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Validation of Radarsat imagery using In situ measurements from first year ridged ice

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VALIDATION OF RADARSAT IMAGERY USING *IN SITU* MEASUREMENTS FROM FIRST YEAR RIDGED ICE

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ABSTRACT

One first year ridge representative of the ridges characterized during a field program off West Coast Newfoundland in March 1999 is used to develop a comprehensive methodology for on-ice SAR validation studies. This validation study includes measurements such as the temperature, salinity, density, microstructure and *in situ* confined compressive strength of the ice. A RADARSAT-1 ScanSAR scene is used to illustrate how the ice properties influence the microwave signature of ridged ice and to determine the feasibility of using ScanSAR images for ridge identification. Analysis showed that ScanSAR scenes could be used successfully to identify areas of deformed ice.

INTRODUCTION

Ridged and highly deformed ice can be formidable features that result in potentially significant loads on structures. Deformed ice features such as those are best avoided by vessels transiting ice-covered waters. Images acquired from space-borne synthetic aperture RADAR (SAR) offer excellent means of identifying areas of deformed ice without the need for reconnaissance (using low-level flying aircraft) or direct on-ice contact. Studies have been conducted formerly to determine the feasibility of using SAR imagery to identify ridged ice (Pearson and others, 1980; Johansson, 1989; and Simila and others, 1992). Those studies were based upon SAR imagery acquired at a resolution of 40 m or less and, typically, aerial photography was used to validate the SAR imagery.

This paper also examines the microwave signature of the ice using SAR imagery. Two aspects of this study differ from previous work. In this analysis, the properties of the ice were measured *in situ.* Reported here are the ice properties of most relevance to SAR validation studies; properties such as the ridge surface topography, ice temperature, salinity and density, microstructure of the ice and the *in situ* mechanical strength of the ice. Second, coarse resolution (100 m) imagery from RADARSAT ScanSAR mode was selected for this study because of the wide application of ScanSAR scenes and because it was proposed by Melling (1998) that the inability of a RADAR to fully resolve features does not necessarily preclude feature identification.

BACKGROUND

A two-week field program to characterize first year ridges off the West Coast of Newfoundland was conducted in March 1999. The field program was conducted from 7 to 22 March 1999 in the northern part of the Gulf of St. Lawrence, with Plum Point as the point of base operations. Ice conditions in the Gulf during the winter of 1998/99 were light, due to the unseasonably mild temperatures and the large amount of open water. During the field project the air temperatures reported for the nearest weather station (Stephenville, 450 km south of Plum Point) were from 1.2 to 10°C above normal. The light ice conditions made it difficult to find first year ridges suitable for this study; only ten first year ridge sites were sampled during the two-week field program (Figure 1).

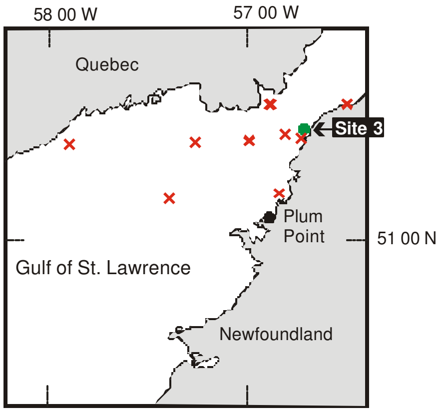


Figure 1 Sampled first year ridges

Although the ridge characterization studies off the West Coast of Newfoundland were initiated by hydrocarbon development, the *in situ* ice measurements acquired during the study provided an excellent data set with which to validate RADARSAT imagery. This paper focuses upon the first year ridge that was most completely characterized during the fieldwork, Site 3. The reader is referred to Johnston and Flett (2001) for a more complete discussion of additional ridges sampled during the field program and subsequently examined in the ScanSAR scenes

RIDGE MEASUREMENTS AT SITE 3

Most of the ridges sampled during the field program were accessed by helicopter, weather permitting. An aerial reconnaissance of the ice along the Northern Arm of Newfoundland indicated that there were two closely spaced ridges north of Plum Point (Figure 2). One of the ridges, designated as Site 3, was about 100 m long and 3.8 m high and was bounded by a large slab of smooth ice on its north side. The spatial coordinates of Site 3 were 51°18.7N, 56°45.4W (noted by GPS, ±30 m). The ridge at Site 3 was the most extensively examined site of the sampled ridges. Measurements at Site 3 were acquired on four different days, between 11 and 16 March.

Figure 2 First year Ridge at Site 3, photos taken on 11 March

Surface Topography

The surface topography of the ridge at Site 3 was surveyed along two lines. Figure 3 shows the results of the survey; where the survey stations have been marked. The keel of the ridge was measured along four well-documented auger lines. Those measurements indicated that the ridge was grounded in about 5.5 m of water. Most of 39 sail blocks that were measured in the ridge were about 0.30 m thick. The uniform thickness of the sail blocks indicated that the ridge most likely formed during a single ridging event that involved floes of equivalent thickness. The lengths of the sail blocks typically ranged from 1 to 2 m and were more randomly distributed than the sail block thickness.

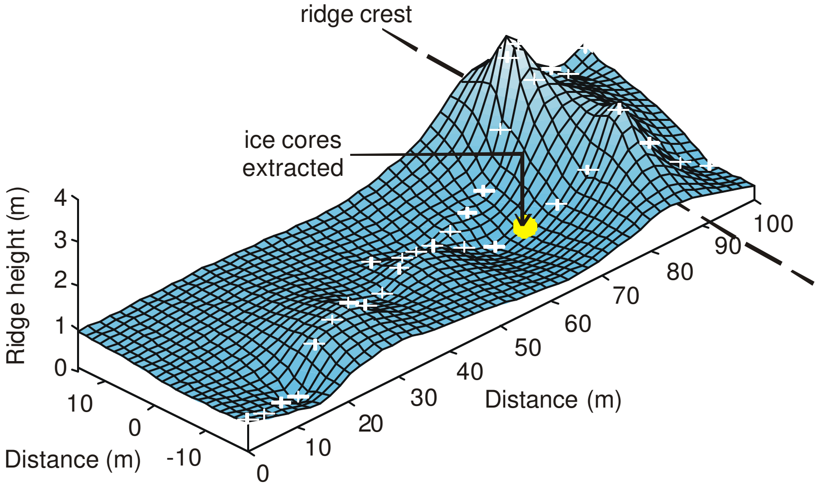


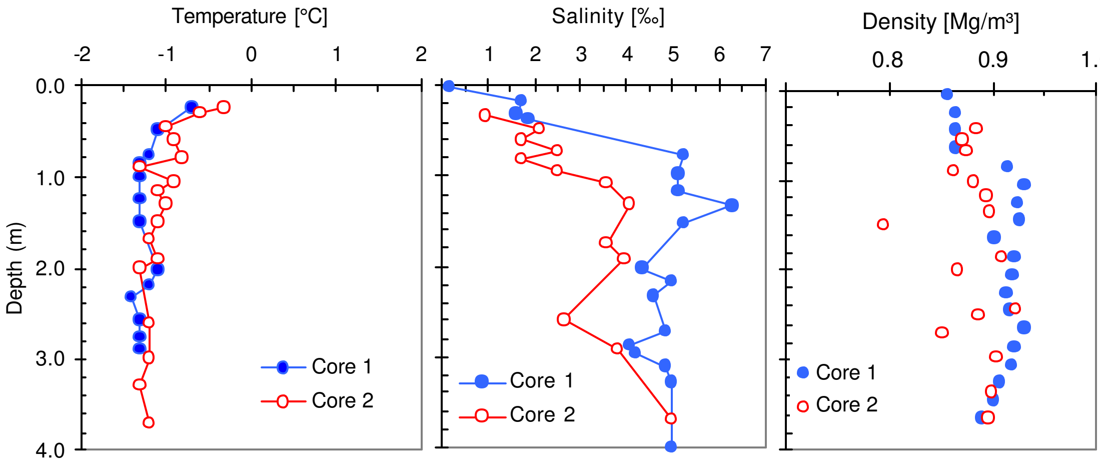
Figure 3 Surface topography of first year ridge at Site 3

Temperature, Salinity and Density

Two ice cores were extracted from a relatively level area of ice on the perimeter of the ridge, about 25 m from the ridge crest (Figure 3). Both ice cores fragmented during coring. The ice core was pieced together based upon information about the presence of voids noted while using the mechanical corer to remove the cores. The estimated thickness of the two cores was about 4.0 m.

Ice Temperature

The temperature of the cores was measured as quickly as possible to minimize ambient air temperature effects on the ice temperature. Small holes were made in the cores at 0.25 m intervals. Most the holes required simply pushing the drill bit into the ice; such was the lack of integrity of the ice. Figure 4 shows the temperature profiles of the two cores. The ice temperature ranged from approximately 0°C at the top ice surface to –1.4°C. The temperature of the uppermost ice surface was not reported because the loosely consolidated surface layer of ice (snow ice) fell apart during handling.



(a) ice temperature (b) salinity (c) density

Figure 4 Physical properties of ridged ice from Site 3

Ice Salinity

After the temperature of the two cores had been measured, the cores were sectioned into discs and bagged for future salinity measurements. Due to the mild air temperatures, brine drainage occurred as the temperature profiles of the core were taken and while the core was sectioned into discs. Consequently, the measured ice salinity would have been less than the *in situ* salinity. Figure 4-b shows that the ice salinity ranged from near zero to 6.3 ‰.

Ice Density

Figure 4-c shows the density of the ridged ice for two ice cores from Site 3. The reported densities were measured using the submergence technique (Croasdale et al., 1999), whereby ice samples were submerged in a fluid of known density and the displaced volume and change in sample weight were measured. The submerged ice density from the two cores ranged from 0.85 to 0.93 Mg/m³ (with the exception of the one sample density of 0.79 Mg/m³).

Alternately, the ice density was calculated by the bulk volume technique, which is based upon the measured weight and dimensions of the sample. The bulk volume technique produced ice densities that were, on average, about 3% lower than the submerged ice densities (Croasdale et al., 1999).

Ice Microstructure

Full-thickness pieces of ice from two sail blocks and a one-metre piece of ice along the perimeter of the ridge crest were removed for microstructural studies. The ice pieces were placed in a thermal cooler, packed with snow and transported (at below freezing temperatures) to laboratories at the Canadian Hydraulics Centre (CHC) in Ottawa, Canada. The ice was inspected upon arrival at CHC; the cores remained solidly packed with snow and showed no evidence of melt. After the ice had been inspected it was again packed into the thermal coolers and stored at –10°C until microstructural work was undertaken, several weeks later.

Microstructure of Representative Sail Block

The ice sheet thickness at the time of ridge formation can be inferred from the thickness of the sail blocks (taking into account changes in ice thickness due to erosion). In addition, the sail blocks preserve information about the basic granular structure of the ice sheets involved in the ridging process. Weathering does not change the ice crystallography, however it can radically change the size and composition of the brine and air inclusions embedded in the ice. Since brine and air inclusions are especially important for characterizing the microwave scattering properties of the ice, they are focused upon below.

Figure 5 shows portions of the horizontal and vertical thin sections prepared from a piece of one of the sail blocks from Site 3. The thin sections were prepared at below freezing temperatures using the double-microtoming technique (Sinha, 1977). To illuminate inclusions in the ice, both sections are shown under parallel-polarized light. The horizontal thin section in Figure 5-a shows numerous centimeter-sized voids (each marked by an "X"). The section also contains thousands of millimeter-sized air pockets. The small air pockets are shown more clearly in the zoomed photograph of the vertical section (Figure 5-b). When the ridge formed, most of the inclusions in the ice resulted from entrapped brine. The weathering process leached brine from the ice which created an abundance of air pockets. The original brine inclusions would have been considerably smaller than the air pockets shown in Figure 5.

(a) horizontal thin section, with voids marked (b) vertical thin section, zoomed

Figure 5 Thin sections of sail block under parallel-polarized light

Microstructure of Ridged Ice

A one-metre thick ice block was removed from the ice on the perimeter of the ridge crest, near the location from which ice cores were extracted (Figure 3). The microstructure of the top metre of ice was documented with vertical and horizontal thin sections. There was a 30 mm layer of freshwater ice crystals at the top surface of the ice (Figure 6-a). The freshwater layer most probably resulted from refrozen melt water that had pooled on the ice surface. Beneath the surface crust, the ice consisted of fine-grained, snow ice that extended to a depth of about 0.50 m.

At a depth of 0.50 m, columnar grains (20 to 30 mm long) became established (Figure 6-b). The horizontal section (not shown) revealed that the ice consisted of randomly oriented columnar grains (about 10 mm wide) with jagged grain boundaries. The ice at this depth contained numerous inclusions about 2 mm long. The thin sections below a depth of 0.67 m (not shown) were comprised of mostly fine-grained ice with a few narrow, columnar grains.

(a) ice depth 0 to 0.20 m

(b) ice depth 0.50 to 0.67 m

Figure 6 Vertical thin sections of ridge ice at Site 3

In Situ Confined Compressive Strength

Traditionally, SAR validation studies with an on-ice component have characterized the ice using the ice temperature, salinity, density and microstructure (Shokr, 1994; 1995). Validation studies would benefit from measurements of *in situ* ice strength measurements since one of the primary applications of remotely sensed imagery is to relate the microwave signature of the ice to its thickness and, in turn, the ice strength. Measurements of the *in situ* confined compressive strength of the ice require minimal effort when using a borehole jack assembly. The borehole jack has been used extensively to measure the *in situ* strength of first year sea ice (Sinha, 1986, 1990, 1997; Masterson et al., 1997) and river ice (Prowse et al., 1988). Previously, however, only two SAR validation studies have made use of the borehole jack for ice strength measurements (Sinha, 1989; Johnston and Frederking, 2000).

Figure 7 is a schematic of the borehole jack assembly. The borehole jack consists of a high-strength stainless steel hydraulic cylinder with a laterally acting piston. The indentor plates of the borehole jack are curved to match the wall of the borehole, so that the jack fits easily into the 15 cm diameter borehole made by the coring device. Once lowered to a specified test depth, the jack is activated and hydraulic pressure is applied to the indentor plates. The oil pressure and the total displacement of the indentor plates are recorded by an external digital data acquisition system.

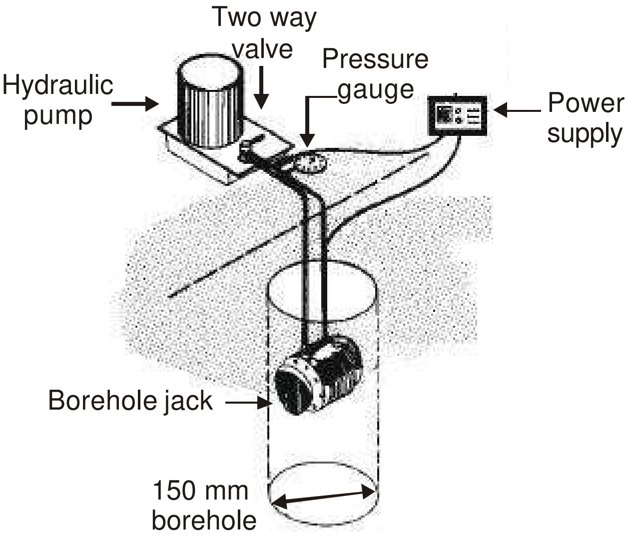
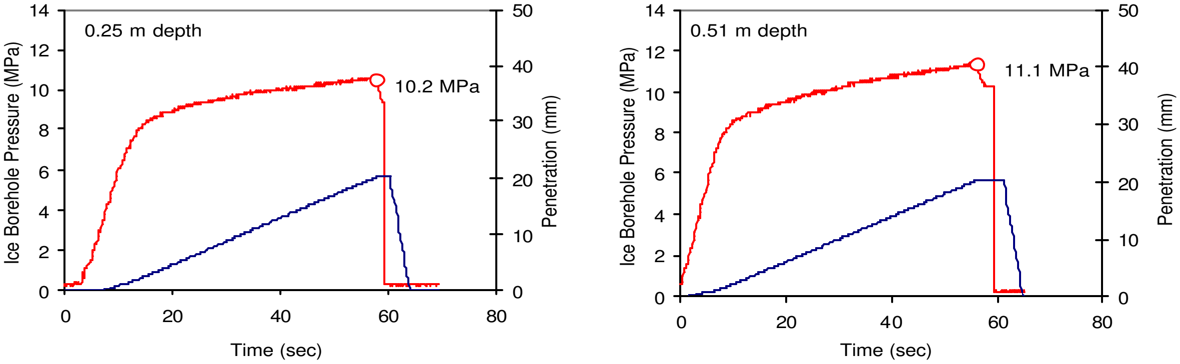


Figure 7 Borehole jack assembly

The *in situ* mechanical strength of the ice was measured for the first year ridge at Site 3. A profile of the ice strength versus depth was obtained near where the cores were extracted (Figure 3). The borehole jack was lowered into the borehole and tests were conducted throughout the full-thickness of the ice (at depth intervals of 0.25 m). Each test was terminated when the maximum penetration of the indentor (25 mm) was approached.

Figure 8 shows results from the two borehole jack tests that were conducted at ice depths 0.25 m and 0.51 m. The ice borehole pressure (or *in situ* confined compressive strength) and the indentor penetration were plotted against elapsed time. The ice borehole pressure increased with increasing indentor penetration until the indentor was retracted, after about 60 seconds (penetration of 20 mm). As the indentor was retracted, the ice borehole pressure rapidly decreased. The maximum ice borehole pressure measured during the two tests was 10.2 MPa and 11.1 Mpa. The surface layer of ice was slightly weaker than the ice at a depth of 0.51 m.



(a) depth 0.25 m

(b) depth 0.51 m

Figure 8 *In situ* confined compressive strength of surface layer of ridged ice

SIGNATURE OF RIDGED ICE IN RADARSAT SCANSAR IMAGERY

Having performed the measurements needed for RADARSAT validation studies, numerous ScanSAR scenes were provided to CHC by Canadian Ice Service (CIS) to determine whether the ridges could be detected in the relatively coarse resolution imagery. Figure 9 shows a sub-image that was extracted from one of the ScanSAR (Wide) images acquired by RADARSAT-1 on 9 March (descending pass). ScanSAR images have a pixel spacing of 50 m (100 m resolution) and cover a range of incidence angles from 20° to 49°. The ScanSAR scenes provided for this analysis were processed using a range-dependent look-up-table (LUT). The LUT balances the RADAR signatures across the entire swath (based upon representative backscatter measurements from first year ice in the Gulf of St. Lawrence). The scenes were an array of digital numbers, ranging from 0 to 255.

The ScanSAR scene from 9 March included Site 3 in addition to four other first year ridge sites sampled during the field program (Figure 9, denoted by crosses). Since the sampled ridges were of the order of one pixel (50 m), a special algorithm was developed to locate the ridge-related pixel (according to the ±30 m GPS resolution). The reader is referred to Johnston and Flett (2001) for a more complete description of the methodology.

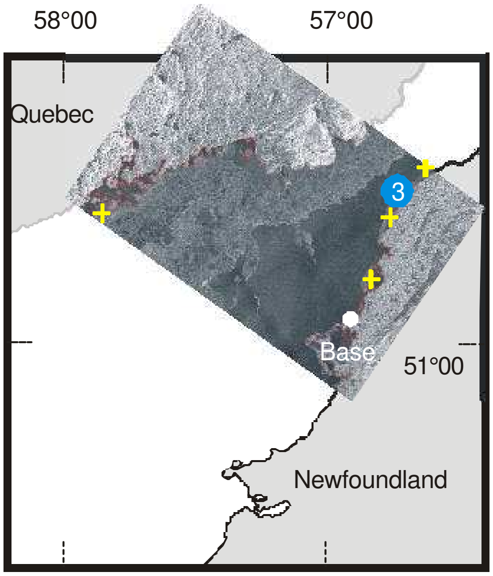
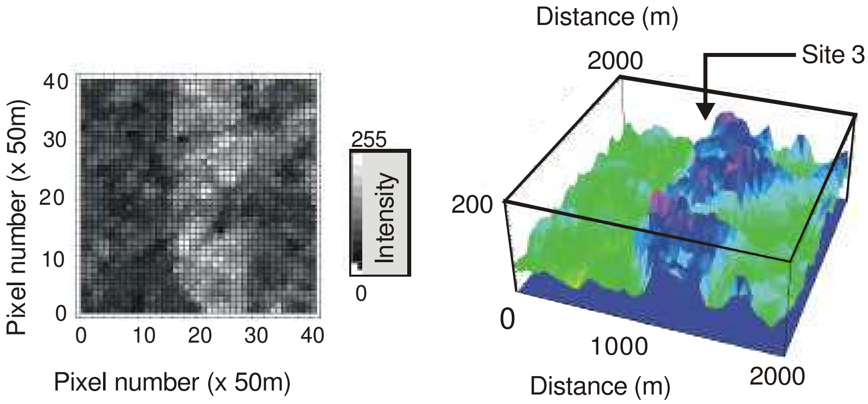


Figure 9 March 9 ScanSAR scene

After the Site had been identified, a sample area of 40 pixels by 40 pixels (2000 m across) was selected for each ridge-related pixel. The pixel intensity of the sample area was examined using a two-dimensional, grey-scale image (Figure 10-a). Given the limitations of the two-dimensional representation, the sample area was also plotted in three-dimensional color, whereby pixel intensity was expressed relevant to the distance in the XY plane (Figure 10-b).



(a) (b)

Figure 10 Digital numbers associated with sample area centered on Site 3

Field measurements showed that, on 9 March, the linear region of high-intensity pixels shown in Figure 10-b corresponded to the ridged and deformed ice around Site 3. Because the ridge at Site 3 was embedded in a region of deformed ice, only the general topography of deformed ice was able to be determined from the ScanSAR scene. Analysis showed (Johnston and Flett, 2001) that it was not possible to resolve individual ridges from the relatively coarse resolution imagery under the conditions associated with the West Coast Newfoundland field project.

CONCLUSIONS

The first year ridge characterization study conducted off West Coast Newfoundland in March 1999 was used to develop a methodology for on-ice SAR validation studies. The methodology established here included ice property measurements of most relevance to the microwave scattering properties of sea ice. Those measurements included elements that traditionally have been measured during validation studies; properties such as ice temperature, salinity, density and microstructure. An additional component was added to the conventional suite of validation measurements however; the *in situ* confined compressive strength of the ice. The *in situ* ice strength was included as important parameter because the potential of using SAR imagery to infer the strength of the ice has both immediate and far-reaching benefits for end-users of remotely sensed imagery.

A representative RADARSAT-1 ScanSAR scene was used to illustrate how the ice properties influence the microwave signature of ridged ice and to determine the feasibility of using ScanSAR images for ridge identification. Analysis showed that ScanSAR scenes could be used successfully to identify areas of deformed ice. The possibility of using ScanSAR scenes to distinguish isolated ridges could not be evaluated under the field conditions experienced in March 1999.

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