Assessing the Accuracy of SIR-C Snow Cover Classification

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ABSTRACT

Timely and accurate maps of snow covered area (SCA) are important to resource managers, planners, and scientists for applications ranging from avalanche hazard assessment to global climate studies. Optical sensors such as Landsat Thematic Mapper (TM) have already demonstrated their effectiveness at mapping SCA. Recently, much work has focused on the use of synthetic aperture radar (SAR) to accomplish this task, due to its high resolution, sun independent, all-weather capability. Though initial results are encouraging, an extensive assessment of the accuracy of these systems under a variety of sensor and target conditions needs to be performed. This study examines the accuracy of a Spaceborne Imaging Radar - C (SIR-C) algorithm for mapping SCA.

We used a well verified Landsat TM fractional SCA image to validate SIR-C SCA images of Mammoth Mountain, CA, USA. We produced images showing the spatial distribution and magnitude of the errors. We also analyzed what surface conditions correlate with large errors in the SCA estimation. The SIR-C algorithm is accurate under some conditions but needs improvement in other areas. It does well in pure snow and snow free areas, but overall, it underestimates snow relative to the TM algorithm. The major source for this underestimation in this study is SIR-C's difficulty detecting snow in moderately vegetated areas.

INTRODUCTION

The measurement of snow covered area (SCA) in seasonally snow-covered alpine regions is very important for investigations of climate and hydrology. Snow's high albedo and low thermal conductivity can have great effects on both local and global climate. With respect to hydrology, snow acts as a water storage reservoir, releasing the water it has accumulated from the winter during the spring melt. Many regions throughout the world rely on this reservoir of water to meet their fresh water resource needs.

Remote sensing offers excellent opportunities for measuring SCA due to its ability to provide timely information over large areas. Optical sensors have demonstrated their utility in the SCA mapping arena (*eg.* Rango and Itten, 1976, Dozier, 1989, Rosenthal and Dozier, 1996). However, optical systems are subject to two major disadvantages. The first of which is that they are dependent on the illumination of the sun which is variable and, for high latitudes may not exist at some times of the year. In addition to this, optical wavelengths are unable to penetrate cloud cover which can be pervasive in some regions.

Radar remote sensing is not subject to these disadvantages. Radar, being an active sensor, provides its own illumination and is therefore able to operate entirely independently of the Sun. Furthermore, because radar operates in the microwave portion of the electromagnetic spectrum, it is able to penetrate clouds and all but the most severe weather events.

These advantages have led some researchers to use radar to map SCA in alpine regions (*eg.* Rott and Davis, 1993, Shi and Dozier, in press). While promising results have been obtained, an extensive assessment of the accuracy of these systems under a variety of sensor and target conditions needs to be performed This study examines the accuracy of a Spaceborne Imaging Radar - C (SIR-C) algorithm for mapping SCA.

BACKGROUND

Imaging radar pulses radiation at a specified frequency in the microwave portion of the electromagnetic spectrum to the imaged area and measures the characteristics of its return. Thus, if ground targets are to be discriminated, there must be distinct radar returns, or "backscatter" for the targets requiring discrimination. In this region of the spectrum, ice, a major component of snow, is almost transparent and radar penetration depth can reach tens of meters for dry snow. In this case, the ground becomes the major scattering source and snow is difficult to detect. However, the presence of liquid water in snow has several effects on the bacscatter properties that allow us to detect and map wet snow. With a small amount of liquid water present in the snow pack the scattering source shifts from the snow-ground interface to a mixture of snow volume scattering and surface scattering at the air-snow interface. Additional water will increase the dominance of the surface scattering and the air-snow interface. These phenomena, along with knowledge of the roughness of the snow surface, can distinguish snow from other ground cover types in the microwave region of the spectrum and allow us to map snow using radar (Shi and Dozier, 1996).

DATA AND METHODS

An image of the Mammoth Mountain, California area was acquired from the SIR-C/X-SAR sensor flown aboard the NASA Space Shuttle on April 11, 1994. The image, centered at 37.6 degrees north and 119.0 degrees west, is approximately 11.5 km wide and 50 km long and is oriented NW-SE which coincides with the orientation of the Sierra Nevada, the local mountain range. The orbit from which the image was acquired was descending and the radar was right looking, thus the sensor was imaging from the northeast.

The image was radiometrically calibrated, corrected for terrain using a 30m digital elevation model, and processed according to the algorithm of Shi and Dozier (1996). For this project, the output of this algorithm which is based on a decision tree classification is an image that is partitioned into four classes: water, bare ground/short vegetation, forest, and snow (figure 1).

For validation, a Landsat Thematic Mapper (TM) image acquired on April 14, 1994 over the same area was used. We performed two types of snow mapping on this image. For our primary validation image, we used the algorithm of Rosenthal and Dozier (1996) to map sub-pixel snow fraction for the scene (figure 4) [note: to facilitate comparison, the figures are not in order]. This algorithm has demonstrated accuracies on par with those obtainable from air-photo interpretation (Rosenthal and Dozier, 1996). Adding to our confidence in this method is knowledge that its accuracy assessment was performed over Mammoth Mountain, eliminating questions about the geographic portability of the algorithm. As a secondary validation image, we classified the TM scene into the above four categories using a decision tree classifier (figure 2). This classification remains unverified so any conclusions drawn from information derived through it must be tempered. To facilitate intercomparison, we coregistered and warped the TM products to the SIR-C ground range geometry.

The primary validation required a method of comparing the output of the snow fraction image (quantitative or *ratio* data) to the output of the SIR-C algorithm (qualitative or *nominal* data). These are two fundamentally different data types. In order to compare we needed to transform one of the data types to the other. In other words, we could either synthesize a fractional snow cover image from the SIR-C classification, or we could generate a nominal image of snow-covered/snow-free from the TM snow covered area map. The transformation from fractional SCA to a binary SCA image would require setting some snow fraction threshold above which pixels are classified as snow and below which pixels are classified as snow-free. Since this process would involve a significant loss of information and the choice of a threshold seemed arbitrary, we pursued the synthesized fractional SCA SIR-C image option.

One method for synthesizing a fractional SCA image from a nominal snow/snow-free image is to select a window size in which to calculate the percentage of pixels that are classified as snow. This window size is bounded, at one extreme, by a window size of one in which all output pixels are either 100% or 0% snow and, at the other extreme, by a window size equal to the entire image in which the output is simply the fraction of the image that is classified as snow cover. Thus we have a situation in which we must weigh the value placed on cell resolution against the value of fractional precision. We selected a window size of 10 by 10 pixels. This choice seemed reasonable since it maintained a moderate resolution with a large number of samples in the scene and the conversion to percent is conceptually simple. Since the square of 10 is 100, the percent is simply the number of pixels in the window that were classified as snow (figure 3)..

With two coregistered images of fractional SCA, all that remained was simply to create a difference image in which every pixel in the image is the SIR-C fraction minus the TM fraction. Positive numbers on this image, therefore, represent areas where SIR-C finds more snow than TM while negative numbers on this image are areas where TM finds more snow than SIR-C (figure 5).

SIR-C/X-SAR Derived Classification

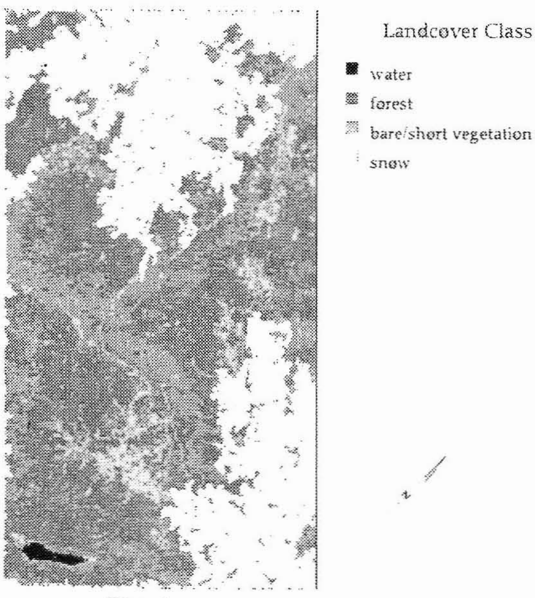

Fig. 1

Landsat Thematic Mapper Derived Classification

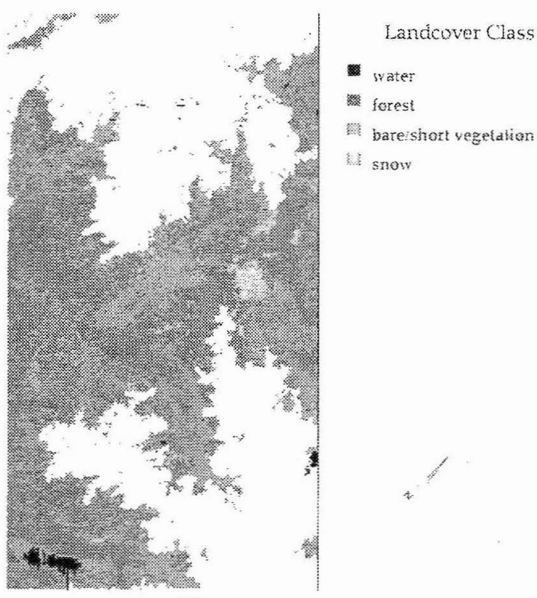

Fig. 2

SIR-C Fractional Snow Covered Area

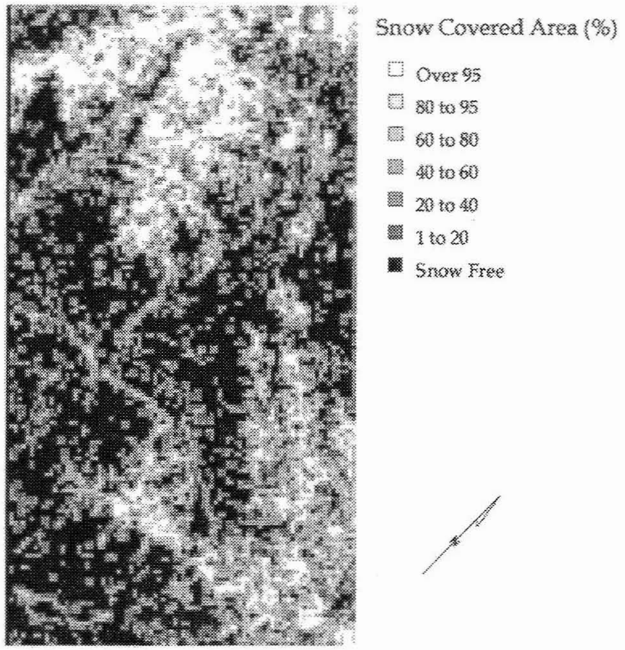

Fig.3

TM Fractional Snow Covered Area

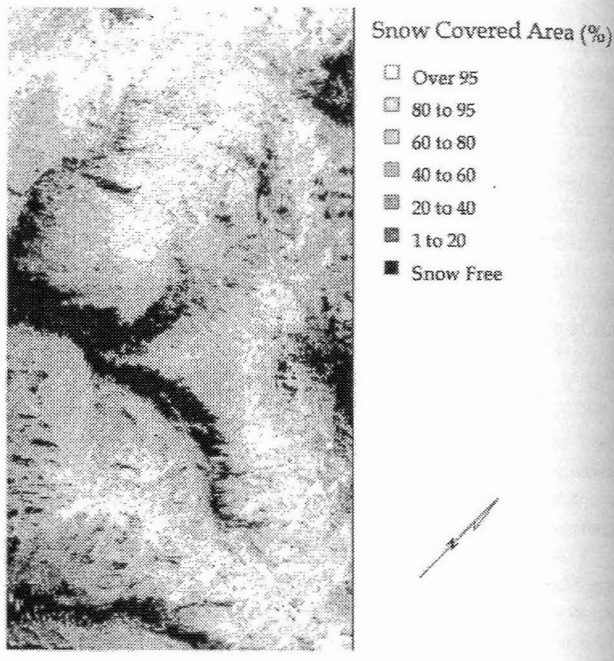

Fig.4

In addition to this image, we deemed it useful to perform a conventional error matrix comparison using the TM classified data (our secondary validation image). This is the conventional method by which accuracy assessment is performed (Congalton, 1991). For snow cover accuracy assessment we aggregated categories so that we were left with a binary image of snow and snow-free cases. We calculated three types of accuracies. The overall accuracy is the likelihood of a pixel being classified into the same category by both classifiers. Producer's accuracy is the likelihood of a pixel classified as snow in the reference image (TM) being classified as snow by the experimental (SIR-C) image. It is sensitive to errors of omission. Another type of accuracy that is reported, user's accuracy, expresses the likelihood that a pixel classified by the experimental sensor as snow was classified as snow by the reference sensor. User's accuracy is sensitive to errors of commission (Congalton, 1991).

RESULTS

The algorithm's accuracy at mapping snow is highly variable across the scene. On the positive side, it is quite successful in the extreme cases. That is, for areas in which TM reports no snow at all, SIR-C is very likely to report no snow (only 13% of TM snow free pixels had snow on the SIR-C image) and areas that are found to be continuous snow fields are also correctly mapped as snow by SIR-C for the most part (63% of TM pixels with 98% or greater snow fraction were classified as snow by SIR-C). This phenomenon is illustrated in figure 6, which depicts the absolute error in percent snow cover estimation over a range of TM snow fractions.

On the other hand, the overall predicted snow fraction by SIR-C is much less than that predicted by the TM algorithm (30% vs. 62%). This underprediction is most prevalent in forested regions. We note that 70% of regions that are underpredicted by SIR-C by 60% or more are classified by SIR-C as forest. Going back to figure 6, the peak errors occur for TM snow fractions of around 70%. The bulk of these pixels is composed of mixtures of forest and snow that the TM mixture algorithm interprets as 70% snow and 30% forest. SIR-C tends to classify these areas as forest. This is the mixed pixel problem inherent in any nominal classification. Regions on the ground that compose a pixel are more often than not made up of several different cover types. A nominal classifier must pick only one of them to represent the entire pixel while a mixture model can select a fraction of each of the land cover types to characterize the pixel. In comparison to woody vegetation, snow's signal in the microwave portion of the spectrum is very weak. Thus, it is likely that pixels that are mixtures of snow and forest will be classified as forest by such a system.

Further obscuring the detection of snow by radar is the side looking nature of radar sensors. While optical systems typically look very near nadir, this SIR-C image has a look angle around 25 degrees. In a forested region, it is clear that higher look angles will result in seeing less of the surface underneath forest canopy, while nadir and near

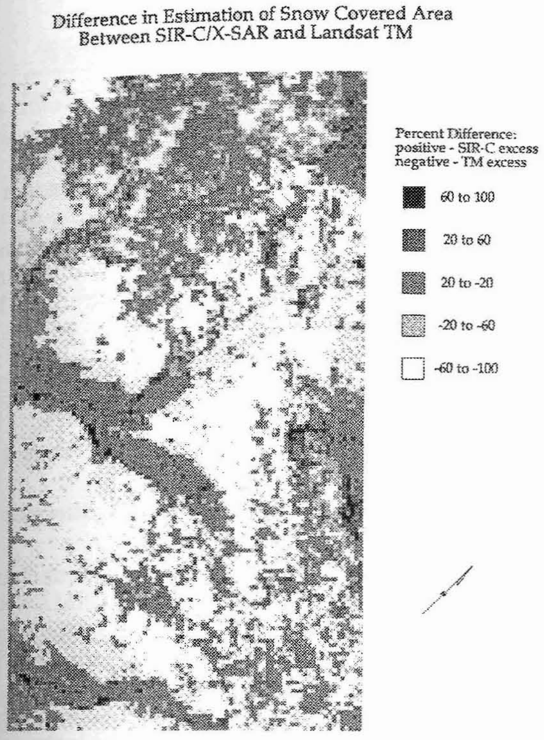

Fig.5

nadir systems will be able to see much more of the underlying surface.

Though limited, there are some areas where SIR-C predicts more snow than TM. Most notable, are the linear overestimation features near the center of the image between the short vegetation / bare surface and the forest. These features may be linked to the transitional vegetation in these areas. This requires further investigation.

Turning our attention to the confusion matrix analysis, the overall accuracy for the binary image is 74%. The producer's accuracy is 57%, implying that for this scene, SIR-C often fails to detect snow where TM finds that it exists.

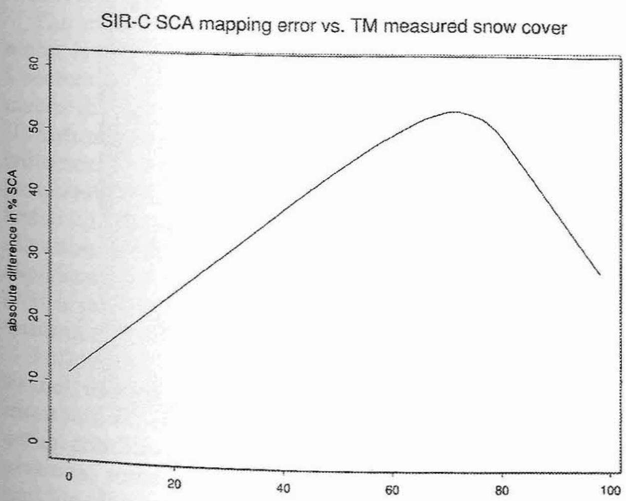

Fig.6

User's accuracy for this scene is 71%. This suggests that what SIR-C classifies as snow is also likely to be snow according to TM. These results are consistent with what the difference image analysis has shown.

CONCLUSION

We have examined the spatial, qualitative, and quantitative properties of the accuracy of a SIR-C snow map. The image is reasonable accurate for the pure snow case and the pure snow-free case, but has difficulties with mixed pixels. There remains much work to be done in this area. In particular, we plan on investigating the linear overestimation features and performing some analytical statistical test on the data, so that misclassification likelihood can be better characterized. Additionally, the algorithm must be tested on a different geographic area to test its portability. We are currently pursuing this goal for a site in the Himalaya and a site in the Bolivian Andes.

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