# DETERMINATION OF SNOW COVERED AREA USING RADARSAT IMAGERY ON TWO SMALL TEST SITES IN SOUTHERN ONTARIO

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## ABSTRACT

This study was performed in order to determine if the areal extent of a wet discontinuous snowcover could be effectively mapped using a RADARSAT image. The sites chosen for the experiment were two agricultural areas located in southern Ontario. On March 27, 1997 oblique aerial photography was acquired and used to create a ground reference map for two sites, showing the location of bare ground and snowcovered ground in selected fields. On March 26, 1997 a RADARSAT C-HH SAR image was acquired, which was classified into bare ground and snowcovered ground and then compared to the ground reference map. The classification accuracies were 62.3% and 67.3% for the sites, however the percent snowcovered area was calculated to be within 5% of the ground reference map estimate after accounting for the melt that occurred in the day between the acquisition of the two images.

## INTRODUCTION

The development of distributed hydrologic models that can account for the spatial variability of basin physiography and meteorological inputs creates opportunities for the use of remotely sensed data. More specifically, there is a need to generate detailed snowcover information as input for these models. Of particular interest are timely estimates of the percent snowcovered area in each model element during the melt season.

Remotely sensed data have been used primarily for properties such as land cover classification which do not, by nature, vary greatly with time. An example is the use of LANDSAT imagery to determine percentages of land cover units within each grid square for a distributed hydrologic model (Kouwen *et al.,* 1995). However, as snowcovered area can change dramatically within a matter of hours, the repeat time of 16 days for LANDSAT makes its use unattractive for operational monitoring of snowcovered area. In fact, in southern Ontario, the snowpack can melt completely within 16 days during the spring melt.

Conventional snow surveys provide detailed information on snowpack properties, but their site-specific nature and infrequent occurrence limit their potential for use in distributed models (Goodison *et al.*, 1987). Passive radar sensors such as the NOAA SSM/I have proven useful in determining the presence of a snowpack, as well as its snow water equivalence (Goodison , 1989 and Seglenieks *et al.*, 1994), however their large spatial resolution of approximately 25 km by 25 km restricts their application to very large basins.

Active microwave sensors, such as ERS-1 and RADARSAT, offer improved spatial and temporal resolution over passive systems. Also, they provide their own radar signal and thus are unaffected by darkness and cloud. ERS-1 imagery has previously been used to monitor snowmelt on mountain tallus slopes (Maxfield, 1995).

Mapping of snowcovered area during the melt season with active radar signals relies on the fact that liquid water has one of the highest dielectric constants of any natural material (Ulaby *et al.*, 1986). The contrast between the melting snow, with a layer of meltwater, and the surrounding bare soil is the distinction that allows mapping of the snow covered area with active radar imagery. Melting snow will, however, be easily confused with wet soil, limiting pixel-by-pixel classification accuracy. However, if comparable misclassification of dry snow occurs, snowcovered area fractions will be satisfactorily estimated.

This paper describes an experiment to determine the applicability of using active radar data collected from the RADARSAT satellite to efficiently and accurately map snowcovered area. This experiment was performed in the same manner as a study by Donald *et al.* (1993) and Seglenieks *et al.* (1995), where radar imagery was collected and compared to concurrent oblique aerial photography. In these studies, the authors found that classification accuracies of snow-covered versus bare fields were in the order of 80% using airborne C-HH SAR data and 72%

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using ERS-1 C-VV satellite imagery. Percent snowcovered area was within 5% of observed in all cases, which is well within the range acceptable for hydrological modelling.

## THE EXPERIMENT

On March 26 and 27, 1997, an experiment was conducted to map the snow-covered area of a wet discontinuous snowpack using RADARSAT. The sites chosen for the experiment were two areas located within the Grand River watershed in southwestern Ontario. The sites are agricultural areas, primarily consisting of fields and woodlots. Site 1 is located between the towns of Fergus and Guelph along Highway 6 and has an area of 15.4 $km^2$. Site 2 is 23.5 $km^2$ in area and is located along Highway 9 just east of the town of Arthur (Figure 1). Site 2 is approximately 20 km north of site 1.

On March 26, 1993, a RADARSAT S1 image, containing both of the study sites, was acquired at 5:00 p.m. as part of the ADRO program of the Canadian Space Agency. The ground resolution of RADARSAT imagery in this orbit is 27m by 26m, the incidence angle varies between 20° and 27°, and the swath width is 100 km.

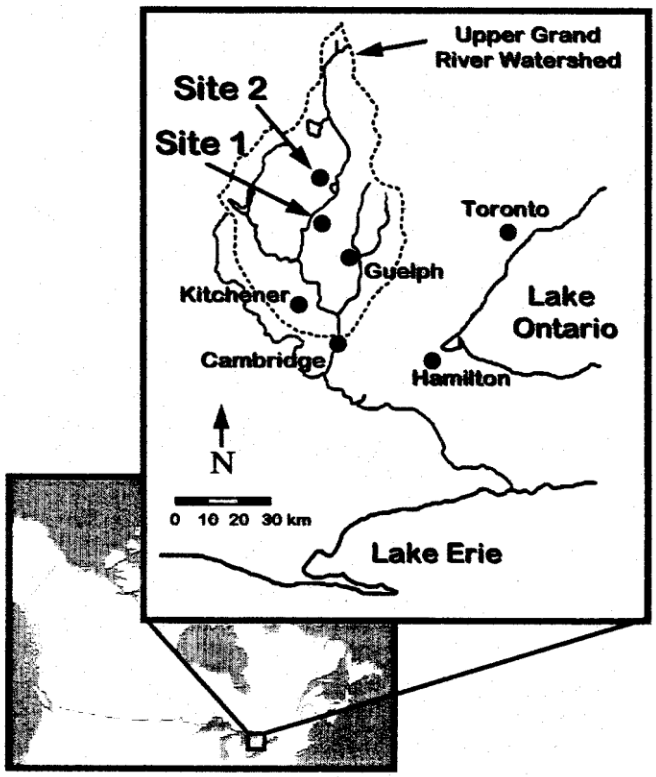
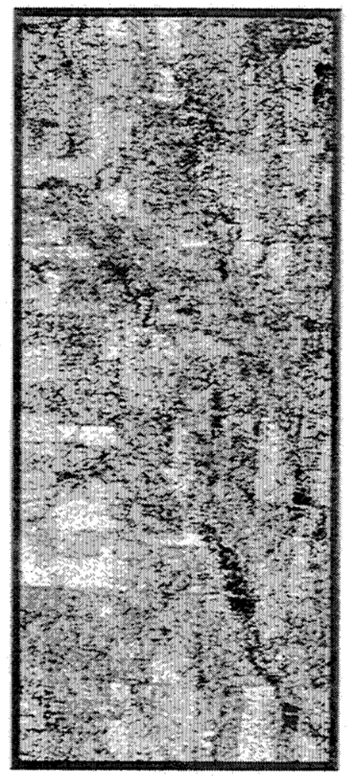



Figure 1: Location of study areas

On March 27, 1997, oblique black and white aerial photography was acquired from a light aircraft between 3 and 4 p.m. from an altitude of approximately 800 m . The aerial photography was used to establish the areal distribution of the snowcover at the time of the experiment. On that day, the average surface air temperature was 11°C in the town of Orangeville, just east of the sites, with mostly sunny skies, although a haze is evident in the background of the photographs. Ground surveys conducted that day indicated that the snowpack contained a wet melt layer at the base of the snowpack at both sites. Snowdepths ranged from 0 to 16 cm in the open field areas of the study sites.

(a) Ground reference map - snowcovered areas are white



(b) Raw RADARSAT C-VV image - snowcovered areas are generally dark gray to black

Figure 2: Ground reference map and raw RADARSAT image for site 1 (2.4 km X 6.4 km)

## IMAGE PROCESSING

Ground truth reference maps for both sites were derived from oblique aerial photography and ground surveys (Figures 2a and 3a). Approximately 18 overlapping oblique photographs were used for each site; each photograph had a ground area of approximately 4 $km^2$ with an overlap between photos of about 50%. The oblique photographs were digitized, ortho-corrected, registered and mosaiced to provide a map of the two classes at the time of the experiment. The sites were classified into two categories: bare ground and snow covered ground.

Windows containing the two study sites were extracted from the original RADARSAT image and registered to local UTM coordinates using third-degree polynomial transformations and nearest neighbour interpolation. A 7 pixel by 7 pixel Lee adaptive filter was used to reduce speckle (PCI, 1994). The image shows low backscatter in snowcovered regions and higher backscatter in the bare fields (Figures 2b and 3b).

## IMAGE CLASSIFICATION

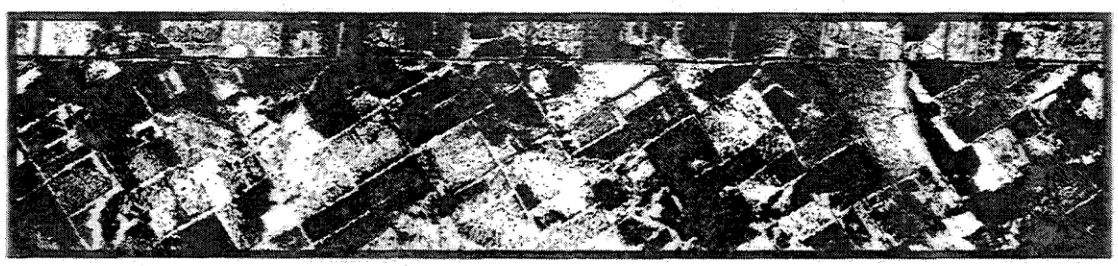
A supervised classification was applied to the SAR image for each of the study sites independently. Training areas were chosen for bare fields and snowcovered fields for each site; the same training areas were used for the radar imagery and mosaiced photography .

To compare the results of the classification between the differently filtered images, the Kappa coefficient of agreement (Rosenfield and Fitzpatrick-Lins, 1986) was calculated for each classification result. The Kappa coefficient of agreement is given by

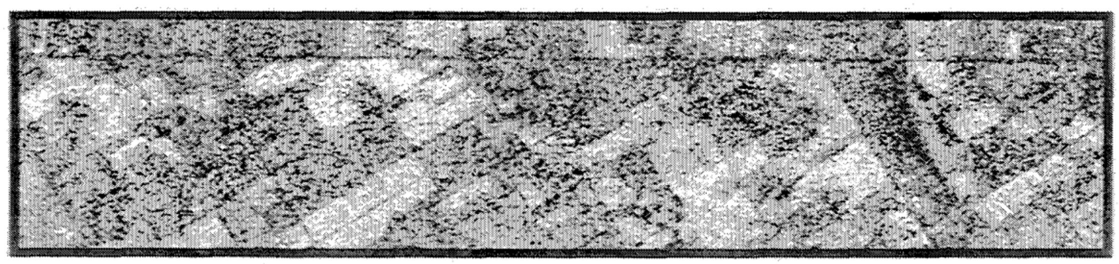
$$K = \frac{P_o - P_c}{1 - P_c}$$

where $P_o$ is the observed classification accuracy and $P_c$ is the probability of chance agreement. This test indicates the degree to which the classification is better than a chance agreement of classes and thus provides a statistical basis for classification comparison. If K is statistically significantly greater than zero, then the classification is significantly better than would be expected due to chance alone.

The resulting training site histograms are shown in Figure 4. These show that there was very good separation in the spectral signatures between the two land cover classes for both sites 1 and 2. The transformed divergence is a measure of the separibility of class signatures on a scale from 0 to 2, where 0 is complete overlap and 2 means complete separation. For site 1 the transformed divergence is 1.70 and for site 2 it is 1.83, indicating good separation between the class signatures.

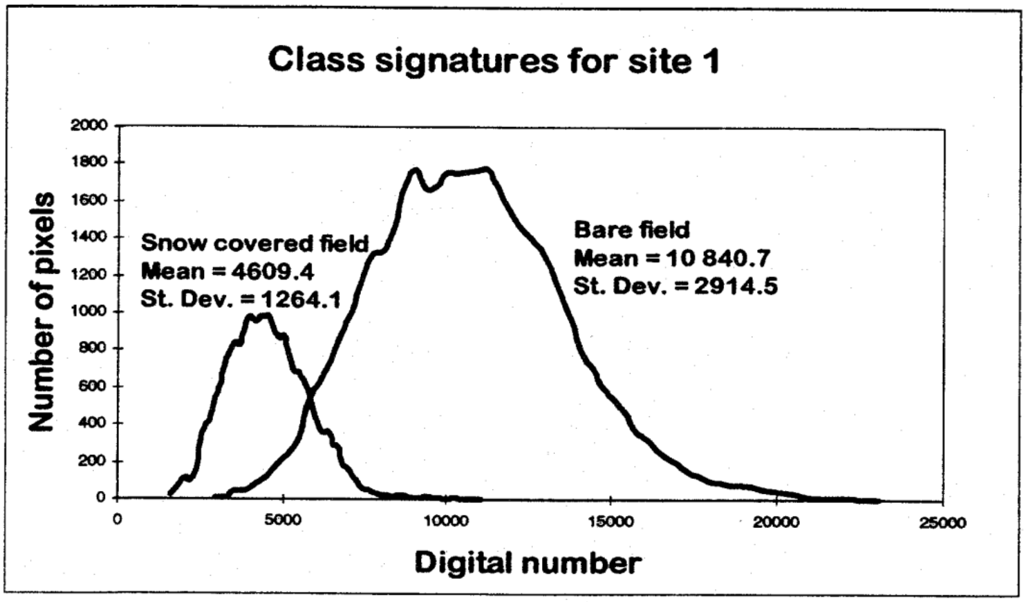


(a) Ground reference map - snowcovered areas are white



(b) Raw RADARSAT C-VV image - snowcovered areas are generally dark gray to black

Figure 3: Ground reference map and raw RADARSAT image for site 2 (9.8 km X 2.4 km)



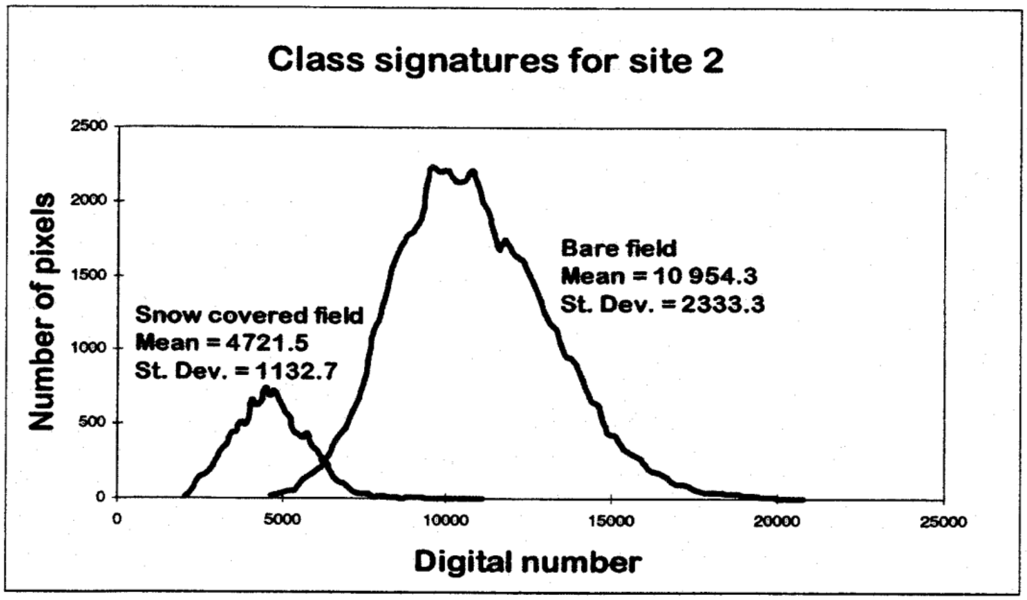




Figure 4: Class signatures for site 1 and site 2

The results of the maximum likelihood classification on bare versus snowcovered fields are shown in Figures 5 and 6 for sites 1 and 2 respectively. The classification results are summarized in the contingency tables of Tables 1 and 2.

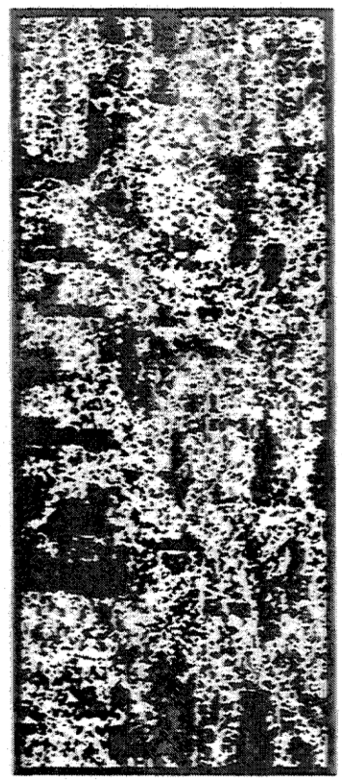


Figure 5: Classified RADARSAT image for site 1 - snowcovered areas are white

Figure 6: Classified RADARSAT C-VV image for site 2 - snowcovered areas are white

The Kappa coefficient was much higher for site 2 than site 1, with values of 0.37 and 0.24, respectively. However, when comparing classification accuracies, site 2 at 67.3% is only slightly higher than the 62.3% at site 1. Visual comparison of the ground reference maps with the classified images confirms that the classification was better and more consistent for site 2. For site 1, the classification was quite poor in the lower portion of the image, particularly in the south eastern corner.

The standard error of the Kappa coefficient is very low for both sites indicating that Kappa is significantly greater than zero and thus the classification is better than would be expected from pure chance alone.

Table 1 : Contingency table for site 1

| Reference Image | RADARSAT | | |
|---|---|---|---|
| | Bare | Snow | Total |
| Bare | 40.30% | 26.69% | 66.99% |
| Snow | 10.98% | 22.03% | 33.01% |
| Total | 51.28% | 48.72% | 100.00% |

| Classification Accuracy | Kappa Coefficient | Standard Deviation of Kappa |
|---|---|---|
| 62.32 % | 0.23707 | 0.00095 |

Table 2 : Contingency table for site 2

| Reference Image | RADARSAT | | |
|---|---|---|---|
| | Bare | Snow | Total |
| Bare | 28.67% | 27.75% | 56.42% |
| Snow | 4.99% | 38.59% | 43.58% |
| Total | 33.66% | 66.34% | 100.00% |

| Classification Accuracy | Kappa Coefficient | Standard Deviation of Kappa |
|---|---|---|
| 67.26 % | 0.37110 | 0.00087 |

Forested areas are a potential source of confusion. They appear dark in the RADARSAT image indicating snow, and they also appear dark in the photomosaic indicating bare ground. Classification statistics were calculated both using all pixels and using all pixels except for the forested areas. But, the exclusion of the forest improved the classification only slightly, 62.32% to 63.21% for site 1 and 67.26% to 68.92% for site 2.

The classification accuracy is much lower than in the earlier studies. In both cases, the major source of error was the mis-classification of bare areas as snow-covered, which is consistent with the one day delay in acquisition of the ground reference images. The mean air temperature during the period was 11 °C, which corresponds to a melt of 7.2 cm snow water equivalent. Typical snowpack density for the ripe pack is 0.5 g/cm$^3$, so this melt is equivalent to a depth loss of 14.4 cm. This will produce a reduction in snowcovered area of 14.4% based on snow cover depletion curves for the study area (Donald *et al.*, 1995).

Table 3 compares the estimated snowcovered area for the sites with the fractions calculated from the RADARSAT imagery. The differences are small after the correction for the consequences of the day's melt, which suggests that the potential classification accuracy is much higher than achieved in this study. Furthermore, the accuracy of the radar image estimation of snowcovered area is well within the limits required for hydrologic modelling.

Table 3: Comparison of percent snowcovered area

| | Aerial Photography | | RADARSAT | Difference |
|---|---|---|---|---|
| | Observed | Prior Day Estimate | image | |
| Site 1 | 33.0% | 47.4% | 48.7% | -1.3 |
| Site 2 | 43.6% | 57.9% | 66.3% | -8.4 |
| | | Mean Absolute Difference | | 4.85 |

CONCLUSION AND DISSCUSSION

The results of the experiment indicate that RADARSAT imagery is capable of mapping the areal extent of wet snowcover in mixed agricultural regions. Within the limits of the study, the RADARSAT scenes estimated percent snowcovered area with an accuracy satisfactory for hydrologic modelling.

The major difference in the snow cover classification was the one day delay in taking the photos for the ground reference map and is consistent with the known snow cover depletion characteristics of the area.

Limitations of this type of analysis are that the snow must be wet and therefore imagery can only be taken once surface melt has begun. Nevertheless, this is a critical time and the imagery can be used to monitor the progress of the melt.

This type of study has now been attempted using 3 different sensors and with airborne imagery reprocessed to simulate the then planned RADARSAT satellite (Table 4). These studies were done over many years in different locations and thus conditions may have been considerably different for each study, yet all produced similar results. As an example, the first study only used test site areas of 4 $km^2$ while in the last study, test site areas were around 30 $km^2$. In general, it appears that SAR imagery can detect the presence of snowcovered pixels during melt with an accuracy of about 80% and, at the scale of about 10 km, can map the percent snowcovered area within about 3.6% absolute error.

Table 4: Summary of snowcover analysis results using various sensors in southern Ontario

| Sensor | Site | Classification | Snowcover | | Difference |
|---|---|---|---|---|---|
| | | Accuracy | Actual | Predicted | |
| Airborne C-HH | Site 4 | 83.1 | 34.7 | 37.7 | -3.0 |
| | Site 5 | 82.4 | 18.2 | 13.5 | 4.7 |
| Simulated RADARSAT | Site 4 | 79.9 | 34.7 | 34.2 | 0.5 |
| | Site 5 | 79.9 | 18.2 | 13.5 | 4.7 |
| ERS-1 C-VV | Site 9 | 71.7 | 24.8 | 22.0 | 2.8 |
| | Site 25 | 73.5 | 21.9 | 18.6 | 3.3 |
| RADARSAT C-HH | Site 1 | N/A | 47.4 | 48.7 | -1.3 |
| | Site 2 | N/A | 57.9 | 66.3 | -8.4 |
| | | | Mean Absolute Difference | | 3.59 |

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