This is due to change in the local incidence angle when the radar signal passes through the snow layer which causes a spatial baseline decorrelation. We also expect that the radar echoes will be close to completely decorrelated when measuring correlation between wet snow cover and bare ground passes. This is because the radar signal in a snow-covered pass can only penetrate a few centimetres so that the radar senses two different targets. The coherence measurements from the bare surface are significantly higher than those from lake and snow as shown in Fig. 1. For the bare surface, a change of soil moisture will result in a decorrelation. However, the amount of decorrelation is expected to be smaller because radar senses the same target with the same scattering mechanism (there is only a magnitude change). The short vegetation (mainly sagebrush and grass in our study area) has very similar coherence measurements to the bare surface mainly because the dominant scattering source is from the ground surface at L-band. However, the coherence measurements from forest can have very low values—similar to those from snow and lake—especially from dense forest.

CLASSIFICATION AND VALIDATION

Figure 1 shows that the coherence measurement between a snow covered scene and one without snow provide a very good separation between snow cover and bare surface as well as short vegetation. These two targets are the most difficult to discriminate from snow cover. Thus, the correlation measurement provides significant information with which to map snow covered area. We could use the coherence measurements to discriminate forest, open water, and snow with short vegetation and bare ground. Then use backscattering intensities to separate forest and open water with snow.

We used decision tree classifier (DTC) to establish a pixel-based classifier based on training sets. In order to verify the classification results, we acquired a cloud-free Landsat Thematic Mapper scene for 14 April 1994 (the SIR-C/X-SAR data-take on
13 April 1994). We classified the TM data using same technique. We geocoded the TM classification map and projected (or co-registered) them to the slant range presentation of the SAR images by using the Shuttle ephemeris data and ground control points. In the classification of the TM scene, there are only four target categories: lake, snow, forest, and range land which includes bare ground and short vegetation. Figure 2 shows the SAR classification map (Fig. 2(a)) and the TM classification map (Fig. 2(b)). Comparison of these two results indicates that 86% accuracy can be obtained for snow cover area relative to the TM classification map which is assumed as ground-truth.

**CONCLUSIONS**

This paper demonstrates the utility of SAR for mapping snow in an alpine region by means of repeat pass measurements. For large-scale snow mapping, the major problem is topographic effects since accurate high-resolution DEM data are not available for many parts of world. Mapping snow in remote alpine regions by conventional SAR backscattering measurements requires topographic information in order to remove their effects on the radiometric properties measured in SAR imagery. With the coherence measurements of repeat passes (with and without snow cover), both dry and wet snow can be mapped without requiring any topographic information. The validation, compared with TM classification, indicates that an acceptable accuracy can be achieved.

**REFERENCES**


