RADARSAT SAR FOR IMAGING COASTAL ZONES AND OCEANS: AN UPDATE OF CCRS ACTIVITIES*

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ABSTRACT

The potential of the RADARSAT SAR for the detection of ships and the mapping of atmospheric phenomena is discussed. The ship detection algorithm described is implemented in the Ocean Monitoring Workstation (OMW). The capability of the RADARSAT/OMW combination to detect a range of ships is demonstrated with a 97% detection rate for those radar beams most suited to ship detection (F1-5, S4-7, W3). Sample images illustrate that the RADARSAT SAR shows good potential for the mapping of different atmospheric phenomena. It is proposed that RADARSAT is able to provide a unique contribution to operational marine meteorology. The application potential of RADARSAT is expected to improve with the launch of RADARSAT-2 in the year 2001.

1.0 INTRODUCTION

RADARSAT synthetic aperture radar (SAR) images have many potential coastal and ocean applications (Gower *et al*., 1993). The operational use of RADARSAT data is facilitated by the satellite's variable acquisition swath, multiple beam modes and 24-hour, all-weather imaging capability. Since the launch of RADARSAT-1 in 1995, the Canada Centre for Remote Sensing (CCRS) has taken an active role to evaluate the satellite's capabilities and promote its utility. Often these CCRS activities were undertaken in partnership with other government departments and/or private industry.

In this paper, we provide an update of the RADARSAT related work as carried out at CCRS's coastal zones and oceans group. This work concerns the validation of the Ocean Monitoring Workstation (OMW) and the mapping of atmospheric phenomena. In addition, we look ahead to the year 2001, i.e. the year when the successor of the current RADARSAT satellite is scheduled for launch. The new features of this RADARSAT-2 satellite are expected to enhance its application potential.

2.0 OCEAN MONITORING WORKSTATION VALIDATION

The OMW was developed by Satlantic Inc. with technical and financial contributions from various government departments [Henschel *et al*., 1997; 1998]. The system was designed to provide operational users of marine data with near real-time, value added ocean information

* Presented at the 21st Canadian Symposium on Remote Sensing, Ottawa, Ontario, Canada, 21-24 June 1999.

products derived from RADARSAT SAR images. 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. A prototype of the system was first implemented at the Gatineau Satellite Station (GSS) in 1995. Operational evaluation of the software has since led to significant improvements. Yet, the validation of individual OMW modules is ongoing. The latest results from an evaluation of the OMW's ship detection algorithm are discussed below.

2.1 SHIP DETECTION

Ships are often visible in RADARSAT SAR ocean images as bright point targets against the ocean clutter background. The OMW ship detection algorithm uses a Constant False Alarm Rate (CFAR) with a data-adaptive K-distribution to model the fluctuating intensity returns from the sea clutter and to identify pixels with significant intensity deviations. Candidate significant pixels are clustered and ordered based on maximum ship size and minimum ship proximity parameters. Candidate ship positions, estimated sizes, headings and speeds (based on analysis of the ship's wake, if present) form the basis of the OMW ship report (see Henschel *et al*., 1998).

The data set for validation of the RADARSAT SAR/OMW combination includes ship name, latitude/longitude position, and ship size and type when available. These data were acquired during dedicated field experiments conducted with the Department of Fisheries and Oceans (DFO) in 1996 and 1997. Vachon *et al*. (1997) discuss the results from one particular validation experiment off the coast of Halifax, Nova Scotia. The findings reported in the present paper were obtained using all of the validation information available. Hence, they are expected to better reflect the capabilities of the RADARSAT SAR/OMW combination for ship detection.

The validation approach adopted is straightforward and involves the comparison of ship validation positions with RADARSAT/OMW candidate target positions. Table 1 shows the three possible validation scenarios. Twenty-seven RADARSAT SAR images representing 11 different beam modes and variable wind conditions (0.4 to 13.2 ms^{-1}) were analysed. The images comprised 246 validation samples corresponding to a variety of ship sizes and types such as tugs, small fishing vessels, naval ships, fish-factory ships, research ships, and large container ships.

Table 2 summarises the most important results of the study. The overall detection rate, defined as [*Validated-Positives* / (*Validated-Positives* + *Negatives*)], was 84%. However, roughly half of the data sets were RADARSAT beam modes S1 to S3, and W1 and W2, which

Table 1. Validation Scenarios

Scenario	Validation Data Available	Detected by RADARSAT/OMW
Validated-Positives	Yes	Yes
Unvalidated-Positives	No	Yes
Negatives	Yes	No

Table 2. Ship Detection Results

Beam Modes	Images	Validated-Positives	Negatives	Detection Rate
Overall	27	174	34	84%
Least Favourable (S1-3, W1, W2)	13	95	28	77%
ScanSAR Narrow Far	2	17	4	81%
Recommended (F1-5, S4-7, W3)	12	62	2	97%

are not recommended for ship detection due to their relatively small incidence angles and expected lower ship detection performance. These modes had a 77% detection rate. The detection rate for the two ScanSAR Narrow Far images was 81%. The RADARSAT beam modes recommended for ship detection had a detection rate of 97%, showing reliable performance for those RADARSAT/OMW combinations. The ship detection rates compiled are not absolutes, but are strongly dependent on the wind conditions at the time of acquisition. However, the quoted rates are expected to be representative of the ship detection performance of the RADARSAT/OMW combination. False targets, due to either land-masking problems or transient oceanographic phenomena, may be identified and culled utilising the OMW Graphical User Interface. Hence, it is possible to improve OMW products through operator interaction.

3.0 MAPPING OF ATMOSPHERIC PHENOMENA

SAR images acquired over open water are well known to mirror the presence of atmospheric phenomena such as meteorological fronts, turbulent jet streams, convective cells, polar mesoscale cyclones and hurricanes (e.g. Alpers, 1995; Johannessen *et al.*, 1994; Vachon *et al.*, 1995). Atmospheric phenomena are seen in SAR images because they modulate the ocean surface wind stress and hence the small-scale surface roughness that governs the ocean's backscatter. In the present paper, we will consider the capabilities of the RADARSAT SAR to map atmospheric gravity waves, polar mesoscale cyclones and hurricanes.

3.1 ATMOSPHERIC GRAVITY WAVES

Atmospheric gravity waves (AGWs) occur at the boundaries of stable atmospheric layers and are induced by phenomena such as meteorological fronts, turbulent jet streams, and convective storms. AGWs are important because they affect the atmospheric circulation and the vertical structure of wind and temperature fields. SAR images often show AGWs as wave-like patterns with wavelengths ranging from a few to several tens of kilometers (Alpers, 1995; Vachon *et al*., 1995; Vachon *et al*., 1997).

Figure 1 shows an 18 by 18 km subset of a RADARSAT standard beam (S5) image acquired off the coast of Halifax on March 26, 1996. The mean wavelength of the group of

AGWs shown was measured to be 1100 ± 40 m. The bright spot near the centre of the image marks the Canadian Coast Guard vessel *Sir William Alexander*. SAR images often show both the AGWs and their source, e.g. meteorological fronts. Clearly, SAR can be a valuable tool in studies concerning the development and effects of AGWs.

3.2 POLAR MESOSCALE CYCLONES

Polar mesoscale cyclones (MCs) or polar lows develop at high latitudes poleward of major jet streams in cold air masses or frontal zones. Moore *et al*. (1996) hypothesise that MCs are a source of sudden atmospheric forcing or cooling of seawater and hence have a significant impact on the climate. Numerical simulation and forecasting of polar lows is still a problem due to their small spatial scales (< 800 km), short life times (24 to 48 hours) and the absence of validation information (Heinemann and Claud, 1997).

Figure 2 shows a RADARSAT ScanSAR wide image of an intense mesoscale cyclone over the Labrador Sea. The Canadian Ice Service acquired the image for routine ice surveillance on 29 December 1997. The RADARSAT image shows a spiral-form structure imprinted on the surface of the ocean. This feature is the result of the atmospheric low creating an intense surface air flow which spirals around the "eye" (the dark ellipsoid-shaped pattern) of the cell with sharp wind speed gradients across the frontal boundary that converges towards the "eye". The advection of cold air from Baffin Island to the warmer open water is apparent as the bright area in the southern portion of the image. The strong airflow becomes organised downstream from the ice edge into a second-order flow known as boundary layer roll vortices. The aspect ratio of the roll vortices increases downstream from the ice edge due to deepening of the atmospheric boundary layer. Deep cellular convection is evident north of the "eye".

3.3 HURRICANES

Hurricanes are tropical cyclones with winds that reach a sustained speed of 64 knots (33 ms^{-1}) or more. Hurricane winds blow in a spiral pattern around a relatively calm "eye". The "eye" may be 30 to 50 km in diameter and the storm may extend outward more than 500 km. As hurricanes move towards land with unpredictable trajectories, they can bring torrential rains, high winds, and storm surges. Their effect is devastating and can last several weeks. Along the eastern seaboard the hurricane season peaks in August and September.

Figure 3 shows a RADARSAT ScanSAR wide image of Hurricane Danielle when it was located off the US eastern seaboard on 31 August 1998. The RADARSAT image clearly shows the calm eye of the hurricane, with a diameter of about 40 km. The storm covers the full extent of the 500 km ScanSAR wide swath. The structure of the hurricane is imprinted on the surface of the ocean and shows strong convection (probably squall lines) in the arms that radiate outwards from the eye. The image brightness around the eye is modulated by the wind direction relative to the SAR look direction. This unique "view from below" is complementary to traditional, lower resolution IR cloud pattern imagery that is the mainstay of hurricane observation and trajectory modelling.

4.0 RADARSAT-2

RADARSAT-2 is scheduled for launch in 2001. The new satellite will be fully compatible with RADARSAT-1 but will also have some new features. These include an enhanced spatial resolution (up to 3 m), multiple-polarisations and a left- or right-looking mode. Moreover, the satellite's response time will be reduced through improvement of the ground segment. The reduction in response time and the choice of look direction augment the satellite's temporal resolution and hence improve its potential for almost any application. A higher spatial resolution will be of benefit for the detection of ships in particular. This application may also gain from the availability of multiple-polarisations. Likewise, the introduction of multiple-polarisations may improve the capabilities for oil slick detection. Depending on polarisation, the water-oil backscatter contrast will vary.

5.0 CONCLUSIONS

The capability of the RADARSAT/OMW combination to detect a range of ship targets has been demonstrated with a 97% detection rate for those beam modes most suited to ship detection (F1-5, S4-7, W3). Furthermore, we have shown that RADARSAT images make a valuable basis for the mapping of atmospheric phenomena. Hence, we believe that RADARSAT can provide a unique contribution to operational marine meteorology. The anticipated launch of RADARSAT-2 is important because this will ensure the data continuity required for the upkeep and development of operational marine (and other) applications. RADARSAT-2's new features are expected to improve its utility.

6.0 ACKNOWLEDGEMENTS

The Canadian Ice Service is acknowledged for supplying the RADARSAT images of atmospheric phenomena. We thank the Canadian Coast Guard for its highly significant input to the ship detection study. Julie Cranton and John Wolfe (CCRS) contributed to the processing of the RADARSAT data. Sylvia Thomas (Noetix Research Inc.) assisted in the final editing of the paper.

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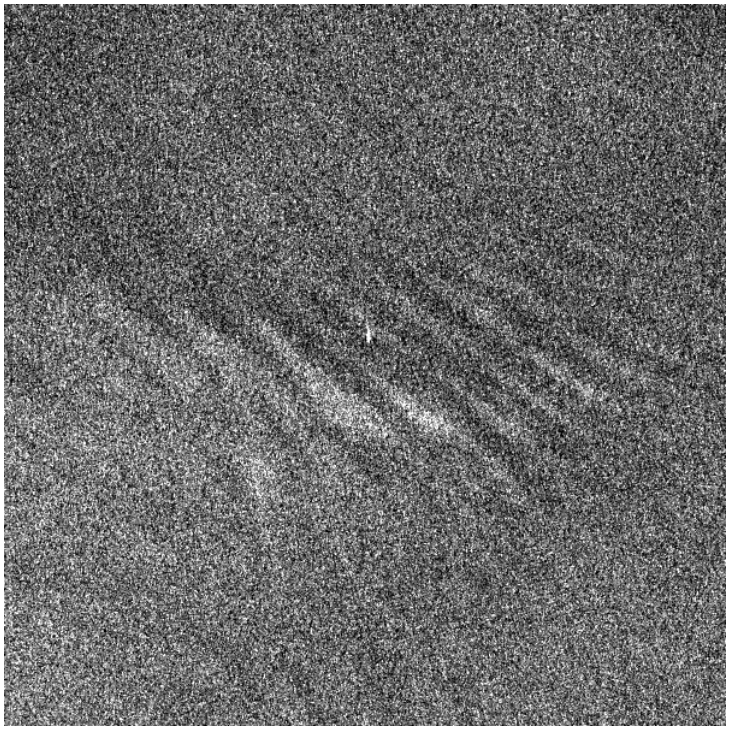

Figure 1. Subscene from S5 RADARSAT image showing atmospheric gravity waves off the coast of Halifax. The area shown is 18 km by 18 km.

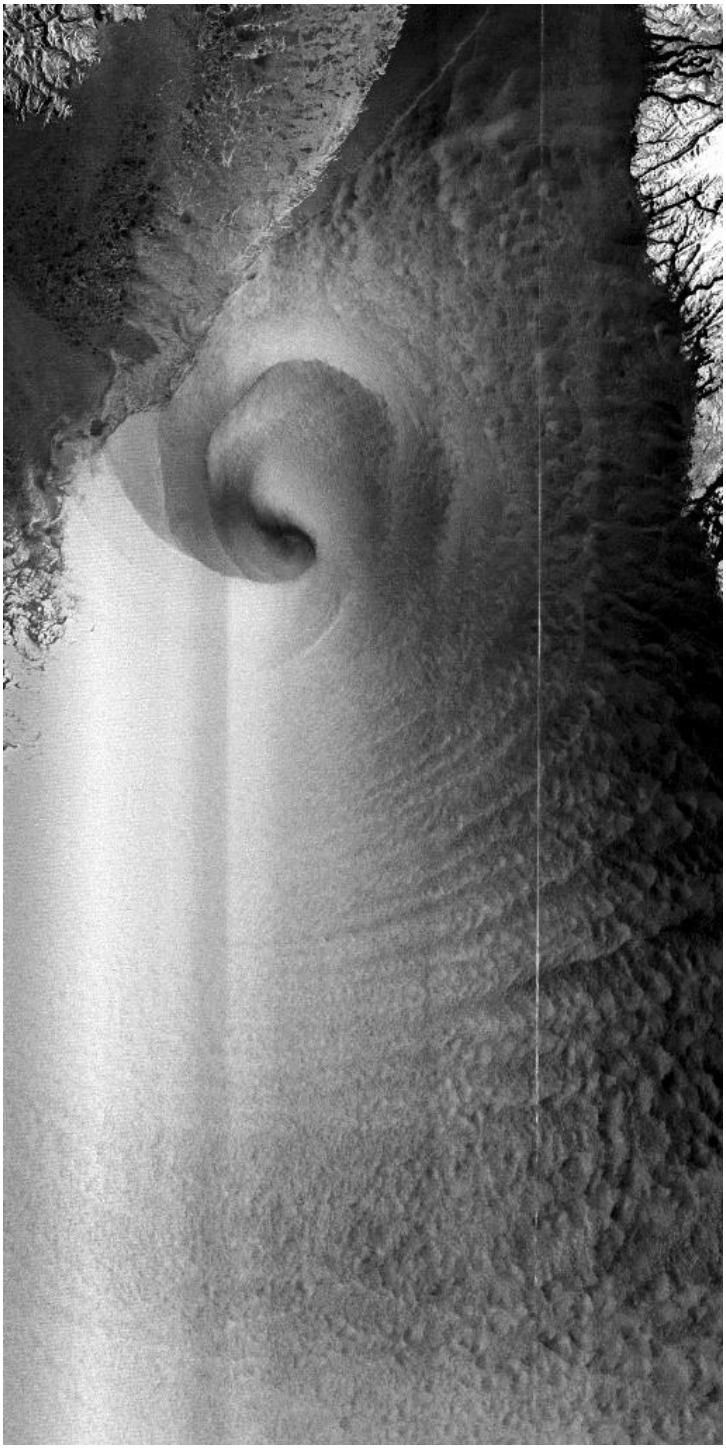

Figure 2. RADARSAT ScanSAR wide image of a polar mesoscale cyclone over the Labrador Sea. The area shown is approximately 1000 km by 500 km.

Figure 3. RADARSAT ScanSAR wide image of Hurricane Danielle off the East Coast of the USA. The area shown is approximately 1000 km by 500 km.