Combining Radarsat, Envisat, AMSR-E, and ASPeCt Ship-Based Ice Observations to Determine Ice Concentration at 90°W Longitude in the Bellingshausen Amundsen Sea for SIMBA 2007.

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1. Abstract

The SIMBA cruise in the austral winter season of 2007 conducted in situ measurements and used additional remote sensing resources to study the varied sea ice types at and inside the ice edge of western Antarctica in the Bellingshausen/Amundsen Seas. An element of the research aimed to ground truth satellite measurements by comparing with actual measurements performed on the sea ice. A combination of passive and active satellite data was selected to determine ice concentration and types for the period during and after the trip to see how it seasonally changes for this region. This research will include processing 11 images recorded from the Radarsat-1 instrument provided by the National Ice Center (NIC), and subsequent images from AMSR-E, and Envisat products. Part of the research will be trying to establish how to exactly overlay each image to determine the ice concentration for these three products, using ground-truth data, and GPS coordinates from ASPeCt ship-based ice observations and drifting buoys from the SIMBA cruise. The ENVI image processing program will be used to process the raw data from each satellite product to determine how the ice concentration depicted in the images, relates to backscatter signals.
2. Introduction

The Sea Ice Mass Balance in the Antarctic (SIMBA) cruise departed began September 1, and ended on October 31, 2007. Our goal was to use remote sensing tools, and in situ measurements to begin to characterize Antarctic sea ice thickness/types on a circumpolar quantitative basis. This was an exceptional trip for the reason that its main purpose was to study the sea ice, therefore, passed through the western region of Antarctica in the Bellingshausen/Amundsen Sea at approximately 70° S and 90°W during the austral winter. Since this was the only trip in this region during the winter since 1898, a fully quantitative baseline data was established for monitoring future changes in the Antarctic sea ice cover. Methods consisted of incorporating the coupling between thickness, in situ and remote sensing measurements, a full validation of elevation (for ice thickness), and passive and active radar (for thin and thick ice characterization). This will help to enable future monitoring to rely more on remote sensing than previously performed field surveys that are costly and tedious.

A combination of passive and active remote sensing data was used for our purposes on this trip. These consisted of microwave images from AMSR-E from the National Snow and Ice Data Center (NSIDC), and Quicksat from Polarview. Radar images were made up of Envisat from Polarview, and Radarsat from the National Ice Center (NIC). A collection of 11 Radarsat-1 images pertaining to the main ice station on the SIMBA cruise were ordered. Radarsat-1 images have capabilities that benefit sea ice applications due to the multi-polarization options that improve ice-edge detection, ice-type distinction, and ice topography and structure information. My research will focus on processing these 11 data files to determine how the sea ice concentration relates to backscatter signals as well as ice-edge detection, ice-type distinction, and ice topography and structure information. These images pertained to the area on the main ice
station on the dates of October 12, 18, 20, 26, and November 2, 8, 12, 16, 19, 26, and December 6. The time frame given will allow us to observe the transition of sea ice conditions, concentration, and ice types as the austral spring approaches. This project will focus on combining the AMSR-E, Envisat, and Radarsat-1 images to determine the ice concentration using GPS coordinates from buoy data and ship-based ice observations following the ASPeCt protocol. However what is critical is to match up pixel locations for each of these products.

3. Data

The Canadian Space Agency-Earth Observing Satellite (CSA-EOS) developed Radarsat-1 to respond to specific needs for radar data in hundreds of environmental monitoring applications in Canada and around the world. It was launched on 1995 above the Earth on a sun synchronous orbit with an altitude of 798 kilometers and inclination of 98.6 degrees. It uses a synthetic aperture radar (SAR) sensor that images the earth at only one microwave frequency of 5.3 GHz at 5.6 cm (C-band) (CSA). The energy transmitted records reflections and backscatter on the Earth’s surface. More important, it is thus able to create images despite cloud cover or other interferences that may be in the atmosphere.

Radarsat-1 has an orbital period of 100.7 minutes, and circles the Earth 14 times a day. The orbit path repeats every 24 days, which means that the satellite is in exactly the same location and can take the same image every 24 days. It also consists of 7 beam modes in order to administer different image resolutions. Figure 1 below is a chart put out by the CSA-EOS that describes each beam.
<table>
<thead>
<tr>
<th>Mode</th>
<th>Nominal Resolution (m)</th>
<th>No. of Positions / Beams</th>
<th>Swath Width (km)</th>
<th>Incidence Angles (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>8</td>
<td>15</td>
<td>45</td>
<td>37 - 47</td>
</tr>
<tr>
<td>Standard</td>
<td>30</td>
<td>7</td>
<td>100</td>
<td>20 - 49</td>
</tr>
<tr>
<td>Wide</td>
<td>30</td>
<td>3</td>
<td>150</td>
<td>20 - 45</td>
</tr>
<tr>
<td>ScanSAR narrow</td>
<td>50</td>
<td>2</td>
<td>300</td>
<td>20 - 49</td>
</tr>
<tr>
<td>ScanSAR wide</td>
<td>100</td>
<td>2</td>
<td>500</td>
<td>20 - 49</td>
</tr>
<tr>
<td>Extended high</td>
<td>18 - 27</td>
<td>3</td>
<td>75</td>
<td>52 - 58</td>
</tr>
<tr>
<td>Extended low</td>
<td>30</td>
<td>1</td>
<td>170</td>
<td>10 - 22</td>
</tr>
</tbody>
</table>

**Figure 1.** Seven beams located on the Radarsat–1 arranged by CSA-EOS.

The AMSR-E product used is derived from the Advanced Microwave Scanning Radiometer from the Earth Observing System (EOS). The AMSR-E/AQUA daily L3 12.5 km Brightness Temperature, Sea Ice Concentration, & Snow Depth product will specifically be used for this project. This was launched June 19, 2002 – present. This device provides data for brightness temperatures, snow depth on sea ice, and sea ice concentration that consist of daily averages, and averages of ascending and descending daily averages. The spatial resolution for our images are at ~1.5km per pixel. The data contains horizontal and vertical brightness temperatures that vary a different frequencies: 18.7GHz, 23.8 GHz, 36.5GHz, and 89.0 GHz.

The Envisat product collects data on a sun-synchronous orbit at an altitude of ~800km with a temporal resolution of 35 days. However the wide swath allows it to cover the whole Earth within 1-3 days. The ASAR instrument will be used for this project, which stands for an Advanced Synthetic Aperature Radar that is operating with the C-band, similar to the Radarsat-1 product. The radiometric resolution consists of a range from 1.5 – 3.5 dB, whereas the Radarsat range is 0-(-25). We will be using the wide swath mode so the pixel resolution will be ~150m.
with an overall swath resolution of ~400km. The polarization is either VV or HH using the pushbroom method, however, once the data is processed, this description will be more definitive.

This research will include using specific Radarsat-1 data that overlaps with the date, and time of ASPeCt observations, with coinciding AMSR-E and Envisat products to determine the ice concentration for area in which SIMBA in situ measurements were acquired. The necessary steps will be researched to process this data and finally use the tools from the ENVI image processing program to conduct the analysis of these images. We received 11 Radarsat-1 images during the period of October 12 – December 6, during and after the SIMBA cruise in the Bellingshausen Sea between ~65ºS - ~95ºW. The coordinates are as follows in Figure 2:

<table>
<thead>
<tr>
<th>Scene ID</th>
<th>NIC Order #</th>
<th>Date</th>
<th>lat</th>
<th>lon</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0528049</td>
<td>62309</td>
<td>10/12/2007</td>
<td>69º 26'S</td>
<td>91º 32'W</td>
</tr>
<tr>
<td>P0528306</td>
<td>62362</td>
<td>10/18/2007</td>
<td>70º 09'S</td>
<td>89º 51'W</td>
</tr>
<tr>
<td>N0529084</td>
<td>62423</td>
<td>10/20/2007</td>
<td>69º 51'S</td>
<td>90º 11'W</td>
</tr>
<tr>
<td>N0529690</td>
<td>62509</td>
<td>10/26/2007</td>
<td>69º 50'S</td>
<td>90º 22'W</td>
</tr>
<tr>
<td>N0531553</td>
<td>62609</td>
<td>11/2/2007</td>
<td>70º 06'S</td>
<td>96º 07'W</td>
</tr>
<tr>
<td>P0533319</td>
<td>62695</td>
<td>11/8/2007</td>
<td>70º 07'S</td>
<td>96º 12'W</td>
</tr>
<tr>
<td>P0533750</td>
<td>62752</td>
<td>11/12/2007</td>
<td>69º 52'S</td>
<td>97º 30'W</td>
</tr>
<tr>
<td>N0533331</td>
<td>62805</td>
<td>11/16/2007</td>
<td>69º 53'S</td>
<td>95º 36'W</td>
</tr>
<tr>
<td>P0534675</td>
<td>62852</td>
<td>11/19/2007</td>
<td>69º 55'S</td>
<td>96º 36'W</td>
</tr>
<tr>
<td>P0535304</td>
<td>62952</td>
<td>11/26/2007</td>
<td>70º 07'S</td>
<td>96º 08'W</td>
</tr>
<tr>
<td>P0536586</td>
<td>63095</td>
<td>12/6/2007</td>
<td>69º 01'S</td>
<td>89º 34'W</td>
</tr>
</tbody>
</table>

**Figure 2.** Table of Radarsat-1 scene numbers and coordinates for the SIMBA cruise.

From the 7 modes, we are only using the ScanSAR narrow sensors for all images. The nominal spatial resolution for these images are at ~50m resolution, although the pixel resolution on all 10 images are at ~30-35m per pixel (1225m²) that was measured with the ENVI measurement tool. The swath has a single HH antenna polarization using a push broom process
and has an incidence angle between 20°- 49°. The initial pixel values are given in DN. The offset for the ScanSAR narrow is as follows:

-250km - ~400km nadir offset
~Swath Width: 300km

The Radarsat-1 images have been projected in the Geographic Lat/Lon WGS 84. The Envisat and AMSR-E products will be matched according to the Radarsat-1 images.

4. Methods

The ENVI image processing program was used to process and interpret all the satellite images for sea ice concentration using the region of interest tool, masking methods, and statistical analysis. Based on ground truth information, the sea ice in this area consisted of multiyear, firstyear, pancake, frazil, brash, and grease ice. This caused a problem with interpreting the ice concentration, because the values of the mixed pixels of sea ice, and open water for the western part of Antarctica are unknown. The DN values for the AMSR-E product was aligned with the SAR image dB values to determine the ice concentration for the SIMBA area in the Bellingshausen Sea for the spring 2007 season. The obstacle of finding the method of combining three different products with three different spatial resolutions to accurately reflect ice conditions was corrected using ArcGIS.

The AMSR-E products were georeferenced and bilinearly interpolated using the HEGtool to match the SAR images, and using GIS applications to accurately match the products together with an Antarctica feature class used by researchers working in studies in Antarctica shown in figure 9. For this exercise, Peter I island in the Bellingshausen Amundsen Sea was used as a reference point and the products were combined with the projection tool in the data management toolbox. However, AMSR-E pixels already have the sea ice concentration values in the 12.5km
pixels so there was no need for further processing once the georeferencing was complete. However, the AMSR-E product was adjusted to reflect the range of ice concentration for each pixel in order to compare pixels from other satellite products accurately. This was done by adjusting the symbology in the properties for the AMSR-E product. For the SAR images, a polygon was used to initially mask these images, though due to the assymetrical properties of the images, the area selected sometimes excluded 1-2 pixels (~30-60m) located at the edges. This ROI polygon was used to create a mask, which was used to only select the RADARSAT-1 image for computation purposes. A mask was created for the SAR images to omit any 0 values that could be factored into the statistical computations as shown in figure 3. The SAR values are based on a logarithmic unit of measurement (dB) that represents the magnitude of the mean surface backscatter related to the amount of snow that is present in the SAR images. Vector files created from the ship-based ice observations of the GPS information were also used to determine that the products lined up correctly (Figure 5).

![Image N0528049 shown the raw image (left) and image with ROI overlay (right).](image.png)
The DN values that characterized the pixel intensities were converted to dB values for the total image to determine the backscatter coefficient $\sigma$ (dB) - (Williams, et al., 1999). This is represented by the standard equation:

$$\sigma = 10 \log_{10}[a_2(DN^2 - a_1 N_{(r)})] = dB$$

However, this value can also be obtained by using a shorter method postulated by Harry Stern on the SHEBA Camp in the Arctic (Kwok, et al., 2003):

$$\sigma = (DN - 255)/10 = dB$$

The range of pixel values that represent open water have already been represented and shown as the dark areas in the leads, between the floes. The highest backscatter values were established by using the snow cover on Peter I island, located near the ice edge. Peter I island was used as a reference point for the backscatter variation of ice types because we have images to help ground truth the ice types observed en route, and surrounding the island, and of the snow cover on top of the island. Therefore, basic interpolation of the sea ice and snow cover conditions were used to establish dB values. After these pixel values were established, open water areas or low dB values were masked to determine at what range is the and classify the pixels that represent sea ice which should produce results as to ice concentration (Giles, et al, 2008).

For this project, ROI’s have been created to mask the area of ship based ice observations with the ASPeCt protocol, with Radarsat-1-1 image 6509 for October 26, 2007 for ice concentration because this is the only corresponding data that is available for preliminary processing shown in figure 4.
Figure 4. Image 62509 for October 26, 2007 with ASPeCt ship-based ice observations.

After establishing the location to determine the ice concentration for one area, this process was conducted for all the ASPeCt observations using the ROI tool at a 1km radius shown in figure 5.
Figure 5. Radarsat ROI for 1 km to match with corresponding data with ASPeCt.

This same method was used to compare with AMSR-E ice concentration data for a 12.5 km pixels, therefore, 6.25 km radius ROI’s were created for the same Radarsat image shown in figure 6.
Figure 6. Radarsat ROI for 1 km to match with corresponding data with AMSR-E.

The following image in figure 7 corresponds to the pixel comparison used for the Radarsat and ship-based ice observations.
For initial comparison with Radarsat and ASPeCt in the area between 0GMT -9GMT, visual observation of the Radarsat shows 100% ice concentration. Since dB values or classification tools cannot be used to calculate ice concentration, the 1km ROI’s were visually measured for ice concentration (figure 8). However, beginning for the area of 10GMT, a k-means unsupervised classification technique was used to separate the ice values into 5 classes. This represents the beginning of the MIZ, therefore, we can infer that there will be significantly less flooding in this area due to the lack of Multi Year Ice (MYI), therefore, the lowest values in the classification scheme will essentially represent open water, as opposed to a mixture of MYI (Figure 8).

The Radarsat 12km ROI’s created had to be processed using the k-means unsupervised classification for all the ASPeCt points, because although the areas from 0GMT-9GMT were observed to have 100% ice concentration with ASPeCt, it was apparent that some leads were present in these segregated areas in the Radarsat. Therefore, to accurately determine ice
concentration, some smaller 1km ROI’s were created within each 12.5 km pixel to establish the percentage of overlap of MYI values with open water values. This was done by selecting these smaller areas that included no leads, and classified each area. The lowest value will represent MYI since no leads are present and after 10 ROI’s were calculated, the average range of MYI values were between 9% - 13%. Therefore, when applying the unsupervised classification for the areas before the MIZ (0GMT-9GMT), the lowest class statistics (1 – represented by the red pixels) were used to represent a combination of MYI and open water, and was subtracted by 11% to represent the percentage of the area that is overlapped with these values.

5. Results

Some limitations applied for this exercise due to the array of data available. Since it is necessary to compare all products from the same period, this preliminary dataset is only limited to data from October 26, 2007. For this reason, only 1 Radarsat product was available that accurately matched the ship-based ice observations taken. Therefore, the AMSR-E product was ordered accordingly, and there was no Envisat images available for this date either. However, once the correlation for ice concentration is established for all combined products, then subsequent processing for all other corresponding data will be conducted. Figure 9 shows how all products for October 26, 2007 were combined using the ArcGIS program.
Figure 9. Radarsat and ship-based ice observations (above) and AMSR-E and ship-based ice observations (below) combined together in ArcGIS.
A good correlation for both ASPeCT (1km) and AMSR-E (12.5km) was shown with preliminary results for the area before the MIZ even though slightly different methods were used (figure 10). This shows that the visual interpretation and classification scheme developed for the MYI and open water overlap can prove to be successful for a large scale ice concentration measurement. There was also a good correlation with the Radarsat 1km and ASPeCt calculations for the MIZ, except for areas closer to the ice edge (21GMT). The Radarsat 12.5 km correlation with the AMSR-E proved to perform very well throughout the MIZ except for the areas between 11GMT-12GMT and 18GMT-20GMT. This could be attributed to the AMSR-E product underestimating ice conditions toward the MIZ where there is very thin ice, and due to the constant drift of the sea ice around this area that is a polyna (Comiso et al., 2003). Figure 11 shows an image of this area next to Peter I island where there was a large area of open water (polyna) that was saturated with a mixture of thin ice (frazil and grease) and broken up thicker ice floes (first year and pancakes). This has posed a problem with the Radarsat and AMSR-E product in previous studies with Antarctica sea ice due to the mixed pixels (Ozsoy-Cicek, et al (2008), Comiso, et al (2003), and Giles et al (2008). The initial concentrations are shown below in figure 10.
Figure 10. Comparison of ASPECT protocol, AMSR-E, and Radarsat. The results show a good correlation with all three data sets until 10GMT.
Figure 11. Peter I Island at approximately ~10GMT beginning at the Marginal Ice Zone (MIZ).

The AMSR-E product appears to have underestimated the ice concentrations more than the other products, however, this is expected due to the fact that the 12.5km consists of an average of ice concentration for each pixel. The ship-based ice observation also appears to overestimate the ice concentration, however, this is due to the perspective limited from the ship’s observing point that, in previous studies, normally has an error of ±10% with thinner ice types shown in figure 8 (Worby et al, 1996).

6. Summary or conclusions

This preliminary study shows the ambiguity to detect ice concentration at the Marginal Ice Zone (MIZ), which is why this is coincidentally a good dataset to compare the in situ and satellite products. The winter sea ice for the southern hemisphere is easier to detect at a higher concentration with the passive microwave, and ship-based observations, but not as well with
SAR data. This is due to the overlapping dB values with open water and multiyear ice in the Antarctic from the flooded interface between the sea ice and snow cover. Instead of a high backscatter, which should be expected for thicker ice in the Arctic, the slush layer in the flood zone is actually absorbing the microwave signal from the SAR sensor to read as open water (Kwok et al, 2003). Therefore, SAR data has to be visually interpreted for 100% concentration for comparison and classified with areas that contain leads. However, at the MIZ a k-mean classification can be applied to approximate the ice concentration. Now that this method is established, further comparisons with the remaining 10 Radarsat observations will be calculated for ice concentrations using the same ASPeCt GPS points for the same area to view how this area has changed with regards to ice concentration. Further comparisons with ice cam data from the trip will be compared for a more accurate result for ice concentration before further processing can begin with other datasets that will not use in situ measurements (Weissling et al 2008).
7. References


Eicken, H., Blahak, U., Dierking, W., Dmitrenko, I., Spatial and temporal variability of SAR backscatter signatures of coastal sea-ice types off the Lena River Delta (Laptev Sea), IEEE, 0-7803-5207-6, 1999.


