# Validation of Ship Detection by the RADARSAT Synthetic Aperture Radar and the Ocean Monitoring Workstation[1]

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**SUMMARY** – The capability of the RADARSAT synthetic aperture radar (SAR), in combination with the Ocean Monitoring Workstation (OMW), for automated ship detection has been assessed using *in situ* ship validation information collected during field experiments conducted in 1996 and 1997. Our analysis of the available validation data indicates a 97% ship detection rate for the RADARSAT single beam modes that are best suited to ship detection (i.e. those beam modes having the largest incidence angles), and an 84% ship detection rate overall. Due to limitations of the validation data, the false alarm rate cannot be explicitly addressed, nor can the wind speed dependence of the detection rate be measured. The validated ships tended to be large in size, 120 m in length on average. Our results indicate reliable automated ship detection performance using the RADARSAT/OMW combination.

**RÉSUMÉ** – La capacité combinée du radar à synthèse d'ouverture (RSO) de RADARSAT et de la station de travail de surveillance des océans (OMW de l'anglais Ocean Monitoring Workstation) pour la détection automatique des navires a été évaluée par une validation *in situ* lors des campagnes de terrain de 1996 et 1997. Notre analyse des données de validation disponibles montre un taux de détection de 97% pour les données à faisceau simple qui sont le plus utile pour la détection des navires (les faisceaux ayant un grand angle d'incidence) et un taux de détection global de 84%. Le taux de fausses détections est toutefois difficile à expliquer à cause des limites des données de validation. On ne peut non plus évaluer la dépendance du taux de détection avec la vitesse du vent. Les navires détectés ont tendance à être de grande dimension (120 m de longueur en moyenne). Nos résultats indiquent que la performance du système de détection automatique utilisant la combinaison RADARSAT et OMW est fiable.

## 1. INTRODUCTION

RADARSAT synthetic aperture radar (SAR) images have many potential coastal and ocean applications (Gower *et al*., 1993). For example, the marine operational user community has recently become interested in the use of RADARSAT data for ship surveillance in support of fisheries enforcement activities (Clemente-Colón *et al*., 1998; Manore *et al*., 1998; Montgomery *et al*., 1998; Wahl, 1998). The RADARSAT SAR has a variable acquisition swath and multiple beam modes (Raney *et al*., 1991), enabling repeat coverage within 0.5 to 5 days, depending on latitude. To develop the ship detection application, automated RADARSAT SAR ship detection algorithms have been developed and implemented in an Ocean Monitoring Workstation (OMW) (Henschel *et al*., 1997; 1998).

In this paper, we investigate the RADARSAT SAR/OMW combination for ship detection and assess the accuracy of the OMW ship product. The RADARSAT imagery were downlinked to the Gatineau Satellite Station (GSS), were processed to standard image products at the Canadian Data Processing Facility (CDPF) (Denyer *et al*., 1993), and ship products were generated using an implementation of the OMW at the Canada Centre for Remote Sensing (CCRS). The *in situ* ship validation data were collected during a number of field opportunities in 1996 and 1997.

Theoretical RADARSAT Ship Detection Performance and Beam Mode Recommendations

This validation study draws upon a theoretical model developed to predict the RADARSAT SAR's ship detection performance (Vachon *et al*., 1997). The model leads to the definition of a Figure-of-Merit (FOM), which represents the minimum detectable ship size for the various RADARSAT beam modes, subject to assumptions about the ocean clutter as a function of wind speed, the image fading statistics, and the radar cross section of ships. The FOM allows a relative comparison of the available RADARSAT beam modes, as well as selection of optimal RADARSAT beam modes based on surveillance requirements (Vachon and Olsen, 1998).

The ship detection model shows that RADARSAT's ship detection performance improves with higher resolution, larger incidence angle, and lower wind speed. For ship surveillance, which requires frequent wide area coverage, the ScanSAR Narrow Far beam mode is recommended as it provides a useful trade-off between swath coverage (300 km) and ship detectability. Although the ScanSAR Wide mode provides the largest swath coverage (500 km), its relatively coarse resolution (100 m) may cause limitations in its performance, especially for smaller incidence angles. For ship tracking, which assumes the nominal location of a ship is known and requires smaller area coverage, the single beam modes with large incidence angles are recommended: W3, S4 to S7, F1 to F5, and EH1 to EH6.

## 2. OCEAN MONITORING WORKSTATION

The OMW (Henschel *et al*., 1997; 1998) was developed by Satlantic Inc. with technical and financial contributions from CCRS, the Department of Fisheries and Oceans (DFO), the Canadian Coast Guard (CCG), the Department of National Defence (DND), and the Canadian Space Agency (CSA). The system was designed to provide operational users of marine data with near real-time, value added ocean information products derived from RADARSAT SAR images. The workstation 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.

Trials have been conducted to assist in the demonstration and validation of the RADARSAT SAR/OMW combination for ship detection. Fig. 1 illustrates the data flow for RADARSAT/CDPF/OMW near-real time delivery for the OMW installed at GSS. RADARSAT SAR data ordered by users are acquired by the satellite, downlinked to GSS, and processed by the CDPF to standard format image files. The SAR image files are transferred to the OMW 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. Ocean information products are generated and automatically delivered to the Marine Environmental Data Service (MEDS) ftp site at DFO, where they are made available to end users and archived. Data ordering requires a few days to 2 weeks of lead-time. In an operational environment, the images are available for analysis within hours of the satellite overpass time; each OMW product is produced within a few minutes of processing effort. Recent trials for DND of an OMW installed in a transportable ground station with a high rate SAR processor (Henschel *et al*., 1998) resulted in OMW products within 30 minutes of the SAR acquisition time.

## 2.1 Ship Detection Algorithm

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 excursions. The algorithm calculates the image intensity mean and variance for consecutive image frames allowing for a range of incidence angles and for wind variability within a scene. The wind variability within a frame is modeled by an order parameter $\nu$, which defines the shape of the K-distribution. The order parameter is estimated from the frame mean and variance and the number of statistically independent looks produced by the SAR processor. A critical intensity level $I_c$ is estimated for each frame using $\nu$, the mean frame intensity, and the user-specified significance level $\alpha$ as inputs. The significance level is defined as $\alpha$ = (1 - CFAR) and represents the percentage of pixels above the threshold value when our assumption of homogeneity holds. It is chosen such that less than one false alarm is expected for a frame that uses an entire standard image product that covers 100 km by 100 km.

The detector proceeds by searching each frame for pixels exceeding $I_c$ that are more than a user-defined distance away from land, beam seams, nadir ambiguities, and other candidate ship targets. Candidate significant pixels are clustered and ordered based on maximum ship size and minimum ship proximity parameters. Recommendations for the user-configurable OMW parameters such as the frame size and the user-defined distances have been made elsewhere (see, Campbell and Vachon, 1997). Candidate ship positions, estimated sizes, and headings and speeds (based on analysis of the ship's wake, if present) form the basis of the OMW ship report (Henschel *et al*., 1998).

# 3. FIELD VALIDATION PROGRAMS

Our ship validation data were acquired during a number of field validation opportunities in 1996 and 1997.

## 3.1 Dedicated field validation program

From March 20 to April 10, 1996, a dedicated RADARSAT ship detection validation program occurred off the coast of Halifax, Nova Scotia. The experiment was a collaborative effort between CCRS, DND, DFO (CCG and the Bedford Institute of Oceanography), and the Atmospheric Environment Service. A DND Aurora surveillance aircraft was tasked to underfly the RADARSAT passes in March and provided information on ship traffic density as well as ship course, speed, and name. CCG fisheries surveillance deployed a research ship near a wind and wave buoy location at the times of the RADARSAT overpasses, providing Global Positioning System (GPS) ship location data. Detailed results from this experiment have been reported elsewhere (Vachon *et al*., 1997).

### 3.2 DFO/CCG Fisheries Enforcement 1996/97

Several field validation experiments were conducted by DFO/CCG in 1996/97 covering fishing grounds off the east and west coasts of Canada. The CCG Vessel Traffic Service (VTS) radar and GPS positions from the Automatic Identification System (AIS) provided validation information. The majority of our ship validation information was acquired during these opportunities.

## 4. VALIDATION DATA

Our set of validation data includes ship name, latitude/longitude position, and ship size and type when available. In most cases, ship lengths were acquired after the fact from various sources (e.g. Jane's Fighting Ships, 1995; Lloyds Register of Ships, 1997-98; Record of the American Bureau of Shipping, 1997).

### 4.1 AIS GPS

The AIS transponder system (Penney, 1997) was used to obtain GPS ship position data during the DFO/CCG fisheries enforcement experiments. The AIS system was onboard a number of foreign factory ships, a few DFO ships, and most tankers leaving Prince William Sound on the Alaska coast. The AIS system has a range greater than 60 nautical miles. Ships with transponders onboard transmitted GPS data on time, location, and heading via radio link to the Tofino VTS office. Fish-factory and DFO ships reported their position every 10 seconds; tankers reported less frequently, generally every 2 or 5 minutes depending on their range from the radio site.

### 4.2 VTS

The Canadian Coast Guard maintains a network of Marine Communication and Traffic Services centres across Canada. Tofino, located at Ucluelet, B.C., is an Offshore centre with a radar capable of tracking ships to a distance of 60 nautical miles. The radar is equipped with an automatic tracking system that provides position as well as course and speed data for a maximum of 40 ships. Position data are updated every 18 seconds. At times, more than 700 targets can be displayed on the radar, but rarely are more than 40 of these considered "Targets of Consequence" (ships 20 m or more in length) that require tracking. Smaller ships are not legally required to participate in the system; therefore details of these ships are unknown. However, ship locations would be given as traffic to the larger vessels. If more than 40 large ships are within the system, those that present the highest risk of environmental damage are given tracking priority.

## 5. VALIDATION RESULTS

The OMW validation process is straightforward, requiring comparison of ship validation positions with RADARSAT/OMW candidate target positions. Several scenarios are possible (Table 1). Candidate targets detected by the OMW and collocated with one or more of the validation sources are referred to as *Validated-Positives*. Candidate targets detected by the OMW for which there was no validation data are referred to as *Unvalidated-Positives*. These can include smaller ships, transient oceanographic phenomena (such as breaking waves), landmasking inaccuracies in the OMW, and outlying rocks, shoals, and islands. Validation data locations for which no OMW target was detected are referred to as *Negatives*.

We have compiled 27 RADARSAT SAR images that contain ships detected by both the OMW and one or more of the validation data sources. Table 2 summarizes the validation data set. The 246 validation samples include a variety of ship sizes and types such as tugs, small fishing ships, naval ships, fish-factory ships, research ships, and large container ships. The validation data were checked to ensure their accuracy and suitability for validation purposes. For example, some of the validation data were culled due to time errors caused by infrequent reporting intervals.

Wind speed data were acquired from nearby buoys, as available. The winds at the RADARSAT pass times were generally low, varying from 0.4 to 13.2 $ms^{-1}$. The wind speed data provide a general reference for the environmental conditions at the time of imaging. Ultimately, we could not correlate the occurrence of *Negatives* with higher wind speeds.

Collocation maps were produced to compare the target location information (see Fig. 2, for example). A total of 174 OMW targets were validated. Of these, 16 were trilocations (targets detected by the OMW and two different validation data sources). Validated ship sizes ranged from 20 m for a fishing boat to 294 m for a large tanker. RADARSAT Standard beam modes S2, S3, S6, and S7 (nominal resolution 25 m), Wide mode W2 (nominal resolution 27 m), and ScanSAR Narrow Far mode (nominal resolution 50 m) detected the smallest validated ships, between 20 m and 30 m in length. To better illustrate the nature of our validation data, we now consider four case studies in detail.

**5.1 Case Study 1 – GPS Collocations**

Fig. 2 shows OMW and GPS collocations for a RADARSAT S5 image acquired October 7, 1996 off the West Coast of Vancouver Island. Sub-scenes of the RADARSAT image and the collocated targets are included in Fig. 3 to provide a detailed view of the group of targets near 48.6N, 125.6W. All of the point targets visible in the image were detected by both the OMW and the GPS data and are identified as fish-factory ships. Table 3 includes the details of ship name, size (L), and distance from the OMW target (D). This distance is non-zero due to time differences between the RADARSAT data and validation observations, georeferencing errors in the RADARSAT data and/or OMW products, and possible differences in the reference datum. Considering these possible error sources, we usually assume that the RADARSAT/OMW combination was unable to detect a particular ship if the distance from the validation location was greater than 3 km.

### 5.2 Case Study 2 – GPS/VTS Trilocations

Fig. 4 shows collocations for a RADARSAT ScanSAR Narrow image acquired August 15, 1997 off the West Coast of Canada, along with a close-up of a group of targets southwest of Vancouver Island. Four trilocations have been identified; the close-up shows a detailed view of three of these, the Cassiopeia (103 m), Acrux (86-95 m), and Overseas Alaska (223 m). Ship identification details are included in Table 4. In this table, the Acrux spans a range of lengths since three ships with that name were found in the references, and it was uncertain which of these ships the VTS/GPS validation data had tracked. A fourth ship, the Foka (94 m), was identified by both validation sources, but was not detected by the RADARSAT/OMW combination. Visual analysis of the RADARSAT data confirms the presence of a possible target at the Foka's location, however the ship was rejected since it lay under the OMW beam seam mask that is applied to ScanSAR imagery. The purpose of the beam seam mask is to eliminate regions of fluctuating mean intensity where the individual beams composing a ScanSAR image overlap, as this may skew the OMW calculated frame statistics and change the false alarm rate. The size of the beam seam and nadir ambiguity masks is a user configurable parameter. In an unattended mode of operation, as in this study, the beam seam mask is usually set at a larger value to ensure that no false alarms from the masked area are present in the end products. In an interactive setting, the masks can be reduced in size to ensure that no candidate targets are missed.

In total, 16 trilocations were identified. The validation sources agree in 11 (69%) of these cases. Of the 5 cases where the validation data exhibited inconsistencies, 3 may have been incorrectly matched to an OMW target as other targets were visible within 3 km of the validation location. For the remaining 2 cases (12% of trilocations), inconsistencies in the validation data could not be explained. For example, an OMW candidate target identified as the Aquarius by the GPS data was identified as both the Aquarius and Langusta by VTS (see Fig. 4). It appears that the VTS information placed both ships at the same position, suggesting that the VTS data were in error.

### 5.3 Case Study 3 – *Validated-Positives/Unvalidated-Positives*

All datasets contained candidate targets that were detected by the OMW, but not collocated with data from any of the validation sources (*Unvalidated-Positives*). In total, the RADARSAT/OMW combination detected 1042 candidate targets, of which 174 were collocated with one or more of the validation data sources and, therefore, were positively identified ships (*Validated-Positives*). A visual/contextual assessment of the remaining 83% of targets suggests that the majority is likely small ships (probably less than 20 m in length). A few were attributed to landmasking inaccuracies and outlying rocks, shoals, and islands that are not contained in the landmask database. Validation information for these smaller ships is scarce due to the noted limitations of the VTS system in tracking small ships and the absence of GPS transponders on such ships. Therefore, we are not able to explicitly assess the RADARSAT/OMW false alarm rate.

Fig. 5 shows an example of the additional ship information that can be extracted from RADARSAT data by the OMW. Of the 44 candidate targets identified by the OMW, only 9 were collocated with the validation data. Consequently, there may be up to 35 ships within the image that the validation sources have not identified. The RADARSAT subimage on the right shows a group of 4 of these 35 candidate targets. The distinct point return and location suggests that these are likely small ship targets.

**5.4 Case Study 4 – *Negatives***

Sixteen percent of validation data samples were not collocated with an OMW target. A visual assessment of these *Negatives* indicated that there were no nearby ship-like targets within the image. The ship sizes for the *Negatives* ranged from 29 m to 292 m. The occurrence of *Negatives* may be due to time and ship location errors in the validation data, resulting in relative positions separated by more than 3 km. It is also possible that the target was not detected by RADARSAT due to the selected beam mode, the local wind speed at the time of imaging, the ship size, or the ship orientation. The majority of *Negatives* (82%) were acquired for the S1 to S3, W1, and W2 RADARSAT beam modes, which are less favorable for ship detection than the larger incidence angle modes. This group of beam modes also had the lowest detection rate, at 77% (see Table 5).

In several cases, validated targets visible within RADARSAT imagery were not detected by the OMW as they lay under a beam seam mask. These have not been considered in establishing the detection rates. In another 3 cases, targets visible in the RADARSAT imagery within 3 km of the validation data location may not have been detected by the OMW algorithm due to the trade-off between reduction in false alarm rate and success rate in detection. The algorithm attempts to maximize the detection rate, while keeping the false alarm rate at a practical level.

Fig. 6 shows a RADARSAT W1 image acquired October 13, 1996 off the West Coast of Vancouver Island. This image had a detection rate of only 25%. The wind speed as measured by a buoy within the image was 0.4 $ms^{-1}$, however, the spatial variability in the image brightness, caused by local convection and internal waves, suggests spatial variability in the wind field. The collocation results, together with a RADARSAT subimage showing two validated ships and the location of two *Negatives*, are shown in Fig. 7. Barring errors in the validation data, the local variability appears to have masked the ship signatures.

**5.5 Results**

Table 5 summarizes the key results of this study. The overall detection rate, defined as [*Validated-Positives* / (*Validated-Positives* + *Negatives*)], was 84%. However, roughly half of the datasets were RADARSAT beam modes S1 to S3, and W1 and W2, which 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 mean ship length among *Validated-Positives* was approximately 120 m. The smallest *Validated-Positive* ship was 20 m in an S2 mode image with a wind speed of 4.4 $ms^{-1}$. The largest *Validated-Positive* ship was 294 m in an S7 mode image with a wind speed of 1.6 $ms^{-1}$. The case of highest wind speed with a *Validated-Positive* was a ScanSAR Narrow Far mode image with a wind speed of 13.2 $ms^{-1}$. The case of lowest wind speed with a *Negative* was a W1 mode image with a wind speed of 0.4 $ms^{-1}$. These cases clearly illustrate that the ship detection rates we have compiled are not absolutes. However, we expect that our observed detection rates are representative of the ship detection performance of the RADARSAT/OMW combination.

The operational implementation of the OMW will include an interactive Quality Control component. False targets, due to either landmasking problems or transient oceanographic phenomena, may be identified and culled utilizing the OMW Graphical User Interface. The width of beam seams applied to ScanSAR imagery may also be modified, or the seam mask not applied, thus reducing the occurrence of masked ships. This operator interaction will improve OMW ship products for operational users.

**6. CONCLUSIONS**

Representative samples of RADARSAT imagery, along with validated ship data, have been acquired during several field validation opportunities over the past two years. A total of 174 OMW targets were matched to at least one validation data point, demonstrating good agreement between the RADARSAT/OMW detected targets and the VTS/GPS/Aurora ship validation data. Due to current limitations in the validation information sources, the ship data are biased toward longer ships and lower wind speeds.

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. In the case of *Unvalidated-Positives*, it was concluded that the majority of these were likely smaller ships. Discrepancies in the validation data were observed for some of the trilocations. Furthermore, 16% of the validation data samples were not collocated with an OMW target. Eighty-two percent of these *Negatives* were acquired for the smaller incidence angle RADARSAT beams (S1 to S3, W1 and W2), whose performance for ship detection is expected to be lower than that of the larger incidence angle modes.

Based on this data set, we were not able to quantitatively address the RADARSAT/OMW false alarm rate or the wind speed dependence of the detection rate.

In an operational scenario, OMW ship products could be available within hours of data acquisition and could be used to cue other ship surveillance activities. To quantify the ship detection capabilities of RADARSAT and the OMW for the more interesting and difficult small ship cases, a representative sample of validation data for ships under 20 m in length, together with wind data, is still required.

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**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:** RADARSAT imagery, validation data, and ship detection results.

| | Location | Scene | Date | Mode | Validation | Wind [$ms^{-1}$] | Val-Pos | Neg | Rate [%] | Case |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | West Coast | M87005 | 03/10/96 | W2 | GPS | 8.9 | 7 | 0 | 100 | |
| **2** | West Coast | M87671 | 07/10/96 | S5 | GPS | 5.5 | 9 | 1 | 90 | 1 & 3 |
| **3** | West Coast | M87730 | 07/10/96 | F5 | GPS | 0.9 | 1 | 0 | 100 | |
| **4** | West Coast | M87731 | 07/10/96 | F5 | GPS | 0.9 | 1 | 0 | 100 | |
| **5** | West Coast | C3422 | 13/10/96 | W1 | GPS | 0.4 | 3 | 9 | 25 | 4 |
| **6** | Bay of Fundy | M86589 | 28/09/96 | S7 | VTS | | 5 | 0 | 100 | |
| **7** | West Coast | M120380 | 15/07/97 | S6 | VTS | 6.4 | 14 | 0 | 100 | |
| **8** | West Coast | M120864 | 18/07/97 | W2 | VTS | 4.3 | 8 | 2 | 80 | |
| **9** | West Coast | M120328 | 22/07/97 | W2 | VTS | 2.9 | 15 | 0 | 100 | |
| **10** | West Coast | C7025 | 22/07/97 | S7 | VTS | 1.6 | 10 | 0 | 100 | |
| **11** | West Coast | C7027 | 25/07/97 | W2 | GPS/VTS | 8.5 | 18 | 0 | 100 | |
| **12** | West Coast | M121882 | 29/07/97 | S3 | GPS/VTS | 5.1 | 9 | 3 | 75 | |
| **13** | West Coast | M122910 | 01/08/97 | F2 | GPS/VTS | 0.7 | 2 | 0 | 100 | |
| **14** | West Coast | C8336 | 01/08/97 | F5 | GPS/VTS | 3.5 | 4 | 0 | 100 | |
| **15** | West Coast | M123757 | 04/08/97 | S2 | GPS/VTS | 4.4 | 10 | 1 | 91 | |
| **16** | West Coast | M123008 | 08/08/97 | S6 | GPS/VTS | 10.9 | 13 | 1 | 93 | |
| **17** | West Coast | C6849 | 12/08/97 | W1 | VTS | 4.9 | 9 | 7 | 56 | |
| **18** | West Coast | C6850 | 15/08/97 | SCNB | GPS/VTS | 13.2 | 6 | 1 | 86 | 2 |
| **19** | West Coast | C6851 | 18/08/97 | SCNB | GPS/VTS | | 11 | 3 | 77 | |
| **20** | West Coast | C6852 | 21/08/97 | W1 | GPS/VTS | 5.9 | 10 | 6 | 63 | |
| **21** | Scotian Shelf | M0007545 | 06/04/96 | S2 | GPS | 5.7 | 1 | 0 | 100 | |
| **22** | Scotian Shelf | M9006513 | 20/03/96 | S3 | GPS/Aurora | 11.2 | 3 | 0 | 100 | |
| **23** | Scotian Shelf | C0002571 | 03/04/96 | W3 | GPS | 11.9 | 1 | 0 | 100 | |
| **24** | Scotian Shelf | M9006955 | 23/03/96 | W1 | GPS/Aurora | 6.9 | 1 | 0 | 100 | |
| **25** | Scotian Shelf | C0003333 | 27/03/96 | S4 | GPS | 4.9 | 1 | 0 | 100 | |
| **26** | Scotian Shelf | M9006936 | 26/03/96 | S5 | GPS | 7.4 | 1 | 0 | 100 | |
| **27** | Scotian Shelf | M9006945 | 30/03/96 | W1 | GPS | 4.3 | 1 | 0 | 100 | |

**Table 3:** GPS ship validation information for collocation product in Fig. 3. D is the distance between the OMW and the GPS positions, while L is the ship length.

| Ship | Validation | Name | D [m] | L [m] |
|---|---|---|---|---|
| **1** | GPS | WLocznik | 87 | 88 |
| **5** | GPS | Cassiopeia | 88 | 103 |
| **6** | GPS | Rekin | 143 | 89 |
| **7** | GPS | Tunek | 133 | 90 |
| **8** | GPS | Aquarius | 88 | 103 |
| **9** | GPS | Gemini | 89 | 88 |
| **11** | GPS | Langusta | 100 | 94 |
| **12** | GPS | Sirius | 77 | 88 |
| **13** | GPS | Otol | 56 | 90 |

**Table 4:** GPS/VTS ship validation information for close-up region of Fig. 4.

| Ship | Validation | Name | D [m] | L [m] |
|---|---|---|---|---|
| **1** | GPS | Acrux | 284 | 86-95 |
| **2** | GPS | Langusta | 326 | 94 |
| **3** | GPS | Cassiopeia | 585 | 103 |
| **4** | GPS | Aquarius | 2500 | 102 |
| **5** | GPS | Foka | under mask | 94 |
| **6** | GPS | Overseas Alaska | 898 | 223 |
| **1** | VTS | Overseas Alaska | 745 | 223 |
| **10** | VTS | Aquarius | 2707 | 102 |
| **11** | VTS | Cassiopeia | 645 | 103 |
| **12** | VTS | Langusta | 2707 | 94 |
| **13** | VTS | Foka | under mask | 94 |
| **14** | VTS | Acrux | 399 | 86-95 |
| **15** | VTS | ? | Not detected | ? |

**Table 5:** Summary detection statistics for ship validation study.

| Beam Mode | Images | *Validated-Positives* | *Negatives* | Detection Rate |
|---|---|---|---|---|
| **Overall** | 27 | 174 | 34 | 84% |
| **Least Favorable (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% |

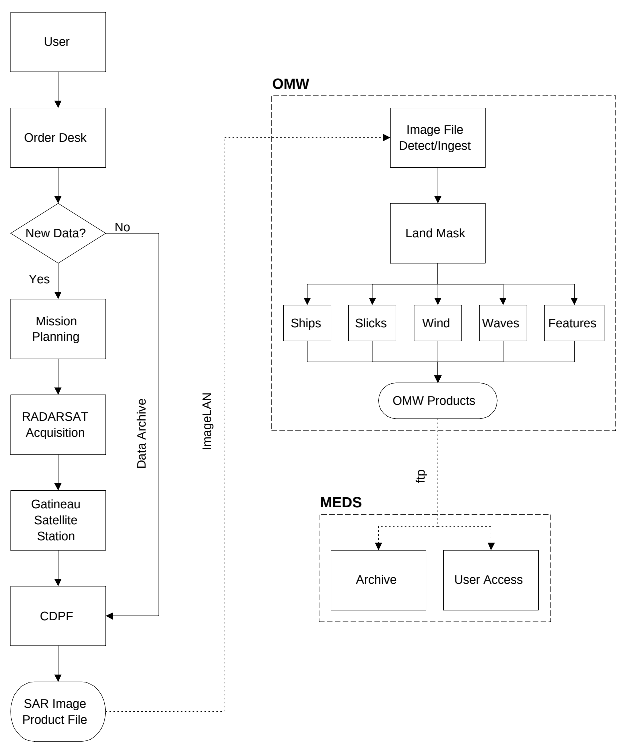


**Figure 1:** Operational data flow for the OMW installation at GSS.

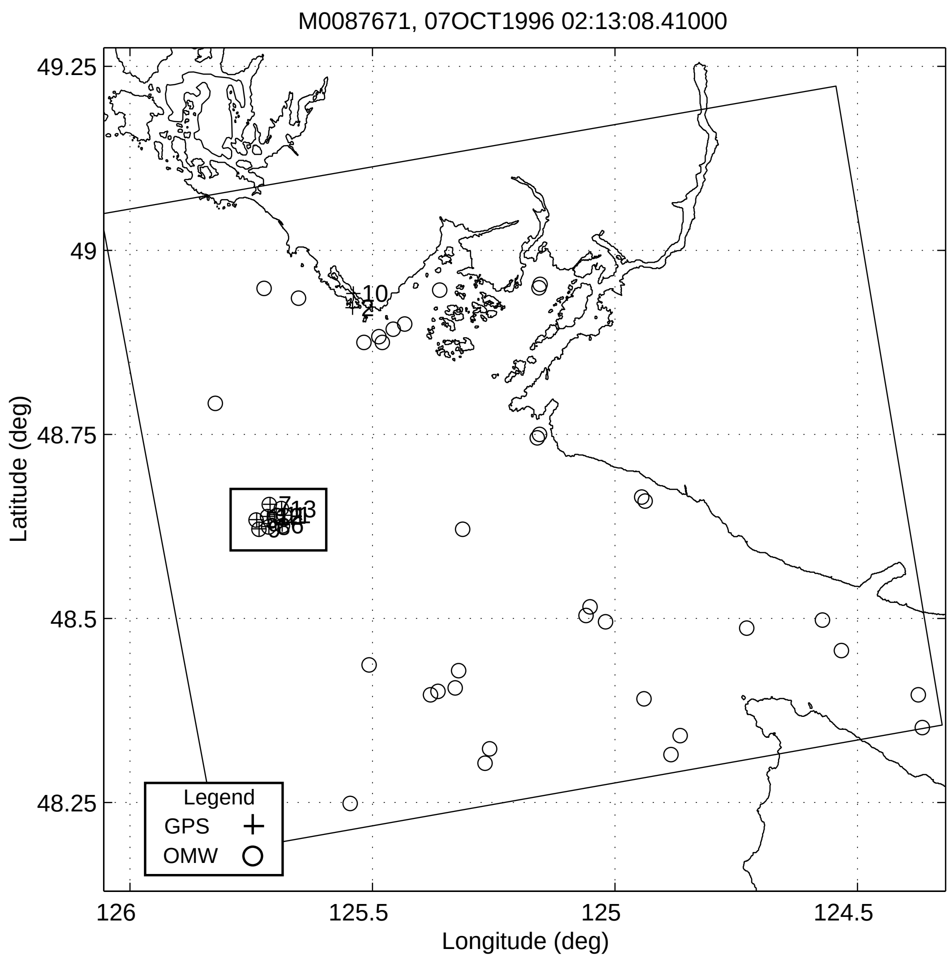


**Figure 2:** Collocated RADARSAT/OMW and GPS targets for the image of October 7, 1996.

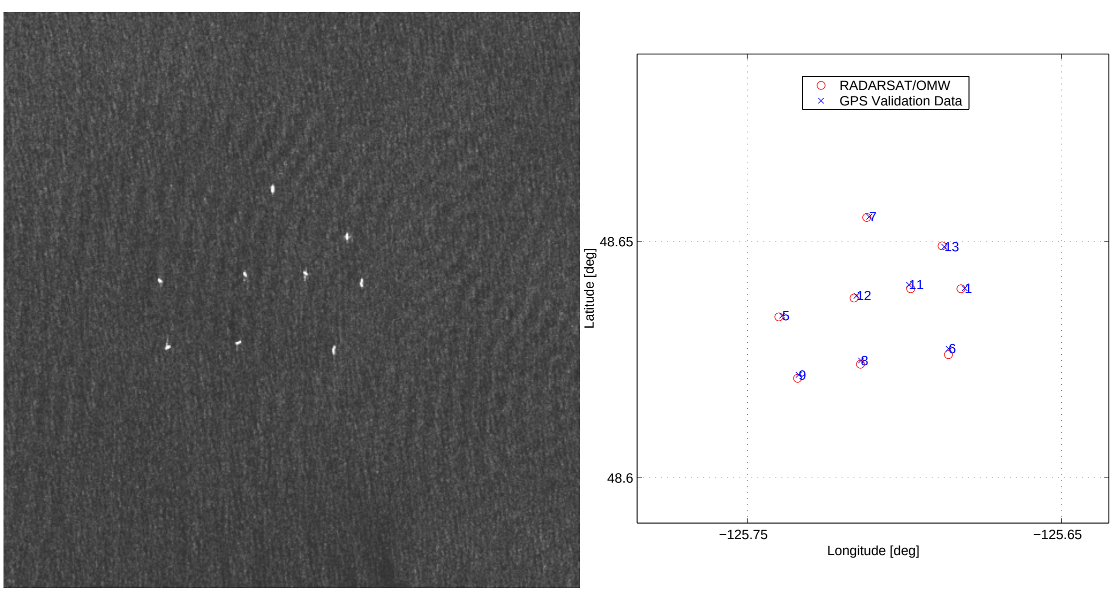


**Figure 3:** RADARSAT S5 subimage (© CSA 1996) and corresponding collocations for the small region outlined in Fig. 2. The subimage covers an area of 12.5 km by 12.5 km.

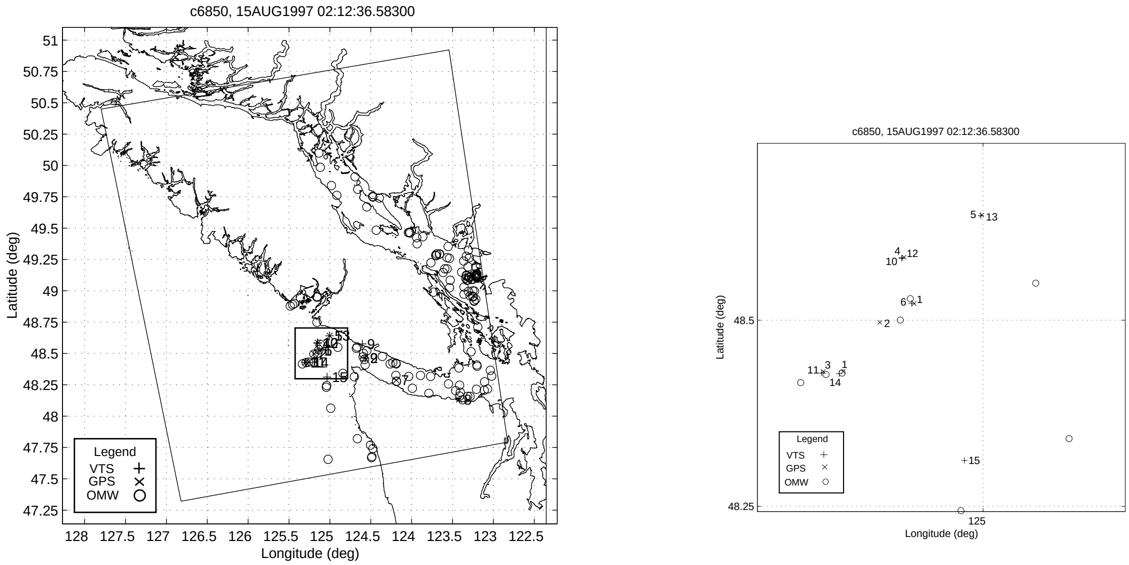


**Figure 4:** Collocated RADARSAT/OMW, GPS, and VTS targets for the image of August 15, 1997. A close-up of the outlined area is shown on the right.

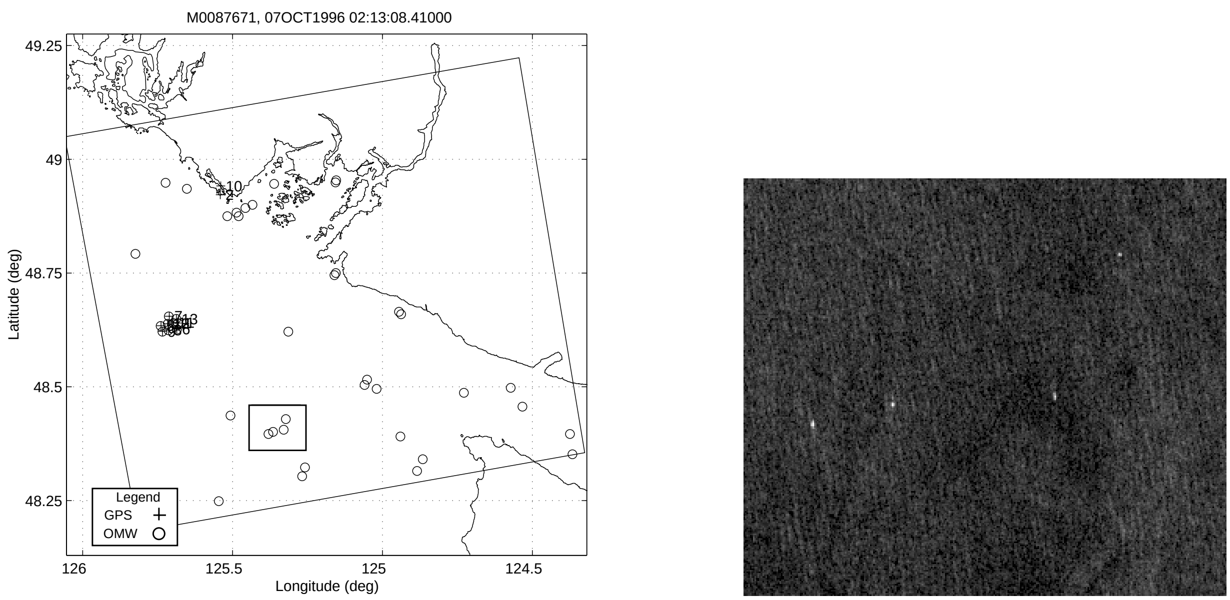


**Figure 5:** Collocated RADARSAT/OMW and GPS targets for the image of October 7, 1996, together with the RADARSAT S5 subimage (© CSA 1996) showing *Unvalidated-Positives* for the small outlined region. The subimage covers an area of 7.7 km by 6.9 km.

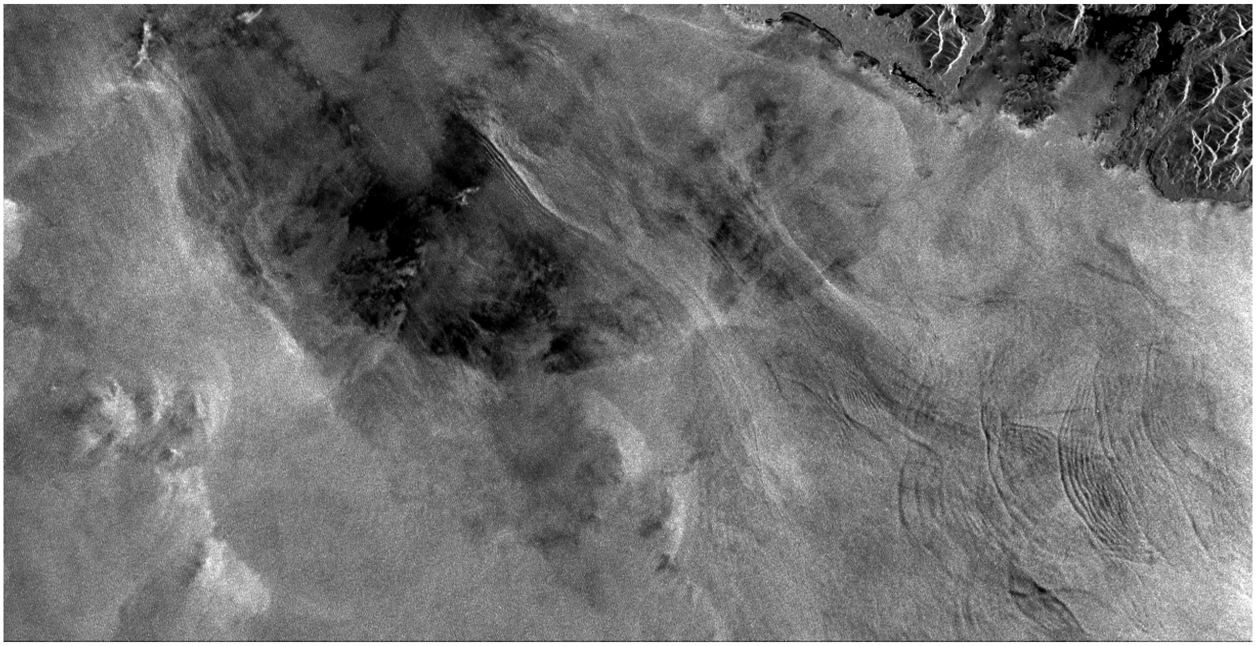

**Figure 6:** RADARSAT W1 image (© CSA 1996), West Coast of Vancouver Island, October 13, 1996.

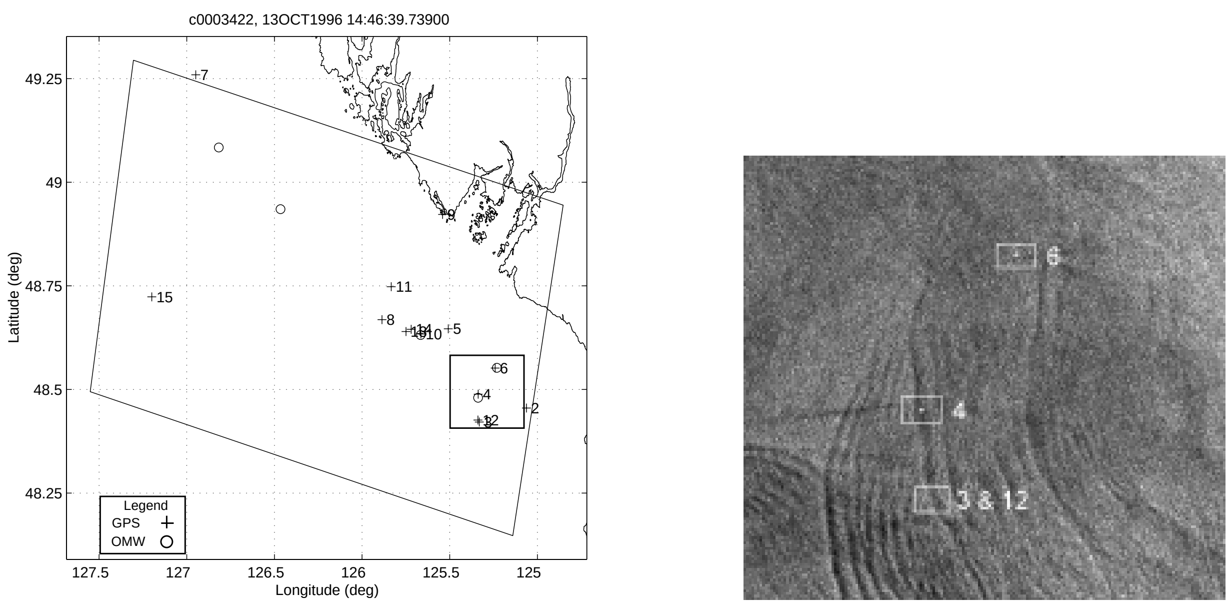


**Figure 7:** Collocated RADARSAT/OMW and GPS targets for the W1 image of Fig. 6, and RADARSAT subimage (© CSA 1996) from the outlined region showing *Validated-Positive* ships (#4 and #6), as well as location of two *Negatives* (#3 and #12). The subimage covers an area of 29 km by 27 km.