EVALUATING ALOS-PALSAR FOR ICE MONITORING – WHAT CAN L-BAND DO FOR THE NORTH AMERICAN ICE SERVICE?

Matt Arkett(1), Dean Flett(2), Roger De Abreu(3), Pablo Clemente-Colón(4), John Woods(5) and Brian Melchior(6)

(1)(2)(3) Canadian Ice Service – Meteorological Service of Canada - Environment Canada, Ottawa, CANADA, K1A 0H3
(4)(5)(6) National Ice Centre – Washington, D.C., UNITED STATES

ABSTRACT

The Canadian Ice Service (CIS), the U.S. National Ice Center (NIC), and the International Ice Patrol (IIP), partners in the North American Ice Service (NAIS), have individually and jointly used airborne and spaceborne synthetic aperture radar data extensively for almost three decades in their daily ice monitoring operations. SAR’s unique ability to penetrate clouds and weather make these data invaluable to the NAIS’ efficient environmental stewardship and safe operation in Canadian and U.S. waters. Since 1992, solely C-Band satellite radar has been in use as operational SAR missions such as ERS 1 & 2, RADARSAT-1, and Envisat ASAR have selected it as the band of choice. With the launch of RADARSAT-2 on December 2007 and approved plans for Sentinel-1, the NAIS intends to continue utilizing C-Band data in its daily operations. However, it is important to understand the unique and complementary capabilities of other SAR bands. The January 2006 launch of the JAXA ALOS satellite and present availability of L-band SAR data from its PALSAR instrument provides a unique opportunity to assess L-band data for application to ice monitoring. ALOS/PALSAR availability also provides the potential for examining the synergies between L-Band data and C-Band data available from the current and planned C-Band missions. The existing literature suggests that the use of different frequencies could be advantageous in certain ice conditions, which is of interest to the NAIS because of the vastness of the geographical area monitored annually and the associated variations in ice regimes and conditions.

This paper summarizes the preliminary results of a NAIS evaluation of near-coincident C-Band (RADARSAT-1) and L-Band data sets collected in various ice regimes. Through both quantitative and qualitative analysis we attempt to identify the unique and complementary sea ice information PALSAR can provide. In doing so, we identify the role these data could play in the NAIS’ operational programs, both in a complementary role to existing C-Band SARs and its potential as a contingency platform. This work will also help us better understand the potential for future possible multi-frequency SAR platforms.

Index Terms— Synthetic Aperture Radar, Sea ice, Navigation

1. INTRODUCTION

Marginal ice zones, such as those off Canada’s east coast generally provide the most challenge for proper interpretation of ice conditions from SAR due to the highly dynamic nature of the ice environment. For all regions of interest, as the ice cover evolves over the annual cycle from freeze-up, through consolidation, into melt and break-up, the transformation of the ice cover during this cycle adds further complexity and challenges to ice interpretation. Cold, stable, winter ice conditions generally provide the easiest conditions for C-Band SAR interpretation. However, this period is the least important from a navigation perspective and it is the ice (and snow) surface conditions during freeze-up and break-up which most adversely affect the SAR signatures and make the interpretation and extraction of ice information most difficult. Discriminating between multi-year ice and first-year ice during the seasonal melt and summer break-up, concurrent with the busiest vessel traffic seasons, is a key information gap for the CIS. Related to this is our inability to extract information which can be related to ice strength – a very important piece of information for navigation. The state of decay of the ice is used as a proxy for strength and is usually expressed in terms of surface melt features (melt ponds, thaw holes, etc.), features which can be seen in SAR (and other) imagery but for which there is insufficient scientific knowledge as to how to relate them to ice strength. Ridging – the location, quantity, thickness and orientation of ice ridges – is another parameter which would be desirable to extract reliably from SAR imagery. Single polarization C-Band SAR alone is limited in this regard based on our current experience. Some capability to extract information on larger ridge features may be possible with medium resolution (e.g. 25-50m), but
detailed information would require a higher resolution on the order of 5m without a sacrifice in swath width or noise floor.

From previous research it is known that, due to the longer wavelength and thus greater penetration of the microwave energy, the L-band backscatter of first-year and multi-year ice are very similar [1]. Thus, it may be marginal for primary ice typing as compared to higher frequencies (such as C and X-band). However, while C-band backscatter is dominated mostly by surface scattering from the ice and volume scatterers in the upper ice and snow layers, L-band is less sensitive to the small-scale surface roughness and penetrates much further to provide information on the mechanical deformation features of the ice. At L-Band the contrast between sea ice deformation features and smooth ice is greater than at C- or X-Band [2] while the higher frequencies detail the ice surface. This includes large-scale topographic features such as pressure ridges, ridgelines, fractures, and rubble zones – features for which we presently have little information as noted earlier. Deformation features such as these are a significant navigation hazard. This information will be very useful and complementary to the current C-band data sources from which these features are very difficult to characterize and quantify.

The increased penetration depth capability at L-Band coupled with the greater sensitivity to structural deformation also has advantages over C-band during the melt period. L-Band data is better at separating between ice types during these periods than higher frequencies [2] which are very sensitive to the presence of moisture at or near the ice (and snow) surfaces, which masks the underlying ice. Model results and analysis of airborne L-Band data by Nghiem [3] support this statement. Analysis by Dierking & Busche [2] comparing ERS-1 (C-Band) and JERS-1, as well as an exhaustive review of the L-Band literature, concludes that the optimal situation for sea ice monitoring is a combination of L-Band and C- or X-Band. Polarization diversity at one of the bands is noted as a further, though not essential, advantage.

C-band wavelengths are very sensitive to surface roughness and during the freeze-up period the presence of frost flower formations on thin ice causes high backscatter which can cause confusion with other thicker ice types. The longer wavelengths of L-band are not sensitive to this roughness and thus should result in the ability to resolve this condition when compared and integrated with C-band imagery. It has been suggested that L-band may also improve the contrast between areas with thin and thick snow cover during the summer melt period. This would be an excellent result as during this time when the snow cover is wet and sticky, the thickness of the snow cover can exert much influence on the ability to navigate through ice as the ice thickness. Early work also showed that L-band has some potential to discriminate between thick and thin ice at this time in the seasonal cycle due to reduced absorption loss as compared to C or X-band [1]. More recent analysis by Nghiem [3] suggests that thin, young ice may be difficult to detect and discriminate with L-Band co-polarizations, depending on the noise floor, although VV is slightly higher. Combination with C-Band may alleviate this potential limitation to some degree.

2. DATA

In order to fully evaluate the potential of L-Band for ice monitoring, it was important to analyze PALSAR data in different geographic areas and in different ice regimes. Table 1 lists the location of the 43 PALSAR WB1 images acquired at CIS to facilitate this analysis. Although ALOS-PALSR offers a number of beams and polarizations, we concentrated our acquisitions on WB1 imagery at HH polarization. This allowed comparison with RADARSAT-1 ScanSAR data; the preferred choice at CIS for sea ice monitoring. A large concentration of ALOS images were acquired over the Circumpolar Flaw Study (CFL) area in the Western Arctic. CIS personnel, onboard the CCG Amundsen, collected in situ observations which helped in the characterization of ALOS signatures.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Frames</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaufort Sea</td>
<td>5</td>
</tr>
<tr>
<td>CFL Area</td>
<td>16</td>
</tr>
<tr>
<td>Barrow Strait</td>
<td>1</td>
</tr>
<tr>
<td>Gulf of St. Lawrence</td>
<td>6</td>
</tr>
<tr>
<td>Labrador Coast</td>
<td>10</td>
</tr>
<tr>
<td>Ayles Ice Shelf</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1. ALOS-PALSAR data

3. METHODS

To date, the analysis of these data has been predominantly qualitative. ALOS data and near coincident RADARSAT-1 were processed to image format which allowed a visual comparison of ice features present in both sets of imagery. CIS ice charts were coupled with meteorological data to aid in understanding ice conditions at time of acquisition. These ice charts are based primarily on RADARSAT-1 data and are considered the most accurate representation of ice conditions at time of issue. Field measurements accumulated by CIS personnel onboard the CCG Amundsen were available for the CFL data set. The ALOS-PALSAR data were geocoded using the ASF Map Ready software.

4. RESULTS

Figure 1 contains a PALSAR Wide Beam image acquired January 13th, 2008 at 20:10Z and a near coincident
RADARSAT-1 ScanSAR Wide image acquired at 15:31Z on the same day. The corresponding CIS image analysis chart, based solely on the RADARSAT-1 image, identifies this area as a mixture of thick first-year ice (FYI) and multi-year ice (MYI). The MYI is clearly identifiable in the RADARSAT-1 image, appearing bright against the darker thick FYI. Although the MYI is visible in the PALSAR image, its tone is very similar to that of the thick FYI and it is this similarity in tone between the ice types that makes MYI delineation extremely difficult during analysis. Although typing is constrained in the PALSAR data, the amount of ridging information contained in the image is far superior to that of the C-Band data. Large ridges are clearly defined in the PALSAR data and would provide valuable navigation information to ships traversing the area.

Figure 1. Multi-year ice clearly delineated in R1 data. Improved ridging information present in PALSAR data.

A recurring problem for NAIS analysts is the separation of ice types in the summer season. Increased temperatures lead to melting and the addition of liquid water to the snow volume. As a result, the wet snow volume masks the underlying ice floes making accurate analysis extremely difficult. Figure 2 contains a PALSAR Wide Beam image acquired June 10th, 2007 at 20:41Z and a near coincident RADARSAT-1 ScanSAR Wide image also acquired on June 10th at 15:00Z. Summer melt has begun in this area and the snow pack is likely wet. When comparing the two images, the thick FYI floes in the PALSAR data are clearly defined within the pack. The companion C-Band image appears “washed-out” and floe edge delineation is severely compromised. Coupled with its clear delineation of floes is the increased amount of roughness information, most likely pressure ridges, present in the PALSAR image. As with the last example, the avoidance of these areas by marine vessels is paramount during navigation.

Figure 2. Thick FYI is clearly identifiable in PALSAR data during spring melt conditions.

The mapping of fractures at L-Band, particularly for cold conditions, appears to be superior to C-Band which details the ice surface. In Figure 3 the areas of thin ice are easily identifiable as dark areas in the PALSAR data and provide ships’ captains with valuable routing information as they travel through a complex ice matrix. These same areas in the C-Band image are much more difficult to identify. Because C-Band is so sensitive to small scale surface roughness, many of these same fractures appear bright and can be confused with thicker ice types. This Jan 15th PALSAR image, centred over the CCG Amundsen, was provided to the captain and proved to be extremely useful in identifying thin ice areas and aiding navigation.

Figure 3. Thin ice types are clearly visible in the PALSAR image.

The presence of ice fragments in navigable water is an emerging problem in the marine environment. On August 13 2005, an enormous section of the Ayles Ice Shelf broke off the northern coast of Ellesmere Island in the Canadian High Arctic into the Arctic Ocean. The ice island was an estimated 66 square kilometers in size, 15km long by 5km wide and 30 to 40 m thick. The ice in the Ayles Ice Island is suspected to be up to 4,500 years old. The CIS began monitoring the movement of the ice shelf as it got caught up in the pack ice drift southwestward along the northern coast of the Canadian Arctic Archipelago.
Since January 2007, it moved down the west coast of Ellesmere Island and entered the Arctic Archipelago at the end of August / beginning of September 2007. On September 4th 2007, the ice shelf fragment (ISF) fractured into two separate pieces. RADARSAT-1 and ALOS PALSAR data were acquired, the latter from the archive, of the ice shelf fragment during March, July, and August 2007 to roughly correspond to winter, spring, and summer ice conditions. The objective was to compare the appearance (backscatter) of the Ayles ISF in both RADARSAT-1 (C-Band) and PALSAR (L-Band) images for the various seasons.

Figure 4 shows RADARSAT-1 and PALSAR images, respectively, of the Ayles ISF acquired in March. It is readily apparent that, in these cold winter conditions, the C-Band SAR imagery does a better job enabling discrimination of the shelf fragment against the surrounding ice pack.

Figure 4. Ayles Ice Shelf fragment more visible in C-Band during cold winter conditions.

Figure 5. Ayles Ice Shelf fragment more visible in C-Band during cold winter conditions.

Figure 5 shows a similar pair of RADARSAT and PALSAR images acquired during the summer melt period. In this example, the ability to identify the ice shelf is clearly better in the L-Band imagery with significantly greater contrast with the surrounding pack ice.

5. CONCLUSIONS

This initial assessment of L-Band data for sea-ice monitoring has shown the many advantages to using these data in concert with our existing SAR data sets. To date, sea-ice monitoring within NAIS has been dominated by the use of C-Band satellite SAR and although the use of higher frequency SARs has revolutionized sea ice analysis in modern times, there are certain conditions where this shorter wavelength data underperforms. Based on the examples shown here, an integration of L-Band data into current sea-ice monitoring practices could greatly enhance the accuracy and information content of products. In particular, ALOS-PALSAR’s detection of large scale topographic features coupled with its ability to penetrate through the wet snow volume in melt conditions provides valuable information not available using C-Band SARs.

The NAIS intends to continue its evaluation of L-Band data through the 2008 summer season and into the fall freeze-up. A more complete analysis will incorporate quantitative comparisons between L-Band data and shorter wavelength SARs in an attempt to further validate these initial results.

ACKNOWLEDGEMENTS

All ALOS-PALSAR data was provided by JAXA under JAXA_AO_052. The authors also wish to thank the Alaskan Satellite Facility (ASF) for their efforts in processing our PALSAR data, and especially their near-real time delivery during the CFL Study PALSAR validation.

REFERENCES

