Using Temporal Information in an Automated Classification of Summer, Marginal Ice Zone Imagery*

Donna Haverkamp and Costas Tsatsoulis
Department of Electrical Engineering and Computer Science
The University of Kansas, Lawrence, KS

Center for Excellence in Computer-Aided Systems Engineering
2291 Irving Hill Road, Lawrence, KS 66045
Tel: (913)864-7767 Fax: (913)864-7789
E-mail: haverkam@cecase.ukans.edu

Abstract -- Synthetic aperture radar (SAR) imagery is difficult to classify under summer melt conditions, even with the human eye. Backscatter instability causes the intensities of the firstyear ice, multiyear ice, and open water classes to intermix, thus making an intensity-based classification invalid.

The method presented in this paper supplements backscatter information from SAR data with wind and temporally-analyzed temperature records and regional statistics in order to achieve an automated ice/no-ice classification of summer imagery in the marginal ice zone (MIZ). Referring to a database of prior area statistics (ice percentages, ice types, temperatures), an expert system forms conclusions to guide a current classification of the same area. Using parameters set by the expert system, an algorithmic floe extraction procedure divides the image into two classes (one assumed to contain floes and the other assumed not to contain floes) and then subdivides those two classes into ice and water. Classification results are then compared to the expected values derived from temporal adjustments of prior ice percentages. Unacceptable differences are called to the attention of the user for further inspection and possible manual correction.

The study area for testing is the Beaufort Sea, with data taken from the ERS-1 SAR. Results show that temporally-accumulated data can be used to provide a basis for an automated classification of MIZ imagery under summer melt conditions.

INTRODUCTION

Satellite remote sensing provides data for the continuous monitoring of sea ice distributions and concentrations over the polar oceans. The amount and thickness of ice in the polar regions is a key indicator of global climate, particularly in the summer season [1].

Although summer ice concentrations are no less important to obtain than winter ice concentrations, the analysis of summer ice imagery remains as yet unautomated. The backscatter contrast between first-year and multi-year ice is stable only from October through May; the summer season is characterized by nearly indistinguishable backscatters for all ice types [2]. Surface melt affects the backscatter of the ice adversely, and different ice thicknesses cannot be distinguished based upon backscatter alone.

A source of information which heretofore has not been utilized for summer sea ice imagery is *time*. Combining cumulative previous knowledge of an area's ice/water concentrations and melt state with temperature and wind data, a current interpretation of that same area can be guided, resulting in the automated measurement of ice distributions in MIZ areas during the summer season.

BACKGROUND

The summer ice season consists of several stages [3], beginning with the *early melt* stage in which the snow pack begins to undergo transformation due to melt/freeze cycling which ends when moisture is continuously present in the snow cover. This phenomenon also marks the beginning of the *melt onset* stage, which is characterized by dampness at the snow - ice interface and an average surface temperature near the melting point. This stage ends when most of the snow cover has become completely saturated, signalling the beginning of the *advanced melt* stage. From this point, the ice continues to decay until the freeze-up season begins.

While the signatures of the different ice types/thicknesses are stable under winter conditions (with multi-year ice typically having a higher backscatter than first-year ice), once the melt season begins, the signatures quickly begin to move closer together. After converging, they remain indistinguishable until midsummer [3,4]. At this point, because of the cumulative effect of melt on the perceived roughness, a backscatter reversal between first-year and multi-year ice occurs. Melt and drain cycles subsequently cause multiple backscatter reversals until the end of the summer, when the backscatters of multi-year and first-year ice again stabilize [4,5].

In [6], a number of notable conclusions are made concerning the backscatter changes in the summer ice cover: 1) when the snow begins to melt in early summer, the contrast between multiyear and first-year signatures vanishes, 2) when no snow remains in the first-year ice, the winter contrast between first-year and multiyear ice is reversed, which causes the first-year ice returns to exceed the multiyear ice returns by a few decibels - the shift can occur in less than a week, 3) the melting of superimposed ice can cause the reversed contrast to disappear in less than a week, and

*This work is supported in part by NASA Graduate Students Researcher Fellowship NGT-5064.

Table 1: Compositions of floe and non-floe classes corresponding to melt stage.

	Early Melt		Melt Onset		Advanced Melt		Freeze-Up	
Wind	< 4m/s	> 4m/s	< 4m/s	> 4m/s	< 4m/s	> 4m/s	< 4m/s	> 4m/s
Floe Class	ice	water	ice+ matrix	water+ matrix	ice+ matrix	water	ice	water
Non-floe Class	matrix+ water	ice+ matrix	matrix+ water	ice+ matrix	water	ice+ matrix	matrix+ water	ice+ matrix

4) because of the rapid fluctuations in the backscatter of first-year and multiyear ice, it is very difficult to classify C- and X-band radar images using intensity-based algorithms.

These investigations indicate that, due to backscatter fluctuations and general instability of sea ice signatures during the melt season, any attempt at an automated classification of corresponding imagery cannot depend upon intensity alone. It was therefore decided that additional information was needed in order to classify summer ice.

Pre-existing work at the University of Kansas performs segmentation of summer ice imagery into floe and non-floe classes in order to calculate floe statistics in the MIZ [7]. Rather than discard this body of work, which is based upon local dynamic thresholding and feature extraction techniques as described in [8], it was decided that it should be used as a central part of the summer ice classification procedure.

The major problem with the segmentation procedure was that it had no knowledge concerning the imagery which it segmented. A human operator had to look at the image and "tell" the segmentation procedure in what gray-level range it might expect to find floes. After dividing the image into floe and non-floe classes, it then subdivided those two classes based on the assumption that the floes class is composed of ice floes and "undesignated" areas while the non-floe class is composed of background matrix (usually consisting of ice bits) and open water. These assumptions work only in the ideal case (when they happen to be true).

However, the state of melt of an area, along with temperature and wind information, can supply guidelines for estimating the average backscatter of ice floes with respect to other classes present in the image, and for estimating the composition of the floe and non-floe areas found in the segmentation process (see Table 1).

METHODOLOGY

The approach used here is to utilize expert systems to interpret information such as time-of-year, latitude, wind, and previous knowledge of area conditions (including temperature and previous ice distribution statistics) to assist an algorithmic classification of SAR imagery into ice/no-ice categories during summer melt conditions in the MIZ.

Expert systems can provide interpretation of wind and melt stage information (and thus expectations of the relative backscatter of the floe class *and* of the compositions of the floe and non-floe classes), and guidelines for expected ice percentages based upon previous percentages in the same area. Combining this with local, dynamic thresholding and a feature extraction technique, we are provided with an expert system-guided segmentation and classification of SAR summer, MIZ imagery. The technique separates an image into ice floes, background matrix (assumed, for ice percentages, to consist of ice), and water.

IMPLEMENTATION

The system utilizes expert information along with a segmentation procedure to differentiate between ice and water and to define individual ice floes in synthetic aperture radar imagery of the MIZ during the melt season. It is necessary to coordinate several components, including two expert systems and a database, in order to realize the complete classification system. The study area has been limited to the Beaufort Sea, in the interest of both time and space.

Database

Information from analyses of different areas of the Beaufort Sea are kept in a database, indexed to nearest latitude and longitude degree blocks. Temperature records are also included, along with current melt state, ice percentages, and floe size distributions. This database is updated with such information as it becomes available from incoming data and from expert system analyses.

Algorithmic Parameters Expert System

This expert system determines the settings of key parameters used by the algorithmic segmentation and classification procedure. The parameters are determined by melt conditions (requiring analysis of cumulative temperature information) and wind - these are the factors which indicate whether the floes in the image will be bright or dark or "in-between" relative to other ice forms in the image. This information is used by the segmentation and feature extraction technique to determine the floe and non-floe classes. These factors also indicate what classes will be similar in backscatter and will combine to form the floe and non-floe classes subsequently found in the image segmentation. This information is used by the classification to further segment the floe and non-floe areas into ice and water classes.

This expert system generates the updated melt stage information and updates the database accordingly.

Segmentation and Feature Extraction

A dynamic thresholding and feature extraction procedure for segmenting SAR imagery into unlabeled classes already exists [8], and it has been adapted to segment summer MIZ SAR imagery into two classes, assumed to be simply floe and non-floe [7].

The summer adaptation of the dynamic thresholding and feature extraction technique will be utilized to divide the image into floe and non-floe regions. Floe class will be selected as dark or bright according to parameters set by the algorithmic parameters expert system.

Classification: Ice/No-Ice

Variables set by the algorithmic parameters expert system indicate the expected compositions of the floe and non-floe classes found (see Table 1). Within these classes, shape characteristics are used to distinguish floes, and texture measures are applied to the raw imagery to distinguish water areas. The remaining features are assumed to consist of background matrix (ice).

Floe Analysis

After the classification is complete, floe analyses are performed to calculate floe statistics of the area based upon floe size distributions. This information is entered into the database.

Post-Classification Expert System

In this stage, there are three error checks performed on the data.

1) Based upon prior ice percentages of the same area and cumulative temperature data, a projected set of ice percentages are calculated. These numbers must agree reasonably with the new percentages.

2) Ice floe size distributions should reflect a decrease in floe size over the summer (as the ice melts).

3) Ice type distributions should also agree with historical information taken from the area (over past years), at least in a general sense (i.e., "at *x* time of year, there is usually more ice than water present in the area" should hold true for current statistics).

If any of the above do not hold, attention is called to the user to verify (or negate) the current classification. The database is then updated with the new regional statistics.

RESULTS

The system was run on a small collection of test images from the Beaufort Sea. A SAR strip was acquired for three consecutive passes, each spaced three days apart.

In all cases, the sea ice was in a state of advanced melt. Tthe imagery did, however, exhibit varying wind speeds. Based upon these and a fabricated temperature record for corresponding areas, the system was run on the test images. The floe and non-floe classes and their subclasses were all assigned properly according to visual evaluation. Results were within expected error bounds, with the exception of the results from one test image which exhibited very poor contrast. In that case, notification of error was made to the user, and a manual correction of the statistics was allowed.

CONCLUSIONS

Automated classification of summer, MIZ SAR imagery is a desired, if difficult, task. Supplementing intensity data with wind and temperature data, a classification can be made which is at least semi-automated. By analyzing classification results with respect to prior area statistics, the classification can be evaluated for correctness, and the need for user intervention can be assessed (and minimized).

REFERENCES

[1] Bentley, C. R., "Some Aspects of the Cryosphere and its Role in Climatic Change", in *Geophysical Monograph 29: Climate Processes and Climate Sensitivity*, J. E. Hansen and T. Takahashi, editors. American Geophysical Union, 1984, pp. 207-220.

[2] Thomas, R. H., "Ice Sheet Margins and Ice Shelves", in *Geophysical Monograph 29: Climate Processes and Climate Sensitivity*, J. E. Hansen and T. Takahashi, editors. American Geophysical Union, 1984, pp. 265-274.

[3] Livingstone, C. E., K. P. Singh, and A. L. Gray, "Seasonal and Regional Variations of Active/Passive Microwave Signatures of Sea Ice", *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-25, no. 2, March 1987, pp. 159-172.

[4] Onstott, R. G., "SAR and Scatterometer Signatures of Sea Ice", in *Geophysical Monograph 68: Microwave Remote Sensing of Sea Ice*, F. D. Carsey, editor. American Geophysical Union, 1992, pp. 73-104.

[5] Onstott, R. G., T. C. Grenfell, C. Matzler, C. A. Luthre, and E. A. Svendsen, "Evolution of Microwave Sea Ice Signatures During Early Summer and Midsummer in the Marginal Ice Zone", *Journal of Geophysical Research*, vol. 92, no. C7, June 1987, pp. 6825-6835.

[6] Gogineni, S. P., R. K. Moore, T. C. Grenfell, D. G. Barber, S. Digby, and M. Drinkwater, "The Effects of Freeze-Up and Melt Processes on Microwave Signatures", in *Geophysical Monograph 68: Microwave Remote Sensing of Sea Ice*, F. D. Carsey, editor. American Geophysical Union, 1992, pp. 329-341.

[7] Soh, L. K., D. Haverkamp, and C. Tsatsoulis, "Separating Ice-Water Composites and Computing Floe Size Distributions", *IGARSS 1996.*

[8] Haverkamp, D., L. K. Soh, and C. Tsatsoulis, "A Comprehensive, Automated Approach to Determining Sea Ice Thickness from SAR Data", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 33, no. 1, Jan. 1995, pp. 46-57.