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Determination of Snowcovered Area Using ERS-1 C-VV SAR Imagery on Two Small Test Sites in Southern Ontario

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ABSTRACT

This study was performed in order to determine whether the areal extent of a wet discontinuous snowcover could be effectively mapped using an active radar satellite image. The sites chosen for the experiment were two agricultural areas located in southern Ontario. On April 6, 1993 oblique aerial photography was acquired and was used to create a ground reference map showing the location of bare ground and snowcovered ground. On April 7, 1993 an ERS-1 C-VV SAR image was acquired, classified and compared to the ground reference map. The classification accuracies were 71.7% for Site 1 and 73.5% for Site 2. The C-VV SAR image could not identify snow along ditch lines and fences; the classification also had difficulty in distinguishing between fields with ponded water and wet melting snow. However, the total snowcovered area estimates were reasonably close to the ground reference map indicating that type of information could be used with land cover based snowcover depletion curves to give mean snow depth estimates.

Key words: ERS-1, active microwave, snowcovered area.

INTRODUCTION

The development of distributed hydrologic models that can account for the spatial variability of basin physiography and meteorological inputs, combined with the ability of such models to use remotely sensed data, has the potential to have these models run operationally using near real time data. More specifically, there exists the potential for effective use of detailed snowcover information as input into these models.

Up to now 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 Thematic Mapper (TM) imagery to determine percentages of land cover units within each grid square for a distributed hydrologic model. However, as snow properties can change greatly within a matter of hours, the repeat time of 16 days for the LANDSAT TM makes its use unfeasible for operational monitoring of snow properties. 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). Remote sensing has the potential for extending snowcover information to areas where ground based snow survey data do not exist.

The high albedo of snow makes it easily distinguishable using visible band imagery such as that from the LANDSAT TM or SPOT HRV, however other snow properties such as depth or density cannot easily be determined directly from these sensors.

Many studies have investigated the relationship between passive microwave energy and snow properties, for example Stiles and Ulaby (1980) and Hallikainen and Jolma (1992) and have been summarized by Foster *et al.* (1984). Passive microwave sensors such as the NOAA SSM/I have proved useful in determining snow water equivalence

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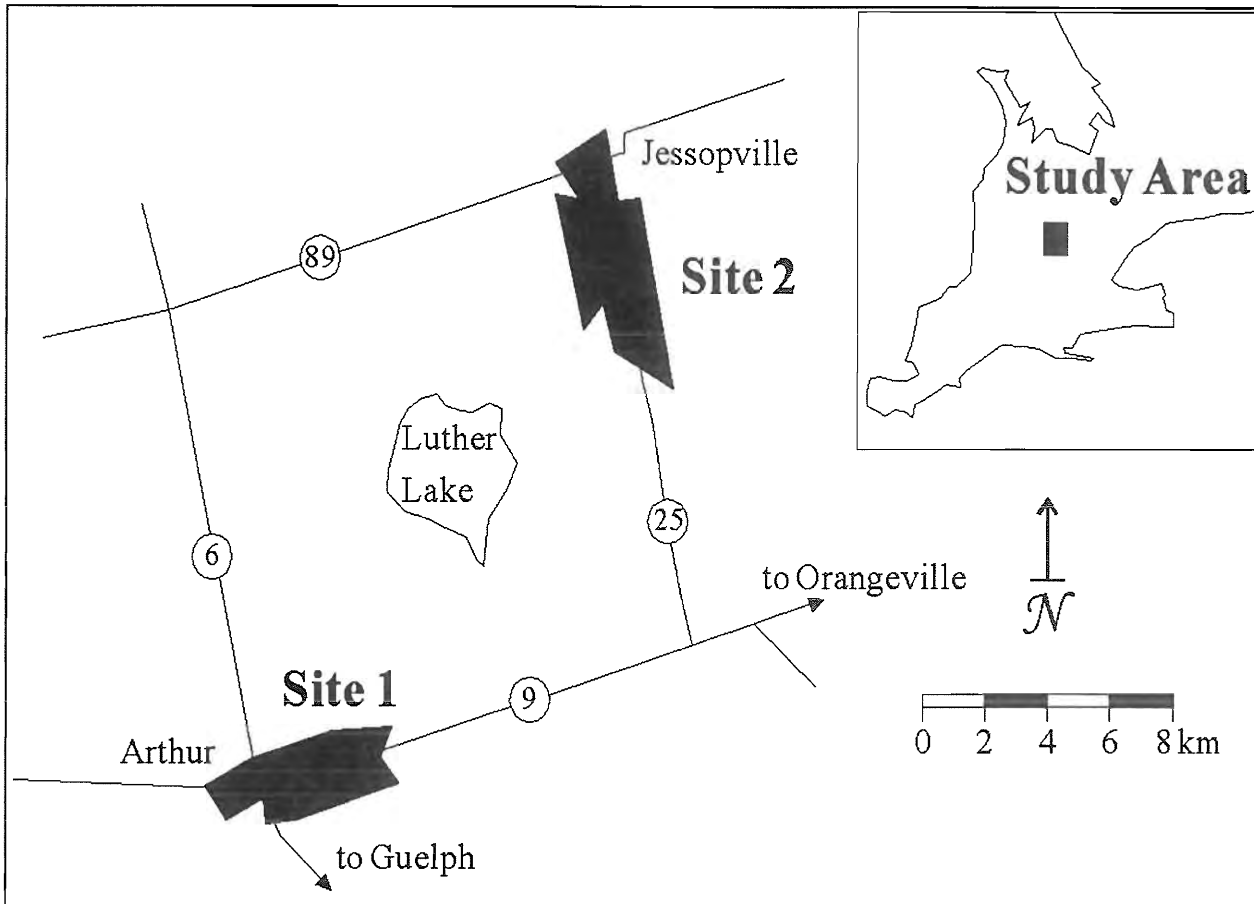


Figure 1 : Site Locations

(Goodison , 1989 and Seglenieks *et al.*, 1994), however their large spatial resolution of approximately 25 km by 25 km makes them applicable to only very large basins.

Active microwave sensors, such as aboard the ERS-1 satellite and the proposed RADARSAT, offer improved spatial resolution over passive systems. Also, unlike visible imagery systems, they provide their own radar signal and thus are unaffected by darkness and cloud.

Mapping of wet snowcover with active microwave signals relies on the fact that liquid water has one of the highest dielectric constants of any natural material (Lillesand and Kiefer, 1987). Therefore the contrast between the melting snow, with a layer of meltwater, and the surrounding bare soil is the distinction that allows mapping of the snowcovered area with active microwave imagery. Matzler and Shanda (1984) studied this relationship using a noise scatterometer situated 15 m above the ground testing snow free and snowcovered ground. In agreement with the study by Stiles and Ulaby (1980), Matzler and Shanda found that the backscatter coefficient of the radar signal drops dramatically when the snowpack is wet.

This paper describes an experiment to determine the applicability of using active radar data collected from the ERS-1 satellite to efficiently and accurately map snowcovered area. This experiment was performed in the same manner as a study by Donald *et al.* (1993) where airborne active radar data were collected and compared to concurrent oblique aerial photography. The authors found that classification accuracies of snowcovered versus bare fields were in the order of 80% using airborne SAR data. This study uses test sites which are much larger in area but in the same region as the above study.

THE EXPERIMENT

On April 6 and 7, 1993, an experiment was conducted to map the snowcovered area of a wet discontinuous

Figure 2 : Raw C-VV SAR imagery of Site 1

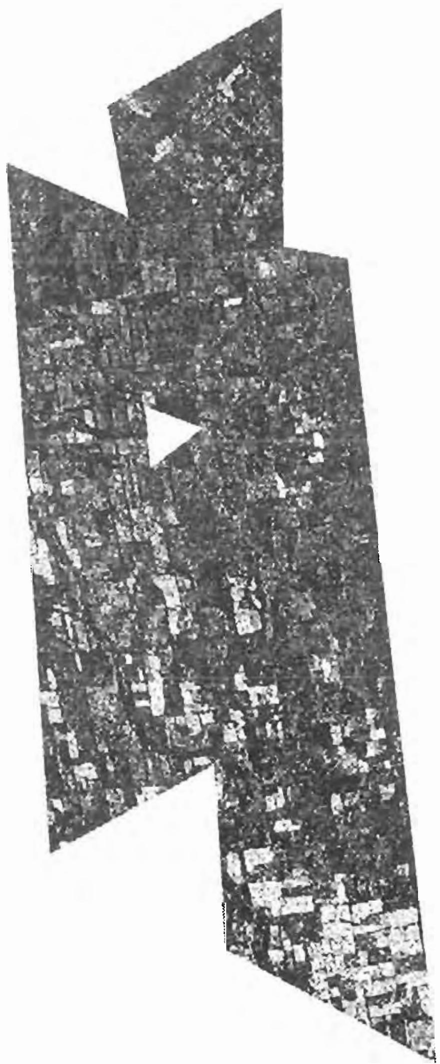


Figure 3 : Raw C-VV SAR imagery of Site 2

snowpack using an active radar sensor. The sites chosen for the experiment were two areas located within the Grand River watershed in southern Ontario. The sites are agricultural areas, primarily containing fields and woodlots. Site 1 is located east of the town of Arthur along Highway 9 and has an area of 80.0 km². Site 2 is 103.7 km² in area and is located along Highway 25 just south of the town of Jessopville, Site 2 is approximately 10 km north and 10 km east of site 1 (Figure 1).

On April 6, 1993, oblique black and white aerial photography was acquired from a light aircraft between 10 and 11 a.m. from an approximate altitude of 600 m . The aerial photography was used to establish the areal distribution of the snowcover at the time of the experiment. On that day, the maximum surface air temperature was approximately 7°C with mostly sunny skies although a haze can be seen in the background of the photographs. Ground surveys done that day indicated that the snowpack contained a wet melt layer at both sites. Snowdepths ranged from 0 to 40 cm in the open field areas of the study sites.

On April 7, 1993, an ERS-1 C-VV SAR image was acquired at 10:07 am from the Canadian Centre for Remote Sensing Applications Division. The image contains both of the study sites. The ground resolution of the ERS-1 C-VV SAR is 30m by 30m, the look angle is 23° and the swath width is 100 km.

IMAGE PROCESSING

The C-VV SAR image had an area of approximately 10 000 km², with a ground resolution of 30 m by 30 m. Windows containing the two study sites were

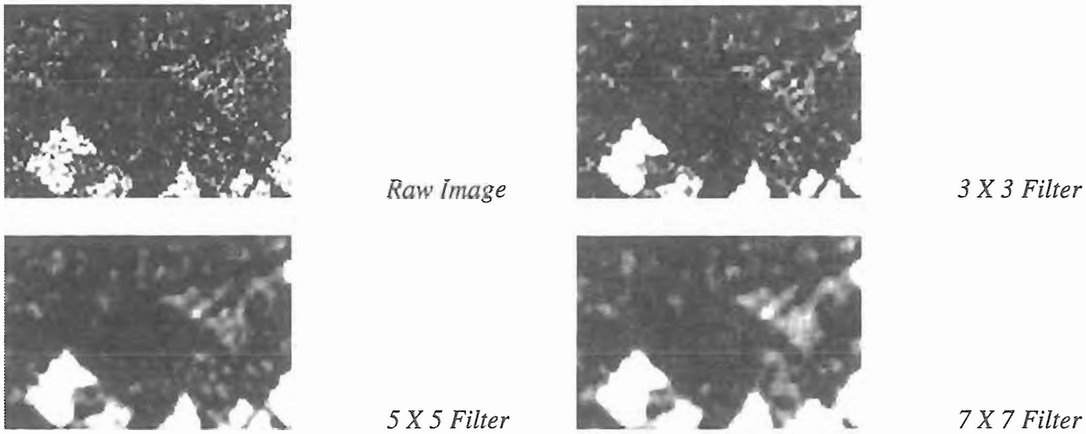


Figure 4 : Comparison of different filter sizes used on the C-VV SAR imagery

extracted from the original image and registered to local UTM coordinates using third-degree polynomial transformations. The image shows low backscatter in snowcovered regions and higher backscatter in the bare fields (Figures 2 and 3).

As a result of the random effects of many small individual reflectors within a given pixel, active radar images have a "pepper and salt" appearance often referred to as speckle. Thus active radar images are usually filtered using an adaptive filter designed to smooth the data while still retaining edges and sharp features. The Frost adaptive filter was used for this study (PCI, 1994).

The amount of smoothing largely depends on the size of the filter used on the image. For this study 3 different filter sizes were used to examine how they would affect the classification. The sizes chosen were 3 by 3, 5 by 5 and 7 by 7. Figure 4 compares the amount of smoothing generated by each filter size compared to the raw image.

Ground truth reference maps for both sites were derived from oblique aerial photography and ground surveys (Figures 5(a) and 6(a)). Approximately 12 overlapping oblique photographs were used for each site; each photograph had a ground area of 18 to 23 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 separated into two categories: bare ground and snowcovered ground.

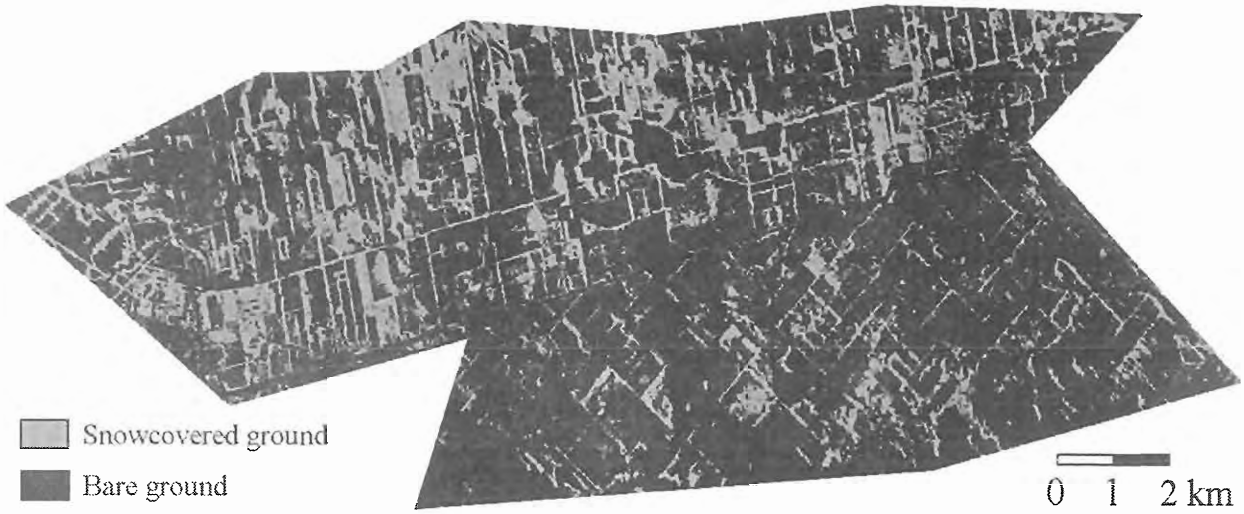
SNOWCOVER MAPPING

A supervised classification was done on the SAR image for each of the study sites independently. Training areas were chosen for bare and snowcovered fields for each site. The same training areas were

Table 1: Comparison of the Kappa coefficient using different sizes of the Frost adaptive filter

Site 1	
Filter Size	Kappa coefficient (%)
raw	18.3
3 x 3	64.5
5 x 5	64.9
7 x 5	64.0

Site 2	
Filter Size	Kappa coefficient (%)
raw	13.3
3 x 3	16.6
5 x 5	18.4
7 x 7	18.9



(a) Ground reference map

(b) Classified C-VV SAR image

Figure 5 : Ground reference map and classified C-VV SAR image for Site 1

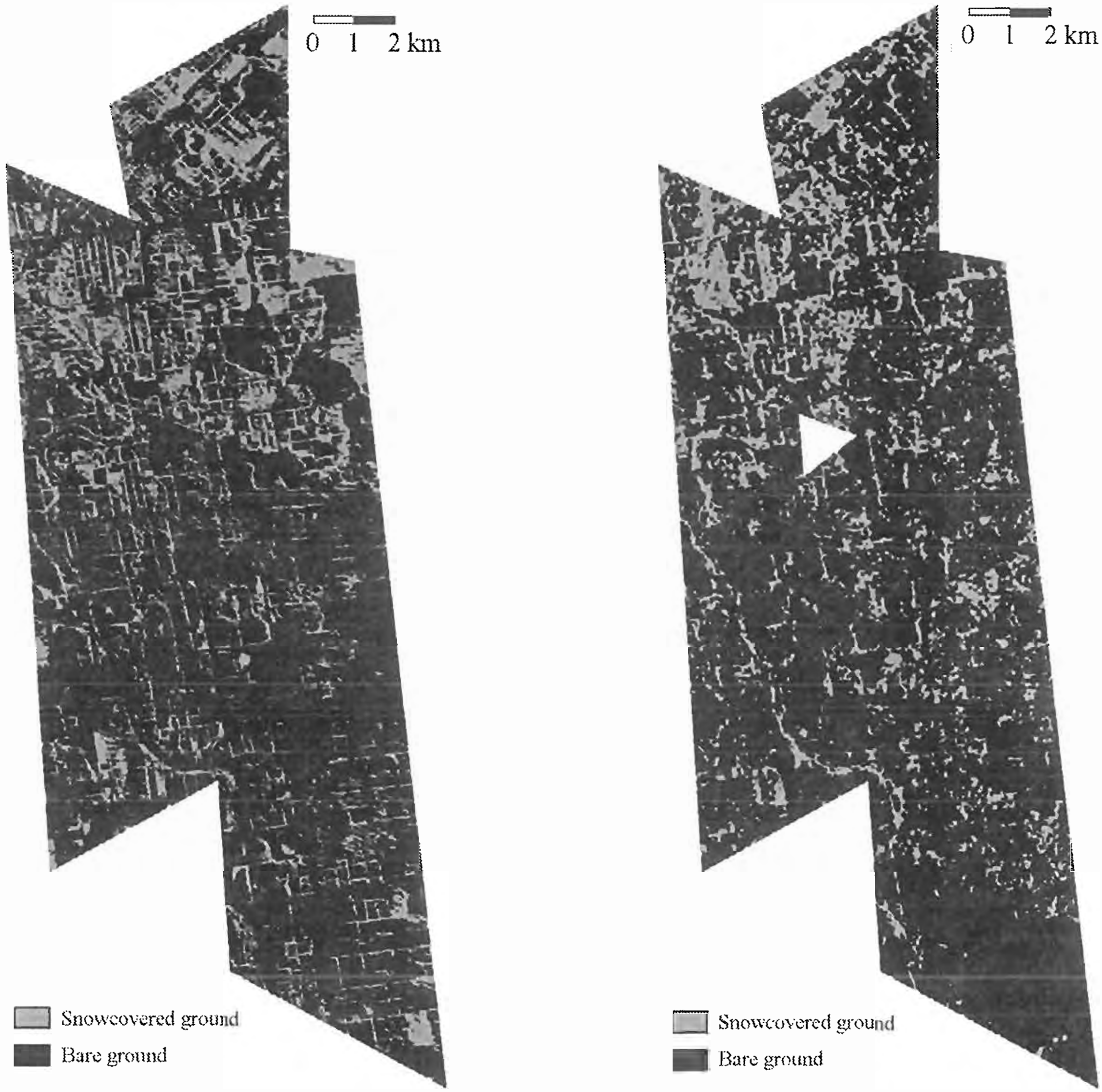
used for each of the differently filtered classified images.

To quantitatively 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_0 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 results of this comparison (Table 1) show that on site 1 there is a vast improvement to the classification using any filter compared to the raw image, with the 5 x 5 filter showing slightly better results than the other two sizes. For site 2, filtering also dramatically



(a) Ground reference map

(b) Classified C-VV SAR image

Figure 6 : Ground reference map and classified C-VV SAR image for Site 2

improves the classification compared to simply using the raw image, with the 7 x 7 filter having only a slightly higher Kappa coefficient than the 5 x 5 filter. For simplicity, the classified C-VV SAR image using the 5 x 5 Frost filter was used for the rest of the study on both sites.

The resulting training site histograms are shown in Figure 7. These histograms show that there is very good separation in the spectral signatures between the two land cover classes for site 1. For site 2 the separation is not quite as good because of the higher standard deviations in class signatures and the fact that the mean values are closer together.

CLASSIFICATION RESULTS

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

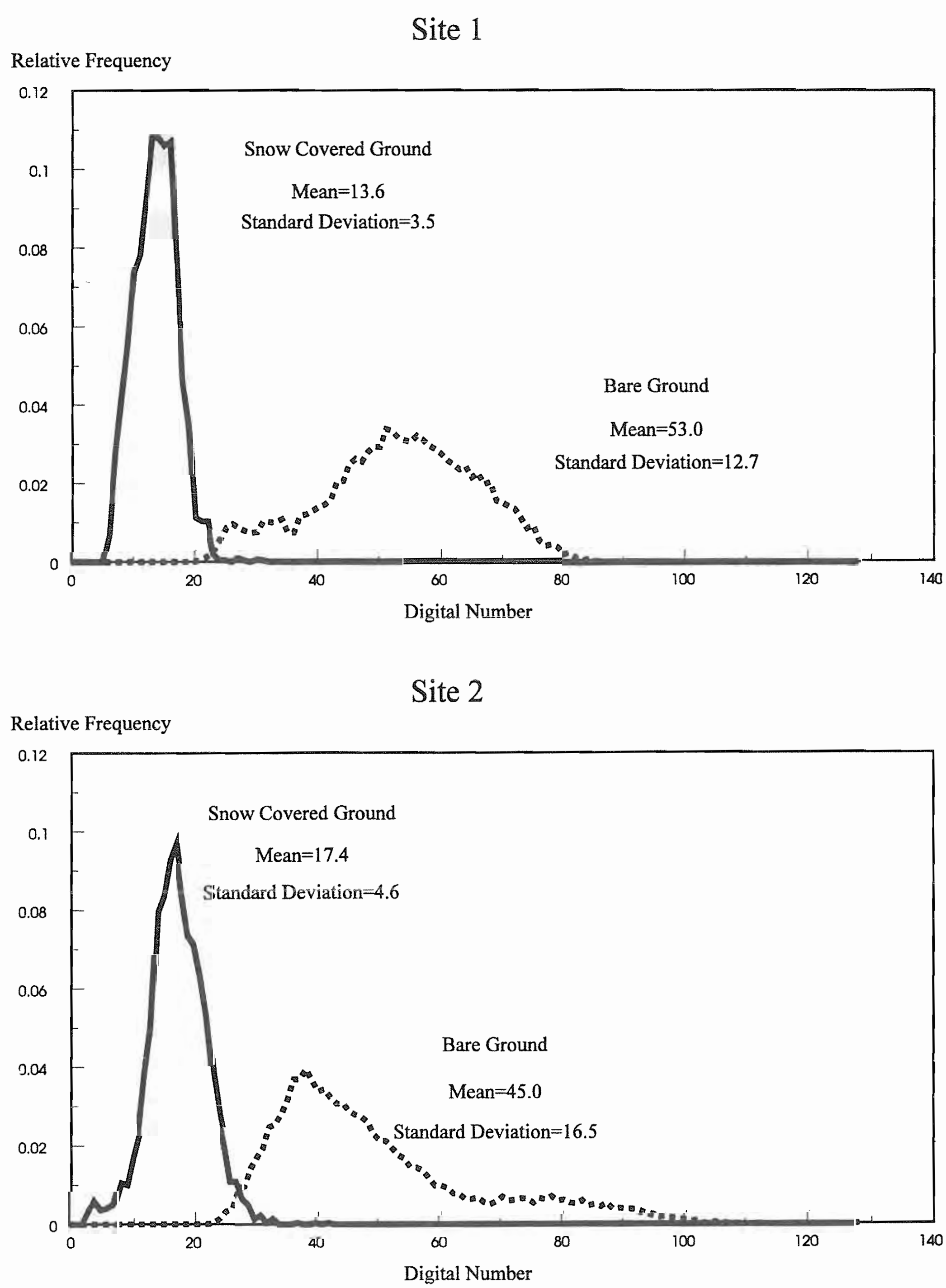


Figure 7: Class signatures of the C-VV SAR image

The Kappa coefficient is much higher for site 1 over site 2, 64.9 % and 18.4% respectively. However, when comparing classification accuracies site 2 at 73.5% is only slightly higher than the 71.7% found at site 1. Visual comparison between the ground reference maps and classified images confirms that the classification is better on site 1. Whereas the classification on site 1 is consistent throughout the image, for site 2 the classification is quite poor in the southern half of the image especially on the south eastern corner.

Table 2: Contingency tables - Classified ERS-1 image versus ground reference map (joint classifications are in percentages).

Site 1			
	Classified ERS-1 image		
Known Class in reference Image	Bare field	Snow covered field	Total
Bare field	62.4	12.7	75.1
Snow covered field	15.5	9.3	24.8
Total	77.9	22.0	100.0

Classificiation Accuracy (%) = 71.7
Kappa Coefficient (%) = 64.9
Standard Error of Kappa = 0.00121

Site 2			
	Classified ERS-1 image		
Known Class in reference Image	Bare field	Snow covered field	Total
Bare field	66.4	11.5	77.9
Snow covered field	14.8	7.1	21.9
Total	81.2	18.6	100.0

Classificiation Accuracy (%) = 73.5
Kappa Coefficient (%) = 18.4
Standard Error of Kappa = 0.00138

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

The estimates of total snowcovered area on both sites are similar; for site 1 - 24.8% and 22.0% for the ground reference image and classified C-VV SAR image, respectively, and for site 2 - 21.9% and 18.6% for the ground reference image and classified C-VV SAR image, respectively.

For both sites, the C-VV SAR image underestimated the amount of snow. This may be a result of the ERS-1 satellite passing over the study area a full day after the photos for the ground reference map were taken and as the daily high was above 5 °C, some melting can have been expected to occur between the two days of measurements.

In general, the C-VV SAR image failed to classify snow in many of the ditches and fence lines present in the ground reference map. This could be a result of the spatial resolution of 30m by 30m on the C-VV SAR sensor. A different type of filtering of the raw SAR image may be able to retain information along these lines.

To examine this, the raw C-VV SAR image was filtered using the 5 x 5 Frost filter using a range of damping factors. A higher damping factor will cause greater preservation of edges but less smoothing while a lower damping factor increases the smoothing effect but does not preserve the edges as well. A damping factor of zero would have the same effect as an averaging filter where all pixels in the filter have equal importance. A damping factor of one was used for all of the previous filtering done during this study. The results (Table 3) show only a very slight difference in the Kappa coefficients even between damping factors ranging from 0.0 to 8.0, indicating that this is not a very important factor. However, another type of filter may have greater success in improving the classification.

The classified C-VV SAR image shows snow in the middle of many fields which the ground reference

Table 3: Comparison of Frost filter damping factor on Site 2

	Damping Factor					
	0.0	0.5	1.0	2.0	4.0	8.0
Kappa Coefficient (%)	18.3	18.4	18.4	18.4	18.4	18.0
Classification Accuracy (%)	73.6	73.5	73.5	73.3	73.1	72.4

maps indicates are bare. This could be a result of ponded water from already melted snow which will be classified as melting snow because the radar signal cannot distinguish between the layer of water within the snowpack and ponded water.

A major difference between this study and the 1993 study by Donald et al.(1993) is the difference in the spectral signature of the forested area. In the previous study, the active radar signal showed such high returns from the areas designated as forest and scrub that they had to be taken out of the analysis. To investigate this point, the locations of forested areas were manually overlain on top of the C-VV SAR image using 1:50 000 topographic maps. It was found that the forested areas do not show an abnormally high or low return on the C-VV SAR image. In fact the mean values of the forested area were 27.5 and 34.6, for Site 1 and 2 respectively, putting them between the means for the bare ground and snowcovered ground land classes (mean values for the bare ground and snowcovered ground land classes are shown in Figure 7).

To determine if the snowcover classification was valid in these forested areas, the classification indices were calculated without using the forested areas. However, because neither site had a very significant amount of forested land, 1.7 % and 11.5% for site 1 and site 2 respectively, their exclusion did not have a significant effect on the classification results.

However, the ground reference maps in the forested areas for both of the images the map indicate that only 0.9% of the forested area was snowcovered in site 1 and 1.9% for site 2. This is unreasonable since snow usually persists in forested areas long after it has melted from open fields in this region. As well, the C-VV SAR image indicates that the amount of snowcovered ground was 26.3% for site 1 and 13.1 % for site 2 in the forested areas. This suggests that the method for obtaining the ground reference map may not allow for determination of snowcovered ground in forested regions. This is probably a result of the snow being redistributed off of the tree branches to the forest ground surface where it could not be seen by the oblique photography used to create the ground reference map.

A reason for the different spectral signatures of the forested area between this study and the one by Donald *et al.* (1993), could be that the active radar system used in the 1993 study utilized HH polarization while the ERS-1 satellite uses VV polarization. This VV polarization may allow the radar signal to penetrate better to the ground surface within a forested region.

CONCLUSION AND DISCUSSION

The results of the experiment indicate that ERS-1 satellite C-VV SAR imagery is capable of mapping the areal extent of wet snowcover in mixed agricultural regions. The spectral signatures of bare fields and snowcovered fields are separable and provide for good classification of snowcovered versus bare fields. Classification accuracies were around 72% for both sites.

The classification was significantly improved by filtering the raw C-VV SAR image to remove speckle, however experiments should be performed with other filters that may be able to preserve some of the linear snow features which the satellite has difficulty in detecting.

A major source of error in the snowcover classification was the inability of the C-VV SAR to distinguish between wet snow and ponded water on fields.

As the total snowcovered area estimates were reasonably close to estimates using the ground reference map, this type of information could be used with land cover based snowcover depletion curves to give mean snow depth estimates (Donald et al., 1995). These estimates could then be used in distributed hydrologic models of snowmelt runoff in low relief regions with shallow snowcover.

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.

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