Great Lakes Ice Cover Classification and Mapping Using Satellite Synthetic Aperture Radar (SAR) Data*

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ABSTRACT

Owing to the size and extent of the Great Lakes and the variety of ice types and features found there, the timely and objective qualities inherent in computer processing of satellite data make it well suited for monitoring and mapping ice cover. However, during winter months cloud cover over the Great Lakes impairs the use of satellite imagery from passive sensors operating in the visible, near infrared, and thermal infrared regions and passive microwave data currently lacks the spatial resolution required for Great Lakes ice cover monitoring and analysis. The all-weather, day/night viewing capability of satellite Synthetic Aperture Radar (SAR) makes it a unique and valuable tool for Great Lakes ice identification and mapping providing that data analysis techniques can be developed. The European Remote-Sensing Satellite (ERS-1) SAR with vertical polarization launched in 1991 and more recently RADARSAT, an operational satellite carrying a SAR operating at 5.3 GHz (C-Band) with horizontal polarization launched in 1995, provide an opportunity for this development.

Using airborne and shipborne data as "ground truth", preliminary computer analysis of ERS-1 and RADARSAT ScanSAR narrow images of the Great Lakes using a supervised (level slicing) classification technique indicates that different ice types in the ice cover can be identified and mapped. During the 1997 winter season, shipborne polarimetric backscatter data were acquired using the Jet Propulsion Laboratory (JPL) C-band scatterometer, together with aerial reconnaissance data, surface-based ice physical characterization measurements, and environmental parameters, concurrently with RADARSAT and ERS-2 overpass. The scatterometer data set, composed of over 20 ice types or variations measured at incident angles from 0° to 60° for all polarization's, was processed to radar cross-section and establishes a library of signatures (look-up table) for different ice types to be used in the machine classification of calibrated satellite SAR data. This method is used to obtain ice classification maps from ERS-2 SAR data.

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1.0 INTRODUCTION

Computer analysis of ERS-1 and RADARSAT ScanSAR narrow images of Great Lakes ice cover using a supervised (level slicing) classification technique indicates that different ice types in the ice cover can be identified and mapped and that wind speed and direction can have a strong influence on the backscatter from open water (Leshkevich et al., 1995,1997). The SAR images were displayed and analyzed using commercial and government-developed image processing software. Photographs were used along with ice charts and field notes to interpret and analyze ice types and patterns seen in the SAR images. It should be noted that the pre-commissioned scenes received from the Gatineau readout station and used in this study were "banded" or "striped" evidently due to an artifact in processing (mosaicing different antenna patterns). Although training sets were taken and processed within a "band", they could not be used to classify the entire scene (eg. results of the classification outside the band in which the training set was taken could be subject to error). Calibration should solve this problem.

A supervised, level slicing classification (Lillesand and Kiefer, 1979), based on a comparison of brightness or digital values in the SAR scene representing known ice types as identified in the ground data, was used in this initial analysis. Using photographs, ice charts, and field notes, two ice types (snow ice and new ice) and open water were identified in the computer displayed SAR image (16 March), and a representative training set, consisting of a range of digital values, was extracted for each type. A color was assigned to each type (range of values) and then applied to the entire scene producing a color-coded classified image. However, as explained above, the classification is only valid for the "band" in which the training set was taken.

To continue the development and validation of an algorithm for remote sensing of Great Lakes ice using SAR data, two winter experiments were conducted across the Straits of Mackinac and Lake Superior during the 1997 winter season. The experiments acquired shipborne polarimetric backscatter data together with surface-based ice physical characterization measurements and environmental parameters in conjunction with aerial ice reconnaissance. The experiments were timed to include RADARSAT and ERS-2 SAR imaging .

In these experiments, the Jet Propulsion Laboratory polarimetric scatterometer was mounted onboard the U.S. Coast Guard ice breakers *Biscayne Bay* and *Mackinaw*. The scatterometer operates at C band and has full polarimetric capability (Nghiem et al., 1997) including horizontal (HH) and vertical (VV) co-polarizations so that the results are applicable to RADARSAT SAR, ERS SAR, and the future ENVISAT SAR data. A video camera was set up to observe lake ice types and surface conditions in the same direction of the scatterometer incidence at the same time and location. Since different (major) ice types have characteristic radar backscatter at given polarization, incidence angle, and temperature, a look-up table of measured backscatter can be used to classify and map different ice types in calibrated satellite SAR imagery. This data set was processed to radar cross-section (Nghiem et al., 1998) and establishes a library of signatures for different ice types to be used in the computer classification of calibrated satellite SAR data.

2.0 METHODS

RADARSAT ScanSAR Wide imagery of Lake Superior collected during the winter experiment was acquired. However, as the data collected was ScanSAR Wide A, for which there is currently no calibration algorithm, ERS-2 SAR imagery was obtained and used for this study. A scene of the central portion of Lake Superior collected on 22 March 1997 (Fig. 1) was calibrated and linear o^{o} values converted to dB according to the simplified equation for the derivation of o^{o} in Precision Image (PRI) products (Laur et al., 1997). Certain assumptions on the local incidence angle were made:

- A flat terrain is considered , i.e. there is no slope. The incidence angle depends only on the earth ellipsoid and varies from about 19.5 ° at near range to about 26.5 ° at far range (23 ° was used).
- Any change in incidence angle across a distributed target is neglected, i.e. a distributed target corresponds to one average value of the incidence angle.

Measured backscatter values (converted to dB) for 3 ice types and calm water collected with the JPL C-band scatterometer on March 21, 22, and 23 were used as test "training sets" to classify the scene. We assume that the values for the 21 and 23 of March did not change significantly from 22 March as there was no significant change in temperature or precipitation conditions. We feel the assumption is valid as values measured on 23 March for a similar ice type measured on 22 March were very comparable.

The measured backscatter values for rough consolidated ice floes, brash ice, patchy snow cover on snow ice covered black ice (Ice Glossary, 1971), and calm open water were applied to the 8 x 8 pixel averaged digital ERS-2 SAR image. The averaging not only reduced the speckle but resulted in an image similar in resolution to RADARSAT ScanSAR Wide images. The overall uncertainty is about +/- 1 dB due to the averaging and the incidence angle effect.

3.0 RESULTS AND DISCUSSION

Figure 2 shows the color-coded result of the classification. Most of the ice cover in the scene was classified as rough consolidated ice floes (yellow) or brash ice (red). Areas classified as patchy snow cover on snow ice covered black ice (green) are scattered throughout the ice cover, but no calm open water was classified in the scene. This sample was measured on 23 March when we were out of the area covered by this scene. Black and gray represent unclassified areas. The land area (Kewenwa Peninsula (which can be masked out) was classified largely as brash ice (red) owing to similar backscatter intensity from the forested area.

Although our route across Lake Superior appears to have passed through the northwest portion of the scene, the classification appears to be valid based on the ice types we encountered. Further validation needs to be done using this scene, once geo-referenced, as well as on other ERS-2 scenes acquired during the measurement period. However, this study demonstrates the capability of classifying Great Lakes ice types in calibrated satellite SAR imagery using backscatter values measured from different ice types as "training data".

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7.0 REFERENCES

Ice Glossary, U.S. Department of Comerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Lake Survey Center, Detroit, MI (HO 75-602) p.9, 1971.

Leshkevich, G., W. Pichel, and P. Clemente-Colon. Great Lakes SAR ice research applications demonstration. In Proceedings of the Second ERS-1 Symposium - Space at the Service of our Environment, Hamburg, Germany, p.675-679, 11-14 October, 1993. ESA SP-361 (Jan. 1994).

Leshkevich, G., W. Pichel, P. Clemente-Colon, R. Carey, and G. Hufford. Analysis of coastal ice cover using ERS-1 SAR data. *Int. J. Remote Sensing*, 16(17):3459-3479, 1995.

Leshkevich, G.A., S.V. Nghiem, S.V., and R. Kwok. Satellite SAR Remote Sensing of Great Lakes Ice Cover Using RADARSAT Data. In Proceedings: Fourth International Conference on Remote Sensing for Marine and Coastal Environments, Orlando, FL, 17-19 March, ERIM, pp. I-126-134, 1997.

Lillesand, T.M. and R.W. Kiefer. *Remote Sensing and Image Interpretation,* John Wiley and Sons, New York, 1979, p. 612.

Nghiem, S.V., R. Kwok, S. H. Yueh, A.J. Gow, D.K. Perovich, J.A. Kong, and C.C. Hsu. Evolution in polarimetric signatures of thin saline ice under constant growth. *Radio Science,* vol. 32, no. 1, pp.127-151,1997.

Nghiem, S.V., G.A. Leshkevich, and R. Kwok. C-Band polarimetric backscatter observations of Great Lakes ice. In Proceedings: IEEE International Geoscience and Remote Sensing Symposium IGARSS'98) Sensing and Managing the Environment, Seattle, WA, 6-10 July, 1998.

Figure 1. ERS-2 Image (Copyright ESA 1997) Showing Lake Superior Ice Cover Northwest of the Kewenwa Peninsula (lower right) on 22 March 1997.

Figure 2. Classified ERS-2 Scene (Figure 1) Using Measured Backscatter Values For Rough Consolidated Ice Floes (12-yellow), Brash Ice (14-red), Patchy Snow Cover on Snow Ice Covered Black Ice (21-green), and calm water (25-blue).