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Validation of OceanSuite ship detection in RADARSAT-2 imagery with AISSat-1 space-based and MSSIS coastal AIS data

Nicholas Sandirasegaram, Paris W. Vachon, Ryan A. English,
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This report was prepared in the context of the Annex 7 to the MOU between The Department of National Defence of Canada and The Ministry of Defence of the Kingdom of Norway concerning Cooperation in Defence Science and Technology. Annex 7 concerns collaboration in space-based Automatic Identification System (AIS) and wide area surveillance using commercial Synthetic Aperture Radar (SAR) satellites.

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Abstract

OceanSuite (OS) is a software developed by The Department of National Defence Canada to carry out ship detection on RADARSAT-2 images within operational timeframes. In this report, OS ship detections are validated using AISSat-1 and MSSIS (Maritime Safety and Security Information System) Automatic Identification System (AIS) data. AISSat-1 is a Norwegian nanosatellite that carries a space-based AIS payload. MSSIS contains AIS data from coastal-based AIS receivers. A total of 18 RADARSAT-2 data collections were executed for this evaluation. Validation was conducted according to a set of predefined validation criteria. The OS detector performance was quantified in terms of probability of detection and probability of false alarm metrics. Validation results and associations between AISSat-1 and MSSIS, AISSat-1 and OS, and MSSIS and OS are reported. There were 1482 validated ships of which OS-declared 65%. OS alone accounted for more than 21% of the validated ships.

Résumé

OceanSuite (OS) est un logiciel conçu par le ministère de la Défense nationale en vue de permettre la détection des navires sur les images RADARSAT-2 pendant une période opérationnelle établie. Dans le présent rapport, les détections de navires à l'aide d'OS sont validées à partir des données AISSat-1 et MSSIS (Système d'information sur la sécurité et la sûreté maritimes) du Système d'identification automatique (SIA). AISSat-1 est un nanosatellite norvégien qui transporte une charge utile SIA spatioportée. Le MSSIS renferme des données SIA provenant de récepteurs SIA côtiers . Au total, 18 collectes de données RADARSAT-2 ont été réalisées pour la présente évaluation. Les données ont été validées d'après un ensemble de critères de validation prédéfinis. Le rendement du détecteur OS a été quantifié en fonction des indicateurs de probabilité de détection et de probabilité de fausses alarmes. Le présent rapport fait état des résultats de la validation ainsi que des associations entre AISSat-1 et MSSIS, entre AISSat-1 et OS, et entre MSSIS et OS. En tout, 1 482 navires ont été validés, dont 65 % ont été détectés par le logiciel OS. À lui seul, OS a détecté plus de 21 % des navires validés.

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Executive summary

Validation of OceanSuite ship detection in RADARSAT-2 imagery with AISSat-1 space-based and MSSIS coastal AIS data

Nicholas Sandirasegaram; Paris W. Vachon; Ryan A. English; Richard Olsen; Torkild Eriksen;Tonje-Nanette Hannevik; DRDC Ottawa TM 2013-119; Defence R&D Canada – Ottawa; December 2013.

Introduction: Identifying unknown vessels in territorial waters as part of maritime surveillance is a challenging task for maritime stakeholders. Unknown vessels are usually found to be friendly vessels. However, any information that can be obtained about these unknown vessels can be an important contribution to maritime surveillance.

The Canadian Project Polar Epsilon has implemented near-real time ship detection (NRTSD) with the Canadian RADARSAT-2 satellite, which carries a Synthetic Aperture Radar (SAR). The NRTSD system uses the DRDC-developed OceanSuite (OS) ship detection software. OS uses magnitude format, single polarization RADARSAT-2 images to detect ships. OS ship detection performance is validated in this report.

Intended for collision avoidance and Vessel Traffic Services, Automatic Identification System (AIS) is a short range, maritime self-reporting network that transmits and receives information that can be used to identify vessels. International Maritime Organization (IMO) regulations require that all passenger ships and all other ships greater than 300 gross tons continuously transmit their location via AIS.

National maritime security agencies are interested in detecting AIS signals within their areas of maritime responsibility. AIS uses Very High Frequency (VHF) radio transmissions. Space-based AIS (receiver installed on space platform) is one solution for this task. There are several space-based AIS receivers operating today. Launched in July 2010, AISSat-1 is a Norwegian nano-satellite. It was constructed by the University of Toronto Institute for Aerospace Studies / Space Flight Laboratory (UTIAS/SFL), and is managed by the Norwegian Defence Research Establishment (FFI). Coastal-based AIS receivers are installed around coastal regions in many countries. The Maritime Safety and Security Information System (MSSIS, coastal-received AIS data) is a shared, unclassified, near-real time data collection and distribution network that includes AIS data.

Results: Validation of OS is documented in this report. RADARSAT-2 imagery, AISSat-1 data, and MSSIS data were used for this evaluation. An analysis region was selected to increase the accuracy of the evaluation results. The region was chosen to be away from shore and excluded any unusual image artifacts. After selecting an appropriate region, validation was conducted using a predefined set of validation criteria. The validation criteria are described in this report.

A total of 18 collections were obtained in the Greenland, Norwegian, and Barents Sea region. There were 1482 validated ships within the analyzed region. AISSat-1, MSSIS and OS declared 49%, 50% and 65% of the validated ships, respectively. 21% of the validated ships were declared only by OS.

Significance: OS provided additional ship locations that were not reported by MSSIS and AISSat-1. However, OS missed ships that were found by other sources. It is apparent that space-based SAR and space-based AIS are important complementary sensors for surveillance of vast maritime regions. Concurrence of the RADARSAT-2 and AISSat-1 collects, which only occurs at high latitudes, was important for the success of this validation.

Sommaire

Validation of OceanSuite ship detection in RADARSAT-2 imagery with AISSat-1 space-based and MSSIS coastal AIS data

Nicholas Sandirasegaram; Paris W. Vachon; Ryan A. English; Richard Olsen; Torkild Eriksen;Tonje-Nanette Hannevik ; DRDC Ottawa TM 2013-119 ; R & D pour la défense Canada – Ottawa; décembre 2013.

Introduction ou contexte : L'identification de navires inconnus naviguant dans les eaux territoriales du Canada dans le cadre de la surveillance maritime est une tâche difficile pour les intervenants maritimes. Les navires inconnus s'avèrent généralement être des bâtiments amis. Cependant, tout renseignement pouvant être obtenu au sujet des navires inconnus peut contribuer de façon importante à la surveillance maritime.

Dans le cadre du projet canadien Polar Epsilon, on a mis en œuvre un système de détection de navires en temps quasi réel (NRTSD) grâce au satellite canadien RADARSAT-2, qui transporte à son bord un radar à synthèse d'ouverture (SAR). Le système NRTSD utilise le logiciel de détection de navires OceanSuite (OS) mis au point par RDDC. Pour détecter les navires, ce logiciel utilise des images RADARSAT-2 d'amplitude, acquises en polarisation simple. Le présent rapport évalue le rendement du logiciel OS en matière de détection des navires.

Conçu pour prévenir les collisions et pour appuyer le Service du trafic maritime, le Système d'identification automatique (SIA) est un réseau naval d'autosignalisation à courte portée qui transmet et reçoit de l'information permettant d'identifier les navires. Selon les règlements de l'Organisation maritime internationale (OMI), tous les paquebots et autres navires de plus de 300 tonnes brutes sont tenus d'émettre continuellement leur position par l'intermédiaire du SIA.

Les organismes nationaux de sécurité maritime sont intéressés par la détection de signaux SIA dans leurs zones de responsabilité maritimes. Le SIA utilise des transmissions radio VHF. L’exploitation d’une composante SIA spatioportée (récepteur installé sur une plateforme spatiale) constitue une solution pour cette tâche. De nos jours, plusieurs récepteurs SIA spatioportés sont en exploitation. Lancé en juillet 2010, AISSat-1 est un nanosatellite norvégien. Il a été construit par l'Institute for Aerospace Studies et le Space Flight Laboratory de l'Université de Toronto et est géré par l'institut norvégien de recherche pour la défense (Norwegian Defence Research Establishment, aussi appelé FFI). Des récepteurs SIA côtiers sont installés dans les régions côtières de nombreux pays. Le Système d'information sur la sécurité et la sûreté maritimes (MSSIS, données SIA obtenues au moyen de récepteurs côtiers) est un réseau de collecte et de diffusion de données partagées, non classifiées et en temps quasi réel, qui comprend des données SIA.

Résultats : Le présent rapport documente l’évaluation du logiciel OS. Dans le cadre de cette évaluation, on a utilisé des images RADARSAT-2, ainsi que des données AISSat-1 et MSSIS. On a également sélectionné une région d'analyse afin de s'assurer que les résultats de l'évaluation soient plus précis. La région choisie est éloignée de la côte et exclut tout élément inhabituel. Une fois la région appropriée choisie, on a procédé à l’évaluation en fonction d'un ensemble de critères de validation prédéfinis. Ces critères sont décrits dans le rapport.

Au total, 18 collectes de données ont été réalisées dans la région de la mer de Barents, de la Norvège et du Groënland. En tout, 1 482 navires ont été validés dans la région analysée. Les systèmes AISSat-1, MSSIS et OS ont déclaré respectivement 49 %, 50 % et 65 % des navires validés. À lui seul, le logiciel OS a déclaré plus de 21 % des navires validés.

Importance : Le logiciel OS a permis d'obtenir des données sur la position de navires qui n'ont pas été signalés par MSSIS et AISSat-1. Toutefois, certains navires détectés par d'autres sources ont échappé au logiciel OS. Ainsi, il semble que les systèmes spatiaux SAR et SIA sont des capteurs complémentaires importants pour la surveillance des vastes étendues maritimes. La collecte en parallèle des données RADARSAT-2 et AISSat-1, qui n'est possible qu'à de hautes latitudes, a été importante pour la réussite de l'évaluation.

Table of contents

List of figures

List of tables

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1 Introduction

Canada's Department of National Defence (DND) carries out surveillance of the ocean approaches to Canada and the Artic. The Norwegian Coastal Administration (NCA) is responsible for monitoring and managing vessel traffic and maritime safety in Norwegian territorial waters and monitoring vessel traffic in the Norwegian Exclusive Economic Zone and the Fisheries Protection Zones around Svalbard and Jan Mayen (Figure 1). Both nations are using space-based reception of Automatic Identification System (AIS) data to carry out surveillance of these vast ocean regions.

Identification of unknown vessels as part of maritime surveillance is a challenging task. Most of the time, these unknown vessels are identified as friendly vessels. However, any information that can be obtained about these unknown vessels can be a valuable asset for maritime surveillance. Historically, information has been collected by Coast Guard vessels, maritime patrol aircraft and coastal radars. Since the mid-1990's, space based radar surveillance has been employed by both countries.

Intended for collision avoidance and Vessel Traffic Services, AIS is a short range, maritime self-reporting network that transmits and receives information that can be used to locate and identify vessels. Safety of Life At Sea (SOLAS), a treaty brought in by the International Maritime Organization (IMO), makes it mandatory for vessels to carry AIS systems [1]. The message format used by AIS includes vessel identification, location, speed, heading, length, type of vessel, and so on [2]. AIS communication is conducted via Very High Frequency (VHF) transmissions between ships and between ships and coastal stations.

The IMO regulation requires all passenger ships and all other ships greater than 300 gross tons to continuously transmit their location. This allows other AIS users nearby to receive the signals and be aware of ships around them. However, each nation has adopted its own regulation requirements. AIS signals can be received by costal-based as well as space-based AIS receivers. A VHF terrestrial-based AIS receiver typically has a 20 to 40 nmi (horizontal) detection range. This range depends on the height of the antenna. Further offshore, elevated platforms such as aircraft and satellites equipped with AIS receivers are required to gain large area coverage. In a space-based AIS system, the AIS receiver is placed in a space-based platform so that it can receive AIS signals within the horizon-to-horizon satellite field of view with global coverage. The disadvantage of this system is that the satellite field of view is very large and this causes signal collisions because of many Self-Organizing Time Division Multiple Access (SOTDMA) cells occurring within the field of view. However, various solutions have been proposed and demonstrated to address this signal collision problem [3].

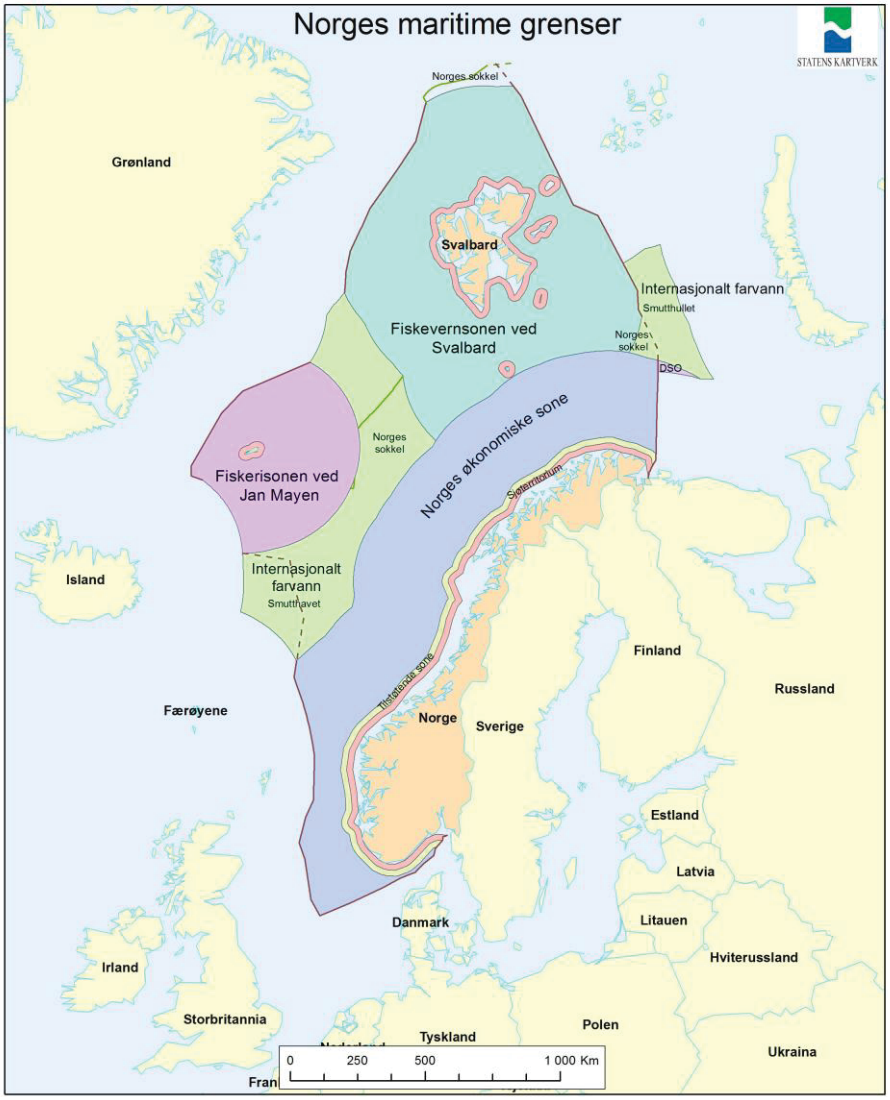


Figure 1: Areas subject to Norwegian maritime surveillance. Source: Norwegian Mapping Authority.

AISSat-1 is a space-based AIS nano-satellite. This Norwegian satellite is a 20 cm cube with a weight of 6 kg that was launched on 12 July 2010. The AISSat-1 implementation project was managed by the Norwegian Defence Research Establishment (FFI) and funded by the Norwegian Space Centre. The AIS payload was designed and built by Kongsberg Seatex in Norway, whereas the satellite bus was constructed by the University of Toronto Institute for Aerospace Studies / Space Flight Laboratory (UTIAS/SFL) [4]. FFI also conducted space qualification of the AIS receiver, while UTIAS was responsible for integration of the satellite and payload, and preparation for launch. The purpose of this satellite is to demonstrate the operational capability in the high north and to serve as an R&D platform for further development of space-based AIS.

The Maritime Safety and Security Information System (MSSIS) is a shared, unclassified, near-real time data collection and distribution network that includes AIS data [5]. Many countries contribute their shore-based AIS data to this network in exchange for access to other nations' data. Both Norway and Canada contribute to the network. The shore-based data for this study were contributed by the NCA.

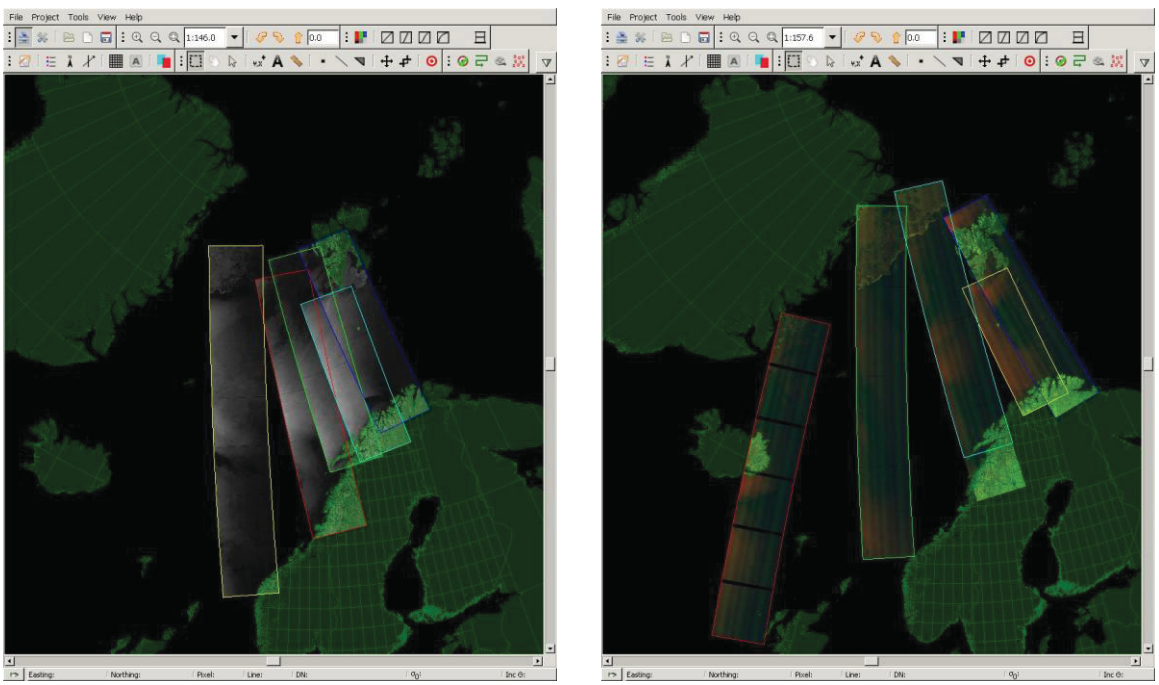
Ship detection is a mature application of synthetic aperture radar (SAR) imagery. The Canadian Project Polar Epsilon has implemented near-real time ship detection (NRTSD) using SAR imagery from the Canadian RADARSAT-2 satellite by building new ground stations and implementing network infrastructure that facilitates delivery of ship detection reports to operational centres within 10 minutes of data downlink. The NRTSD system uses the DRDC-developed OceanSuite (OS) [6] ship detection software. OS uses single polarization RADARSAT-2 images to detect ships. For dual polarization RADARSAT-2 images (*i.e.*, HH + HV) two sets of detections are operated; one for HH (horizontal transmitted and horizontal received) polarization and the other for HV (horizontal transmitted and vertical received) polarization. In this project, we have validated the ship detector performance of the OS software applied to RADARSAT-2 ScanSAR Narrow B imagery using both AISSat-1 and MSSIS AIS data.

The report is organized as follows: section 2 describes the acquired data; section 3 presents the analysis procedures; section 4 presents the results; and conclusions are drawn in section 5.

2 Data

Both RADARSAT-2 and AISSat-1 are in polar orbits. They operate at different altitudes and therefore have different orbital periods. In general, their footprints are well separated and independent, meaning that an arbitrary point on the Earth is unlikely to be in the observation footprint of both sensors at the same point in time.

However, because the satellites both pass near the poles on each and every orbit, locations at high latitudes will periodically have significant windows of opportunity during which both sensor footprints cover the same location within a short time difference. These concurrence windows occur when the polar crossing of the satellite orbits come close together in time. As such, we focussed on high latitude regions within the Norwegian Area of Interest (AOI) (Figure 1), for which we found that when this alignment occurred in summer 2011, there were concurrent windows above 70° N every second day over two-week periods in the Barents, Norwegian, Greenland Sea areas, each followed by at least a week with no concurrence opportunities. The spatial location of the concurrence window progressed eastwards (see Figure 2). Discovery of these concurrent opportunities was achieved using the DRDC-developed Commercial Satellite Imagery Acquisition Planning System (CSIAPS) [7].



(a) (b)

Figure 2: (a) June 2011 SAR acquisitions: 2011-06-13 (red), 2011-06-15 (yellow) 2011-06-17 (green), 2011-06-21 (cyan), and 2011-06-25 (blue). (b) August 2011 SAR acquisitions: 2011-08-17 (red), 2011-08-19 at 15:50 (yellow), 2011-08-19 at 17:30 (green), 2011-08-21(cyan), and 2011-08-23 (blue). RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

For this evaluation, 18 RADARSAT-2 image swaths were acquired, each of which was composed of at least three image frames, as summarized in Table 1. The acquisition campaign occurred between 2011-06-13 and 2011-08-23. Both ascending (asc) and descending (desc) pass images were acquired in single and dual polarizations (*i.e.*, HH and HH+HV). All of the acquisitions were made using ScanSAR Narrow B (SCNB). The SCNB pixel and line spacings are 25 m with a nominal resolution of 50 m.

Table 1: RADARSAT-2 data.

Collection	Date	Time [UTC]	Pol.	Pass	#Frames
1	2011-06-13	16:43:01	HH	asc	3
2	2011-06-15	17:24:07	HH	asc	3
3	2011-06-17	16:27:09	HH	asc	5
4	2011-06-21	16:10:28	HH	asc	4
5	2011-06-25	15:54:03	HH	asc	4
6	2011-07-03	05:27:24	HH&HV	desc	4
7	2011-07-07	05:09:14	HH&HV	desc	4
8	2011-07-11	04:51:48	HH&HV	desc	3
9	2011-08-09	19:00:47	HH&HV	asc	3
10	2011-08-11	16:23:01	HH&HV	asc	5
11	2011-08-13	15:24:28	HH&HV	asc	5
12	2011-08-15a	16:06:18	HH&HV	asc	5
13	2011-08-15b	17:44:27	HH&HV	asc	6
14	2011-08-17	18:25:37	HH&HV	asc	5
15	2011-08-19a	15:49:58	HH&HV	asc	3
16	2011-08-19b	17:28:31	HH&HV	asc	6
17	2011-08-21	16:30:44	HH&HV	asc	6
18	2011-08-23	15:33:02	HH&HV	asc	5

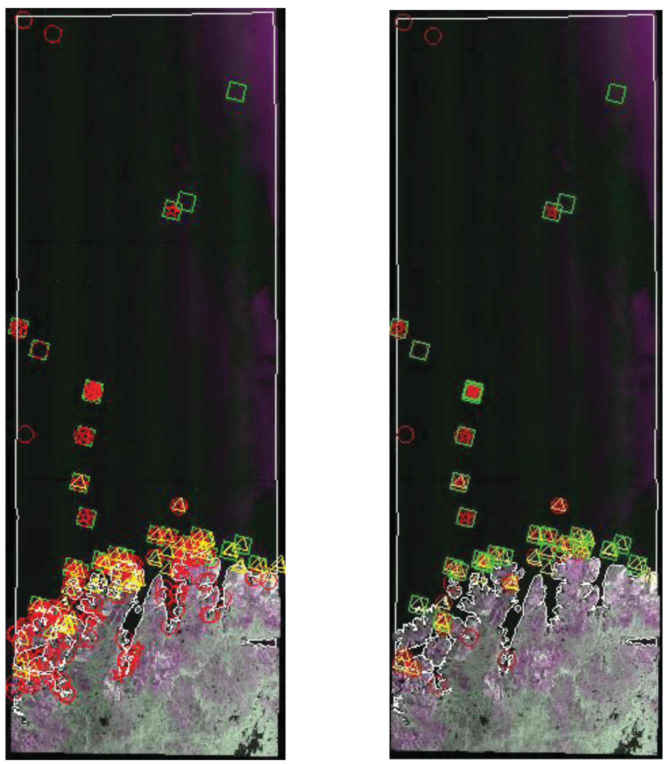
The MSSIS AIS data corresponding to the RADARSAT-2 collections were acquired and AIS messages with timestamps within ±20 minutes of the RADARSAT-2 image acquisition times were extracted. MSSIS was not available on 2011-07-03 and 2011-08-21 within the RADARSAT-2 footprint region.

The AISSat-1 data corresponding to the RADARSAT-2 collections were also acquired. The concurrent coverage area was estimated using CSIAPS, as listed in Annex A. Table A-1 shows the RADARSAT-2 and AISSat-1 estimated start and end times for the selected regions. Figure A-1 to Figure A-18 show the coverage area of collected data from the RADARSAT-2 and AISSat-1 sensors. Again, AIS data from within ±20 minutes of the RADARSAT-2 image acquisition times were extracted. Most of the collections were found to be concurrent collections and covered almost 100% of the SAR image, except for three collections (2011-07-03, 2011-07-07 and 2011-07-11). In these cases, AISSat-1 did not fully cover the SAR swath. Note that only AISSat-1 data within the RADARSAT-2 footprint and collected within ±20 minutes of RADARSAT-2 acquisition times were considered in this validation.

3 Analysis Procedure

3.1 Analysis Region

There is no ground truth for the collected RADARSAT-2 and AIS data (MSSIS and AISSat-1). To minimize the number of confusers (false targets) and to increase the accuracy of this evaluation, an analysis region was selected for each image. This region was chosen to be away from shore (so as not to evaluate land mask performance), excluded unusual image artefacts and was away from image edges. In this analysis, an area 1000 m away from the shore was selected. All of the target declarations from OS, MSSIS and AISSat-1 were removed outside of this region. An example is shown in Figure 3(a), which shows all of the declarations and the selected region. Green squares and yellow triangles indicate the predicted vessel locations by AISSat-1 and MSSIS, respectively. Red circles and red stars show vessels declared by OS in HH and HV polarization images, respectively. The white polygon shows the analysis region for the 2011-07-11 images. Figure 3(b) shows the results after removing the declared targets outside of the analysis region.



(a) (b)

Figure 3: RADARSAT-2 data acquired on 2011-07-11 (3 frames): (a) All declared vessels within the RADARSAT-2 footprint; and (b) All declared vessels within the analysis region. RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

3.2 Data Processing

OS was run on the image channel data (HH and HV separately) for all the collections (see Table 1) and the results were stored in ShapeFile format. AISSat-1 and MSSIS AIS data were mapped to the AIS-predicted signature position through dead-reckoning and azimuth shifting operations [8] and the results were also stored in a ShapeFile. Associations were made among the AISSat-1-predicted locations, the MSSIS-predicted locations, and the OS detection locations when within 500 m of each other. Association results, RADARSAT-2 dual polarization channels (single polarization or dual polarization, as the case may be), and analysis region masks were loaded into Image Analyst Pro (IA Pro) [9]. IA Pro is DRDC Ottawa's image analysis test bed and demonstration software. IA Pro includes many tools to facilitate and streamline the interactive target validation task. The IA Pro Interactive Target Validation (ITV) tool was used for validation. As a first step, all target declarations outside of the analysis region mask were removed. Then, each associated result was validated visually. Visual validation was carried out using the following criteria to declare a ship:

- Cross-polarization and co-polarization detection, or;
- AIS declaration and candidate ship target visible in SAR, or;
- AIS declaration of a small ship (<40m), or;
- Manual association of AIS declaration with a SAR detection, or;
- Cross-polarization detection only and candidate ship target visible in co- and cross-polarization, or;
- Co-polarization detection only and candidate ship target visible in co- and cross-polarization, or;
- Cross-polarization detection only and candidate ship target visible in cross-polarization for incidence angle <35°, or;
- Co-polarization detection only and candidate ship target visible in co-polarization for incidence angle >35°, and;
- Candidate ship target within the region of interest, and;
- Not an azimuth ambiguity, and;
- No evidence of range ambiguity, and;
- No land (island) or permanent manmade structures, and;
- Not a double detection, watch out for:
  - Multi-part ship signatures;
  - Signature too long;
  - Wake declared as target;
  - Rotator signature;
  - Side lobes;
  - Other range artifacts (*e.g.*, due to pulse stitching in higher resolution modes).

4 Results and discussion

Validation was carried out for all 18 collections with the results listed in Table 2 and Table 3. In Table 2, columns 2 to 4 describe the analyzed RADARSAT-2 imagery including collection date, polarization and pass direction. The fifth column shows the number of validated vessels available in each collection. The next three columns (6-8) show the number of declared vessels by AISSat-1, MSSIS and OS. The ninth column shows the number of declared vessels by OS that are false targets (confusers). The tenth column shows the analyzed area for each of the image in square kilometers. The eleventh column shows the Percentage of Ships Declared (P_d^*) by OS and the last column shows the OS false alarm rate which is calculated as the open ocean equivalent of the number of Confusers Declared per 3600 km imaged along track (FAR_{3600}).

There were a total of 1482 validated ships within the 18 collections (see Table 2). The overall OS performance in P_d^* was 64.7%; P_d^* varied from 21.8% to 88.7%. Poor detection (21.8%) was found for the RADARSAT-2 image collected on 2011-08-09 since most of the ships were small (<20 m). Only one confuser was found out of a total of 960 OS-declared potential vessels according to the validation criteria. Overall, the false alarm rate was 0.196.

In Table 3, columns 2 through 4 show the description of the RADARSAT-2 data, including acquisition date, time, and polarization. Column 5 indicates the total number of validated ships in the analyzed region for each of the collections. Columns 6 through 15 show the number of ships declared by each source, including AISSat-1, MSSIS, OS, only AISSat-1 and OS, only AISSat-1 and MSSIS, only MSSIS and OS, all three sources, only AISSat-1, only MSSIS and only OS. The second last row shows the summary for all of the acquired images. The last row shows the summary as a percentage. MSSIS data were not available within the RADARSAT-2 footprint on 2011-07-03 and 2011-08-21.

OS declared 21% of vessels that were not declared by others. At the same time OS missed around 35% of the vessels. Some of the vessels were not visible in the image (small vessels). The rest of them may be detectable by tuning the Constant False Alarm Rate (CFAR) to a higher value, but at the expense of declaring more confusers, thereby increasing the false alarm rate.

Table 2: Overall summary for OS, AISSat-1, and MSSIS.

Image	Date	Pol.	Pass	#Ships	AISSat-1	MSSIS	OS	OS - #Confusers Declared	Area [km^2]	OS - P_d^*	OS - FAR_{3600}
1	2011-06-13	HH	asc	32	18	18	18	0	174,049	56.3	0
2	2011-06-15	HH	asc	65	28	30	54	0	234,559	83.1	0
3	2011-06-17	HH	asc	59	30	40	37	0	321,194	62.7	0
4	2011-06-21	HH	asc	86	40	51	36	0	213,729	41.9	0
5	2011-06-25	HH	asc	114	54	55	65	0	253,327	57.0	0
6	2011-07-03	HH&HV	desc	108	81	-	95	0	219,846	88.0	0
7	2011-07-07	HH&HV	desc	84	29	43	63	0	205,579	75.0	0
8	2011-07-11	HH&HV	desc	60	30	41	43	0	188,043	71.7	0
9	2011-08-09	HH&HV	asc	174	57	151	38	0	208,930	21.8	0
10	2011-08-11	HH&HV	asc	79	41	47	47	0	353,810	59.5	0
11	2011-08-13	HH&HV	asc	51	25	23	37	0	294,473	72.5	0
12	2011-08-15a	HH&HV	asc	103	76	68	74	0	302,381	71.8	0
13	2011-08-15b	HH&HV	asc	124	26	30	110	0	468,166	88.7	0
14	2011-08-17	HH&HV	asc	63	6	45	37	0	502,822	58.7	0
15	2011-08-19a	HH&HV	asc	85	68	50	49	0	211,934	57.6	0
16	2011-08-19b	HH&HV	asc	38	17	9	33	0	604,447	86.8	0
17	2011-08-21	HH&HV	asc	90	66	-	79	1	390,607	87.8	2.73
18	2011-08-23	HH&HV	asc	67	34	35	44	0	289,727	65.7	0
Desc. Pass				252	140	84	201	0	613,468	79.8	0.000
Asc. Pass				1230	586	652	758	1	4,824,155	61.6	0.221
All				1482	726	736	959	1	5,437,623	64.7	0.196

Table 3: Number of SAR detections for AIS-declared vessels.

Image	Date	Time[UTC]	Pol.	#Ships	#ships declared									
					AISSat-1	MSSIS	OS	Only AISSat-1 & MSSIS	Only AISSat-1 & OS	Only MSSIS & OS	All three	Only AISSat-1	Only MSSIS	Only OS
1	2011-06-13	16:43:01	HH	32	18	18	18	4	2	2	7	5	5	7
2	2011-06-15	17:24:07	HH	65	28	30	54	2	11	16	9	6	3	18
3	2011-06-17	16:27:09	HH	59	30	40	37	8	6	10	12	4	10	9
4	2011-06-21	16:10:28	HH	86	40	51	36	14	7	8	6	13	23	15
5	2011-06-25	15:54:03	HH	114	54	55	65	4	16	26	7	27	18	16
6	2011-07-03	05:27:24	HH&HV	108	81	-	95	-	68	-	-	13	-	27
7	2011-07-07	05:09:14	HH&HV	84	29	43	63	1	15	21	7	6	14	20
8	2011-07-11	04:51:48	HH&HV	60	30	41	43	5	7	12	15	3	9	9
9	2011-08-09	19:00:47	HH&HV	174	57	151	38	26	0	2	22	9	101	14
10	2011-08-11	16:23:01	HH&HV	79	41	47	47	7	14	9	13	7	18	11
11	2011-08-13	15:24:28	HH&HV	51	25	23	37	5	10	7	6	4	5	14
12	2011-08-15a	16:06:18	HH&HV	103	76	68	74	11	27	11	33	5	13	3
13	2011-08-15b	17:44:27	HH&HV	124	26	30	110	2	18	14	4	2	10	74
14	2011-08-17	18:25:37	HH&HV	63	6	45	37	2	0	15	4	0	24	18
15	2011-08-19a	15:49:58	HH&HV	85	68	50	49	17	20	1	22	9	10	6
16	2011-08-19b	17:28:31	HH&HV	38	17	9	33	0	13	2	3	1	4	15
17	2011-08-21	16:30:44	HH&HV	90	66	-	79*	-	55	-	-	11	-	24
18	2011-08-23	15:33:02	HH&HV	67	34	35	44	3	15	10	9	7	13	10
Total				1482	726	736	959	111	304	166	179	132	280	310
Total (%)				100.0	49.0	49.7	64.7	7.5	20.5	11.2	12.1	8.9	18.9	20.9

* OS declared 1confuser

Coastal AIS data could be subject to terrain shadowing effects, but are not subject to the same atmospheric/ionospheric effects as spaceborne AIS. Not all vessels are required to carry and operate an AIS transponder, and vessels at rest or proceeding slowly transmit messages less frequently than vessels travelling at higher speeds. Operational experience with AISSat-1 has also shown that the vessel detection rate varies quite strongly throughout the day, depending on the orientation of the satellite ground track (Figure 4). The requirement to match up data passes with specific RADARSAT-2 pass times could, therefore, bias the detection rates achieved by AISSat-1.

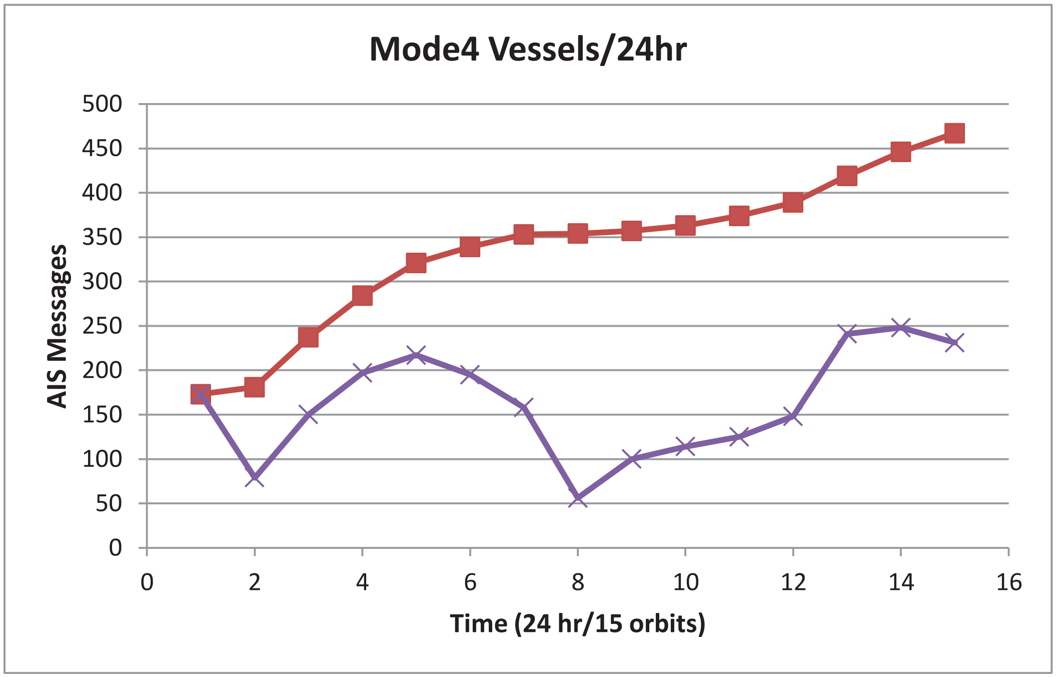


Figure 4: Example of AISSat-1 detection variations over a time span of a few hours. The blue line indicates the number of ships detected in a single pass for a specific region, the red line is the cumulative sum of unique ships in the region.

Figure 5 shows the plot of P_d^* versus FAR_{3600}. This plot is presented in the format of a Receiver Operating Characteristic (ROC) curve but is not a true ROC curve since only one point has been plotted. Performance results for OS are shown along with AISSat-1 and MSSIS results. AISSat-1 and MSSIS are included here to illustrate the observed P_d^*. OS performed better for descending passes than for ascending passes. However, only three descending pass images were included in the validation.

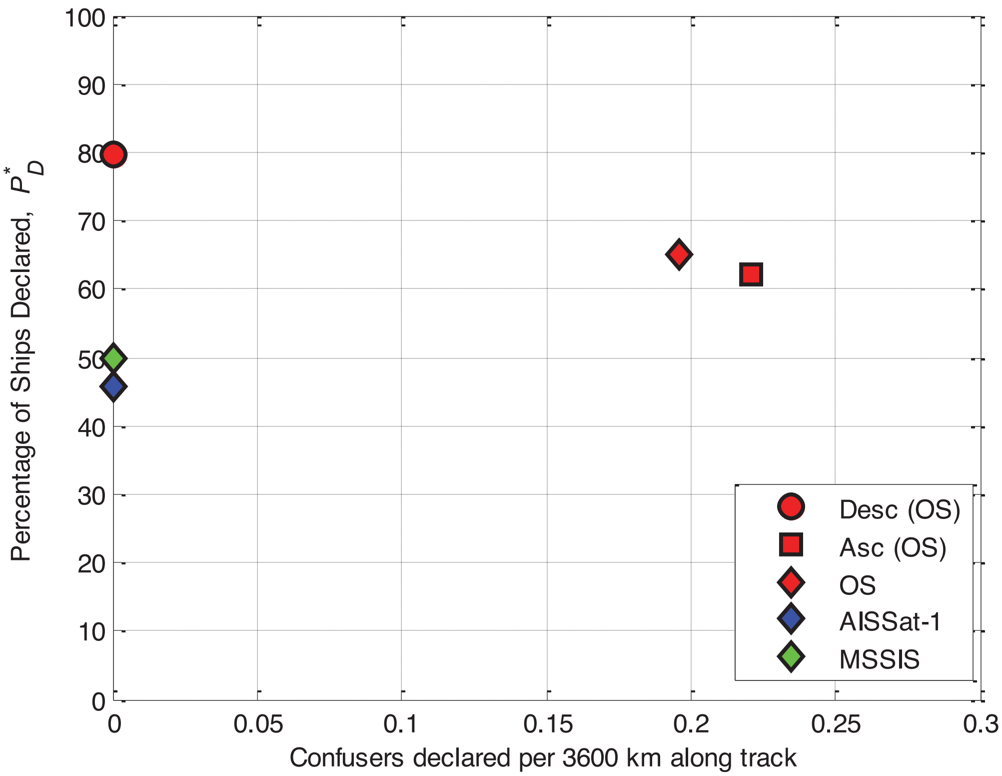


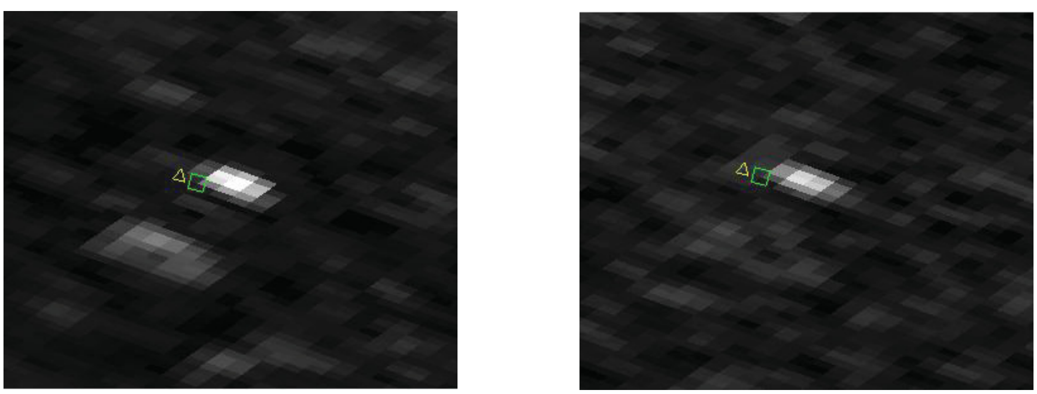
Figure 5: Ship detection performance summary for OS (including the AISSat-1 and MSSIS declaration rate) expressed by P_d^* (along the y-axis) and FAR_{3600} (along the x-axis) as a quasi-ROC curve.

As shown in Table 3, in some cases, all three sources declared the same ship; an example for such a case is shown in Figure 6. The ship is called *Olma* and is a general cargo ship of 80 metres length. This information was verified via Lloyd's Register - Fairplay using the Maritime Mobile Service Identity (MMSI) number. This MMSI number is a nine-digit identification number that uniquely identifies a ship and is included in each AIS message. The MMSI number for *Olma* ship is found in both the AISSat-1 and MSSIS messages. 10.9% of the validated ships were declared by all three sources.

(a) (b)

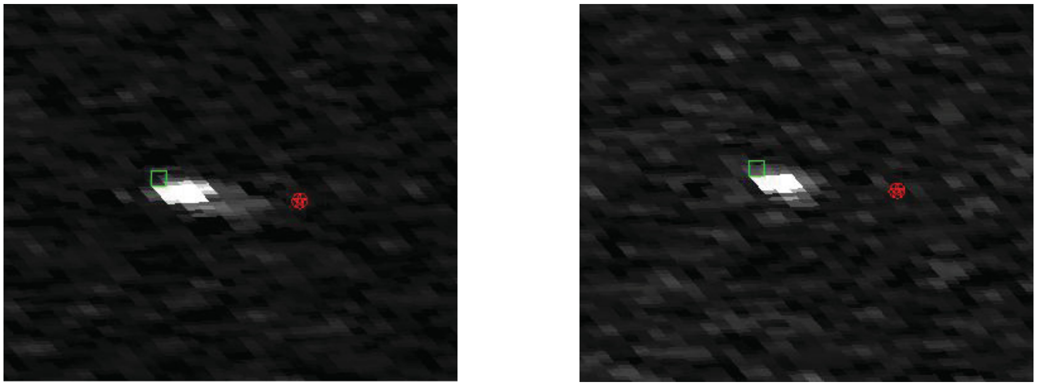
Figure 6: RADARSAT-2 data acquired on 2011-07-11: (a) HH channel; and (b) HV channel. All sources (AISSat-1 (green square), MSSIS (yellow triangle), OS in HH (red circle) and OS in HV (red star)) declared this ship. RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

39% of validated ships were declared by a combination of two sources such as AISSat-1 and MSSIS, AISSat-1 and OS, and MSSIS and OS. An example of a ship declared by AISSat-1 and MSSIS is shown in Figure 7. This ship is visible in the SAR image, but the signature was too faint to be detected by OS. The ship is called *Sveaf Jord* and is a general cargo ship of 59 metres length. 6.0% of the validated ships were declared by AISSat-1 and MSSIS together. A ship declared by AISSat-1 and OS but not by MSSIS is shown in Figure 8. The ship is called *Kapitan Gromtsev* and is a stern trawler of 62 metres length. AISSat-1 and OS together declared 20.6% of the validated ships. An example for such a case is shown in Figure 9. The ship is called *Sea Surveyor* and is a research survey vessel of 64 metres length. A total of 12.5% of the validated ships were declared by both MSSIS and OS.



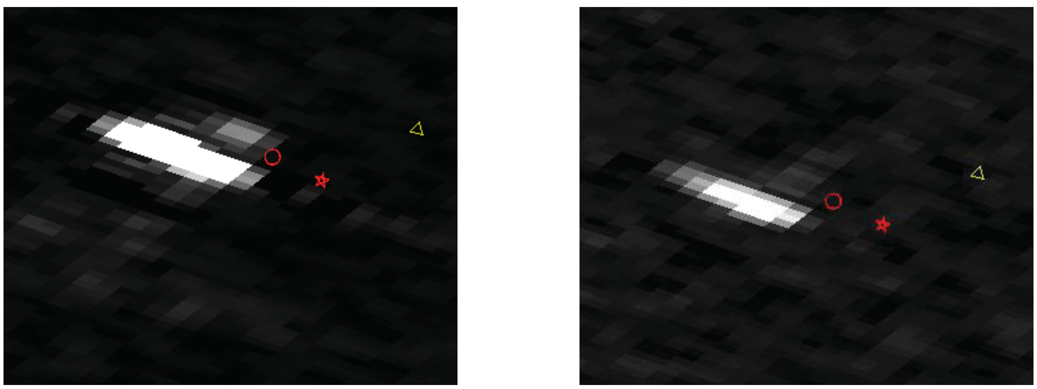
(a) (b)

Figure 7: RADARSAT-2 data acquired on 2011-07-11: (a) HH channel; and (b) HV channel. Both AISSat-1 and MSSIS declared this ship (AISSat-1 (green square) and MSSIS (yellow triangle)) RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved..



(a) (b)

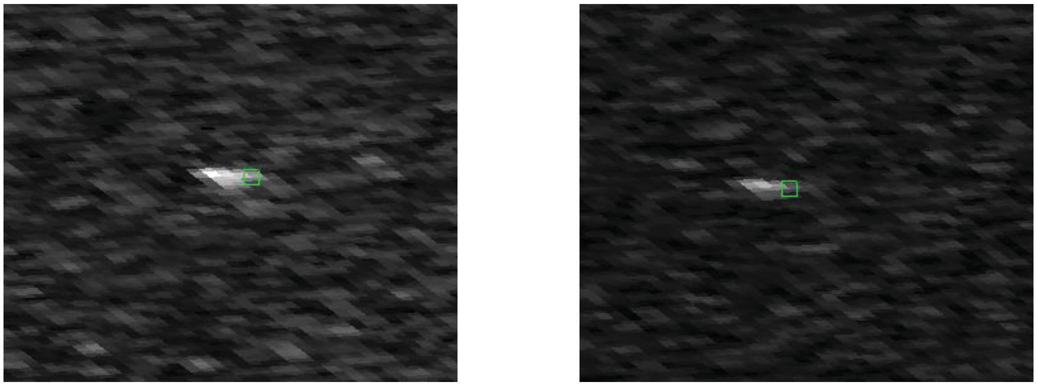
Figure 8: RADARSAT-2 data acquired on 2011-08-15 (16:06:18 UTC): (a) HH channel; and (b) HV channel. Both AISSat-1 and OS declared this ship (AISSat-1 (green square), OS in HH (red circle) and OS in HV (red star)). RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.



(a) (b)

Figure 9: RADARSAT-2 data acquired on 2011-07-11: (a) HH channel; and (b) HV channel. Both MSSIS and OS declared this ship (MSSIS (yellow triangle), OS in HH (red circle) and OS in HV (red star)). RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

Approximately 50% of the validated ships were declared by a single source only (AISSat-1 or MSSIS or OS). An example of an AISSat-1-declared ship is shown in Figure 10. MSSIS and OS failed to declare this ship. The ship is called *Konotop* and is a stern trawler of 70 metres length. AISSat-1 alone declared 8.4% of the validated ships. Another example, shown in Figure 11, is that of a ship declared only by MSSIS. The ship is called *Keltic* and is a fishing vessel of 35 metres length. A total of 20.6% of validated ships were declared only by MSSIS. An example of a ship declared only by OS is shown in Figure 12. According to the point target analysis tool (in the IA Pro software), the ship length in the HH channel is 200 meters and in the HV channel is 150 meters. The peak-to-clutter ratio is 30.24 dB in the HH channel and is 20.84 dB in the HV channel. OS alone declared 21.1% of the validated ships. One false target was declared by OS. That target was visible in the HH channel but not in the HV channel. The incident angle of this ship was less than 35°.

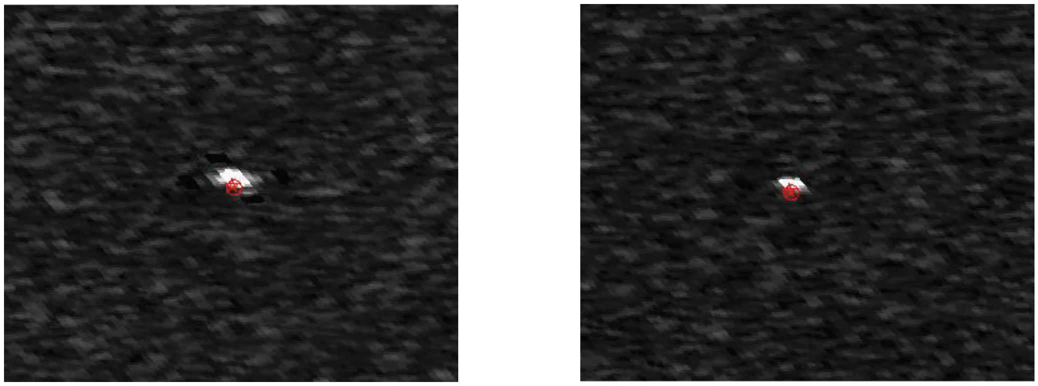


(a) (b)

Figure 10: RADARSAT-2 data acquired on 2011-08-15 (16:06:18 UTC): (a) HH channel; and (b) HV channel. Only AISSat-1 (green square) declared this ship. RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

(a) (b)

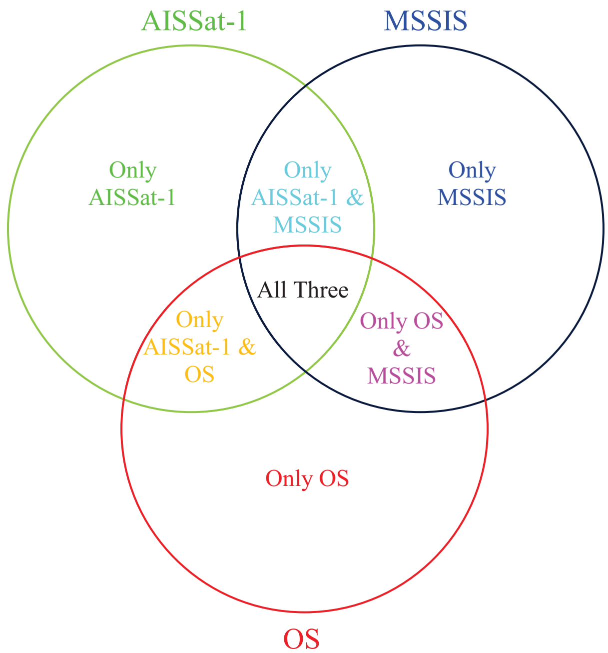
Figure 11: RADARSAT-2 data acquired on 2011-07-11: (a) HH channel; and (b) HV channel. Only MSSIS (yellow triangle) declared this ship. RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.



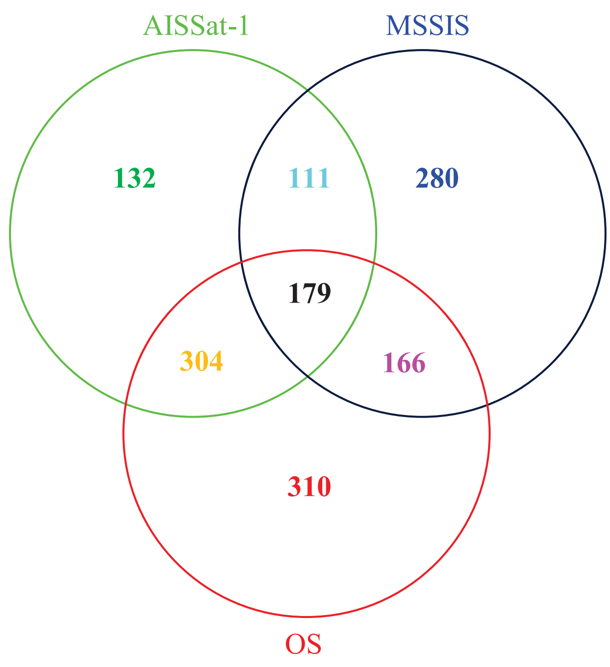
(a) (b)

Figure 12: RADARSAT-2 data acquired on 2011-08-13: (a) HH channel; and (b) HV channel. Only OS declared this ship (OS in HH (red circle) and OS in HV (red star)). RADARSAT-2 Data and Products © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2011) - All Rights Reserved.

In Figure 13a, a Venn diagram illustrates the various cases, including vessels reported by AISSat-1 only, MSSIS only, OS only, AISSat-1 and MSSIS only, AISSat-1 and OS only, MSSIS and OS only, and vessels reported by all three. Based on Table 3 data and the a Venn diagram was populated, as shown in Figure 13b. AISSat-1 and MSSIS declared 1172 vessels within the analyzed area. OS detected 649 vessels and missed the rest. Those missed and detected vessels (1172) were identified and the ship lengths for these ships were investigated. MMSI number was extracted for each of the 1172 vessels. A few of the extracted MMSI numbers were zero and since these are not valid, they were removed from the list. The MMSI numbers for the rest of the vessels were looked up in the Lloyd's Register and if the length could not be found then the length was looked up from previous AIS messages collected by DRDC Ottawa. Lengths for a total of 961 vessels were compiled. Out of these, 624 were detected by OS and the rest (337) were missed by OS.



(a)



(b)

Figure 13: a) Venn diagram to illustrate all possible relations among AISSat-1, MSSIS and OS and b) Venn diagram using AISSat-1, MSSIS and OS sources.

A histogram plot (Figure 14) was created to show the vessel lengths for the OS-detected and missed vessels. The x-axis shows the vessel length with a bin size of 10 meters. The y-axis shows the number of vessels in each of the bins. The green line shows the histogram for OS-detected vessels and red line shows the histogram for OS-missed vessels. For vessels up to 40 meters in length, the number of vessels missed by OS was higher than the number that OS detected. For lengths greater than 40 meters, the number of vessels detected by OS was higher than the number that OS missed. All vessels with lengths greater than 130 meters were detected by OS.

Further statistics were calculated and the results are tabulated in Table 4. The vessel length varied from 8 m to 294 m. Most of the vessel lengths were between 10 m and 110 m. The mean of the OS-missed and OS-detected vessels are 44 m and 82 m, respectively. The standard deviation is lower for the OS-missed vessels (22) compared to OS-detected vessels (55). Most of the small vessels were missed by OS. One reason for this is that the collected RADARSAT-2 data for this study were in ScanSAR Narrow B mode data, which has a spatial resolution of 50 m. Other factors that could have contributed are the structures on the ship, building materials, and ship orientation.

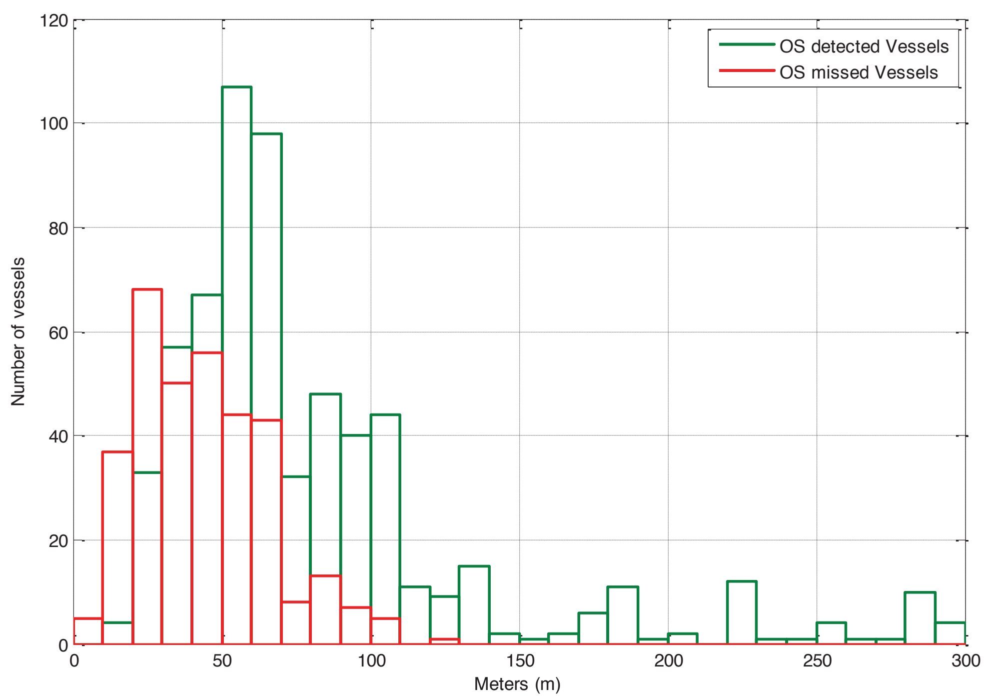


Figure 14: Number of OS-detected and OS-missed ships for 10 m bin size from 0 to 300 m.

Table 4: Summary of OS detected and missed ships based on known ship length.

Ships	Total	Min [m]	Max [m]	Mean [m]	Standard deviation [m]
OS-detected	624	11	294	82	55
OS-missed	337	8	122	44	22

5 Conclusion

OS ship detection results for RADARSAT-2 ScanSAR Narrow B images were validated using coastal AIS (MSSIS), space-based AIS (AISSat-1), and visual validation. A total of 18 RADARSAT-2 collections were obtained. For each of these collections, there were a minimum of three RADARSAT-2 image frames. Validation was conducted within the collected RADARSAT-2 footprint region and the selected region was chosen to be away from land, and image edges. OS was validated using a pre-defined set of validation criteria and the results were summarized for all 18 collections.

There were 1473 validated ships within the analysed region. AISSat-1, MSSIS and OS declared 46%, 50% and 65% of the validated ships, respectively. 11% of ships were declared by all three sources. A total of 39% of the ships were declared by two sources only. These ships were declared by either AISSat-1 and MSSIS, or MSSIS and OS, or AISSat-1 and OS. In this category, the combination of AISSat-1 with OS had the highest declaration rate at 21%. 50% of the ships were declared by only one source. 21% of the validated ships were declared only by OS.

OS provided additional ship locations that were not reported by MSSIS and AISSat-1, but still OS missed many ships found by other sources. Most of the missed ships were small in size (less than 60 m), perhaps due to the 50 m spatial resolution of the ScanSAR Narrow B mode that was used for this analysis.

The success of this validation depended upon having excellent temporal and spatial concurrence between the SAR and AIS data sources. For RADARSAT-2 and AISSat-1, use of high latitude when the satellite orbits were in phase was critical to acquisition of a concurrent data set. At lower latitudes, there could be many hours between the RADARSAT-2 and AISSat-1 observations, rendering cross-validation rather difficult. This serves to justify the collocation of SAR and AIS sensors on the same platform, as will be the case for the RADARSAT Constellation Mission. Furthermore, routine use of coastal AIS data with space-based AIS data helps to complete the AIS picture within maritime areas of responsibility.

These results illustrate that a single ship detection source cannot declare all ships at a given instant in time, thereby emphasizing the importance of using multiple ship detection sources. SAR and AIS represent excellent complementary sensors.

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Annex A RADARSAT-2 and AISSat-1 concurrent data collections

Table A-1: Concurrent RADARSAT-2 and AISSat-1 data.

	Platform	Start Date / Time	End Date / Time	Imgage Dur.
1	RADARSAT-2 / AISSat-1	13-Jun-2011 16:43:03.448 / 13-Jun-2011 16:37:19.638	13-Jun-2011 16:45:11.352 / 13-Jun-2011 16:50:24.647	127.904 / 785.009
2	RADARSAT-2 / AISSat-1	15-Jun-2011 17:24:09.067 / 15-Jun-2011 17:16:32.400	15-Jun-2011 17:26:17.203 / 15-Jun-2011 17:28:47.475	128.136 / 735.075
3	RADARSAT-2 / AISSat-1	17-Jun-2011 16:27:10.596 / 17-Jun-2011 16:18:21.466	17-Jun-2011 16:30:14.385 / 17-Jun-2011 16:32:45.619	183.789 / 864.153
4	RADARSAT-2 / AISSat-1	21-Jun-2011 16:10:29.677 / 21-Jun-2011 15:59:22.057	21-Jun-2011 16:12:49.731 / 21-Jun-2011 16:13:19.644	140.054 / 837.587
5	RADARSAT-2 / AISSat-1	25-Jun-2011 15:54:04.528 / 25-Jun-2011 15:40:23.123	25-Jun-2011 15:56:52.368 / 25-Jun-2011 15:54:48.639	167.84 / 865.516
6	RADARSAT-2 / AISSat-1	03-Jul-2011 05:25:31.168 / 03-Jul-2011 05:24:17.551	03-Jul-2011 05:28:09.176 / 03-Jul-2011 05:34:17.164	158.008 / 599.613
7	RADARSAT-2 / AISSat-1	07-Jul-2011 05:08:32.783 / 07-Jul-2011 05:04:55.420	07-Jul-2011 05:11:10.846 / 07-Jul-2011 05:15:09.052	158.063 / 613.632
8	RADARSAT-2 / AISSat-1	11-Jul-2011 04:51:45.966 / 11-Jul-2011 04:45:49.682	11-Jul-2011 04:53:53.260 / 11-Jul-2011 04:55:56.135	127.294 / 606.453
9	RADARSAT-2 / AISSat-1	09-Aug-2011 19:00:49.469 / 09-Aug-2011 18:58:22.722	09-Aug-2011 19:02:57.809 / 09-Aug-2011 19:10:30.493	128.34 / 727.771
10	RADARSAT-2 / AISSat-1	11-Aug-2011 16:23:02.678 / 11-Aug-2011 16:22:43.466	11-Aug-2011 16:26:30.630 / 11-Aug-2011 16:37:13.383	207.952 / 869.917
11	RADARSAT-2 / AISSat-1	13-Aug-2011 15:24:29.802 / 13-Aug-2011 15:24:28.360	13-Aug-2011 15:27:57.734 / 13-Aug-2011 15:39:05.018	207.932 / 876.658
12	RADARSAT-2 / AISSat-1	15-Aug-2011 16:06:19.110 / 15-Aug-2011 16:03:34.646	15-Aug-2011 16:09:47.074 / 15-Aug-2011 16:18:03.524	207.964 / 868.878
13	RADARSAT-2 / AISSat-1	15-Aug-2011 17:44:28.742 / 15-Aug-2011 17:40:57.705	15-Aug-2011 17:48:37.689 / 15-Aug-2011 17:54:07.493	248.947 / 789.788
14	RADARSAT-2 / AISSat-1	17-Aug-2011 18:25:39.383 / 17-Aug-2011 18:20:05.296	17-Aug-2011 18:29:40.024 / 17-Aug-2011 18:32:24.191	240.641 / 738.895
15	RADARSAT-2 / AISSat-1	19-Aug-2011 15:49:59.202 / 19-Aug-2011 15:44:26.668	19-Aug-2011 15:52:06.700 / 19-Aug-2011 15:58:18.143	127.498 / 831.475
16	RADARSAT-2 / AISSat-1	19-Aug-2011 17:28:33.477 / 19-Aug-2011 17:21:48.189	19-Aug-2011 17:32:42.042 / 19-Aug-2011 17:35:32.587	248.565 / 824.398
17	RADARSAT-2 / AISSat-1	21-Aug-2011 16:30:45.609 / 21-Aug-2011 16:23:30.979	21-Aug-2011 16:34:53.929 / 21-Aug-2011 16:37:51.686	248.32 / 860.707
18	RADARSAT-2 / AISSat-1	23-Aug-2011 15:33:03.325 / 23-Aug-2011 15:25:14.866	23-Aug-2011 15:36:31.214 / 23-Aug-2011 15:39:47.454	207.889 / 872.588

Figure A-1: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-06-13 collection.

Figure A-2: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-06-15 collection.

Figure A-3: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-06-17 collection.

Figure A-4: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-06-21 collection.

Figure A-5: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-06-25 collection.

Figure A-6: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-07-03 collection.

Figure A-7: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-07-07 collection.

Figure A-8: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-07-11 collection.

Figure A-9: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-09 collection.

Figure A-10: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-11 collection.

Figure A-11: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-13 collection.

Figure A-12: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-15a collection.

Figure A-13: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-15b collection.

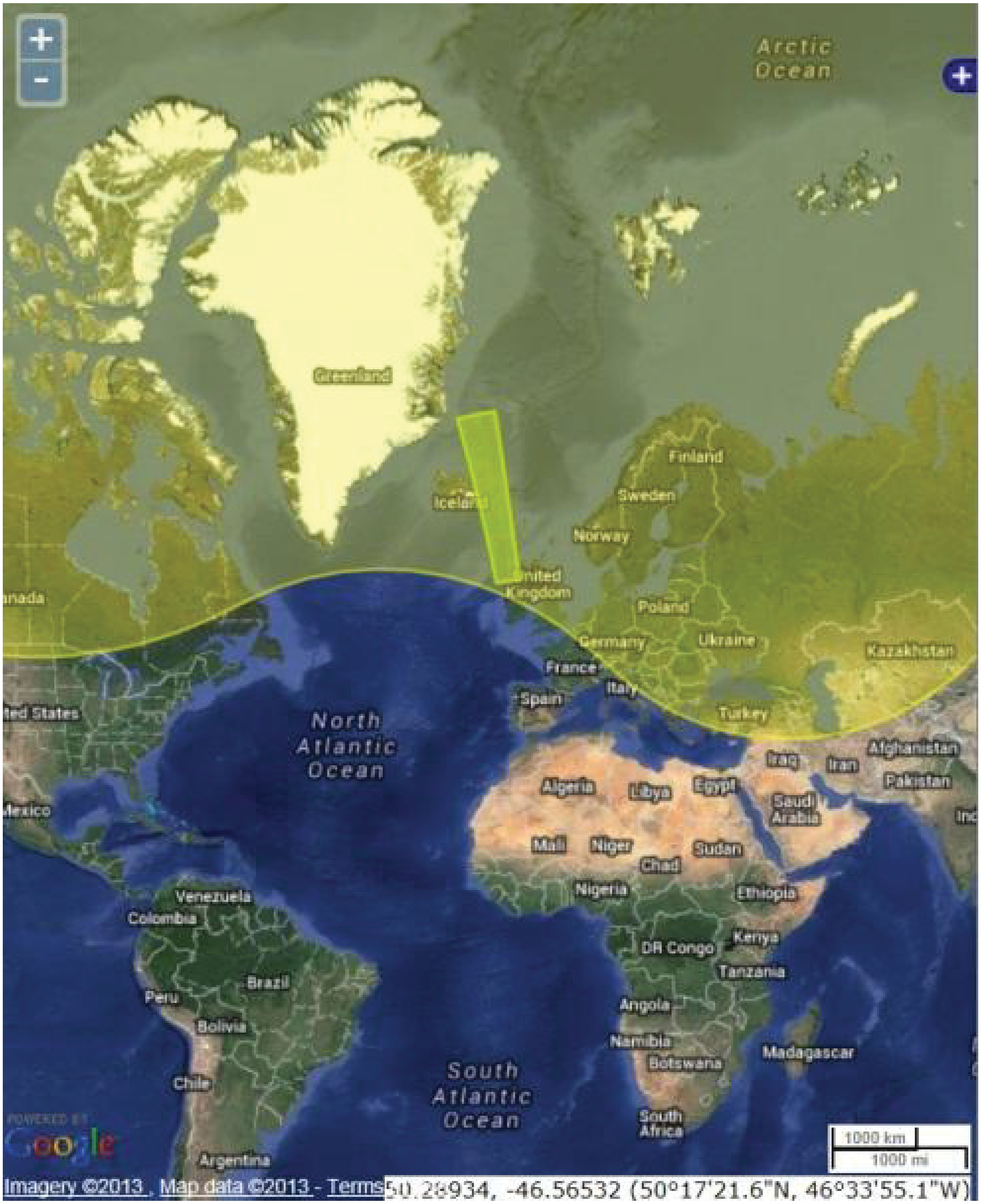

Figure A-14: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-17 collection.

Figure A-15: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-19a collection.

Figure A-16: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-19b collection.

Figure A-17: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-21 collection.

Figure A-18: RADARSAT-2 (dark yellow) and AISSat-1 (light yellow) coverage area for the 2011-08-23 collection.

List of acronyms

AIS	Automatic Identification System
asc	Ascending
CCG	Canadian Coast Guard
CSIAPS	Commercial Satellite Imagery Acquisition Planning System
desc	Descending
DND	Department of National Defence
DRDC	Defence R&D Canada
FAR_{3600}	The number of Confusers Declared per 3600 km imaged along track
FFI	Norwegian Defence Research Establishment
HH	Horizontal transmit and Horizontal receive
HV	Horizontal transmit and Vertical receive
IA Pro	Image Analyst Pro
IMO	International Maritime Organization
ITV	Interactive Target Validating
MMSI	Maritime Mobile Service Identity
MSSIS	Maritime Safety and Security Information System
NCA	Norwegian Coastal Administration
NRTSD	Near-Real Time Ship Detection
OS	OceanSuite
P_d^*	Percentage of Ships Declared
ROI	Region of Interest
SAR	Synthetic Aperture Radar
SCNB	ScanSAR Narrow B
SOLAS	Safety of Life At Sea
SOTDMA	Self-Organizing Time Division Multiple Access
UTIAS/SFL	University of Toronto Institute for Aerospace Studies / Space Flight Laboratory
VHF	Very High Frequency

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Validation of OceanSuite ship detection in RADARSAT-2 imagery with AISSat-1 space-based and MSSIS coastal AIS data

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OceanSuite (OS) is a software developed by The Department of National Defence Canada to carry out ship detection on RADARSAT-2 images within operational timeframes. In this report, OS ship detections are validated using AISSat-1 and MSSIS (Maritime Safety and Security Information System) Automatic Identification System (AIS) data. AISSat-1 is a Norwegian nanosatellite that carries a space-based AIS payload. MSSIS contains AIS data from coastal-based AIS receivers. A total of 18 RADARSAT-2 data collections were executed for this evaluation. Validation was conducted according to a set of predefined validation criteria. The OS detector performance was quantified in terms of probability of detection and probability of false alarm metrics. Validation results and associations between AISSat-1 and MSSIS, AISSat-1 and OS, and MSSIS and OS are reported. There were 1482 validated ships of which OS-declared 65%. OS alone accounted for more than 21% of the validated ships.

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Validation; Automatic Identification System; AISSat-1; MSSIS; AIS; Synthetic Aperture Radar; RADARSAT-2;ADSS

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