PREPRINT/PRÉTIRAGE

Operational Use of RADARSAT SAR in the Coastal Zone: The Canadian Experience

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Abstract -Satellite remote sensing offers the potential to routinely provide information at useful temporal and spatial scales for monitoring the dynamic coastal zone. In the fall of 1995, Canada launched the RADARSAT satellite carrying multiple mode synthetic aperture radar (SAR). Over the past two years, considerable experience has been gained in the operational use of RADARSAT SAR for coastal applications such as sea ice monitoring, vessel detection, and oil slick detection. This paper summarizes Canadian activities in these areas and reports on development efforts in automated algorithms. Observations are made on the potential conflicts among users in coastal environments.

1. INTRODUCTION

Canada's RADARSAT, with its C-band HH-polarized synthetic aperture radar (SAR) [Raney *et al.,* 1991], was launched in November 1995. The SAR has now been operational for over two years, providing radar images in 22 nominal single beam modes and in 4 multiple beam (ScanSAR) modes. This flexibility can provide a variable acquisition swath for short time interval repeat observations (potentially within 0.5 to 5 days, depending on the latitude), or be used to trade image resolution for swath coverage.

RADARSAT is owned and operated by the Canadian Space Agency (CSA). The Canada Centre for Remote Sensing (CCRS) maintains and operates the Gatineau Satellite Station (GSS) and the Prince Albert Satellite Station (PASS) that receive, process, and archive data from a variety of satellites, including RADARSAT. Standard RADARSAT image products are commercially available through the distributor Radarsat International (RSI) and through RSI's network of international ground stations and distributors. RSI also operates the Canadian Data Processing Facility (CDPF) which is the primary radar processor for standard RADARSAT products.

RADARSAT was designed to be an operational system, providing reliable data acquisition to meet the needs of the Canadian Government and for commercial customers. Usually, this requires ordering with a nominal lead-time of two weeks in advance of data. Ordering with a few days lead-time can be accommodated under some circumstances. The CDPF can accommodate image data delivery within a few hours following signal data downlink to one of the Canadian receiving stations. Similar fast-turnaround products are also available from several RADARSAT network stations.

RADARSAT SAR images are now being routinely used for coastal zone applications. A key consideration is selection of beam modes that will offer an appropriate clutter-to-noise ratio (i.e. larger for small incidence angles, and smaller for large incidence angles), though this depends on the wind speed. For sea ice, useful ice/water separation normally is achieved at higher incidence angles, as is the detection of ice topography such as ridges and rubble.

In this paper, we will describe several operational and experimental coastal applications of RADARSAT SAR being addressed in Canada, including ship detection, oil spill monitoring, wind vector retrieval, and sea ice monitoring. One focus of work in Canada has been the development of the Ocean Monitoring Workstation (OMW), a system for extracting ocean information from RADARSAT SAR images. For sea ice reconnaissance, the operation of the Canadian Ice Service is described.

2. OMW COASTAL APPLICATIONS

The OMW [Henschel *et al.,* 1997] was developed by Satlantic Inc. with financial and technical contributions from the Department of Fisheries and Oceans (DFO), the Canadian Coast Guard (CCG), the Department of National Defence (DND), CCRS, and CSA. The system has been designed to provide operational users of marine data with value-added ocean information products derived from RADARSAT SAR images. Significant data compression is achieved since the OMW information products are a few l0's of kilobytes in size, whereas the initial image files may be l00's of megabytes in size. This allows for efficient transfer over low bandwidth communication lines.

The OMW contains user-configurable algorithms to detect ship targets, to calculate two-dimensional ocean wave spectra, to extract wind vectors, to classify ocean features, and to detect dark features that may be related to natural slicks or oil spills. The OMW algorithms are still being refined and improved.

RADARSAT SAR data ordered by users are acquired by the satellite, downlinked to GSS and processed by the CDPF to image files. The SAR image files are then transferred to the OMW software via a high-bandwidth local area network. The OMW operates in an unattended mode and begins processing as soon as an image file is delivered. Image products from the CDPF are available for analysis within two hours from the time of overpass, and each OMW product is produced and available for onward transfer with a few minutes of processing effort.

In this paper, we discuss only three of the available OMW products. The ship detection product has been of greatest interest and could be used to augment and direct current ship and fisheries surveillance activities. It has been of particular interest for fisheries surveillance on the Grand Banks of Newfoundland. Similarly, the slick detection product could be used to alert and direct pollution surveillance activities. The wind vector product, on the other hand, could be useful for nearshore or site-specific weather forecasting, could provide additional information from images acquired for other purposes, or could assist with the interpretation of other OMW products such as those for ship or slick detection.

A. Ship Detection

The OMW ship detection 'algorithm uses a constant false alarm rate with a data adaptive K-distribution to model the fluctuating intensity returns from the sea clutter and to identify pixels with significant intensity excursions: This model has also been used to predict the RADARSAT performance for ship detection [Vachon *et al.,* 1997]. An example OMW ship target product is shown in Fig. 1.

Twenty-nine RADARSAT SAR images that have supporting ship validation information (ship name, type size, and location) have been compiled since early 1996. To date, 187 validated collocations have been identified. Our results indicate a 93% detection rate relative to the validation data, for those beam modes that are most favourable for ship detection.

B. Slick Detection

The OMW slick detection algorithm detects features with backscatter intensity below a user-defined threshold with respect to the local mean. The algorithm spatially averages the image, then searches for pixels that are below the threshold. There is no attempt to classify the candidate slicks or the slick properties. An example OMW slick product is shown in Fig. 2. Quantitative assessment of the performance of this OMW algorithm still requires validated oil spill information.

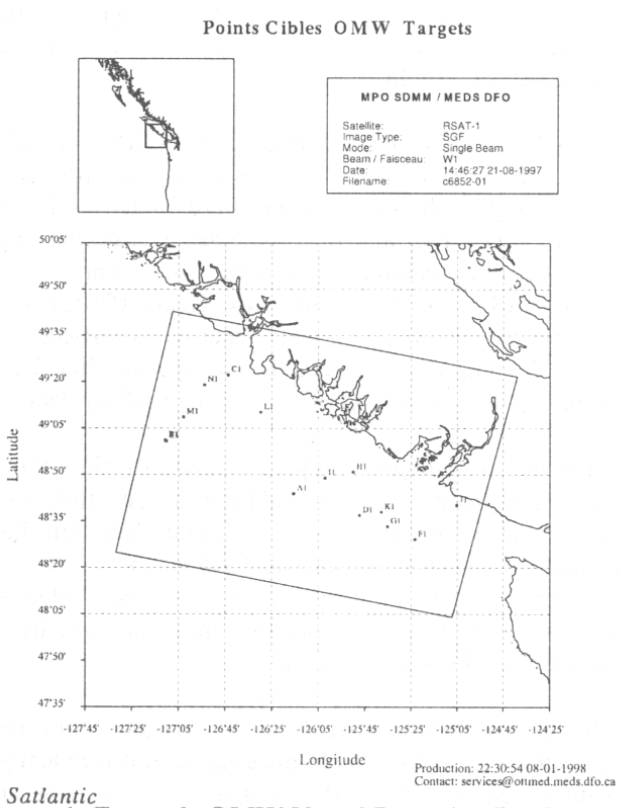

Figure 1: Example OMW Vessel Detection Product

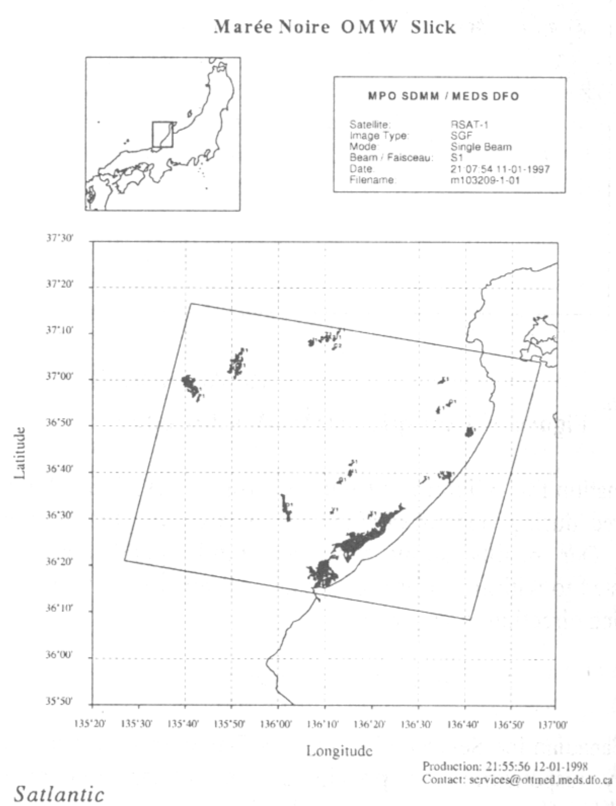

Figure 2: Example OMW Slick product.

C. *Wind Vector Retrieval*

The wind vector retrieval algorithm [Vachon and Dobson, 1996] attempts to estimate the wind direction, with an ambiguity of 180 degrees, from the orientation of the long wavelength energy in the SAR image, under the assumption that such energy is related to secondary atmospheric flow phenomena such as wind rolls. Then, having the wind direction and knowing the geometry, the wind is estimated from the observed C-band HH-polarized radar cross section using a scatterometer wind retrieval model. If the wind direction cannot be retrieved, then upper and lower bounds on wind speed based on crosswind and upwind look directions are estimated. An example OMW wind product is shown in Fig. 3.

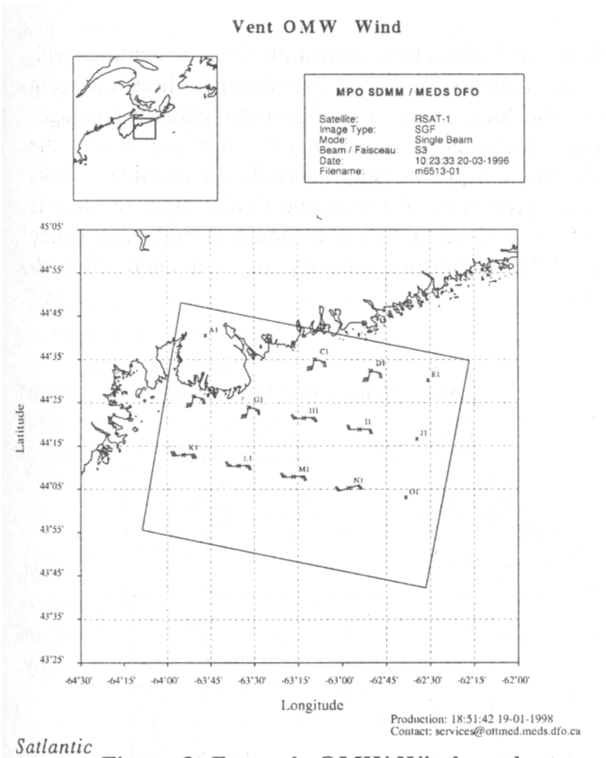

Figure 3: Example OMW Wind product.

Information for validation of wind vector retrieval have been gathered during dedicated field programs over the past 6 years. Our results show that the wind speed may be estimated to within a root-mean-squared error of 2.5 m/s, if the wind direction is known.

3. SEA ICE MONITORING

The Canadian Ice Service (CIS) is the Canadian Government agency responsible for providing ice information over Canada's offshore areas and is the largest single user of RADARSAT data. The CIS had been preparing to make operational use of RADARSAT data as soon as it was available, and were thus ready to take full advantage of the data made in early 1996 [Ram say *et al.,* 1996; Weir, 1997]. The CIS has a long history of operational ice reconnaissance using optical and radar sensors including NOAA. AVHRR, DMSP SSM/I, airborne SLAR and SAR, and ERS-1. Since January 1996, the CIS has received over 6000 RADARSAT ScanSAR scenes for operational analysis.

RADARSAT data are typically ordered 2 to 3 weeks in advance based on past knowledge of ice conditions in the regions of active commercial shipping. The CIS primarily makes use of the ScanSAR modes of RADARSAT which provide nominal swaths of 500km and 300km. These modes are preferred because of the excellent geographic coverage and revisit capabilities at sufficient resolution for the interpretation of significant ice features.

The processed image data is received at the Ottawa Ice Centre through a dedicated TI digital connection - the Image Transfer Network (ITN). Turn-around is guaranteed under contract with RADARSAT International (RSI) to be less than 4 hours from data acquisition, although actual delivery times average less than 2 hours.

The interpretation of imagery is performed visually by experienced ice analysts on an integrated display workstation. The GIS capabilities of the system are used to produce the final "ice chart", familiar to many marine operators, in addition to a variety of other image and map products. Depending on location and season, typically 5 to 10 classes of ice (stages of development and form) may be interpreted from RADARSAT imagery when supported by ancillary data. Details such as ridging and rafting can also be observed under optimal conditions.

The RADARSAT ice analysis charts and RADARSAT sub-images (called "imagettes") have become standard products available through a dial-up bulletin board system. These products are relayed to a variety of marine customers by means of satellite, cellular, and land lines. The major customer of CIS is the Canadian Coast Guard (CCG). All major icebreaker vessels and the Ice Operations Offices are equipped with communication and display systems (Ice-VU) for capture and display of RADARSAT and ancillary data.

In addition to visual image analysis, a series of algorithms are under development for automated information extraction. The most advanced of these is an ice motion algorithm that automatically tracks the displacement of ice between two RADARSAT images acquired at some time interval [Heacock *et al.,* 1993]. An example output product from this algorithm is presented in Fig. 4.

The strength of the RADARSAT system for ice reconnaissance lies in its reliable imaging, repeat frequency, and swath coverage. RADARSAT imagery is used as an important vessel management tool for the deployment or icebreakers. The data is received within hours of acquisition allowing Ice Operations Officers to more effectively deploy their ships to areas where ice poses a hazard.

During the peak winter marine navigation period January to April 1997, an average of 85 image analysis charts and 450 RADARSAT image products were produced each month. The frequency of coverage has lead reduction of airborne surveillance and the flight hours saved have been directed towards tactical support to icebreakers.

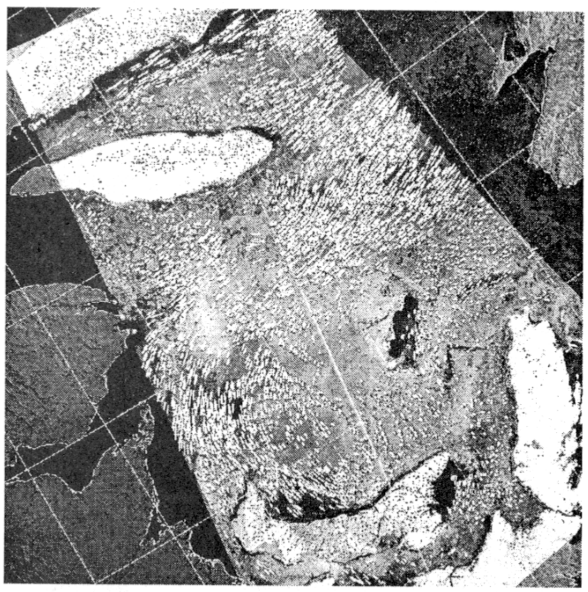

Figure 4: Ice Tracker Results in Gulf of St. Lawrence, March 4/5, 1997. The vectors represent the magnitude and direction of ice movement over the 12-hour interval between the two RADARSAT images.

4. CONCLUSIONS AND OUTLOOK

A significant effort has been undertaken in Canada develop and validate the coastal applications of satellite SAR, in particular RADARSAT. The results have confirmed the high utility of a flexible and operational system such RADARSAT to meet several coastal zone monitor requirements. Sea ice reconnaissance by the Canadian Service is fully operational and RADARSAT has become the primary data source for this activity. RADARSAT is also used operationally for oil spill detection and has become the sensor-of-choice for emergency response because of global coverage, high revisit capability, and fast-delivery. The algorithms for automatic detection of oil slicks in SAR images are still under evaluation. Algorithms for vessel detection are more advanced and have been validated over broad range of image modes and sea states Despite the technical suitability of a system to satisfy y particular information requirement, the Canadian RADARSAT experience has identified issues related system operations that need to be considered in a multi-user system. Each application has its own optimum imaging parameters that can often conflict with other users. This is particularly acute in the coastal monitoring operations a because of the desire by each user to image their region on every available overpass. In single-satellite systems this issue must be dealt with through prioritization of users through data policy. The future holds the prospect of multiple satellites operating simultaneously and increasing the number of imaging opportunities in multiple beam modes (e.g., RADARSAT, ENVISAT, RADARSAT-2).

There are also potential conflicts between monitoring and tracking (or emergency response) applications in the lead time required for satellite tasking. Monitoring operations require a reliable, predictable data stream well served by long lead times, whereas short-term, flexible response desirable for tracking.

5. REFERENCES

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