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Ice Roughness Classification and ERS SAR Imagery of Arctic Sea Ice: Evaluation of Feature-Extraction Algorithms by Genetic Programming

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Abstract — This paper describes a validation of accuracy associated with a recent algorithm that has been designed to extract ridge and rubble features from multiyear ice. Results show that the algorithm performs well with low-resolution ERS SAR data products.

1. INTRODUCTION

Roughness in the polar ice cover—like meso-scale features of pressure ridges and rubble fields—is of significant geophysical interest. Pressure ridges and rubble fields help to transfer kinetic energy from meteorological systems to the ice cover. Pressure ridges can significantly increase sea-ice drag coefficients, which subsequently affect sea-ice movement and deformation. Ridges and rubble fields are also of interest because they account for a large portion of the total ice mass.

In ERS synthetic aperture radar (SAR) imagery, pressure ridges commonly appear as filamentary, curvilinear features of variable width. These features have radar backscatter signatures that differ only slightly from those of non-ridged multiyear-ice; pressure ridges subsequently appear as mostly low-contrast features. Rubble fields often form when sea ice undergoes multiple ridging events in the same geographic region. Not surprisingly, rubble fields have backscatter signatures that are similar to that of pressure ridges, except that rubble fields may have shapes ranging from consolidated blobs to interlaced networks of curvilinear features.

The difficulty in extracting such features has been noted in work such as [1]. The problem has been considered untenable for standard image processing algorithms for a variety of reasons. Such reasons include low signal-to-noise ratios, arbitrariness of feature shapes, and radar cross-sections that change depending on the orientation of a feature. The problem, however, has not been considered impossible, since researchers have been able to link the roughness caused by sea ice deformation (like ridges and rubble fields) with ERS SAR backscatter. [4]

This paper evaluates an ice-roughness algorithm that we have developed over the past year. The next section (2) briefly discusses our algorithm. Section 3 describes our procedure for evaluating this algorithm, which involves validation of a derived data product from this algorithm with an area that has ground truth. Section 4 presents and discusses our results. Section 5 summarizes our major conclusions.

2. ALGORITHM NOTES

Our algorithm has been developed by using a relatively new procedure in computer-assisted software design. This procedure, which uses genetic programming, has been developed to help a user to focus more on the problem at hand and less on programming detail. Another paper in this conference highlights some of the salient characteristics of our procedure [2].

We have designed our algorithm to extract ridge and rubble features in multiyear ice. It has been developed for use with low-resolution (ERS) SAR data products, partly because we desired meso-scale distributions and partly because we wanted to track temporal changes. For more information on the development of this particular algorithm (called a switch filter), see [3].

3. PROCEDURE

The image that we have chosen for validation is part of a larger series of temporal ERS-1 SAR data that we have analyzed. The series, which begins in August 1991 and ends in July 1992, describes the synoptic coverage of an area in the Beaufort Sea gyre (roughly 72°N, 140°W). The particular area and dates of coverage overlap with the Lead Processes Experiment (LEADEX) in 1992, which featured both in-situ and ERS-1 observations around a chosen floe.

Figure 1a shows the low-resolution ERS SAR image taken 29 March 1992, while Figure 1b shows the corresponding data product derived with the ice-roughness algorithm. We note that the algorithm was developed using data from a different image (23 April 1992)—the 29 March data is entirely out-of-sample. The boxed area shown in both these figures corresponds to the ice classification map shown in Figure 1c. Classifications for this map were based on ground observations from the LEADEX base camp.

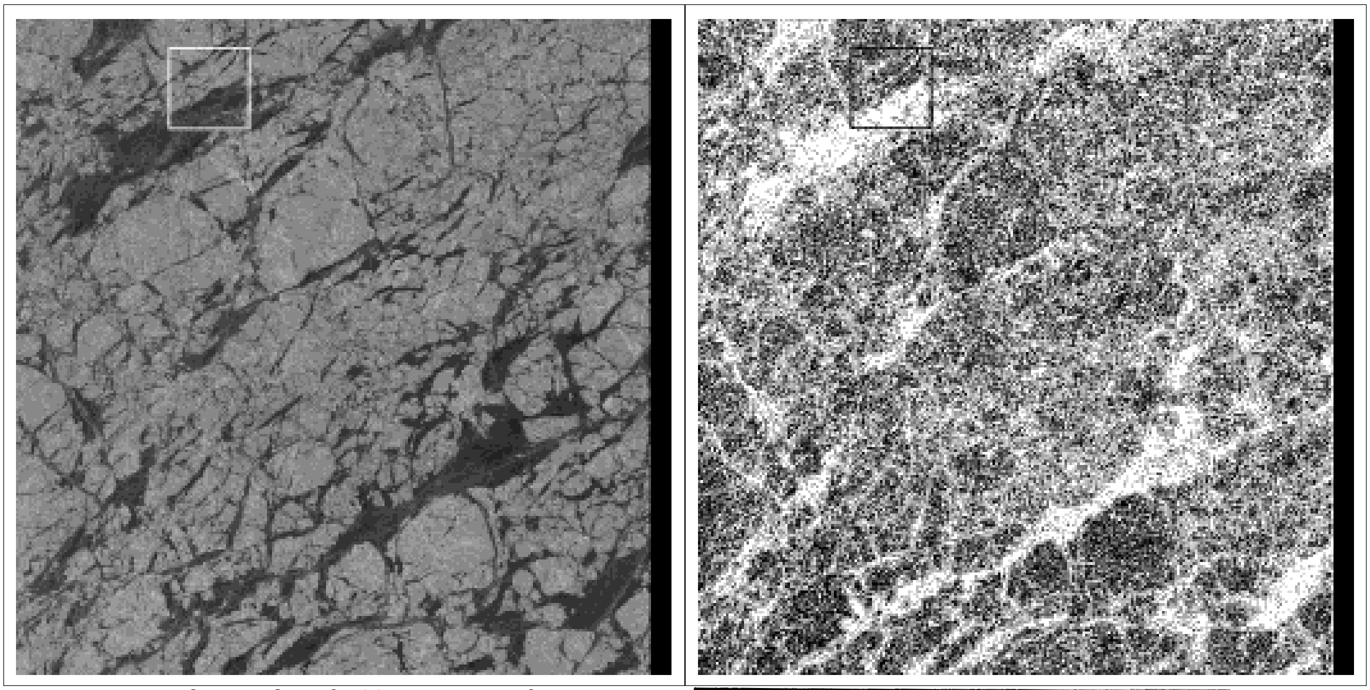
To validate the derived data product, we used a ridge and rubble map that was manually obtained from the high-resolution (nominally 12 m resolution) ERS SAR data product for the same day and area. To ensure accuracy, we limited the extent of this ridge and rubble map to the immediate area (~ one km) around the base camp. The map was verified by personnel present at the base camp at the time the image was taken (i.e., R. Onstott). The boxed area in Figure 1c shows theextent of the manually derived ridge and rubble map.

4. RESULTS AND DISCUSSION

Figures 2a – d show our results. Figure 2a depicts the high-resolution subimage that was used to create the manually derived ridge and rubble map. The image has been enhanced for publication to highlight those features, which show as light gray pixels on a gray background. (Gray generally corresponds to multiyear ice, while dark gray generally corresponds to first-year ice.) The three bright collinear dots in the center of this figure correspond to corner reflectors placed on first year ice. (A fourth dot—another corner reflector—is also visible, but on multiyear ice.)

Figure 2b shows the manually derived ridge and rubble map. (Black denotes ridge and rubble features in multiyear ice, or extreme ridging in first year ice. Note that the three dots have been retained for comparison.)

Figure 2c shows the results from the ice-roughness algorithm.



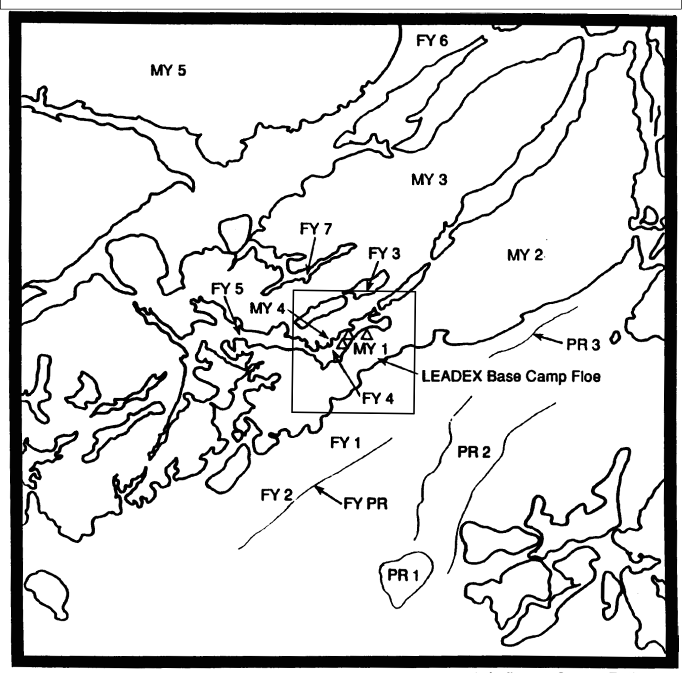


Figure 1. Data and Ground Truth. (a) Top. 29 March 1992 Image (1024 × 1024 pixels) © ESA 1992. (b). Upper right. Derived Data Product. (c) Lower Right. Map of Ground Truth.

Note that the pixels are noticeably larger than those shown in Figures 2a and 2b. This is expected, since the ice-roughness algorithm works on low-resolution data products. (Black and dark grays denote ridge and rubble features.)

Figure 2d shows the results of overlaying the results from the ice-roughness algorithm on the manually derived ridge and rubble map. (Black indicates a high degree of correlation for ridge and rubble features, while white indicates a high degree of correlation for smooth features. Gray without any interior black denotes areas of possible conflict.)

The results show excellent correspondence between the manually derived map and the data product from the ice-roughness algorithm. Much of the identified ridge and rubble features in multiyear ice have been correctly classified in the data product. Tolerance accuracies in the data product are better than ±100 m (± 1 pixel) of a ridge or rubble feature in the high-resolution map.

We note that the data product shows a correct classification of ridge features in an area just below the three collinear dots in Figure 2a. Ground truth corresponding to this area indicates an area of old pressure ridges—worn and smoothed. Radar backscatter signatures corresponding to ridges like these are not much different from non-ridged multiyear ice; such features are difficult to classify.

The ice-roughness algorithm does seem to identify ridges and rubble features regardless of whether such features yield strong or weak signatures in contrast to the mean backscatter values of multiyear ice. If this is the case, such an attribute would help to desensitize the algorithm from ridge orientation effects on radar backscatter.

We further note that the algorithm has classified a series of pixels in the lower right corner of Figure 2c as ridge or rubble features, even though such pixels correspond to areas of first-year ice. The algorithm apparently identifies a few, but not all the ridge and rubble features in first-year ice. These features do appear in the image data but not in Figure 2a. (As mentioned earlier, we enhanced Figure 2a to show, for publication, ridge and rubble features in multiyear, not first-year ice.) We have found that the few first-year ridge and rubble features that have been identified do show a high correspondence with major stress and deformation patterns in first-year ice. (See [3].)

4. CONCLUSIONS

This paper has evaluated the performance of an ice-roughness algorithm that was developed using a relatively new procedure in

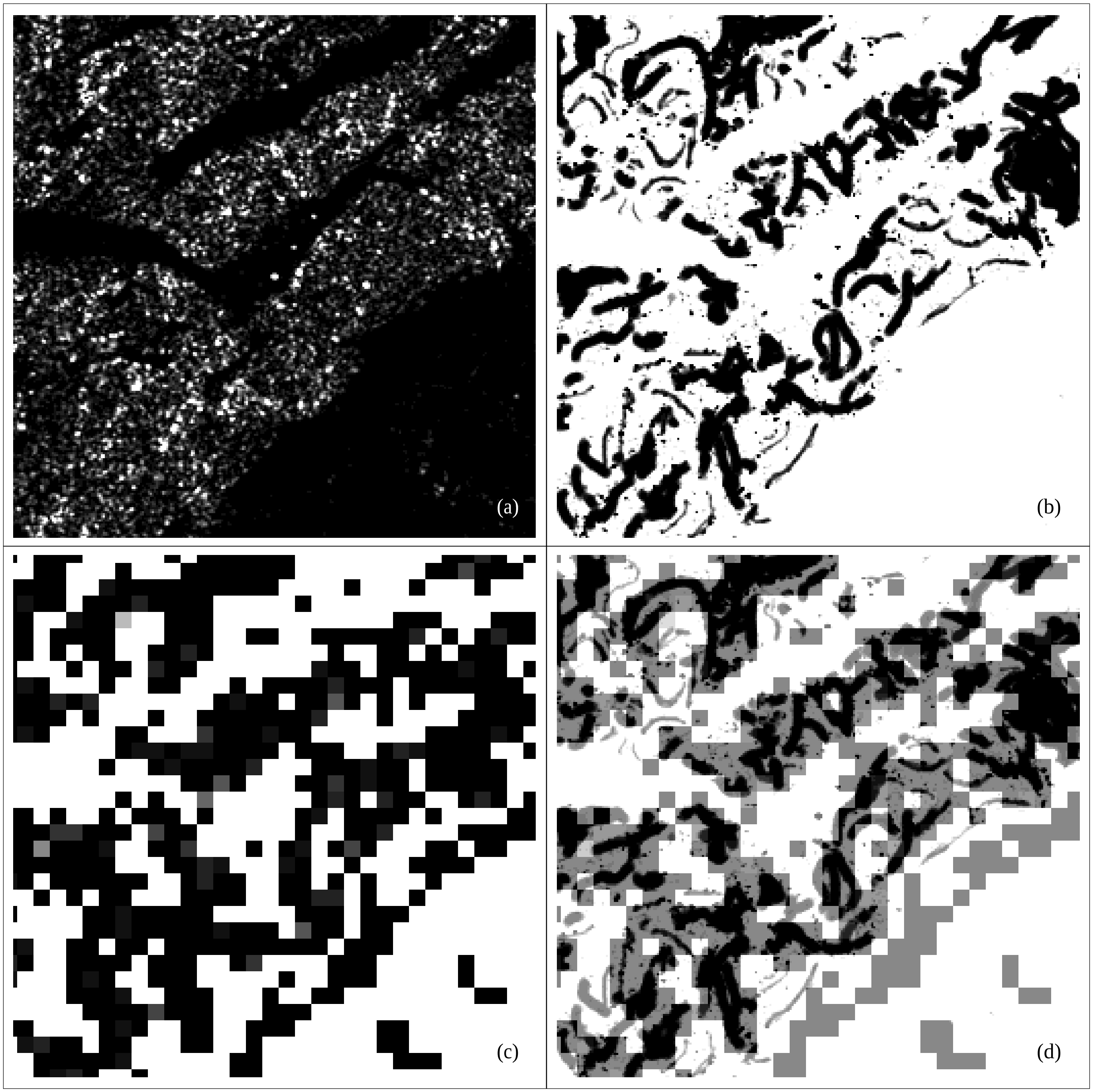


Figure 2. Results. (a) High-Resolution Subimage. (b) Manual Interpretation. (c) Derived Data Product. (d) Comparison.

computer-assisted software design. To evaluate this algorithm, we used ERS SAR image data that coincides with *in-situ* observations obtained during LEADEX '92. The results have shown excellent agreement between the derived data product and a manually interpreted ERS SAR data product. The algorithm has been shown to extract features corresponding to ridges and rubble fields in multiyear ice. We have suggested that the algorithm does extract enough of the ridge and rubble features in first-year ice to show gross deformation patterns. ■

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