EVALUATING THE POTENTIAL OF UNSUPERVISED CLASSIFICATIONS FOR ICEFOOT CARTOGRAPHY USING RADARSAT-2 HIGH RESOLUTION IMAGERY.

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ABSTRACT

With the advent of a new generation of high resolution polarimetric SAR satellites, the extraction of ice structures as narrow as the strip of sea ice that forms the icefoot becomes potentially feasible. One RADARSAT-2 scene was acquired on February 15, 2011 and three processing chains were tested to accomplish this task. It was found that the Lee and Pottier [2, 4] method and more specifically the information imbedded in the class distribution offers a great potential. While some environments such as sea water or a city may be sorted out using a single class, the more diverse range of mechanisms involved into the backscattering processes in icefoot and peat bog areas make the class distribution a better indicator to automatically extract the icefoot.

Index Terms—Polarimetry, Icefoot, RADARSAT-2.

1. INTRODUCTION

Knowing about icefoot climatology recently emerged as an essential part in decision-making policies to address the problem of coastal erosion and natural hazards in the St. Lawrence estuary and gulf (Quebec, Canada). The icefoot sets up on beaches in late fall, cementing sediments in an ice matrix which main impact is to increase the sediments resistance to the erosive action of winter storm waves as well as prohibit sedimentary transport along shore [1] thus protecting vulnerable infrastructures from damage. Yet the icefoot can itself be an erosion vector as it drifts away during melting events. The lack of methods for large-scale icefoot cartography prevents estimating its role in terms of coastal sediment budget. As climate changes may cause a reduction the period which sees a stable icefoot develop along the shore lines of northern environments, it becomes necessary to refine tools to map its distribution and help management of shore lines.

With the advent of a new generation of satellite high resolution polarimetric synthetic aperture radar (SAR) instruments, the extraction of ice structures as narrow of the strip of sea ice that forms the icefoot becomes potentially feasible. However, the classification of a pixel as an icefoot without losing much resolution remains a challenge.

2. ICEFOOT DEFINITION

Landfast ice is a predominant form of ice in the Saint-Lawrence estuary, however the nomenclature of the different forms of coastal ice that can be observed is still in development. In this paper landfast ice will be considered as an immobile icesheet attached to the coast for 20 consecutive days. By opposition, sea ice is any form of ice floating in open water and moving according to currents and winds. The main focus in this paper will be put on the near shore ice complex (NIC) and specifically on the icefoot.

The icefoot (fig. 1) is a narrow strip of ice that anchors landfast ice to the shoreline. It consists of the part of the ice that makes contact with the sea floor eventually incorporating a layer of frozen sediment into its bottom layer. The icefoot can be subdivided in two sections: the upper icefoot and the lower icefoot. [3] They are separated by pressure cracks that form on the beach hinge line. The upper icefoot is located on the upper foreshore which is delimited by the shoreline and the hinge line. In absence of lower icefoot, the upper icefoot is often bordered by a short cliff. The height of this cliff is usually of the same order of magnitude as the maximal winter tide amplitude. The upper icefoot can sometimes be accompanied by a nival icefoot on its upper limit. This ice is the result of the metamorphism of the snowbank into ice. The lower icefoot is localized on the lower foreshore. The lower icefoot is grounded at low tide and floats at high tide, therefore its upper limit is the hinge line and its lower limit is located where the ice is always floating. The length of the lower icefoot depends on the foreshore topography and can be in some cases extend over a few kilometers.

Figure 1: Photograph of Manicouagan Peninsula’s shore line at site #2. The upper icefoot is clearly visible between the base of the cliff and the open water.
3. DATA ACQUISITION

Located on the north shore of the Saint-Lawrence River, the Manicouagan Peninsula presents a coastline of about a 100 kilometers of which one third is in erosion. With erosion rates up to one meter per year in some areas [4], it offers excellent test sites to study coastal erosion factors such as the impact of icefoot development/non-development over the winter season. Two study sites were surveyed in the 2010-2011 winter season. A detailed cartography of the upper icefoot was first performed as a reference data set to validate the classification results. In conjunction with each image acquisition, icefoot profiles and ice cores were collected to document the various parameters influencing SAR backscattering physics. Measurements and samplings performed on these occurrences were geo-referenced with a ± 2m precision.

The upper icefoot surveyed on February 14, 2011 has a mean width of 40 meters. Two ridge lines running parallel to the coast line can be observed at 20 and 35 meters from the base of the cliff delineating the lower limit of the icefoot. Also, a low salinity smooth surface partially covered by dry snow was observed on the upper part of the icefoot area. It results from an input of liquid water flowing down from the peat bog on top of the cliff and characterized by a high content in fine particles. In contrast, the lower portion of the icefoot shows contents of coarser sediments mixed with consolidated frazil. At the time of the acquisition, i.e., February 15 2011 at 11:00 (UTC), low tide conditions was prevailing (height of 0.7m) and the air temperature remained well below the freezing point for the whole day (-18 to -11°C)

The RADARSAT-2 FQ1 scene analyzed in the present paper, was acquired on February 15 2011 at 11:00:27Z in fully polarimetric mode. FQ1 has a mean incidence angle of 37° and a mean spatial resolution of 8m. A Landsat ETM+ scene was also acquired the same day at 15:08:54Z and used for large scale validation and photo-interpretation.

4. DATA PROCESSING AND CLASSIFICATION METHODS

PolsarPro and PCI Geomatica softwares have been used for image processing and orthorectification. The latter was performed using the rational function model developed by PCI for the orthorectification of RS2 data using ground control points extracted from the scene metadata. The ArcInfo software suite was then used to proceed with the validation of the classifications.

SAR processing modules typically includes speckle-removing filters, polarimetric decomposition and classification algorithms. Several processing combinations were tested in order to produce a cartography of the NIC. Based on the literature on ice remote sensing using fully polarimetric SAR data and on their availability in the processing softwares, three processing chains were selected. Methods that had shown potential for the classification of sea ice and river ice using state of the art and high resolution classifications processes were given priority.

The Pauli decomposition is a decomposition of the Sinclair matrix [S] into three orthogonal matrices respectively describing single bounce backscattering (HH+VV), multiple bounce backscattering (HH-VV) and volume backscattering (2HV). The false color image composite thus generated gives indications on the backscattering mechanisms that mostly define the different areas of a scene. The land was masked, a 7x7 KUAN speckle filter, a median filter and then the fuzzy K-mean classifier were applied to the composite image to classify the different surfaces according to their main scattering mechanism. This method was inspired from a study published by Weber et al. [6] in which they classify river ice cover with high resolution RADARSAT-1 data. In the present work this method is extended to benefit RADARSAT-2 QUADpol mode fully polarimetric data.

The other methods tests the Cloude and Pottier HAta decomposition technique [2]. Single look complex (SLC) data were converted into a coherency matrix form [T3] then filtered with a directional polarimetric Lee filter. Five different kernel sizes were tested. IDAN filters of different kernel size were also tested with no significant improvement in classification accuracy to justify the increased resources needed by this filtering algorithm and won’t be discussed any further in the present paper. The polarimetric eigenvector, eigenvalue decomposition was then applied to the filtered [T3] data set, to extract the Entropy (H), Anisotropy (A) and alpha angle (α). Using those results, supervised and unsupervised classifications were performed.

The supervised classifications used the Support Vector Machine (SVM) non-linear classification technique while the unsupervised technique used the Lee et al. [4] method as implemented for the classification of sea ice cover by Scheulch and Caves [5].

5. CLASSIFICATION RESULTS AND VALIDATION

Following the different processing strategies exposed in the previous section, we computed classification statistics over the area that field measurements and observations characterized as the ice foot area. Figure 2A depicts the geo-referenced ice foot area (in peach) on a Landsat ETM, while figures 2B-C-D-E and F give examples of results obtained from a range of methods and filters. On the Pauli composite (Fig. 2B) the red and blue dominating colors over the icefoot and peat bog areas suggest that surface diffusion (odd reflection) and multiple bounce scattering mechanisms may each account for about 50% of the reflected signal.
Table 1:

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Table 1: Results from the different classification processes. In the first column, the case "11+3" means that a 11x11 Enhanced Polarimetric Lee filter was used on the T3 matrix and that boxcar 3x3 filter was also used to further smoothen the classification results.

In addition, as expected, the mainly green colored forest indicates volume scattering and the black water specular reflection. It follows that forest and open water are environments that are more easier to distinguish from the ice foot than the peat bogs is. It illustrates how misclassification problems occur between peat bogs and the icefoot.

Basically, classification techniques classify pixels in 8 (or 16) classes according to one or more parameters value which meaning depends on the applied processing method. As an example, the WHα classification is related to the underlying physical scattering mechanisms and the probability that a single or more mechanisms be of importance in the backscattering processes from a given pixel. As a consequence, the relative distribution of the different classes may be as much an information as the dominant class can be. As a transition area between the land and the ocean, the ice foot is by definition a site characterized by its variability and as such is expected to

Figure 2: A- Landsat ETM+ false color composite B- Pauli decomposition; blue : hh+vv; green: 2hv; red : hh-vv C- 7x7 Fuzzy K-mean classification from a 5x5 kuan and 5x5 median filtered Pauli decomposition. D- SVM classification from 5x5 Lee filtered T3 matrix. E- Wishart classification of Entropy, Anisotropy and α angle decomposition parameters from a 5x5 Lee filtered T3 matrix. F- Wishart, Entropy, α angle classification from 5x5 Lee filtered T3 matrix.
mix pixels from several classes which distribution could be the actual signature.

Table 1 shows statistics computed from the two test sites and give the percentages of the two dominant classes over the ice foot areas. It can be observed that the dominant classes rarely reach 80% and that large filter sizes are necessary to achieve such values which can be detrimental to the extraction of narrow features. Table 2 compiles statistics derived from the WH$_\alpha$ 5x5 classification process over the different types of environments found over our test image. Percentages are compiled for the four dominant classes. These results clearly show it is possible to identify fresh bottom-fast ice, forest and city areas. The differentiation of open water, smooth surface ice and frazil is more problematic. This is probably due to the fact that specular reflection is dominant in these environments. It can also be observed that peat bog and icefoot share a similar primary class, however, the icefoot presents a greater variability in the distribution of classes. In addition these results show that icefoot class repartition is slightly less grouped than the peat bog’s, however this has yet to be statistically proven. Therefore, we must be cautious in interpretation of the classifications results which may vary depending on the incident angles and the weather conditions at the time of the acquisition. Further investigations with more scenes and a range of ice conditions will be the next step. However, it is obvious that while the dominant class could allow to identify some environments it’s clear that for more diverse ones the recourse to several classes would be a better indicator.

5. CONCLUSION

Three processing chains with multiple parameters were tested on a series of RADARSAT-2 QUAdpol images. The results of these analyses were compared and the best classification method were identified according to the ground truth validation data available. Considering the limitations of unsupervised classifications, it was found that results provided by the Lee et al. method and more specifically the information imbedded in the class distribution has a great potential to contribute to a better understanding of coastal ice characterization and contribute to the decision making process concerning northern coastal regions.

11. REFERENCES