Using Satellite Radar Data to Map and Monitor Variations in Great Lakes Ice Cover

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***Abstract* – Satellite-borne radars, including synthetic aperture radar (SAR) and scatterometer data, are used to classify and map Great Lakes ice cover and to derive freeze-up date, break-up date, and ice cover duration. These are important indicators of regional climatic conditions.**

I. Introduction

With the world's largest freshwater surface covering an area of 245,000 km^2, the Laurentian Great Lakes contribute significantly to the economic and social activities of North America. Ice cover on the Great Lakes, the most obvious seasonal transformation in the physical characteristics of the lakes, has a major impact on the regional climate, ecology, commerce, and public safety. Many practical applications such as winter navigation, shore structure protection, hydropower generation, lake ecology, and potential flooding caused by ice jams necessitate mapping and monitoring the ice cover from space.

II. Background

The all-weather, day/night viewing capability of satellite synthetic aperture radar (SAR) and scatterometer data makes them unique and valuable tools for Great Lakes ice identification and mapping, provided that data analysis techniques and capability for using such data in an operational setting can be developed. Previous computer analysis of Earth Resource Satellite-1 (ERS-1) and RADARSAT ScanSAR Narrow images of the Great Lakes using a supervised (level slicing) classification technique has shown 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. However, for image-to-image classification, a library of backscatter signatures of different ice types is needed for use with calibrated SAR imagery.

III. SAR Ice Classification and Mapping

During the 1997 winter season, shipborne polarimetric backscatter measurements of Great Lakes (freshwater) ice types using the Jet Propulsion Laboratory C-band scatterometer, together with surface-based ice physical characterization measurements and environmental parameters, were acquired concurrently with ERS-2 and RADARSAT synthetic aperture radar (SAR) data [1]. This polarimetric data set, composed of over 20 variations of different ice types measured at incident angles from 0° to 60° for all polarizations, was processed to radar cross-section to establish a library of signatures (look-up table) for different ice types. These signature backscatter data were calibrated both radiometrically and polarimetrically. The library is used in the computer classification of calibrated satellite SAR data [2]. Computer analysis of ERS-2 and RADARSAT ScanSAR images of Great Lakes ice cover using a supervised classification technique indicates that different ice types in the ice cover can be identified and mapped, and that wind speed and direction can have an influence on the classification of water as ice based on single frequency, single polarization data (see Fig. 1). In a 2002 winter experiment, NASA AIRSAR C-band and L-band polarimetric and interferometric

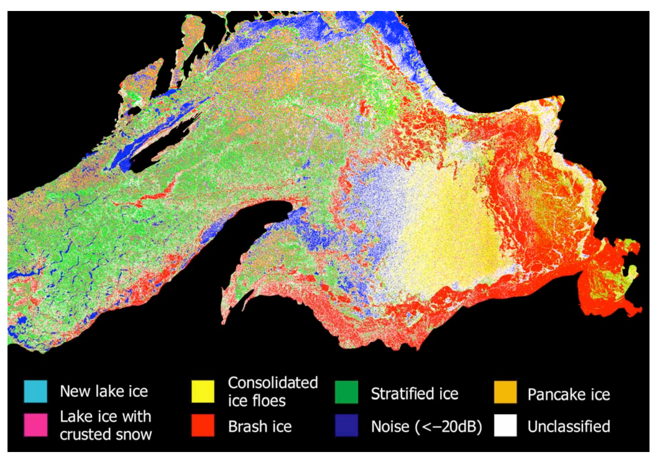

Figure 1. Classified color-coded RADARSAT-1 scene (22 March 1997) calibrated to σ_o by Satlantic, Inc. Measured backscatter values for consolidated ice floes (yellow), brash ice (red), stratified ice (green), new lake ice (cyan), lake ice with crusted snow (magenta), pancake ice (orange) were used as training sets. Areas below the RADARSAT noise floor (–20 dB) are coded blue and unclassified areas are coded white.

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measurements were collected over Lake Superior and Lake Michigan together with in-situ field observations. These measurements reveal that multi-polarization backscatter data is better to map ice and open water without the ambiguity encountered in single polarization data due to variations in wind speed over water.

IV. Scatterometer Mapping

A. *Ice Mapping*

Ice cover in the Great Lakes is also a sensitive index of regional winter climate. A recent study [3], based on observed annual maximum ice cover (AMIC) from 1963 to 2002, found it was at a maximum of 97.4% in 1979 and a minimum of 14.8% in 2002. Winter 2002 set a new record low AMIC, while during winter 2003, three of the Great Lakes froze over for the first time in nearly a decade. The large spatial and high temporal coverage together with its all-weather, day-and-night sensing capabilities make satellite scatterometer measurements well suited to map and monitor Great Lakes ice cover to extend the historical climatological record. To illustrate the potential application of satellite scatterometer (Ku-band) data for Great Lakes ice cover mapping, we used the NSCAT ratio of horizontal (HH) over vertical polarization (VV) data to map ice cover over the Great Lakes in 1997. The NSCAT results are in good agreement with National Ice Center (NIC) ice charts derived from ice reconnaissance, ship, shore, visible/infrared, and radar data. While these results are promising, the NSCAT ice-mapping algorithm cannot be applied directly to the current QuikSCAT (QSCAT) data because the configuration and orbital geometry of these two satellite scatterometers are quite different. We have developed a new algorithm using QSCAT data (see Fig. 2), which have been collected over the world since its launch in June 1999. QSCAT has an 1800-km swath for backscatter at vertical polarization and a 1400-km swath for the horizontal polarization. QSCAT can cover most of the Great Lakes two times per day. Verification of ice mapping results were carried out with in-situ observations from US Coast Guard icebreakers and with time-series imagery from a web camera located on Granite Island in Lake Superior.

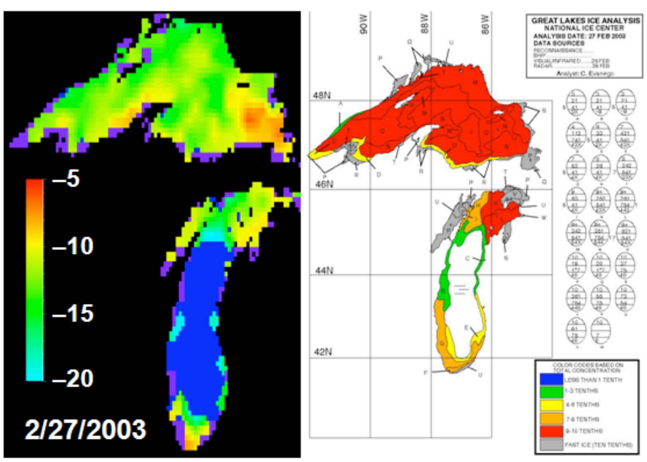

Figure 2. Ice cover over the Great Lakes observed by QSCAT (left, blue is open water, color scale is HH σ_o in dB) and NIC ice charts (right).

B. *Climatic Indicators*

Moreover, using a time series of backscatter in the time domain, ice cover freeze-up and break-up dates can be determined by satellite scatterometer over large lakes in North America and Europe. Results are obtained over selected regions in North America including Lake Superior, Georgian Bay, Lake Huron, Lake Erie, Winnipeg Lake, Great Slave Lake and Great Bear Lake, and Lake Ladoga in Russia (for example, see Fig. 3 on the next page). Over a selected region (25-km radius centered at 47.5^{o}N and 89.5^{o}W) in Lake Superior, a significant ice cover is detected only in 2003 over the past 6 years. In this area, the ice freezeup date was February 13 and breakup date was April 10 for an ice cover period of 56 days. Results for Georgian Bay, Lake Huron, and Lake Erie also show the longest ice duration in 2003 for period of scatterometer record. On Lake Ladoga (25-km radius centered at 60.65ºN and 31.62ºE) in Russia, the most significant ice cover period between the freezeup and breakup date over the last 6 years was also in 2003. The similarity between ice cover response in these two large lakes in opposite hemispheres indicates that ice freezeup date, breakup date, and ice cover duration are appropriate integrated indicators of climatic conditions over the hemispheric scale.

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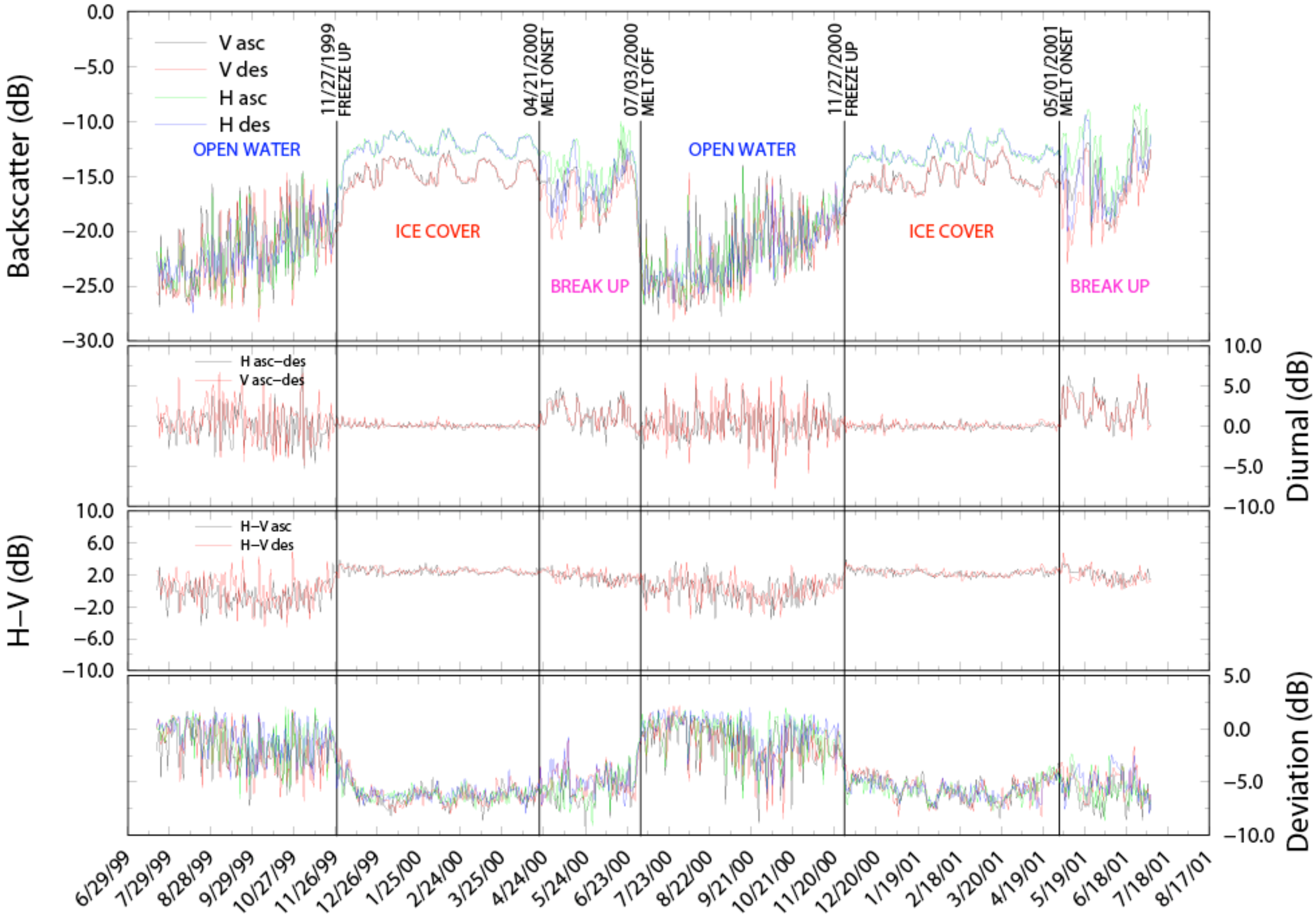

Figure 3. Example for Great Bear Lake, Canada, showing dates of freeze-up, break-up, and open water. QSCAT scatterometer data are plotted in the time domain, which show distinct signatures in the different phases of the lake surface. The center location of the data is at 66.1ºN and 120.5ºW.