GREAT LAKES SAR ICE RESEARCH APPLICATIONS DEMONSTRATION

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ABSTRACT

As part of the NOAA CoastWatch synthetic aperture radar (SAR) applications demonstration, the Great Lakes SAR ice research applications demonstration was developed to assess the utility of satellite SAR data for Great Lakes ice analysis. The primary applications to be studied are ice classification and mapping and ice jam monitoring. A data set for selected areas on the Great Lakes was established covering the period from 18 to 24 February 1993 and includes ERS-1 SAR scenes, AVHRR imagery, side looking airborne radar (SLAR), and ground data consisting of aerial photographs, video, and ice charts. Preliminary analysis using computer aided comparison and statistical techniques indicates that different ice types can be identified and mapped in the digital SAR imagery. The all-weather, day/night viewing capability of satellite SAR make it a valuable tool for Great Lakes ice analysis and monitoring.

Keywords: SAR, ERS-1, Ice, Great Lakes, CoastWatch

1. INTRODUCTION

During winter months, cloud cover over the Great Lakes region (Figure 1) impairs the use of satellite imagery from passive, electro-optical sensors operating in the visible, reflected infrared, and thermal infrared for ice cover monitoring and analysis. Even the twice daily repeat coverage from the Advanced Very High Resolution Radiometer (AVHRR) aboard the National Oceanic and Atmospheric Administration (NOAA) series of weather satellites produces few images (per week) showing enough of the Great Lakes to be of use for operational monitoring during winter months (Figure 2 (a, b)). Although

Figure 1. The Great Lakes of North America.
from The Great Lakes Atlas (USEPA and Environment Canada)

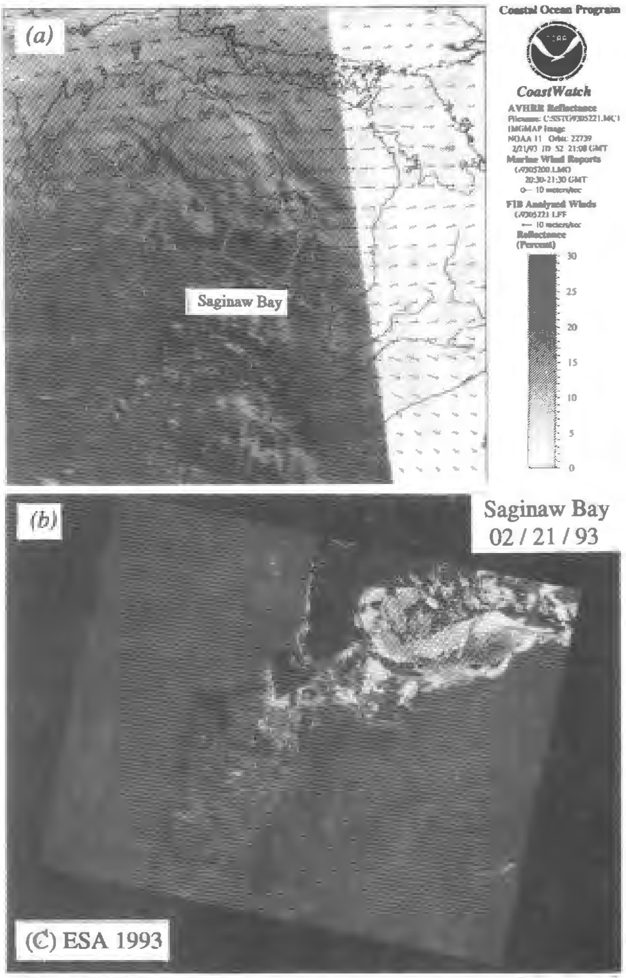

Fig. 2. (a) NOAA-11 AVHRR Ch. 1 (visible) scene showing cloud cover (snow storm) over Saginaw Bay on 21 February 1993. (b) ERS-1 SAR image of Saginaw Bay on 21 February 1993 showing ice cover and characteristics.

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airborne synthetic aperture radar (SAR) or side looking airborne radar (SLAR) are used by some for operational ice mapping (Ref. 1), they are limited in their spatial and temporal coverage and are very costly. The launch of the first European Remote-Sensing Satellite (ERS-1) in July 1991, marks the first time since SEASAT that satellite-borne synthetic aperture radar (SAR) data has been routinely available. The continuity of data and additional SAR coverage available or pending from the Japanese Earth Resources Satellite (JERS-1, launched in January 1992), the Canadian RADARSAT, and the ERS-2 warrants preparation for the operational use of satellite SAR data for environmental applications. To develop expertise in SAR data analysis and the capability to utilize SAR data in an operational setting, an applications demonstration of the use of ERS-1 SAR data for coastal environmental systems management is being carried out within the CoastWatch theme of NOAA's Coastal Ocean Program (Refs. 2, 3). As part of the CoastWatch SAR applications demonstration, the Great Lakes SAR ice research applications demonstration was developed to assess the utility of satellite SAR data for Great Lakes ice analysis. The primary applications to be studied are ice classification and mapping and ice jam monitoring in straits, connecting channels, bays, and harbors.

2. GREAT LAKES DATA SET

A data set for selected areas on the Great Lakes has been established covering the period from 18 to 24 February 1993. This data set includes ERS-1 SAR scenes, AVHRR imagery, U.S. Coast Guard SLAR imagery, and ground (in situ) data consisting of ice charts, photographs, and video taken from a helicopter. Based on projected ERS-1 over flight dates, field data collection was scheduled with the U.S. Coast Guard providing helicopter flight support. Areas covered on ERS-1 over-pass dates include:

- southern Lake Huron, St. Clair River, Detroit River, western Lake Erie on February 18
- central and eastern Lake Erie on February 19
- western Lake Superior, the Apostle Islands on February 23
- Straits of Mackinac, Whitefish Bay, St. Marys River on February 24

Oblique, color aerial photographs and video along with ice charts and locational data were obtained over the study areas from altitudes ranging from approximately 200 to 400 m. Ice thickness was obtained for two of the areas (southern Lake Huron and Straits of Mackinac) from Coast Guard ice breaking vessels. ERS-1 SAR data from the Gatineau readout station in Canada was received at the National Ice Center (NIC) in Suitland, Maryland via a link between the U.S. and Canadian Ice Centers. At the NIC, the data were mapped to a polar stereographic projection. Five scenes covering the study areas, each nominally 100 km square with a 50 m resolution, were downloaded to the Great Lakes Environmental Research Laboratory (GLERL). This data set, along with meteorological data from selected ground stations was used in the analysis. Preliminary analysis of two of the scenes (Straits of Mackinac and southern Lake Huron) will be presented and discussed in this report.

3. METHODS

The SAR images were displayed and analyzed using commercial and government-developed image processing computer software. For each of the two scenes, a 512 x 512 pixel sub-scene was abstracted and used for the analysis. Since the SAR data are mapped or geo-coded, observed ice types and features can be located and identified in the imagery using Loran coordinates recorded in flight. The aerial photographs and video were used along with the ice charts and field notes to interpret and analyze the ice patterns and characteristics seen in the SAR images. It should be noted that SAR scenes received by the Gatineau readout station were not calibrated. Thus, in this study, identification and association of dB (decibel) values with individual ice types was not possible. This was not a limiting factor in this study, but would be for any multi-temporal analysis. However, software has been developed to do a retrospective calibration (Ref. 4) which is planned for use in future analysis and for images obtained this winter season for the demonstration phase of this study.

Two computer-aided techniques were used in this initial analysis. The first was a supervised, level slicing classification (Ref. 5) based on a comparison of brightness or digital values in the SAR scene representing known ice types as identified in the ground data. Using the aerial photographs, ice charts, and field notes (Loran coordinates), ice types, open water, and land were identified in the computer displayed SAR image and a representative "training set," consisting of a range of digital values, for each type was abstracted. A color was assigned to each ice type (range of values) using the convention of dark colors (blue, green, etc.) for lower values and bright colors (red, magenta, etc.) for higher values. The color assigned to each range was applied to the entire sub-scene producing a color-coded classified image. Most of each of the two sub-scenes was classified with six to seven representative ranges.

For operational use, a more objective, less time consuming method of analysis is needed. The second method was an unsupervised, statistical technique called K-means or KCLUS (Ref. 5). This clustering algorithm produces spectral classes based on natural groupings in the image values. After determining six spectrally separable classes, their identity was defined based on the field data and results of the supervised classification. When the clusters were color-coded, it was found that the patterns were very similar between the two techniques and that for most classes (in the Straits of Mackinac sub-scene), the mean value for each cluster fell within or bordered the range of values determined in the first technique using the field data. However, further research needs to be conducted on the repeatability of the technique at different times during the season and identification of the classes under different temperature (melt) and wind conditions. Moreover, since the ERS-1 SAR produces single band, single polarization data (C-band (5.6 cm), vertical), texture (spatial frequency) may be used as an additional dimension in an unsupervised or supervised algorithm, thus integrating both spatial and spectral attributes in the classification procedure.

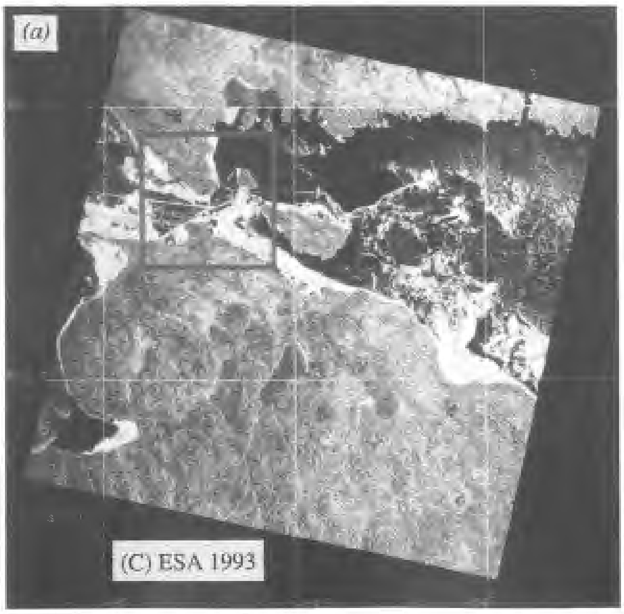
4. RESULTS AND DISCUSSION

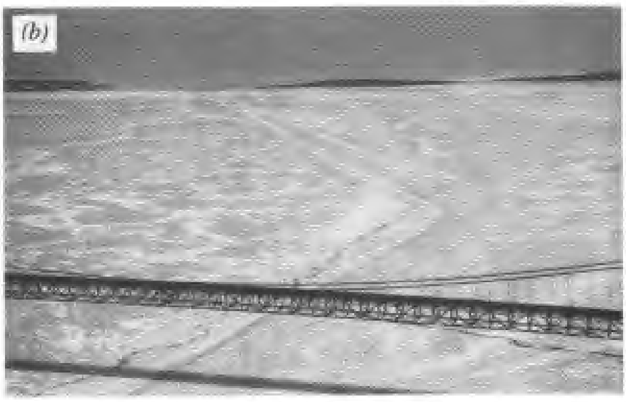
ERS-1 SAR imagery of two areas on the Great Lakes was analyzed using the techniques described. For each of the two images, a 512 x 512 pixel sub-scene (shown on the SAR image) was abstracted and used for the analysis. Ice characteristics in the imagery and interpretation of the classified scenes will be discussed and illustrated. The original color-coded classified images have been annotated to better illustrate features and ice types in the image on the black and white illustrations. Ice types referred to in this report are described in the nomenclature set forth in the "Ice Glossary" (Ref. 6).

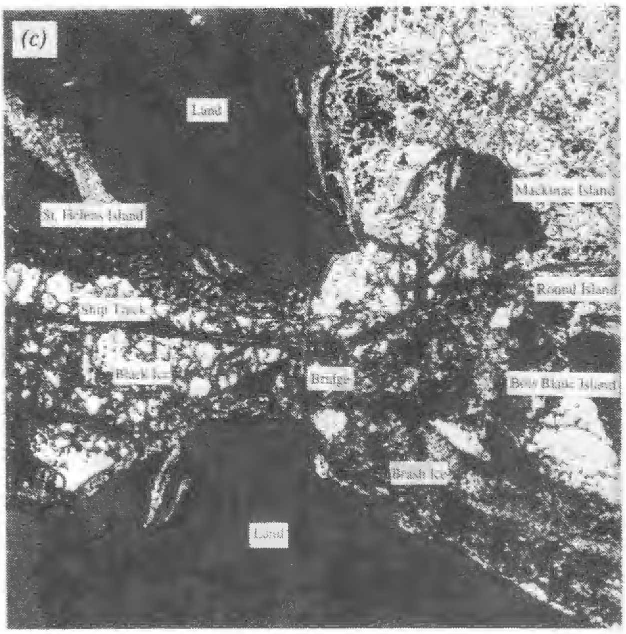
4.1 Straits of Mackinac

On 24 February 1993, the SAR aboard ERS-1 imaged the Straits of Mackinac, connecting Lakes Michigan and Huron (Figure 3a). Prominent features in the scene include the bright, north-south trending line (Mackinac Bridge) connecting the lower and upper peninsulas of Michigan. The bright east-west trending line perpendicular to the bridge is a ship track in the ice which turns to the north-east just east of the bridge. Figure 3b is an aerial photograph (looking eastward) showing the bridge, the ship track, and black ice with some blowing snow (wind rows) on the surface. There are no areas of open water in the sub-scene except perhaps in the ship tracks and some open cracks. Midday temperatures averaged -15°C. The ship tracks show a bright return due to the high backscatter from the rough-textured "brash ice" (broken pieces) in the track. Bright returns from along the shorelines are also caused by the ice broken by wind and wave action being pushed and piled on and near shore. Darker returns in the sub-scene are caused by low backscatter from areas of relatively smooth, "black ice" where the radar pulse either penetrates or is reflected (Ref. 7). Ice west of the bridge and south of the ship track is cracked and ridged and shows up as bright returns in the image. Ice east of the bridge and north of the ship track has few cracks and ridges and is 38-40 cm thick as reported by a Coast Guard ice breaker. Land has a characteristic return (tone and texture) based on terrain and topographical features. Two frozen inland lakes can be seen in the SAR image (outside the sub-scene) at about 45.5°N and 84.5°W. At that location is Mullet Lake and just to the west of it, Burt Lake. Return (tone and texture) from these lakes is noticeably different than that from ice in the study area. This could be due to return from bottom (Ref. 8) although these are relatively deep lakes and are not frozen to the bottom. The backscatter could be caused by (1) a layer of "snowice" or "slush ice" that usually forms on these inland lakes by February or (2) moisture-laden snow cover caused by the diurnal melt cycle or by rainfall.

Land and four or five ice types (two classes could probably be merged) were found to classify most of the sub-scene. Figure 3c illustrates the results of the supervised, level slicing classification. Figure 3d illustrates the results of the unsupervised, statistical (K-means) clustering algorithm. The patterns are definitely similar to the supervised technique and mean brightness values for the clusters were within or bordered the range of digital values picked as "training sets" for the supervised technique. It would be fairly easy to assign ice types to the clusters based on field observations.







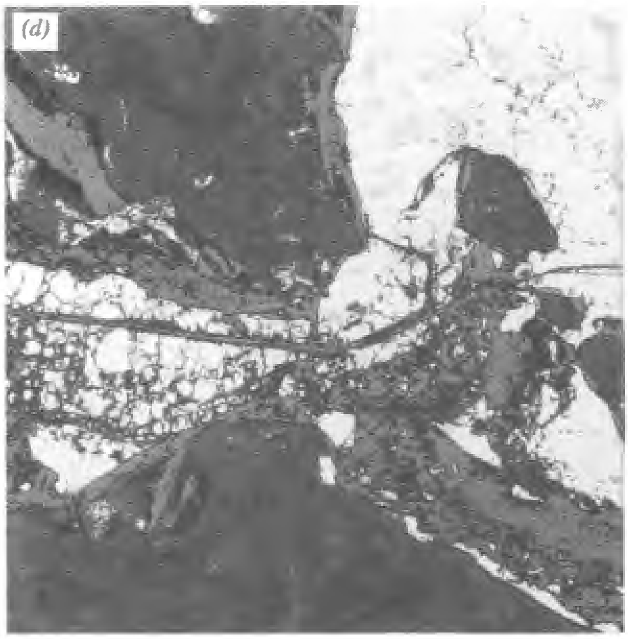
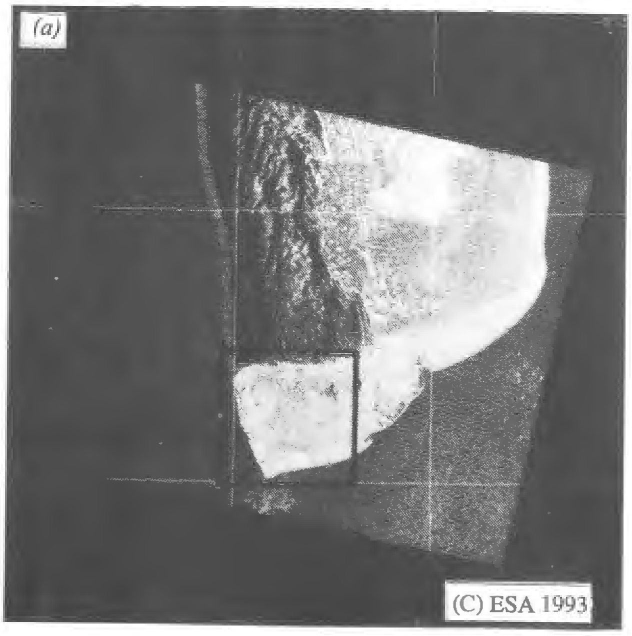


Fig. 3. (a) ERS-1 SAR image of the Straits of Mackinac on 24 February 1993 - study area within box. (b) aerial photograph (looking east) showing Mackinac Bridge, ship track, and ice cover. (c) annotated image showing results of supervised, level slicing classification. (d) image showing results of unsupervised clustering (K-means) classification.

4.2 Southern Lake Huron

Southern Lake Huron (Figure 1) forms an important area on the Great Lakes as its outflow, funneled through the St. Clair and Detroit Rivers, affects volume and level of water on the lower lakes as well as navigation between the upper and lower lakes. During spring breakup, currents and northerly winds can cause severe ice jamming problems in the southern end of the lake and the St. Clair River. This area was imaged by the ERS-1 SAR on 18 February 1993, as shown in Figure 4a. The average midday temperature was -16^{O}C with winds from the southwest at 10 knots. Open water and several types of ice were observed in the study area (sub-scene) including (1) refrozen "brash ice" (Figure 4b), (2) "snow ice" and older snow on ice, (3) "large flows" in open water or new ice at the edge of the consolidated ice pack (Figure 4c), and (4) "grease ice," "new ice," and open water extending northward from the ice edge along the western shore (Figure 4d). The relatively high backscatter (bright return) from this area as well as the area of open water between the ice bridge that formed at the extreme southern end of the lake and the entrance to the river appear to be caused by a wind roughened surface. These returns are higher than would normally be expected from open water. Ice thickness was measured at 30 cm in the southern end of the lake as reported by a Coast Guard ice breaker .

Applying the level slicing classification to the study area, most of the sub-scene was classified by six classes composed of land, open water, new/grease ice, large flows, snow ice (old snow on ice), and brash ice (Figure 4e). The K-means clustering algorithm was then applied to the sub-scene, and the color-coded results (Figure 4f) compared to the original scene and the supervised classification. The clustering algorithm produced the same patterns found in the original data and the supervised classification, but the means for the classes were shifted upward compared to the ranges chosen based on the field data. Based solely on brightness value, the unsupervised algorithm seemed to produce broader classes resulting in a classification somewhat different than that produced by the supervised technique. Thus, it appears that a solely statistical technique, even with a priori knowledge, cannot necessarily be relied upon to produce accurate classification. Calibrated values for different ice types at key temperature ranges, for a given satellite SAR sensor, as well as the use of an additional dimension such as texture, should aid the development of computer techniques for Great Lakes ice type classification and mapping using satellite SAR data.

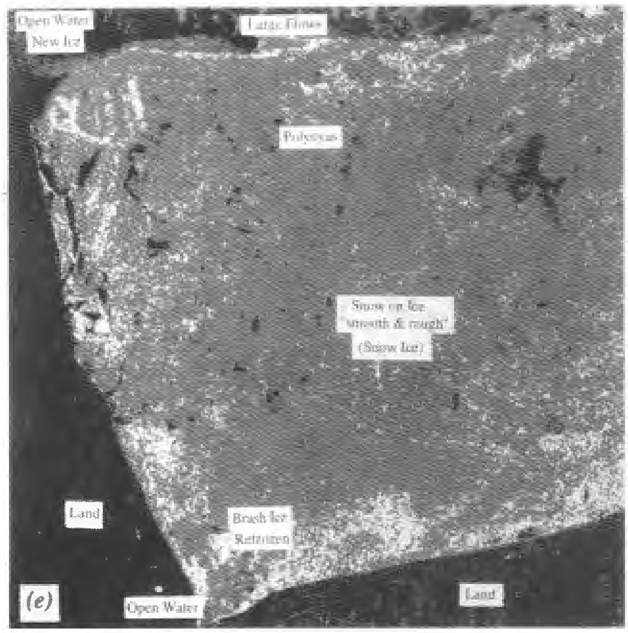


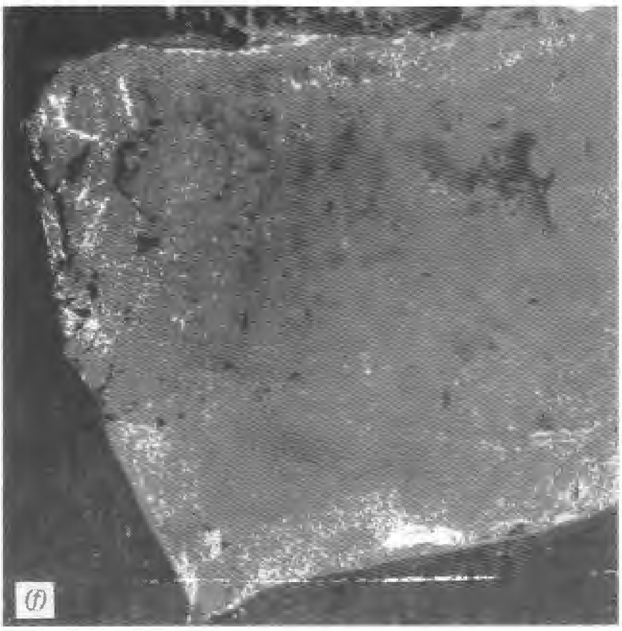
(b)

(c)

(d)

Fig. 4. (a) ERS-1 SAR image of southern Lake Huron on 18 February 1993 - study area within box. (b) aerial photograph (looking north) showing refrozen "brash ice" in southern part of lake (30 cm thick). (c) aerial photograph (looking west) showing "large flows" in open water or "new ice" at edge of consolidated pack. (d) aerial photograph (looking west) showing wind roughened open water, "grease ice", "new ice". (e) annotated image showing results of supervised, level slicing classification. (f) image showing results of unsupervised, clustering (K-means) classification.





5. SUMMARY

Two image processing techniques, a supervised, level slicing classification using aerial photographs, ice charts, and field notes as "ground data" and an unsupervised, statistical cluster analysis were used to interpret and analyze ice types in ERS-1 SAR images of two areas on the Great Lakes as part of an applications demonstration to assess the utility of satellite SAR data for environmental monitoring and coastal management. Preliminary analysis indicates that different ice types in the ice cover can be identified, classified, and mapped. In addition, wind has a strong influence on the backscatter from open water, and new (dry) snow is essentially transparent at SAR C-band wavelength (5.6 cm). The two techniques produced relatively similar results, which may be further improved upon by using texture as an added dimension in a multivariate classification procedure. Further research needs to be conducted on the temporal repeatability of interpretation and classification from scene to scene throughout the winter. The planned "demonstration phase" of the CoastWatch SAR applications demonstration should provide the opportunity to assess the effects of temperature (melt) and wind on the SAR signatures using calibrated SAR data.

6. ACKNOWLEDGMENTS

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