WIND INFORMATION FOR MARINE WEATHER FORECASTING FROM RADARSAT-1 SYNTHETIC APERTURE RADAR DATA: INITIAL RESULTS FROM THE "MARINE WINDS FROM SAR" DEMONSTRATION PROJECT

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1. INTRODUCTION

Since the launch of RADARSAT-1 in November, 1995, the Canadian Ice Service (CIS) has routinely used RADARSAT synthetic aperture radar (SAR) ScanSAR Wide mode (500 km swath, 100 m resolution) imagery in near real-time as a cornerstone of its sea ice monitoring program (Ramsay *et al.,* 1998). The CIS receives nominally 4000 RADARSAT-1 scenes annually, covering all seasonally ice-covered Canadian waters.

Besides imaging the ice conditions, many of the images capture dramatic snapshots of atmospheric boundary layer phenomena imprinted on the ocean (and lakes) surface roughness. Features such as meteorological fronts, areas of convective activity, boundary layer rolls associated with cold air outbreaks, lee waves, and atmospheric gravity waves are often imaged and visually characterized. In addition to the detection and characterization of these types of atmospheric features, there is increasing interest in estimating wind information from SAR ocean images.

Although there are a variety of possible roles for SAR-derived wind speed (see Vachon & Dobson, 2000), of interest here is their potential to improve site-specific weather forecasting in regions that are too small for relatively large (25 to 50 km) scatterometer resolution cells, such as in the coastal or marginal ice zones, or in lakes or estuaries. This potential, combined with the operational availability of relevant SAR data sets from CIS, has motivated the "Marine Winds from SAR" demonstration project that is described in this paper.

2. THE DEMONSTRATION PROJECT

In the fall of 1999, the Canadian Ice Service (CIS) and the Canada Centre for Remote Sensing (CCRS) undertook an effort to demonstrate to the Maritime Weather Centre (MWC) in Dartmouth, Nova Scotia the potential of RADARSAT image products of oceans to provide information relevant to meteorological applications. CIS and CCRS scientists visited the MWC and delivered training to staff on the CIS and its near-real time use of RADARSAT, as well as on the potential of SAR-derived ocean feature and meteorological information. Technical elements were set up to automatically ftp relevant image data sets from the CIS operational data stream (covering primarily Labrador Sea and East Coast waters) to MWC to demonstrate the potential of SAR data. Although all the technical elements were put in place, the actual demo and transfer of files was deferred until fall/winter 20002001.

In the latter part of 2000, a similar project was developed and a demonstration planned to deliver wind products derived from RADARSAT to a second weather centre, the Thunder Bay Regional Weather Centre (TBRWC). In providing their weather and marine forecasts and warnings for the Canadian portions of the Great Lakes the TBRWC usually depend upon Environment Canada and NOAA buoys that are deployed during the ice-free months. During winter, in situ observations are not available. Thus, TBRWC is exploring alternate data sources and felt that RADARSAT-1 SAR images could play a role in providing wind and wave conditions. It should be noted that TBRWC has several levels of requirements that include operational data, forecast verification, and emergency support (such as for search and rescue operations).

The "Marine Winds from SAR" demonstration project was established to utilize the operational CIS data stream to process SAR imagery of the East Coast and Great Lakes regions of interest and to deliver image and wind field products to each weather centre. The wind information is extracted from the SAR data using a system called the Ocean Monitoring Workstation (OMW) as described in the following section.

3. WIND RETRIEVAL WITH THE OCEAN MONITORING WORKSTATION (OMW)

The OMW, as installed at the CIS, is a PC/NT-based system that can derive information from RADARSAT-1 synthetic aperture radar (SAR) images of large open water areas (see Henschel *et al.,* 1997; 1998) and is sold commercially by Satlantic Inc. There are several analysis modules available. The Wind Module is the focus of this demonstration. The OMW derives gridded wind field estimates from SAR images, using the method described below. The OMW first applies a land mask based on a coastline database to exclude land regions from the analysis.

The OMW derives the wind vector autonomously (i.e. without any outside information) from the SAR image. The wind direction is first estimated by measuring the orientation of boundary layer rolls that often appear in ocean images as streaks that are nominally aligned with the wind direction. Boundary layer rolls tend to appear in the images during higher winds and with unstable atmospheric conditions. The orientation of the boundary layer rolls is determined by a spectral analysis that focuses on linear features of 1 km and longer. The resulting wind direction estimate has a 180º ambiguity in direction.

The wind speed is derived from the observed radar cross-section and the geometry (composed of the local incidence angle and the relative wind direction) by using a scatterometry wind retrieval model. For RADARSAT-1 C-band HH polarization image data, the OMW is presently using a hybrid wind retrieval model that is based upon the well-established CMOD_IFR2 model (for C-band VV polarization) and a co-polarization ratio based Kirchhoff scattering theory (see Vachon and Dobson, 2000). This procedure requires a well-calibrated SAR image.

Unfortunately, there are still some image quality and calibration issues with ScanSAR products generated at the Canadian Data Processing Facility (CDPF, the RADARSAT-1 processor that is installed at the Gatineau Satellite Station). The calibration accuracy is ±1.35 dB or better for most cases (see Srivastava et al., 1999). This is not as accurate as the single beam mode calibration, but should be adequate to ensure useful wind speed estimates from the ScanSAR images that are available for the demonstration. Other effects, such as analogue-to-digital converter saturation power loss (see Vachon et al., 1997), and range-oriented image scallops can also occur and effect the radiometric accuracy of the CDPF products and subsequent derivation of wind speed and direction.

In the event that a good wind direction can be found (i.e. in the presence of well defined boundary layer rolls in the SAR image), the OMW returns wind vector solutions corresponding to the two possible wind directions (i.e. with a 180º ambiguity in direction). A pair of opposing wind barbs represents this scenario in the OMW map product. Based on single beam RADARSAT SAR data analysis, the RMS wind speed error has been shown to be about 2.5 m/s (Vachon and Dobson, 2000). It is expected that this would degrade somewhat for ScanSAR data, which is not as well calibrated radiometrically. In the event that a good wind direction cannot be found (i.e. in the absence of well defined boundary layer rolls in the image), the OMW returns the upper (for the cross-wind look direction) and lower (for the up-wind direction) bounds for the wind speed for the observed radar cross section. A pair of perpendicular wind barbs (indicating the up-wind and crosswind look directions) represents this scenario in the OMW map product.

The OMW can generate 3 types of wind products:

- Map product in postscript format;
- Gridded wind values in postscript format to accompany the map product; and
- ASCII wind product

4. DATA PROCESSING/FLOW AND PRODUCT DELIVERY

The CIS routinely receives RADARSAT-1 SAR data for their sea ice surveillance activities through a dedicated T1 data link to the Gatineau Satellite Station (GSS), where data are both received and processed. After nearly five years of operations, CIS has achieved average image delivery times of less than two hours from acquisition. CIS primarily receives ScanSAR Wide mode images (100 m resolution across a 500 km image swath) for their operations and these data are the focus of the demonstration.

The CIS receives Level 1 georeferenced CEOS format image products. Although the data are acquired and processed as strip or swath products, it is framed into square 500x500 km scenes for delivery across the T1 link. Once the imagery arrives at the CIS, the full-resolution data is automatically checked to see if it falls geographically within the two areas of interest – East Coast/Labrador Sea or Great Lakes. Relevant image frames are then concatenated and post-processed as follows to generate reduced resolution image products which are automatically delivered by ftp to the appropriate weather centre.

- 20-by-20 block average to produce image products with 1 km pixels;
- Geocoding (to rotate the image and scale it onto a map grid);
- Square-root intensity enhancement to highlight ocean/lake features of interest (land or ice portions of the image may become saturated);
- Overlay of a 5º map grid, shoreline, and ice edge;
- Conversion to Windows bitmap (i.e. BMP) file format.

While the production and delivery of the image data are automated, as described above, at present the OMW wind products are generated manually and screened prior to delivery to the weather centres. Due to the demonstration nature of the project and limitations of the current version of the OMW, this is to ensure that the products are of a minimum acceptable utility. An important component of the demonstration is to evaluate the utility and presentation of the OMW products in order to recommend improvements and modifications for the future to better suit the weather centres needs.

5. EARLY RESULTS

At the time of preparation of this paper the delivery of products to the two participating weather centres had been underway for almost two months. A total of approximately 125 each of the bitmap RADARSAT images and OMW wind products had been sent to the three weather centres.

From a purely practical viewpoint, there have been a number of issues (product format, file naming convention, display tools, etc.) which have hampered easy use of the products by meteorological staff. Since the OMW products are generated in formats which are not compatible with standard tools available to the forecasters, efficient visualization and use of the information has been limited to date. The SAR bitmap images, although a relatively unfamiliar image product to the meteorologists, have been relatively well received. Although they do not provide the direct quantitative information necessary for forecasting, the often striking visual features have impressed the meteorological staff. One case identified the potential of RADARSAT for detecting lee turbulence. Difficult to identify on visual satellite imagery, particularly in the absence of clouds, the turbulence patterns were clearly evident on the RADARSAT image (Huang, 2001).

Due in part to being in the early stages of the demonstration, very limited verification and validation of the OMW-derived wind information has been done. However, wind speeds for eight (8) RADARSAT passes over the Great Lakes in January/February 2001 were roughly correlated with wind speed observations for one station at Caribou Island. Table 1 summarizes the results which show that, for this very preliminary assessment, generally the wind speeds compare well.

Table 1: SAR-derived wind speeds compared to station observations, Caribou Island (m/s)

OMW	8.6	14.9	7.9	2.5	11.8	8.7	14.8	15.4
Obs.	8.2	13.4	9.8	3.1	8.7	3.1	7.7	11.3

Wind directions are much more problematic at first glance, even with the 180 degree ambiguity removed. Deviations between derived and observed directions were typically 40-60°, with variations ranging between 10° and 90°. As noted in an earlier section, estimation of the wind direction requires clear definition of boundary layer features in the imagery. When not clearly identifiable, these values can be much less accurate than the wind speed derivation. Ambiguity in wind direction is not a significant problem as a few actual wind observations can be used in many cases to determine the correct wind direction. Although the size of the differences in wind direction are not a significant concern for forecast verification purposes, discrepancies in wind direction would be a significant problem for other applications, such as utility in preparing routine forecasts or specialized studies.

6. SUMMARY AND A LOOK AHEAD

Considering the demonstration has been initiated using commercial off-the-shelf software, minimal system and data flow customization, and the use of a data stream and RADARSAT beam mode not well suited to wind extraction nor OMW processing, early results from the project are encouraging. Nevertheless, there is much room for improvement in making the products more readily usable by weather centre staff. Additionally, a thorough post-season validation, verification, and analysis component still remains to be completed. Several enhancements to the OMW software have been identified specific to this project and we intend to address as many as possible over the summer of 2001 prior to continuing with the demonstration program next year. Of high priority will be incorporating the derived wind products into more familiar and readily usable formats and graphical presentations for the operational weather centre staff.

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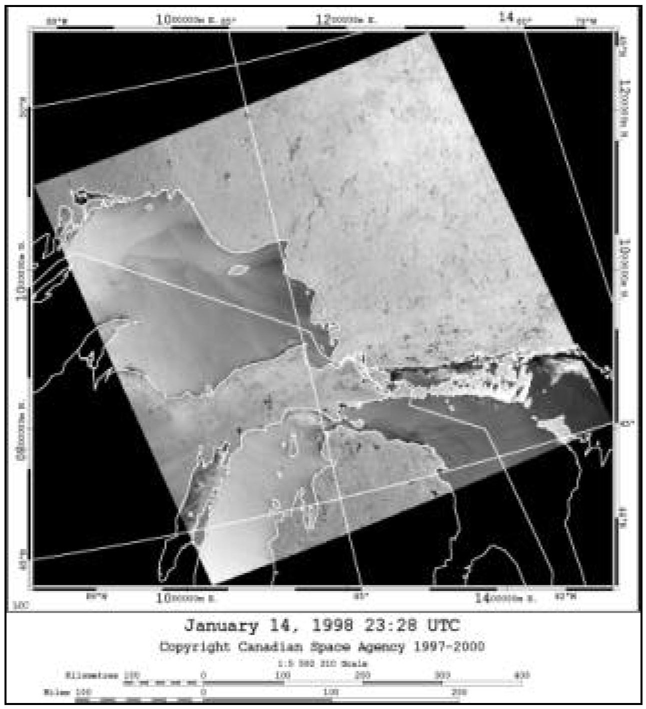

Figure 1: Example of image product automatically delivered to weather centres

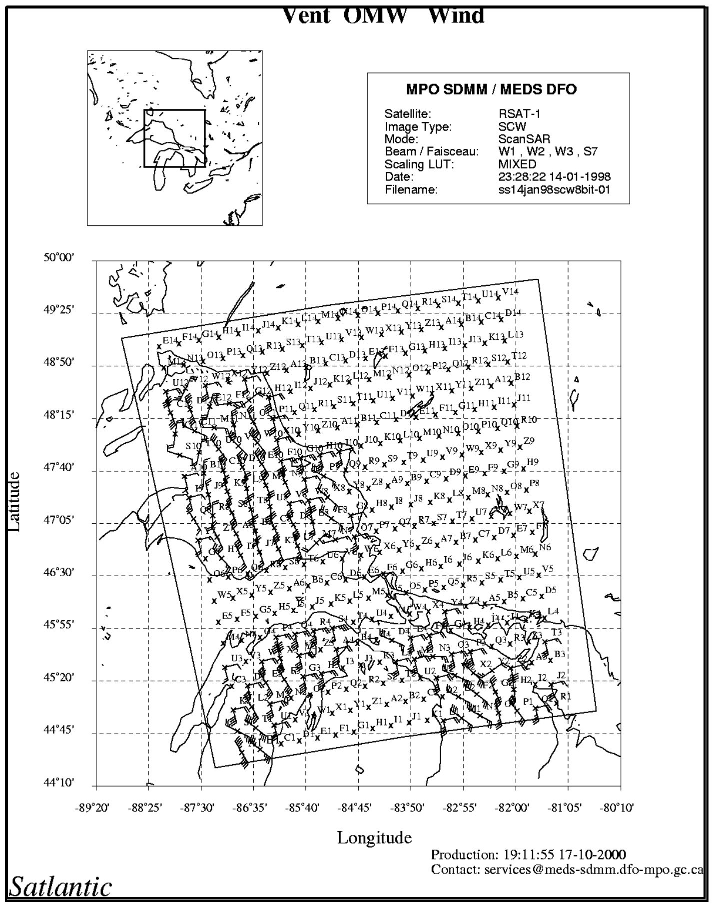

Figure 2: Example of graphical (postscript) wind field product delivered to weather centres