Sea Ice Type and Open Water Discrimination for Operational Ice Monitoring with RADARSAT-2

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Abstract- **Envisat ASAR Alternating Polarization (AP) modes are evaluated to determine the potential utility of multi-polarization data for operational sea ice monitoring in preparation for RADARSAT-2.**

I. INTRODUCTION

The Canadian Ice Service (CIS) promotes safe and efficient maritime operations and protects Canada's environment by providing reliable and timely information about ice and iceberg conditions in Canadian waters. The CIS relies on a suite of both airborne and satellite sensors to operationally monitor ice conditions in Canadian coastal and inland waterways. Wide swath (>300km) C-band HH satellite SAR from RADARSAT-1 and Envisat ASAR, are the primary EO datasets for ice monitoring. CIS has been examining Envisat ASAR Alternating Polarization (AP) mode data to evaluate the potential utility of multi-polarization data for sea ice monitoring, particularly in preparation for RADARSAT-2 wider swath dual-channel ScanSAR modes offering coincident like and cross-polarized data e.g. HH and HV channels.

While the availability of a second polarization channel suggests the possibility for additional information, as an operational user ordering large volumes of SAR imagery for near real-time analysis CIS need to determine if there is significant additional information content to justify ordering two channels of RADARSAT-2 ScanSAR data. Given the associated overhead of additional data volume, potential latencies, and analysis time when using multi-polarization data, this is a very important question. If we are to use multi-polarization data operationally we need to determine the best way to visualize the information and how to display in our operational systems as well as the optimal way to combine and/or enhance the two channels of data. Additionally, we would like to establish if multi-polarization data can improve automated/semi-automated ice classification to levels acceptable for operational implementation and use.

Towards answering the above questions, various studies have been supported and undertaken over the last 2-3 years, with a particular focus on the APH (HH/HV) cross-polarization mode of Envisat ASAR AP data. It has been found that dual polarization mode may enhance our ability to extract sea ice information under certain ice and environmental conditions. As a continuation of this research, new APH data sets were recently acquired in the Canadian Arctic during the late summer and early fall of 2005. The objective was to further assess the potential of HH/HV data sets with a particular comparison between steep and shallow incidence angle modes. We provide some preliminary results from this analysis and comment on the potential utility for operational sea ice monitoring.

II. DATA

To facilitate this ongoing validation and evaluation, several overlapping ASAR APH (HH/HV) data sets were acquired in Canadian Arctic waters to further investigate multi-polarization sea ice signatures from a space-borne platform. While the Alternating Polarization data are only available in narrow swaths (<100km), making it less than ideal for strategic operational monitoring, it gives us the possibility to evaluate the dual-channel ScanSAR planned for RADARSAT-2. Each overlapping data set includes one image acquired at a steep incidence angle while the partner image was acquired at a shallower angle. The images were planned in this way so the quantitative measurements of the same ice features could be categorized at the varying incidence angles. Table 1 indicates the image details of each pair.

TABLE 1.
IMAGE ACQUISITIONS

Location	Image Date	Beam	Inc. Angle Range
McDougall Sound	Oct 16th 2005	IS3	26.0 – 31.4
	Oct 18th 2005	IS6	39.1 – 42.8
Beaufort Sea	Sept 12th 2005	IS6	39.1 – 42.8
	Sept 14th 2005	IS1	15.0 – 22.9

III. METHODS

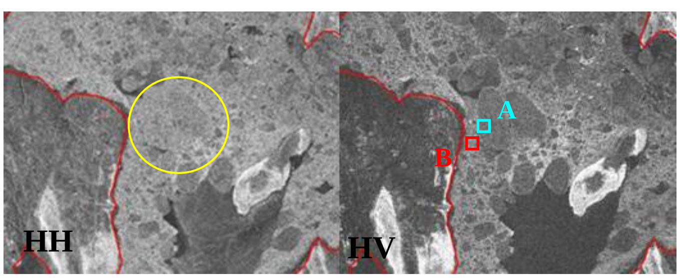
In order to assess the utility of dual-polarization SAR data, both qualitative and quantitative analysis was performed on the image data sets. All image data sets were geocoded to facilitate comparison of features and analyzed visually. CIS ice charts were coupled with meteorological data to aid in understanding ice and environmental conditions at the time of image acquisition. The ice charts were based primarily on RADARSAT-1 data acquired within a day or less of the

ASAR acquisitions, and are considered the most accurate representation of ice conditions at time of issue. Field measurements collected by the Canadian Hydraulics Centre of the National Research Council were available for the McDougall Sound data set. Various in situ measurements provide detailed information on ice conditions and features for this area. Hourly observations made at Sach's Harbour and Tuktoyaktuk meteorological stations were used to categorize conditions for the Beaufort Sea data set. Calibration and the extraction of quantitative measurements were made using the VUSAR software package created by the Canada Centre for Remote Sensing.

IV. RESULTS

A. McDougall Sound– October 2005

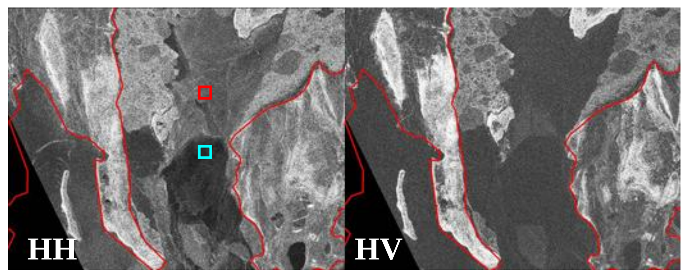
Analysis of airborne polarimetric data in the Central Canadian Arctic suggest that only small differences can be expected between the two co-polarization channels for discriminating between the multi-year and first year sea ice for data acquired under cold and dry winter like conditions [1]. Alternating Polarization data acquired over McDougall Sound in October 2005 under similar conditions (-12 to -16 °C) give us an opportunity to look at this discrimination in cross-polarization data. When visually comparing the two channels in the IS3 image, there is greater contrast between the multi-year floes and the surrounding rough ice in the HV channel when compared with the HH channel (Figure 1). In the HH channel the multi-year floe is almost indistinguishable in the rough first year ice matrix. However, this same floe is easily defined in the HV channel. The quantitative measurements in the table in Figure 1 support these visual observations. In the HH channel, the difference between the measured sigma naught (σ^o) of the multi-year floe (A) and the surrounding rough first year ice (B) is only 0.3dB. However, the difference between the multi-year floe and the rough first year ice in the HV channel is much larger at 1.7dB. Observations are similar for the shallower incidence angle IS6 image, with a slightly less drastic visual contrast appearance between the HH and HV channels, but a similar measured contrast difference of 1.6dB.



IS3 – Oct 16th 2005	HH (σ^o)	HV (σ^o)
MYI Floe (A)	-10.1	-19.7
Rough FY (B)	-10.4	-18.0
Difference	**0.3**	**1.7**

Figure 1. Multi-year floe (inside yellow circle) in a background of first year ice. The larger contrast, both visually and quantitatively, between MYI and FYI in the HV channel makes floe delineation much easier.

Based on early ASAR Cal/Val results there was some concern that Envisat ASAR cross-polarization returns over thin, new ice and open water could be noise floor limited [2]. Further analysis of data sets collected in the Gulf of St. Lawrence [3] and the Canadian Arctic [4] confirmed this. Similarly, our analysis of the McDougall Sound data set supports these earlier findings. Figure 2 shows different consolidation zones of smooth first year ice in McDougall Sound in the IS3 image. Considerable detail indicating the changes in ice thickness can be seen in the HH channel. However, almost all of this detail is lost in the HV channel. Backscatter measurements taken over sample areas in each of the two consolidation zones further substantiate these extremely low contrast figures in the HV channel. A difference of 6.4dB can be seen between the two areas in the HH channel, while the same areas in the HV channel only yield a difference of 0.4dB. This minimal difference makes discrimination of the consolidating, thinner (< 30 cm) first year ice types impossible.

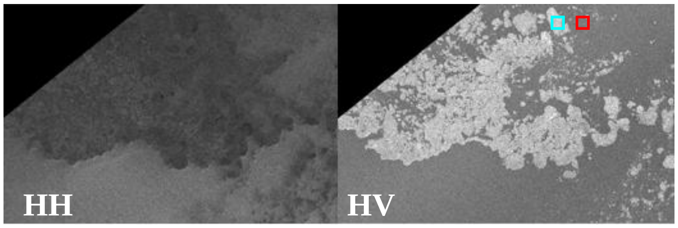


IS3 – Oct 16th 2005	HH (σ^o)	HV (σ^o)
Red Square	-13.8	-22.9
Blue Square	-20.2	-23.3
Difference	**6.4**	**0.4**

Figure 2. First Year Ice (FYI) consolidation zones. Almost all detail is lost in the HV channel. This is due to the fact that the cross-polarization signal response from the ice is at or below the noise floor of the ASAR sensor.

B. Beaufort Sea – September 2005

A recurring problem for CIS Ice Analysts is the tracking and typing of multi-year ice in the summer season. Increased temperatures melt the snow cover on the sea-ice surface. The liquid water added to the snow volume masks the multi-year ice floes in the larger ice pack and makes accurate chart generation extremely difficult. Figure 3 illustrates the "washed-out" appearance of wet-snow covered multi-year ice in the HH channel in a predominantly open water background. Discerning floe structure in the co-polarization channel is extremely difficult while determining the ice water boundary is also complicated. Conversely, the same multi-year ice in the cross-polarization channel can be easily discriminated from surrounding ice types and open water. The quantitative measurements for the co-polarization channel support this lack of visual contrast with a sample area of water measuring -9.7dB and a multi-year floe of -10.5dB for a difference of just 0.8dB. The same areas in the HV measure -20.4dB and -24.7dB respectively for a much larger contrast difference of 4.3dB. Ongoing research is hoped to result in determining if this separation is evident when multi-year ice is combined with a first-year ice matrix.



IS1 – Sept 14th 2005	HH (σ°)	HV (σ°)
Old Floe	-10.5	-20.4
Water	-9.7	-24.7
Difference	**0.8**	**4.3**

Figure 3. The Multi-Year Ice signature is lost in the HH channel when the ice gets wet making ice edge delineation difficult. The HV channel does a good job at removing this ambiguity.

Presently for ice typing, RADARSAT-1's HH polarization is an improvement over the VV polarization available from earlier ERS satellites. However, clear definition of the ice edge can still be difficult with RADARSAT-1, particularly in the near range when varying sea surface signatures can often "contaminate" a scene to such an extent that reliable analysis of ice features is difficult [2]. Figure 4 illustrates how even in low wind conditions (2-3 m/s) there can be a bright return at the near range in the HH image. The various levels of brightness for open water signatures make it very difficult to clearly separate ice from water. This ambiguity is removed when looking at the same ice and open water in the HV channel.

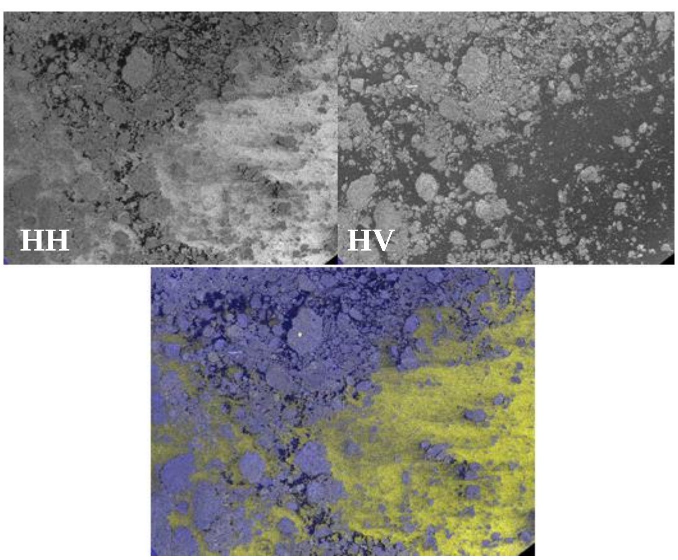


Figure 4. IS1 – Sept 14th 2005. Combining the HH and HV channels helps isolate areas of new ice growth.

Where the HV channel does not perform particularly well in this environment is in the separation of new ice growth from the surrounding open water. This is due in part to the new and thin ice backscatter versus noise floor issue discussed in the previous section. The HV channel in Figure 4 achieves what appears to be a good binary separation of old ice from open water clearly defining the multi-year ice boundaries. Examining those areas in the HH channel which appear to be entirely open water in the HV, there are some signature differences ranging dramatically from bright to dark. Upon further inspection it was found that the bright areas in the HH channel are wind roughened water while the darkened areas between floes likely correspond to new ice growth. Although the HH channel does a good job at isolating this new ice growth, the different open water signatures make delineation of multi-year floes in some areas difficult. In this situation, both channels provide information that would be valuable to an ice analyst. To maximize this information content, a simple RGB composite as illustrated in Figure 4 provides an alternate method of visualizing all of these data in one image. The RGB composite (HH-HH-HV) provides excellent discrimination between the open water (yellow & gray tones), the old ice (light blue tones) as well as the new ice (dark blue tones).

Another potential benefit of the cross-polarization data is thought to be improved mapping of ice topography and structure, because of higher contrast between smooth and deformed ice [5]. Identification of rough floe boundaries are important for estimates of floe size and shape, which aids in ice typing. Also, although the CIS does not currently report on ice ridging, marine clients who are navigating through ice could find the identification of large scale roughness, i.e. ridges, useful as a proxy for ice strength. It is our experience that HH data is sensitive to too wide a range of sea ice roughness to be useful in this regard. Figure 5 illustrates the potential of the HV channel, albeit subtle, in identifying this type of floe structure detail. If coupled with the HH channel in a simple RGB (HH-HV-HV) composite image, the detection of ridges is further enhanced.

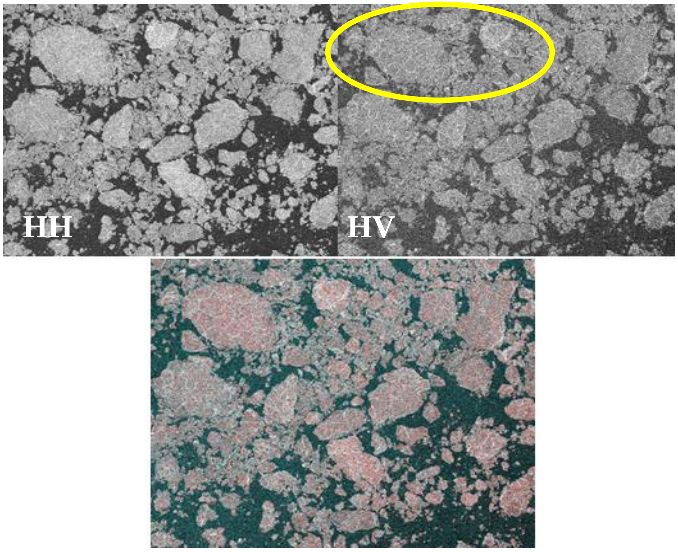


Figure 5. IS1 – Sept 14th 2005.The area marked in yellow indicates an area of increased floe structure detail. The RGB composite image further enhances this intra-floe information.

V. CONCLUSIONS

As the Canadian Ice Service prepares for the launch of RADARSAT-2 it is imperative that the potential utility of dual polarization data is explored. The ENVISAT ASAR sensor offers the first look at how the space-borne cross-polarization channel may provide useful operational ice information in Canadian waters on a daily basis. Analysis of overlapping AP data sets at near and far incidence angles in the Canadian Arctic have yielded interesting results. The HV channel appears to provide good floe delineation and increased information on roughness structure. Discrimination between thick, rough ice, old ice and open water with the cross-polarization channel is also improved. However, the cross-polarization channel is poor in its discrimination of new, thin and smooth first year ice types. It should be noted that this observation is based on AP data from ASAR and reflects the known noise floor limitations of the sensor. It is believed that RADARSAT-2 should improve on these noise floor limits by a few dB.

Sensitivity to incidence angle is dependent on wind and associated ocean roughness conditions. At steep incidence angles during wind roughened conditions, the bright signature seen in the HH channel often makes ice versus open water discrimination difficult. The low response of open water in the HV channel, regardless of wind-induced roughening, makes discrimination of floes much easier but care must be taken that new thin ice areas are not missed. Overall, steep incidence angles are preferred to maximize new and thin ice separability in the HH channel and act as a complement to ice versus open water separation in the HV channel.

Acquisition and analysis of additional ASAR AP data sets continues at the CIS with results expected to further clarify and expand on the observations presented here.

ACKNOWLEDGEMENTS

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