Monitoring the Coastal Zone with the RADARSAT Satellite

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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 a multiple mode synthetic aperture radar (SAR). Coastal zone applications of RADARSAT SAR data and guidelines for beam mode selection are presented. Three applications are considered in greater detail: ship detection; oil spill detection; and wind vector retrieval. Examples and validation of these applications are given in the context of the Ocean Monitoring Workstation (OMW), a system for extracting ocean information from RADARSAT SAR images.

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 about two years, providing radar images in 22 nominal single beam modes and in 4 multiple beam (ScanSAR) modes (see Fig. 1). 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) (see

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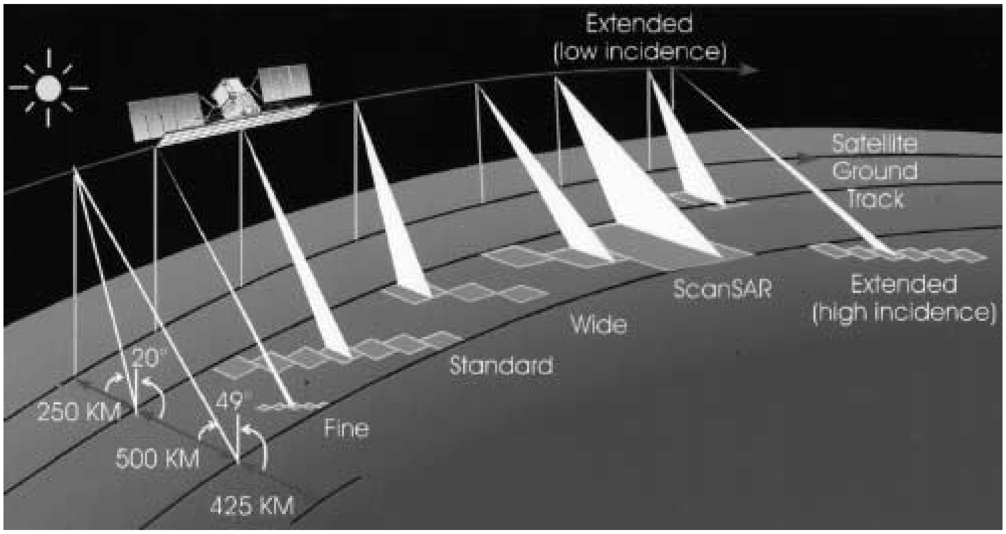


Figure 1: *RADARSAT SAR beam modes.*

Table 1: *Suggested RADARSAT beam modes for coastal applications.*

Application	Surveillance	Tracking
Slick Detection	SCNnear (SCW)	S1–S4 W1
Ship Detection	SCNfar (SCW)	W2 W3 S4–S7 F1–F5 EH1–EH6
Oceanic Features	SCNnear (SCW)	S1–S4 W1
Atmospheric Features	SCNnear (SCW) W1	
Ocean Waves	S1 W1 SCNnear (SCW)	

http://www.rsi.ca). RSI operates the Canadian Data Processing Facility (CDPF) located at GSS. RADARSAT is intended to be an operational system, ensuring data acquisition for paying customers. Usually, this requires ordering with a nominal lead time of two weeks in advance of data acquisition and assumes there are no conflicts with other users for the required satellite resources. Ordering with a few days lead time can be accommodated under unusual circumstance. The CDPF can accommodate image data delivery within a few hours following signal data downlink to GSS.

RADARSAT SAR images are now being routinely used for coastal ocean applications. Some applications, suggested beam modes, and their rationale were discussed by [Vachon and Olsen, 1995], and an updated summary is given in Table 1. The key data optimization issues are to trade image resolution for swath coverage, and to attempt to have 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. In the table, surveillance is assumed to require wide area coverage while tracking assumes that the nominal target location is known. ScanSAR wide (SCW) is best for surveillance due to its wide area coverage, but appears in brackets in the table since its relatively poor nominal resolution of 100 m could cause limitations.

In this paper, we will present a few of the possible coastal applications of RADARSAT

SAR data, including ship detection, oil spill monitoring, and wind vector retrieval. We first discuss the Ocean Monitoring Workstation (OMW), a system for extracting ocean information from RADARSAT SAR images.

2 Ocean Monitoring Workstation

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. Current development activities are based on a proposal from Satlantic Inc. to the RADARSAT User Development Program (RUDP) of the CSA and involves upgrades to certain analysis algorithms and the development of tools for output product quality control. The system has been designed to provide operational users of marine data with value-added ocean information products derived from RADARSAT SAR images. A significant data compression is achieved since the OMW application-specific information products, available in a graphical format, are a few 10's of kilobytes in size, whereas the initial image files may be 100's of megabytes in size. Included in the OMW products for ship reports is a product conforming to US and Canadian Navy standards (OTHGOLD contact reports), allowing the output to be utilized in navy information systems such as the Joint Maritime Command Information System (JMCIS) and the Maritime Command Operational Information system (MCOIN). These products are smaller still, allowing 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.

To aid in the development of a marine operational user community for RADARSAT data in Canada, ongoing demonstration trials have been conducted. Fig. 2 illustrates the RADARSAT/CDPF/OMW product delivery process. 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 installed on a Silicon Graphics O200 workstation via a high-bandwidth local area network (the ImageLAN). The OMW operates in an unattended mode and begins processing as soon as an image file is delivered. Requested ocean information products are generated and automatically delivered to the Marine Environmental Data Service (MEDS) ftp site, where they are made available to end-users and are archived. The data ordering process requires a few days to 2 weeks of lead time. However, in an operational scenario, these images are available for analysis within less than two hours from the time of SAR signal data downlink, and each OMW product is produced and available for onward transfer within 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,

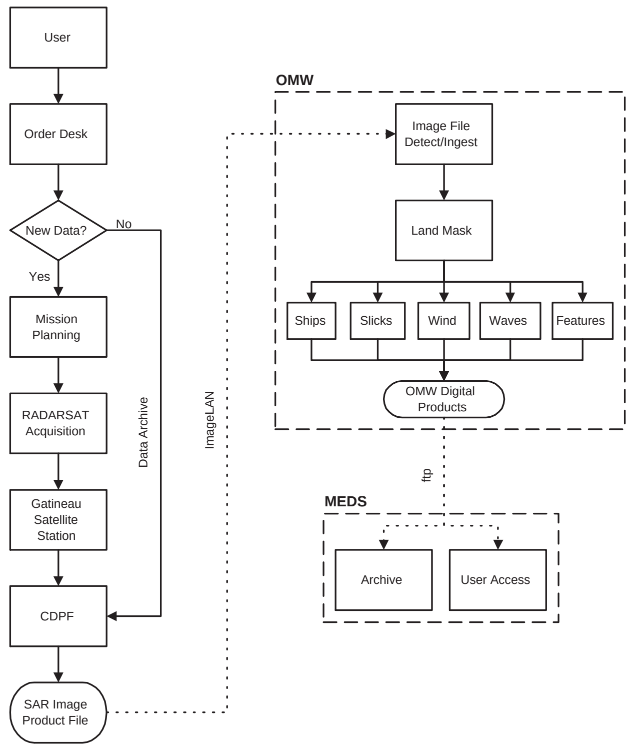


Figure 2: *Operational data flow diagram for the OMW installation at GSS.*

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.

3 Coastal Applications

3.1 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], as shown in Fig. 3. The figure-of-merit represents the minimum detectable ship size for the various RADARSAT beam modes, subject to assumptions about the image fading statistics, the ocean clutter, and the ship cross section, and allows comparison of beam modes and the selection of optimal modes for ship surveillance.

Within the OMW, candidate significant pixels are clustered based on maximum ship size and minimum ship proximity parameters. Candidate ship positions, estimated sizes (based on measurement of the shape of the signature and the observed radar cross section), and headings and speeds (based on analysis of the wake, if present) form the OMW ship report. An example W1 mode image and graphical OMW ship target product are shown in Fig. 4.

Thirty-three RADARSAT SAR images that have supporting ship validation informa-

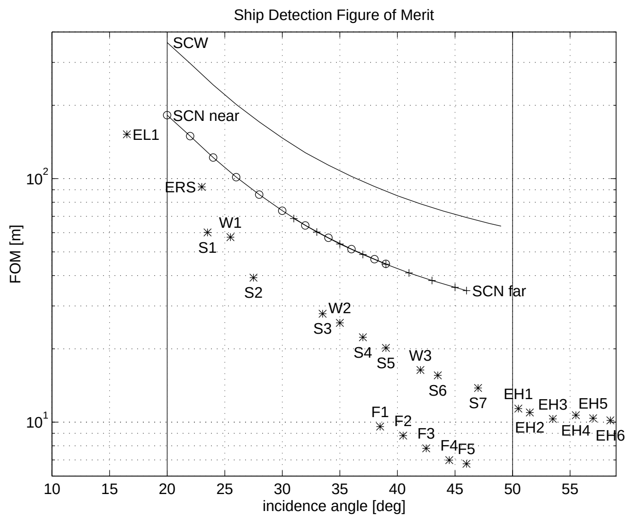


Figure 3: *Figure-of-Merit plot for RADARSAT and ERS SAR ship detection from* [Vachon *et al.*, 1997].

tion (ship name, type, size, and location) have been compiled since early 1996. Validation data have been derived from DND Aurora surveillance flight reports, and from DFO/CCG fisheries surveillance activities including Vessel Traffic System (VTS) and AIS (Automatic Identification of Ships) derived Global Positioning System (GPS) reports. To date, 187 validated collocations have been identified and cover a variety of ship types such as tugs, fishing, naval, fish-factory, research, and large container ships. Unavoidably, most of our validation data are biased towards larger ships.

An example of a validation product showing collocations between OMW ship targets and VTS/GPS ship targets is shown in Fig. 5. The table includes the ship length (L) and the distance between the OMW target location and the VTS/GPS target location (D). D is other than zero due to possible time differences between the RADARSAT and VTS/GPS observations, georeferencing errors in the RADARSAT data (due to use of predicted orbits, for example), and possible differences in the reference datum. Considering these error sources, if $D > 3$ km we assume that the RADARSAT/OMW combination was not able to detect that particular ship.

Referring to the figure, the factory ship *Cassiopeia* was detected by both validation data sources as well as the OMW. However, another large ship ($L > 100$ m) identified as the *Aquarius* by the GPS data and the *Kociewie* by VTS, was not detected by the OMW. Visual inspection of the RADARSAT image confirms the presence of a possible target at that location, however, its radar cross-section was not large enough to be detected by the OMW algorithm. This highlights the importance of RADARSAT beam mode selection (W1 is not the best RADARSAT mode for ship detection). Ship detection performance improves for increasing incidence angle and higher resolution beams (see Fig. 3). Further, the target cross section may be strongly dependent on the ship orientation. In the OMW algorithm, there is also a trade-off between reduction of the false alarm rate and success rate in detection. The OMW algorithm attempts to maximize the detection rate, while keeping the false alarm rate

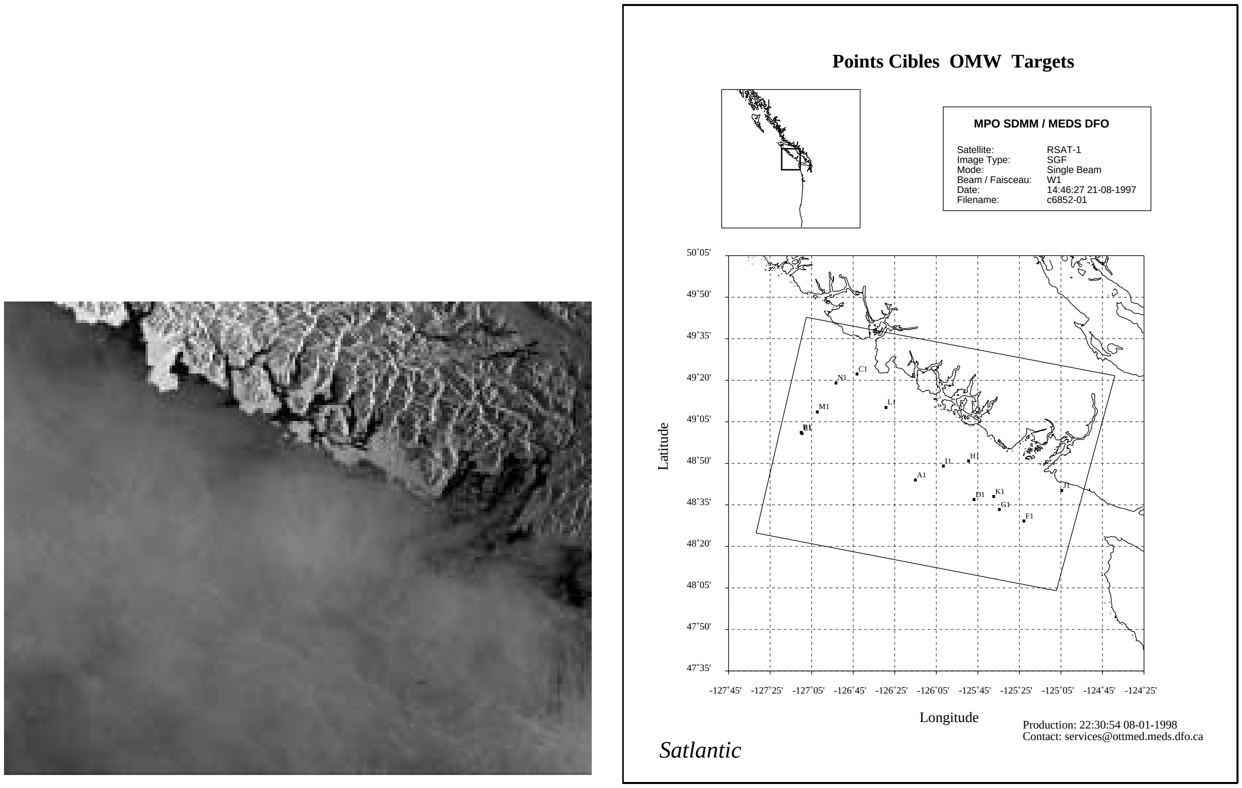


Figure 4: *RADARSAT SAR image (©CSA 1997) and corresponding OMW Ship Target product.*

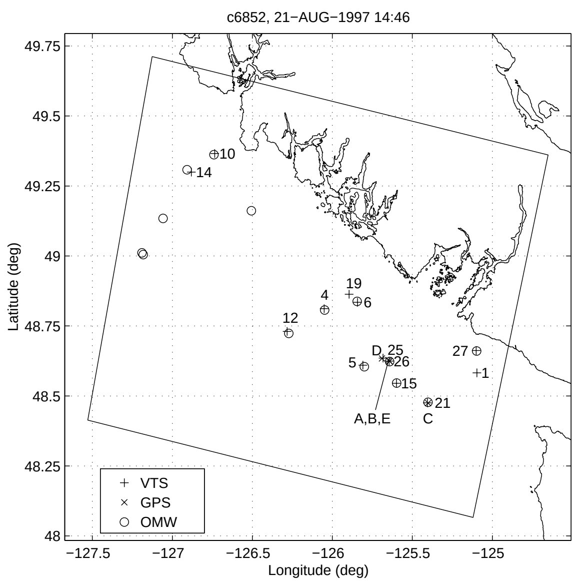
as low as possible.

Many of the datasets contained OMW candidate ship targets without validation information. A visual/contextual assessment of these targets suggests that the majority are likely small ships ($L < 30$ m). A few could be attributed to oceanographic phenomena (transient events such as breaking waves, for example) as well as nearshore rocks and shoals. Validation information for these smaller ships is scarce due to current limitations of the VTS system in tracking small ships and the absence of GPS transponders.

3.2 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. The significant pixels are grouped into candidate slicks, subject to minimum and maximum slick sizes and land proximity parameters. Candidate slick positions and sizes form the OMW slick report. There is no attempt to classify the candidate slicks or the slick properties. An example image and graphical OMW slick product are shown in Fig. 6.

Six RADARSAT SAR images containing suspected oil spills or biological slicks were processed. Since limited validation data are available, the evaluation of the algorithm has been subjective to date. The image of Fig. 6 was acquired over the Sea of Japan a few days



	Data	Name	L [m]	D [km]
A	GPS	*Acrux*	85	0.7
B	GPS	*Langusta*	94	0.1
C	GPS	*Cassiopeia*	103	0.3
D	GPS	*Aquarius*	103	>3
E	GPS	*Foka*	94	0.2
1	VTS	*Fierce Allegiance*	?	>3
4	VTS	*Orient Hope*	174	0.6
5	VTS	*Rubin Stella*	169	0.8
6	VTS	*Northern Jaeger*	102	0.4
10	VTS	*Haida Brave*	?	0.6
12	VTS	*Skauboard*	190	1.1
14	VTS	*Northwest Enterprise*	44	2.2
15	VTS	*Ken Shin*	?	0.1
19	VTS	*Gun Mar*	?	>3
21	VTS	*Cassiopeia*	103	0.4
25	VTS	*Kociewie*	139	>3
26	VTS	*Victor Lyagin*	130	0.2
27	VTS	*Haida Chieftan*	41	0.3

Figure 5: *VTS/GPS/OMW collocations (left) and ship identification (right).*

after the tanker *Nakhodka* broke apart in stormy conditions. The image contains a suspected oil spill from the tanker, as well as regions of variable winds. Both phenomena may result in areas of low backscatter. The OMW algorithm detected a number of candidate slicks. Quantitative assessment of the performance of this OMW algorithm still requires validated oil spill information.

3.3 Wind Vector Retrieval

The wind vector retrieval algorithm [Vachon and Dobson, 1996] attempts to estimate the wind direction, with an ambiguity of 180°, 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 image and graphical OMW wind product are shown in Fig. 7. The image clearly shows the long wavelength features of interest, oriented from left-to-right. The bright line near the right side of the image (from top-to-bottom) is a nadir ambiguity. Such ambiguities were common near scene edges during early RADARSAT operation.

Information for validation of wind vector retrieval have been gathered during dedicated field programs over the past 6 years. Validation data for wind speed and direction for both the RADARSAT and ERS SARs are presented in Fig. 8. The plot on the left side of the figure shows the regression between the SAR-derived wind speed and the *in situ* measurement. The best fit line is dashed, while the line of perfect fit is solid. The wind speed is estimated to

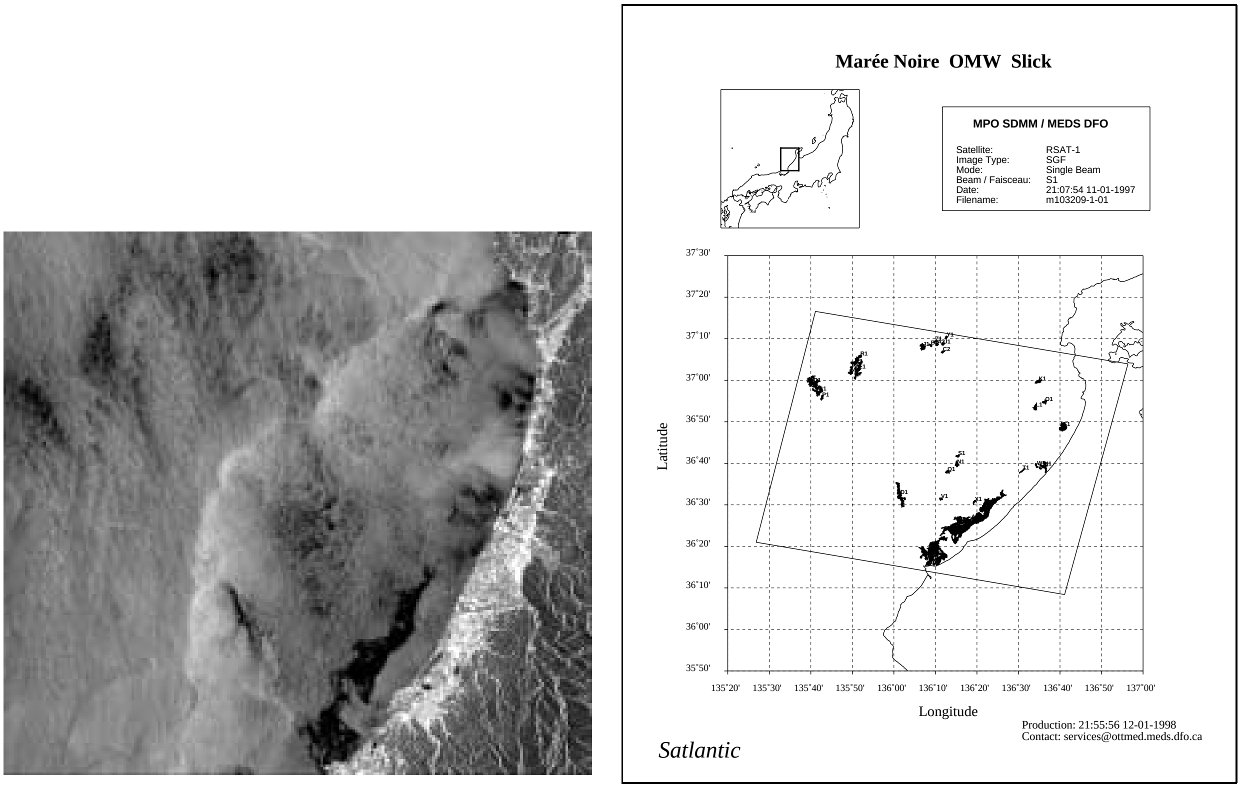


Figure 6: *RADARSAT SAR image (©CSA 1997) and corresponding OMW Slick product.*

within a root-mean-squared (RMS) error of 2 m/s, if the wind direction is known, across all observations from both sensors. The upper limit on validated wind speed is $\sim$ 20 m/s. Higher wind speed collocations are still being sought. The plot on the right side of the figure shows the difference between the SAR-derived wind direction after resolving the wind direction ambiguity and the *in situ* measured wind direction for both RADARSAT and ERS cases. The horizontal solid line represents a uniform distribution of directional differences, which would apply if the SAR-derived wind directions are completely random. The uniform distribution has a standard deviation of 52°. The RMS error for the SAR-derived wind direction is about 40°. We have found that the SAR-derived direction is within 30° of the *in situ* measurement for about half the cases, which is adequate for wind speed retrieval to within 2 m/s.

4 Conclusions and Outlook

Coastal zone applications using OMW ship, slick, and wind products have been demonstrated and certain aspects have been validated. In this paper, we focussed on only three of the possible OMW products.

The OMW ship detection product has been validated using RADARSAT images acquired at the same time as ship surveillance data. To date, 187 collocated ships have been identified, demonstrating good agreement between the RADARSAT/OMW detected targets and the VTS/GPS/DND Aurora ship surveillance data. The ship validation data are biased toward

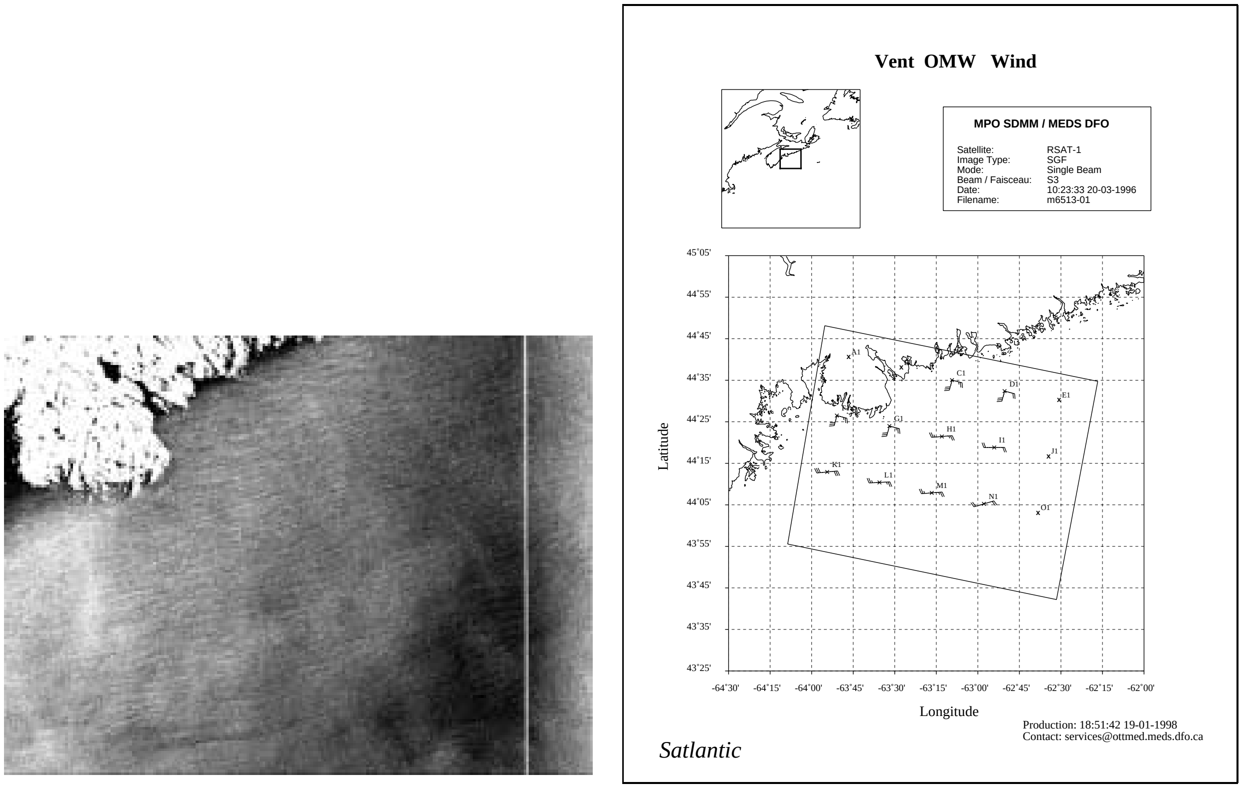


Figure 7: *RADARSAT SAR image (©CSA 1996) and corresponding OMW Wind product.*

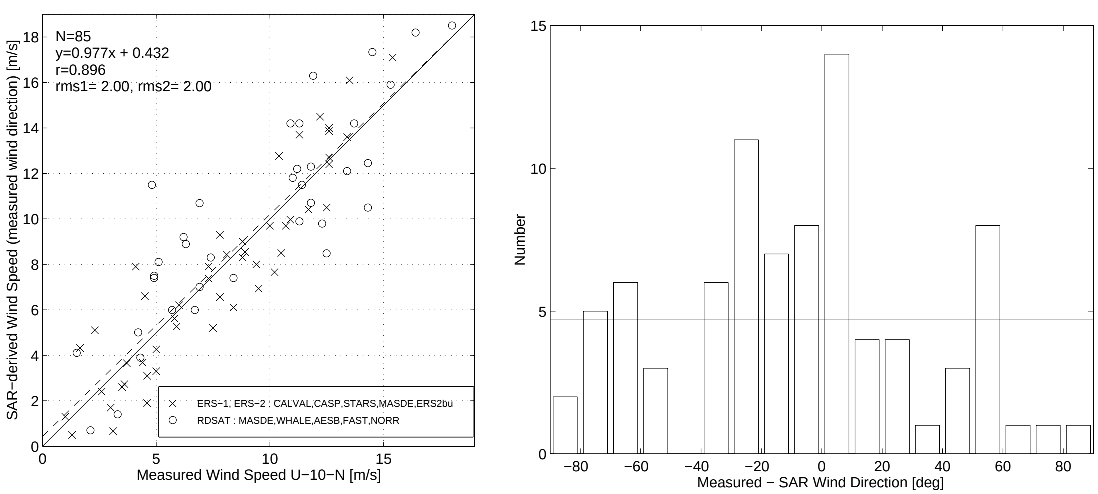


Figure 8: *Validation data for wind speed and direction for RADARSAT and ERS SAR cases.*

larger ships. Larger ships are more detectable, but detectability improves for lower background clutter associated with larger incidence angles and lighter winds, consistent with theoretical predictions. OMW ship products could be used to cue other operational ship surveillance activities.

The OMW slick product shows promise in detecting low backscatter features in SAR images, that could be used to cue other operational pollution surveillance activities. A more extensive sample of validated oil spill images is needed to quantify the success of the algorithm.

The OMW wind vector product can provide a wind vector with an RMS wind speed error of 2 m/s but with a directional ambiguity of 180°. The directional ambiguity may be resolved using other wind observation or synoptic surface analysis charts. The SAR-derived wind direction have been found to be within 30° of the measured wind direction for about half the validated cases. SAR-derived wind vectors could be used for site specific weather forecasting, as additional information from images acquired for other purposes, and to aid in the interpretation of other OMW products, such as those for slicks and ships.

The OMW software, a commercial product from Satlantic Inc., is still under development, with improved algorithms for sea state retrieval and tools for product quality control nearing completion. RADARSAT has now been operational for two years and is expected to remain operational for at least another 3 years. Plans for data continuity through RADARSAT-2 are now being finalized.

Acknowledgements

Many organizations and individuals have contributed to the demonstration and validation discussed in this paper. We wish to acknowledge, in particular, the significant contributions of Roger Beauchesne, Roy Penney, and Richard Nimmo (CCG); John Wolfe (Intermap); Pat Hoyt and Mike Dowd (Satlantic Inc.); John Campbell and Maria Rey (DREO); Howard Edel and Roc Larivière (DFO/MEDS); and Jim Day (DND).

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