FFI-rapport 2011/01693

Ship detection using high resolution satellite imagery and space-based AIS

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15 December 2011

FFI-rapport 2011/01693

1210

P: ISBN 978-82-464-2087-5
E: ISBN 978-82-464-2088-2

Keywords

Syntetisk Aperture Radar (SAR)

Skipsdeteksjon

AIS

Rombasert AIS

Høyoppløselig SAR

AISSat-1

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English summary

This report presents a trial carried out in the Malangen area close to Tromsø city in the north of Norway in September 2010. High resolution Synthetic Aperture Radar (SAR) images from RADARSAT-2 were used to analyse how SAR images and AIS (Automatic Identification System) messages can be used as cooperative reporting and how they can be combined. AIS data, both land-based and space-based, have been used to identify detected vessels in the SAR images. The report presents results of ship detection in high-resolution RADARSAT-2 Standard Quad-Pol (Quad-Polarisation) images, and how these results together with land-based and space-based AIS can be used. Why vessels detected through the land-based AIS chain are not detected by AISSat-1 is discussed.

Sammendrag

Denne rapporten presenterer en test utført i Malangen nær Tromsø i Nord-Norge i september 2010. Høyoppløselige Syntetisk Aperture Radar-bilder (SAR) fra RADARSAT-2 har blitt brukt for å analysere hvordan SAR-bilder og AIS-meldinger (Automatic Identification System) kan brukes som kooperativ rapportering og hvordan de kan kombineres. AIS-data, både landbasert og satellittbasert, har blitt brukt til å identifisere detekterte skip i SAR-bilder. Rapporten presenterer skipsdeteksjonsresultater i høyoppløselige bilder fra moden RADARSAT-2 Standard Quad-Pol (Quad-Polarisation) Mode, og hvordan disse resultatene sammen med landbasert og satellittbasert AIS kan brukes. Hvorfor skip detektert gjennom landbasert AIS ikke detekteres av AISSat-1 diskuteres.

Contents

1 Introduction

The requirements for a national capability to monitor Norwegian waters increase with the increasing shipping and fishing along the Norwegian coast and in the Barents Sea. Space borne Synthetic Aperture Radar (SAR) has been used operationally by the Norwegian Defence since 1998 to monitor the Norwegian economic and fisheries zones. Radar satellites increase the overview in vast areas and help the operational decision-making process. The Norwegian Defence Research Establishment (FFI) is developing capabilities using space borne sensors for monitoring ship traffic in the open ocean. Traditionally, fairly coarse resolution SAR imagery from RADARSAT-1, and now RADARSAT-2, ScanSAR mode (50 m resolution, 300 km swath width) has been used to support the Norwegian Coast Guard in fisheries monitoring. More recently, space-based AIS (Automatic Identification System) receivers have shown the possibility to monitor most of the world's ship traffic by different means. This allows the use of new approaches to obtain higher resolution data for selected areas of interest, using high resolution radar sensors (RADARSAT-2, TerraSAR-X and COSMO-SkyMed) and also optical data from satellites such as Worldview-1 and GeoEye. This report will present some results of ship detection in high resolution satellite imagery. How these analyses can be combined with space-based and land-based AIS is also examined.

1.1 AIS

In addition to developing new SAR processing algorithms and recommendations for future use of SAR imagery, the Norwegian Defence Research Establishment (FFI) has been working on evaluation and the development of space-based AIS services [1;2]. The AIS is a ship-to-shore system as well as a ship-to-ship anti-collision system of shipboard transponders that automatically exchange vessel traffic information for maritime safety, mandated by the International Maritime Organisation (IMO) on larger vessels. All passenger ships, cargo ships over 300 gross tons and all fishing vessels over 45 meters must have an AIS transponder onboard the ship. Information obtained from the AIS system is the ship's position, speed, heading, load, size, ship type and more. AIS signals sent from the land-based stations have a range of 40 nautical miles. A satellite-based AIS system will increase this range tremendously to cover larger ocean areas, thus making it easier to monitor the vast ocean areas in the High North, which are difficult to monitor with the land-based AIS network that exists today [3].

FFI is developing capabilities using space borne sensors for monitoring ship traffic in the open ocean. Norway and FFI has launched an AIS transponder on AISSat-1 on July 12th 2010 to receive AIS signals in space. AISSat-1 is a demonstration mission focusing on vessel detection in waters north of the Arctic Circle. This includes an AIS instrument on a satellite. AISSat-1 is a small Norwegian cube satellite with size 20 cm × 20 cm × 20 cm and mass of 6 kg. AIS messages from vessels are sent via the AISSat-1 satellite and Spitsbergen to a control centre, and then to the users (see Figure 1.1). Figure 1.2 shows an example of the first data received from AISSat-1 after it was launched. The figure shows that the satellite is able to receive much more data (yellow and orange symbols) compared to what the Norwegian Coastal Administration (NCA) is able to receive using land-based AIS (turquoise) [4].

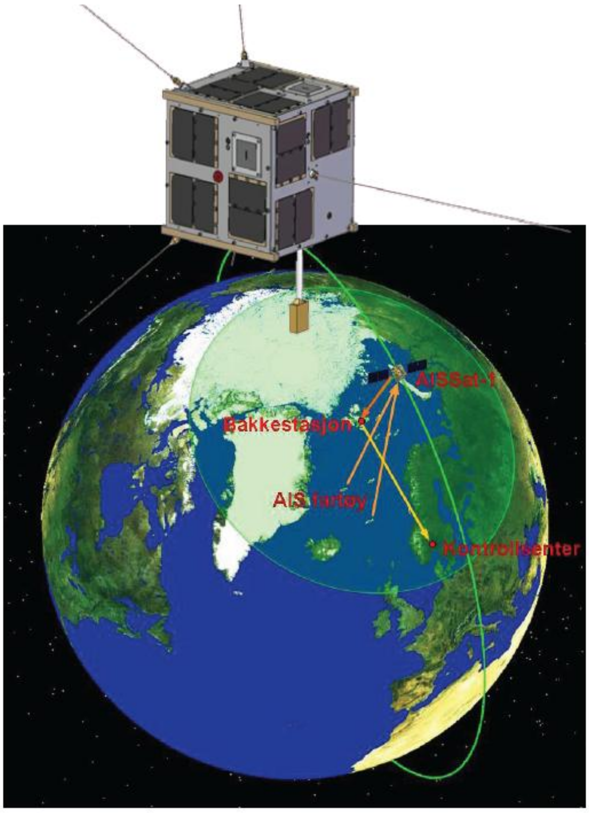


Figure 1.1 *AIS messages from vessels are sent via the AISSat-1 satellite and Spitsbergen to a control centre and then to the users. © FFI and UTIAS Space Flight Laboratory.*

Figure 1.2 *The first AIS data from AISSat-1. The yellow and orange symbols show the new AIS data that the satellite gives in addition to the data from the land-based network shown in turquoise symbols.*

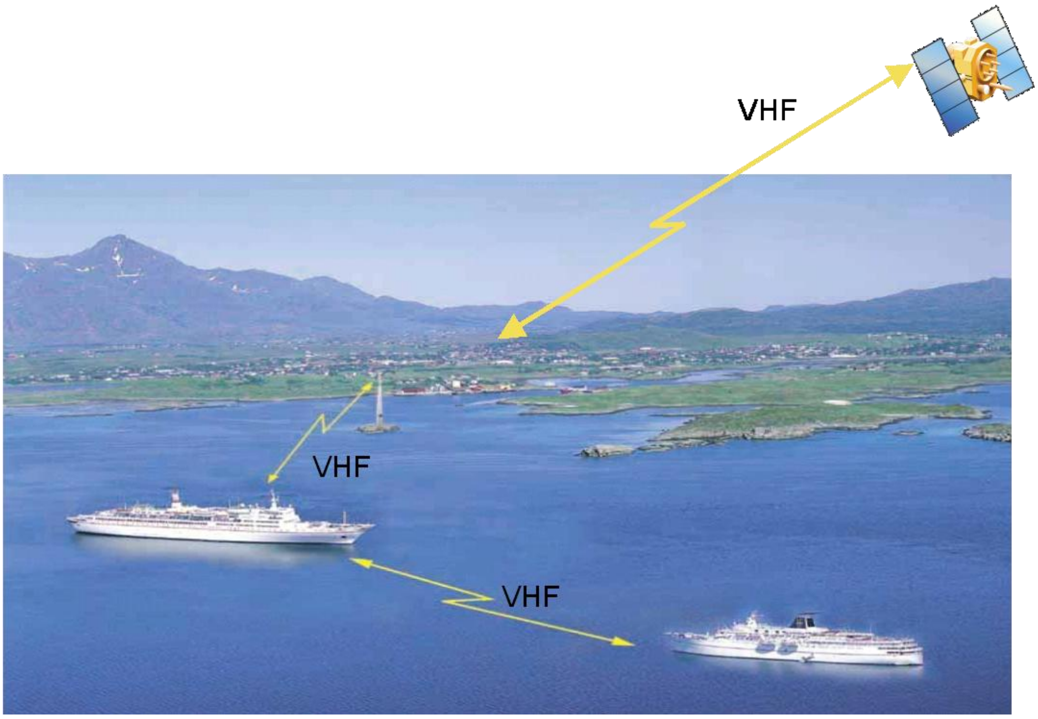


Figure 1.3 AIS signals sent between vessels as well as between vessels and land. The satellite AISSat-1 is a demonstration mission to show that it is possible to send AIS signals between space and vessels. ©Seatex and FFI.

Figure 1.3 shows AIS signals sent between vessels, as well as vessels and the AIS chain on land. The figure also shows how AISSat-1 opens up for a possibility to send AIS signals between vessels and a satellite. More information about space-based AIS and research at FFI is described in [5].

Operationally, vessel tracking based on SAR and AIS will give a picture of all vessels in the area. Ship detection in SAR imagery and tracking based on AIS reports are complementary. SAR and AIS can be combined for surveillance in remote areas. AIS information can identify vessels detected in SAR images, while SAR can be used to detect vessels not reporting through AIS. The combination of sources gives the opportunity to unveil vessels that don’t send mandatory AIS reports.

1.2 RADARSAT-2

RADARSAT-2 was launched in 2007, and offers large flexibility in selection of polarisation, incidence angle and resolution. It offers VV-polarisation and cross-polarisation (HV and VH) in addition to RADARSAT-1’s HH-polarisation. The new opportunities with RADARSAT-2 have led to a change in our recommendations on preferences and strategy for open ocean surveillance. Previously, high incidence angles and HH-polarisation were preferred due to high contrast between the ship and sea. The possibility to use cross-polarisation has been shown to give better detection of ships at lower incidence angles, and gives a new capability for using SAR for ship detection [6]. RADARSAT-2 provides quad-polarisation (quad-pol), with the possibility to look at four different images of the same area in four different polarisations: HH, HV, VH and VV.

The satellite has better resolution than its predecessors with 1m in Spotlight mode and 3 m in Ultra Fine mode. The ScanSAR Wide mode has a combination of a swath width of 500 km and a resolution of 100 m.

RADARSAT-1 had the following heritage beam modes: Fine Standard, Wide, ScanSAR Narrow, ScanSAR Wide, Extended Low and Extended High. In addition to these modes, RADARSAT-2 has Ultra-Fine, Multi-Look Fine, Fine Quad-Pol and Standard Quad-Pol beam modes [7]. Figure 1.4 shows the satellite and the different imaging modes of RADARSAT-2. The figure shows that the satellite has the capability to look either to the right or to the left.

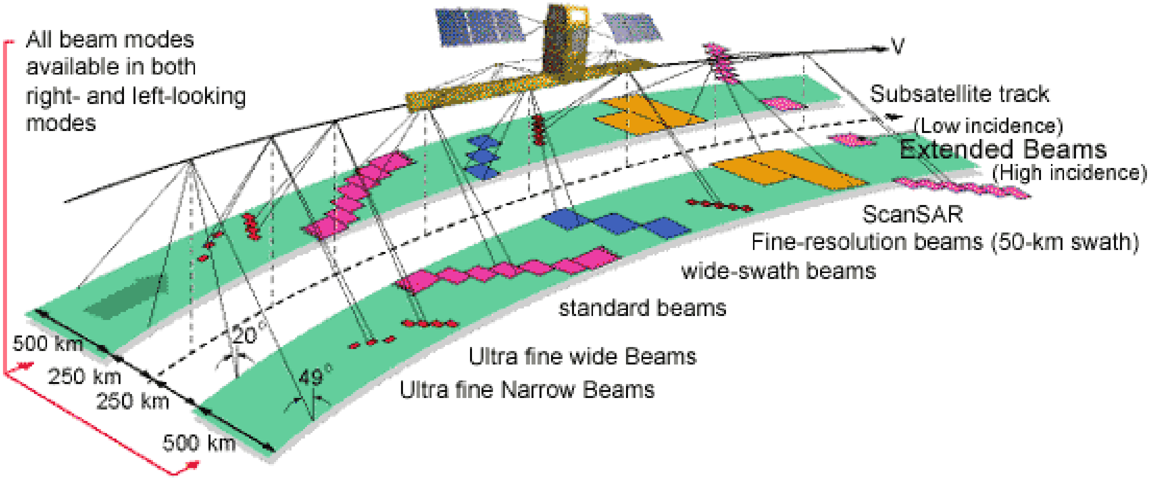


Figure 1.4 RADARSAT-2 modes and the capability of looking either to the right or to the left. © CCRS.

2 Malangen trial

Repeated recordings of the same ships using different SAR modes, polarisations and incidence angles give the ability to evaluate and refine automatic ship detection algorithms. The Malangen area is a good test site since ferries, among other ships, can be imaged multiple times. FFI and the European Commision Joint Research Centre (JRC) did a similar trial in 2006 in the Barents Sea, but then only airborne AIS data was used in combination with SAR data and Vessel Monitoring System data (VMS) [3]. An example from April 6^{th} 2006 in the Hopendjupet is shown in Figure 2.1 where SAR data, airborne AIS data and VMS data are combined. Ten vessels are detected in the SAR image. Only nine vessels reported through AIS, while the vessel in the middle at the top did not report through AIS, but was identified with a Coast Guard airplane.

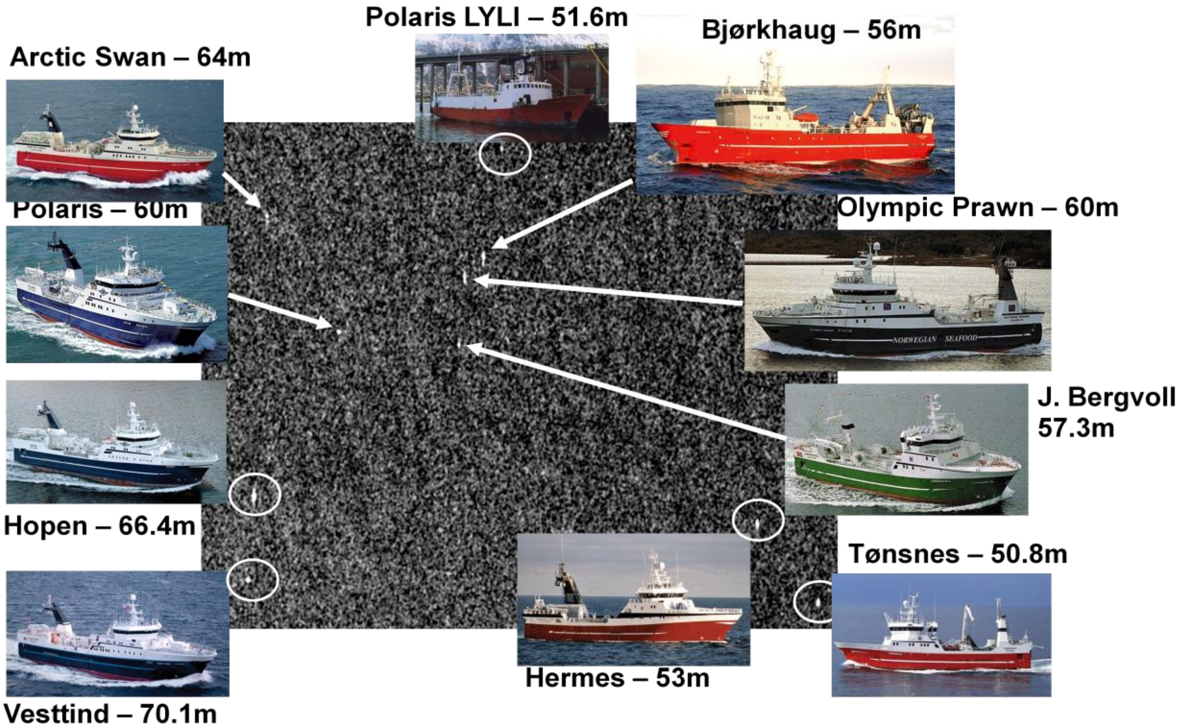


Figure 2.1 Ten vessels detected in the SAR image. Only nine of the vessels reported through AIS.

The Malangen trial was carried out in the Malangen area in September 2010. There were three different data types used in the experiment, SAR images, land-based AIS and space-based AIS. Figure 2.2 shows a map over the Malangen area and the imaged areas close to Tromsø city in the north of Norway. Manual observations of the SAR image were done after plotting and comparing the AIS information available from AISSat-1 and aisonline.com [8]. In this experiment, RADARSAT-2 quad-pol data have been used to do the tests. Table 2.1 shows an overview of the four SAR images obtained as well as the time for AIS data from aisonline.com and AISSat-1. The first time stated for AISSat-1 shows when the satellite's field of view is first over part of the Malangen area and the last time is when the satellite's field of view last sees part of the Malangen area. AIS data from aisonline.com are obtained very close in time to the SAR images, so no propagation of the ships is needed. The aisonline.com page shows the ships' positions for the desired time as well as for a period before. The AISSat-1 performance appeared lower than expected for all passes. This issue and other issues of picking up AIS signals with AISSat-1 will be discussed in chapter 3.

Figure 2.2 The areas imaged during the Malangen trial. From left to right: September 19th, 21st, 23rd and 29th. The imaged areas are close to Tromsø city in the North of Norway. © KSAT.

		Time		
#	Date	SAR	aisonline	AISSat-1
1	19/9	16:31:36	16:30 & 16:35	16:31 - 16:45
2	21/9	15:33:17	15:35	15:35 - 15:48
3	23/9	16:14:54	16:15	16:13 - 16:27
4	29/9	16:39:56	16:40	16:34 - 16:48

Table 2.1 Time for RADARSAT-2 Standard Quad-Pol images and data from both aisonline.com and AISSat-1.

2.1 September 19th

The RADARSAT-2 Standard Quad-Pol image on September 19th was recorded at 16:31:36. AIS data from aisonline.com was downloaded at 16:30 and 16:35 and AISSat-1's field of view was over the Malangen area between 16:31 and 16:45. There were ten ships detected on aisonline.com and eight of them were also detected manually in the SAR HH-polarisation channel. Two of the ships are in port, so it is hard to detect them in the SAR image. The positions of the ten ships are shown in Figure 2.3 (middle and bottom). The top of the figure shows the entire SAR image in HH-polarisation. An overview of the information is shown in Table 2.2.

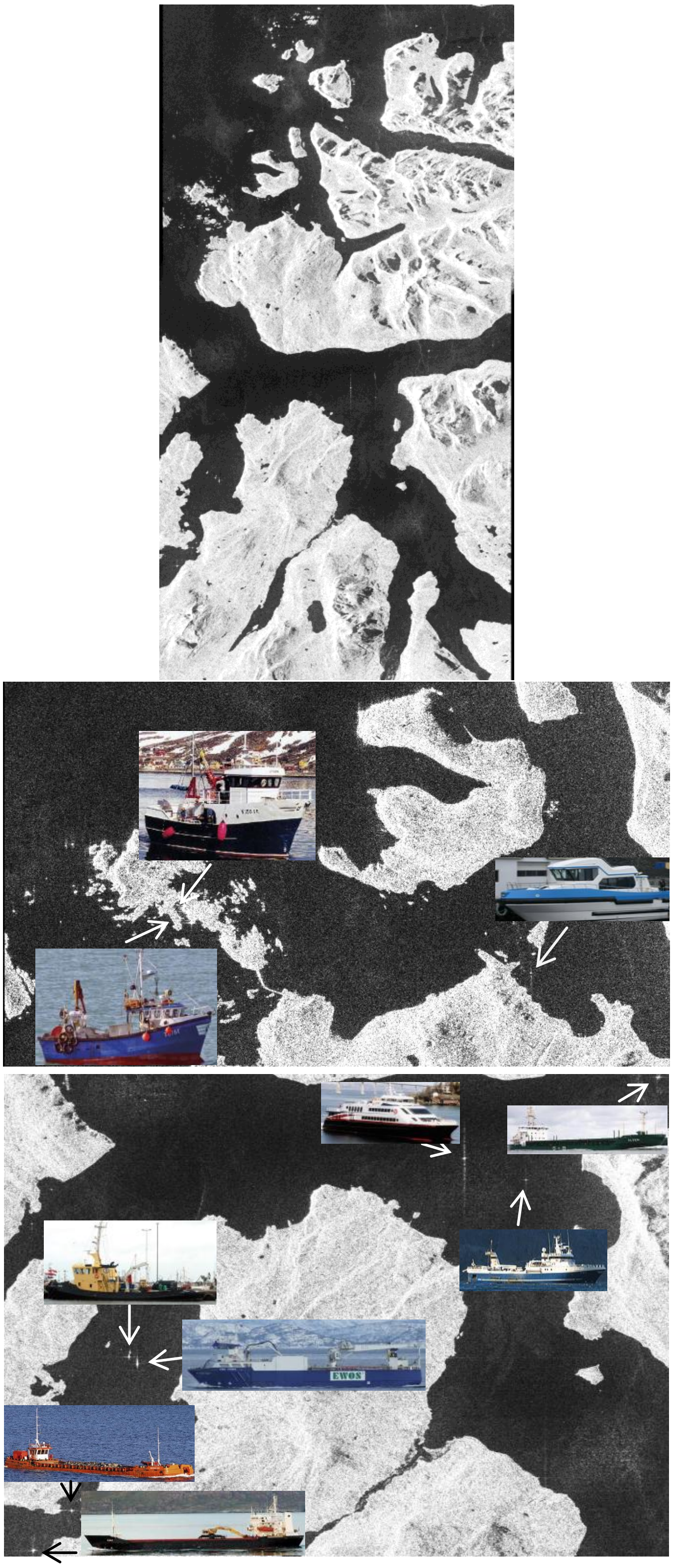


Figure 2.3 RADARSAT-2 Standard Quad-Pol image from September 19th in HH-polarisation shown at the top. Two segments of the SAR image are shown in the middle and at the bottom. The middle segment shows the positions of three ships that are confirmed by aisonline.com. The segment at the bottom shows seven ships that are detected in the SAR image and confirmed by aisonline.com. © [9-12].

AISSat-1 is able to detect four of the ten ships. Two of the six ships that AISSat-1 is not able to detect are class B ships, and that might be a reason that they are not detected. Class B ships transmit AIS signals less frequently and with less power than Class A ships do. Two ships are in port, and ships in port also transmit messages at a lower rate making them harder to detect from space during the limited time the area is in the satellite's field of view. AISSat-1's field of view is shown in Figure 2.4. The field of view covers both part of the Baltic and North Sea and Malangen at the same time, which can lead to saturation in AISSat-1 when reading AIS signals from a large number of ships.

	Detections September 19th		
Ship	**SAR**	**aisonline**	**AISSat-1 Class, detected?**
1	Detected	OK	B, detected
2	Detected	OK	A, detected
3	Detected	OK	A, detected
4	Detected	OK	B, -
5	Detected	OK	A, -
6	Detected	OK	A, -
7	Detected	OK	A, -
8	Detected	OK	A, -
9	Land	OK	B, detected
10	Land	OK	B, -

Table 2.2 Overview of detections on September 19th by SAR, aisonline.com and AISSat-1.

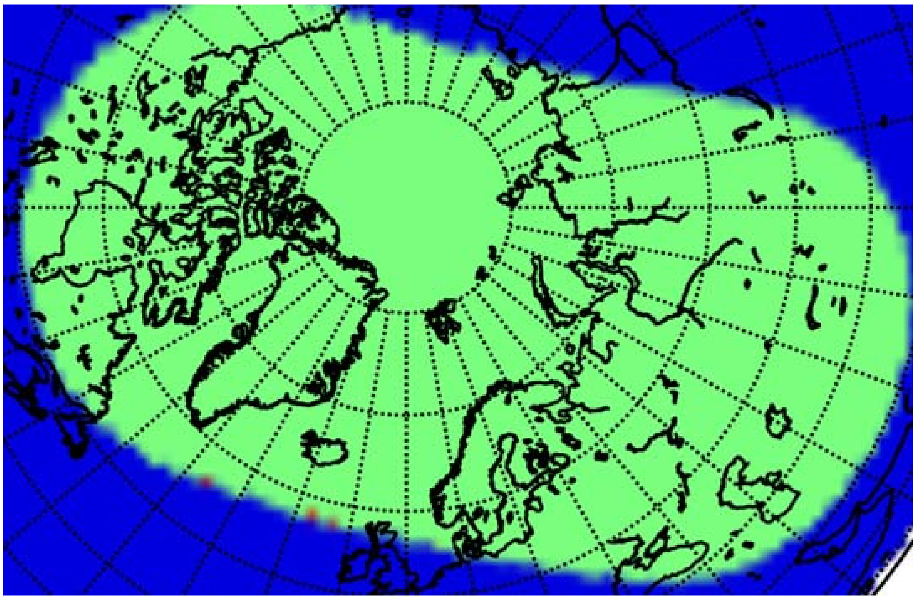


Figure 2.4 AISSat-1 field of view in green on September 19th between 16:31:07 and 16:44:45.

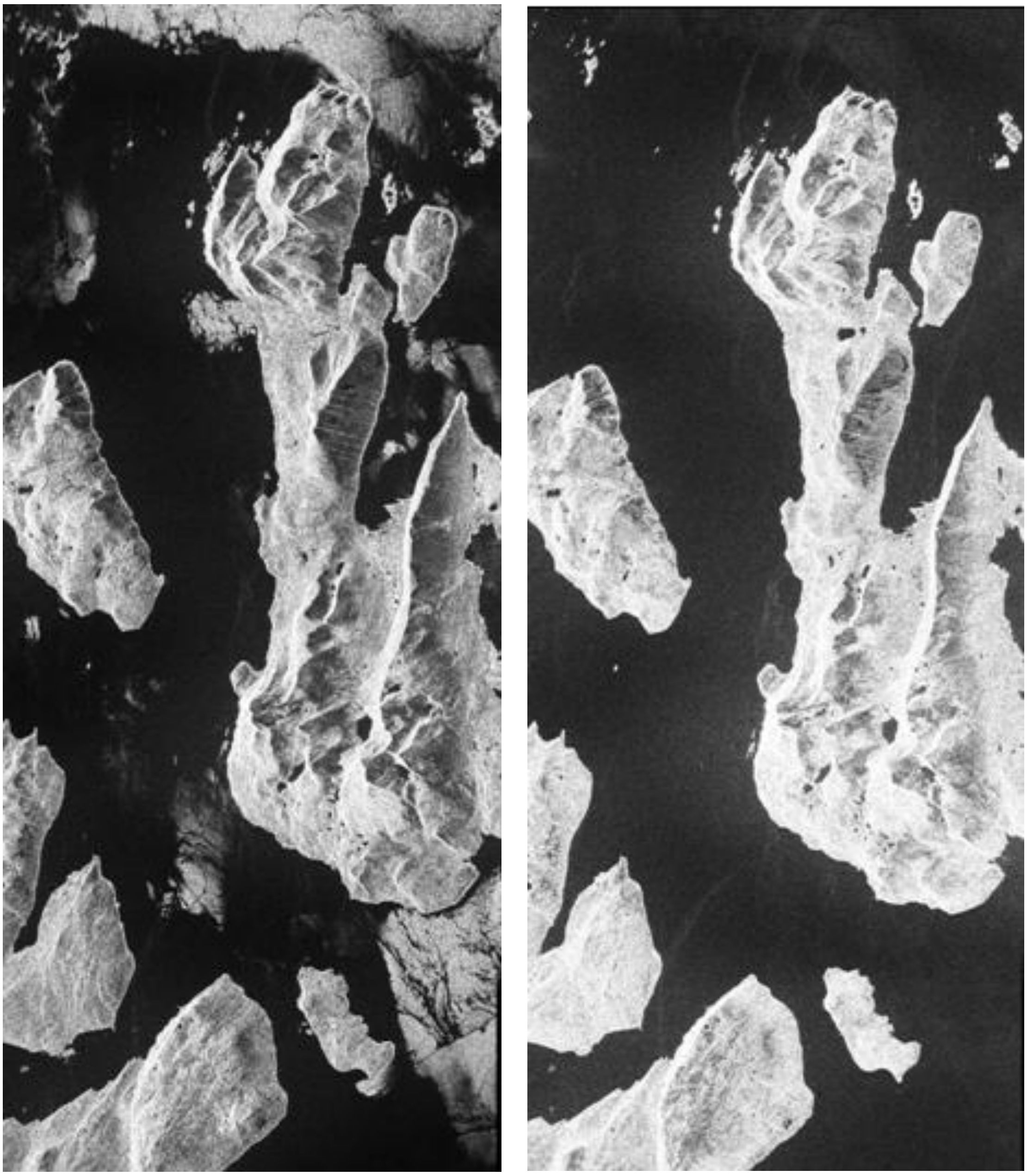
2.2 September 21st

The RADARSAT-2 image on September 21st was recorded at 15:33:17. Figure 2.5 shows a segment of the SAR image for VV-polarisation (left) and HV-polarisation (right). It is easier to see oceanographic phenomena and backscatter from the sea in the VV-channel (co-polarisation) and thus it is easier to see the difference between land and ocean in the HV-channel (cross-polarisation).

AIS data were obtained at 15:35 from aisonline.com and from AISSat-1 between 15:35 and 15:48. Nine ships are reported by aisonline.com. Four of the nine ships reported by aisonline.com are detected in the SAR image, three other of the nine ships are close to land, making it difficult to separate land and ships, and the two last ships are not detected in the SAR image. One of the two last ships not detected in the SAR image is only 10 meters long and the other one has unknown length. None of the nine ships are detected by AISSat-1 close in time when the SAR image is recorded, but three of them are detected by AISSat-1 at earlier times. See Table 2.3 for an overview of the detections made of the different sources: SAR, aisonline.com and AISSat-1. Only one of the nine ships is a class A ship. Seven ships are class B ships, reporting with lower power and at less frequent intervals. Three ships are in port, and ships in port are harder to detect from space due to lower transmit rate while in port. One of the other nine ships is never detected by AISSat-1 and the MMSI (Maritime Service Mobile Identity) number is unknown for aisonline.com and ship-info.com [11]. Figure 2.6 shows AISSat-1's field of view.

	Detections September 21st		
Ship	**SAR**	**aisonline**	**AISSat-1 Class, detected?**
1	Land	OK	B, detected 12/9
2	Land	OK	B, detected 2/9
3	Land	OK	B, detected 6/9
4	Not detected, unknown length	OK	Never detected
5	Not detected – 10 m	OK	B, -
6	Detected	OK	A, -
7	Detected	OK	B, -
8	Detected	OK	B, -
9	Detected	OK	B, -

Table 2.3 Overview of detections on September 21st by SAR, aisonline.com and AISSat-1.



VV *HV*

Figure 2.5 Segments of RADARSAT-2 Standard Quad-Pol image from September 21st. VV-polarisation is shown to the left and HV-polarisation is shown to the right. It is easier to see oceanographic phenomena in VV-polarisation (co-polarisation).

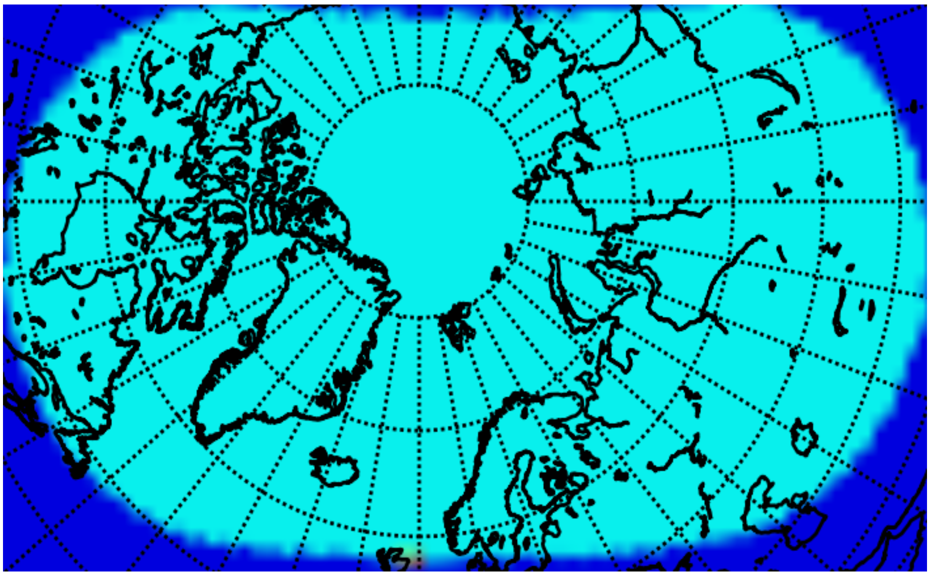


Figure 2.6 AISSat-1's field of view in turquoise on September 21st between 15:34:46 and 15:48:03.

2.3 September 23rd

The RADARSAT-2 image on September 23rd was recorded at 16:14:54. AIS data were recorded from aisonline.com at 16:15 and from AISSat-1 between 16:13 and 16:27. AISSat-1's field of view is approximately the same as on September 19th (see Figure 2.4). Table 2.4 shows an overview of the detections made in the SAR image, as well as AIS data from aisonline.com and AISSat-1. Seven ships are reported by aisonline.com. Five of the ships are detected in the SAR image and the two other ships are close to land making it difficult to separate land and ships. One ship is detected by AISSat-1, and this is the ship that AISSat-1 was able to track over a period (see chapter 2.5). Two of the ships not detected by AISSat-1 are class A, while four of the ships are class B ships. Two ships are in port making them harder to detect from space due to lower transmit rate.

	Detections September 23rd		
Ship	**SAR**	**aisonline**	**AISSat-1 Class, detected?**
1	Land	OK	B, -
2	Land	OK	B, -
3	Detected	OK	A, detected 23/9
4	Detected	OK	A, -
5	Detected	OK	A, -
6	Detected	OK	B, -
7	Detected	OK	B, -

Table 2.4 Overview of detections on September 23rd by SAR, aisonline.com and AISSat-1.

2.4 September 29th

The RADARSAT-2 image on September 29th was recorded at 16:39:56. AIS data were recorded from AISSat-1 between 16:34 and 16:48, while AIS data were downloaded from aisonline.com at 16:40. Four ships were detected by aisonline.com inside the area of the SAR image and all the ships were also detected in the SAR image. Three of the ships were detected by AISSat-1. Figure 2.7 shows a segment of the SAR image on September 29th. The black arrows show the two detections in the SAR image inside the segment, while the white arrows and green diamonds show the detections made by AISSat-1. The ship at the top of the figure is detected three times around 08:37 in the morning (Table 2.5), so AISSat-1's AIS position is at a different place than the position given by aisonline.com further up in the SAR image (not shown in the figure). The two other ships are shown with both the AISSat-1 AIS position and SAR ship detection and aisonline.com AIS position. These positions largely agree. Ship number 2 is reported by aisonline.com to have a velocity southwards. The fourth ship is not shown in the figure, and is not detected by AISSat-1. AISSat-1's field of view on September 29th is approximately the same as on September 19th (see Figure 2.4).

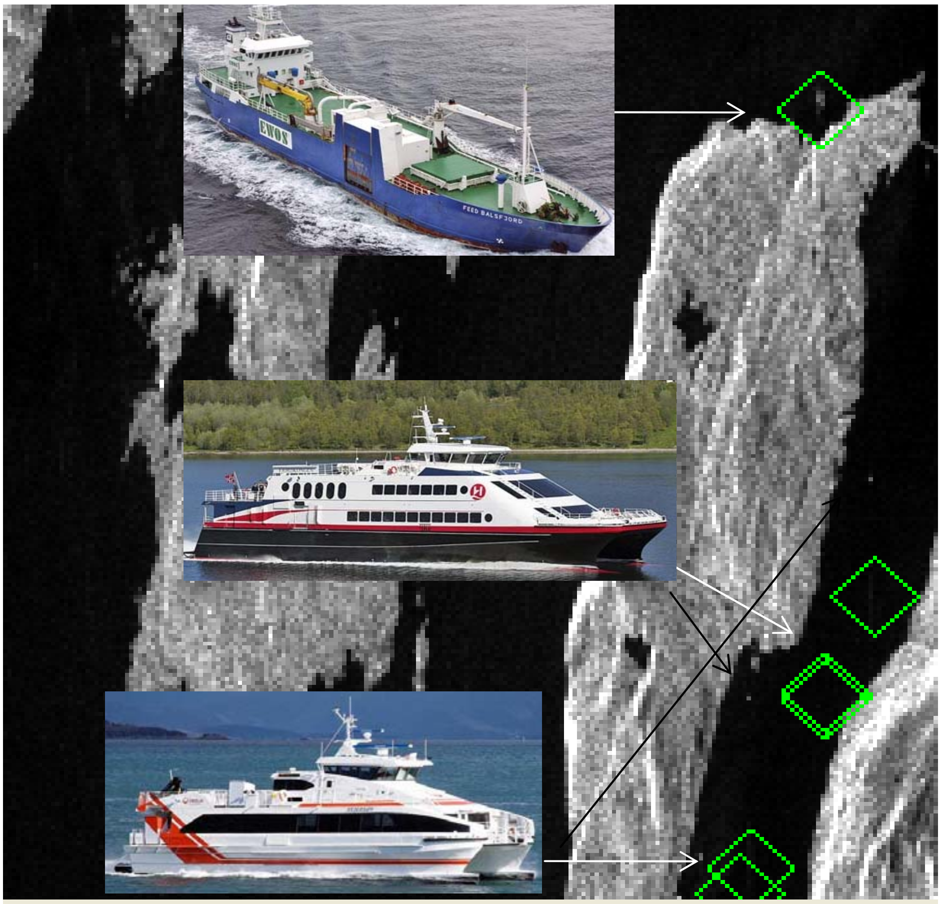


Figure 2.7 AIS positions from AISSat-1 (white arrows and green diamonds) and SAR ship detections (black arrows). © [11;12].

	Detections September 29th		
Ship	**SAR**	**aisonline**	**AISSat-1 Class, detected?**
1	Detected	OK	A, detected 3 times between 07:00-07:02
2	Detected	OK	B, detected 2 times at 16:45
3	Detected	OK	B, detected 4 times at 08:37
4	Land, detected	OK	B, -

Table 2.5 Overview of detections on September 29th by SAR, aisonline.com and AISSat-1.

2.5 Tracking

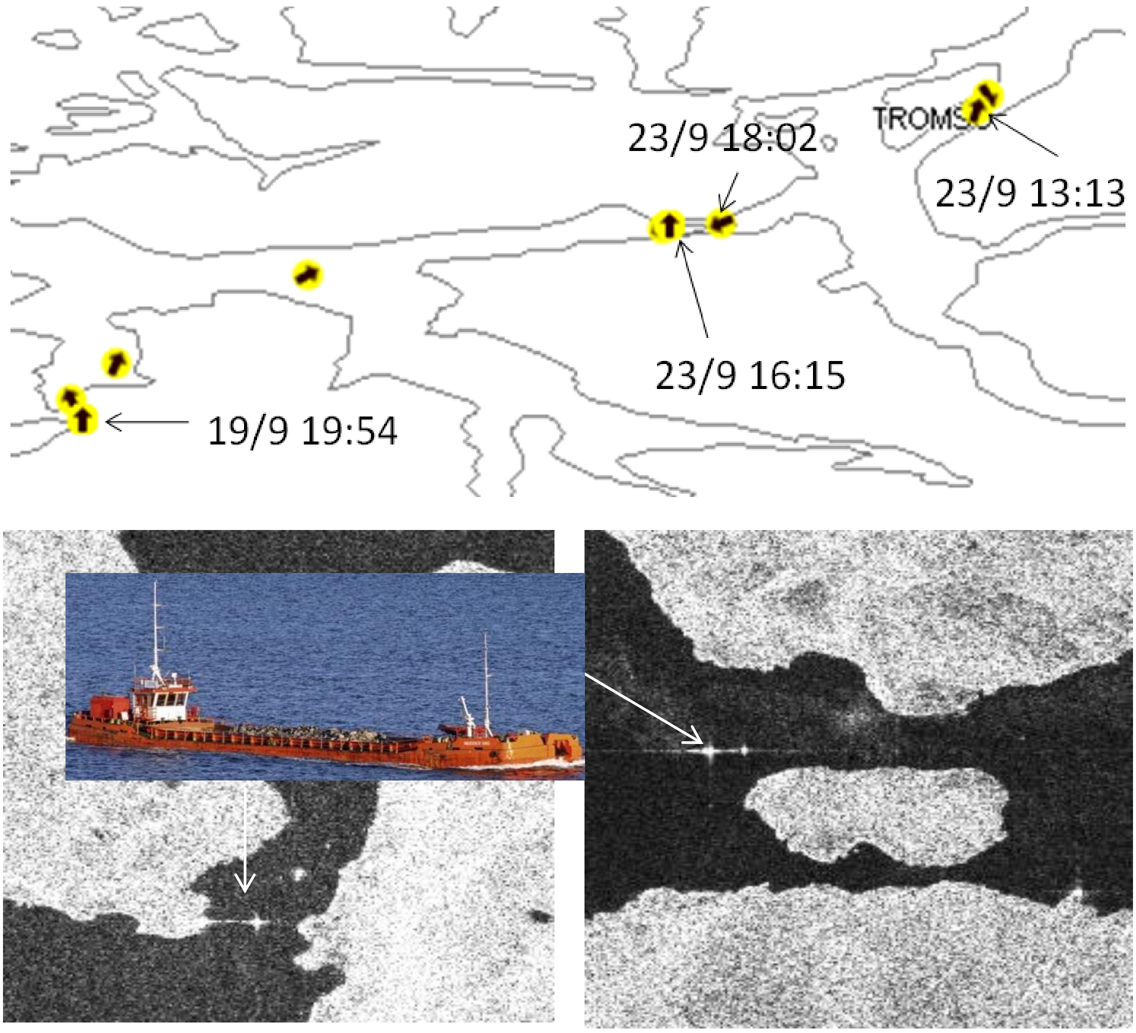


Figure 2.8 Top: Tracking of a ship using AISSat-1 between September 17th at 12:45 and September 23rd at 19:38. The ship is moving from left in the image, then to Tromsø and then to the left again. Bottom: The ship is detected in two different SAR images, on September 19th and 23rd. The arrows point at the detections in the SAR image.

AISSat-1 provides a new possibility to track ships. Land-based AIS from aisonline.com already gives this opportunity, but only for ships that are close to land since land-based AIS only has a range of 40 nautical miles. One ship in the experiment is detected two times in two different SAR images, on September 19th and 23rd. The ship is detected 35 times by AISSat-1 between September 17th at 12:45 and September 23rd at 19:38. The ship track (some of the detections by AISSat-1) is shown at the top of Figure 2.8 and the SAR detections are shown at the bottom of the figure, left for September 19th and right for September 23rd. The ship is moving from left (19/9) in the figure to Tromsø (23/9 at 13:13) and then westwards again on September 23rd. The vessel is approximately in the middle of the figure at the time of the SAR image (16:14:54). The figure shows only some of the times for the detections by AISSat-1.

3 Discussion on AISSat-1 detections

There have been some challenges being able to detect all ships using AISSat-1. Some of the possible reasons are investigated in this chapter.

The main concern about space-based reception of AIS messages has typically been loss of messages caused by message collisions, occurring when high traffic zones with a large number of transmitters are within the field of view at the same time. While the passes selected for this trial do contain parts of the Baltic and North Sea, large parts of the passes should be more or less unaffected by these areas.

Figure 3.1 shows the percentage of received messages by AISSat-1 as a function of time into the pass on September 19, 16:30 – 16:45. It is clear from the figure that for all practical purposes no messages are received within the first 8-9 minutes, limiting the effective pass duration from 15 to only 6-7 minutes. Comparison with simulated results for a similar pass geometry in Figure 3.2 shows a large discrepancy between expected and achieved performance. Since the vessel distribution in the simulation is based on real data, the discrepancy is not believed to be caused by something as simple as no ships being within the field of view in the beginning or from the large number of ships in the Baltic and North Sea alone. On the other hand there appears to be a relationship between increasing performance and decreasing land area within the receiver field of view. Such a relation suggests that the receiver performance is reduced due to considerable land based interference. For this trial, performed in the fjords around Tromsø, the elevation angle between the receiver and ship antenna will be small at the beginning and end of the pass. Thus, for fjords with high mountains there may not be line of sight access between the ship and the satellite at the beginning and end of the pass, further reducing the effective pass duration. The detection of ships in port or ships that otherwise transmit AIS messages with a 3 minute interval is particularly vulnerable to such a reduction in effective pass duration.

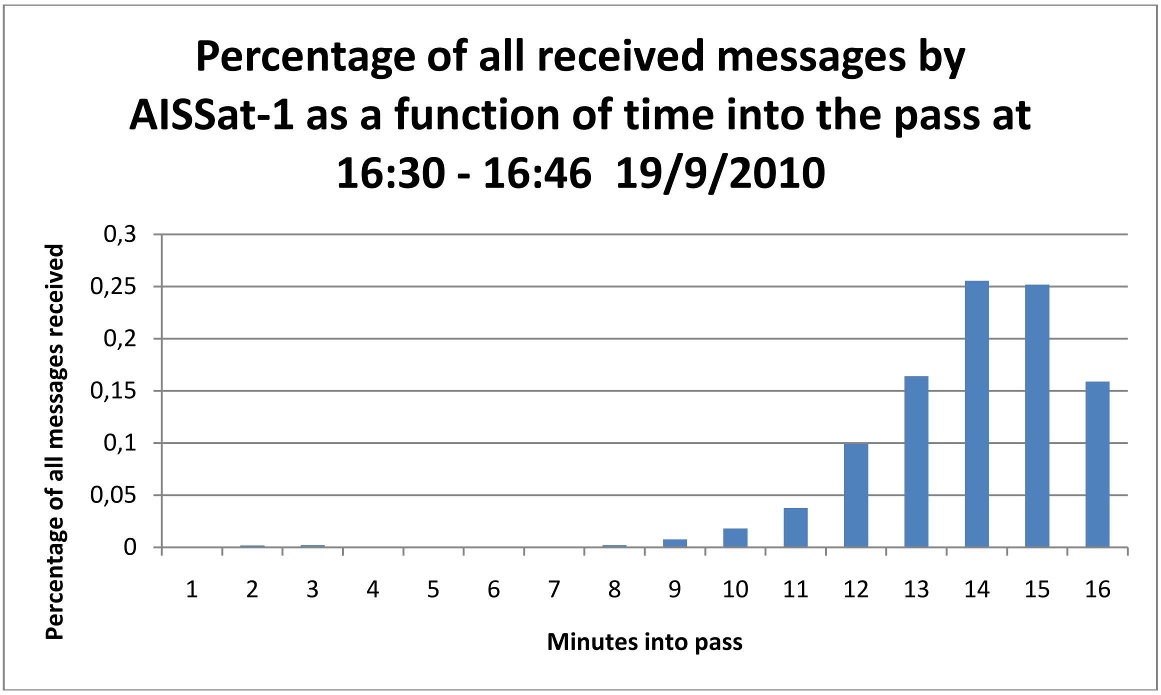


Figure 3.1 *Plot showing the percentage of all messages received by AISSat-1 as a function of time into the pass at 16:30 - 16:45 September 19th 2010.*

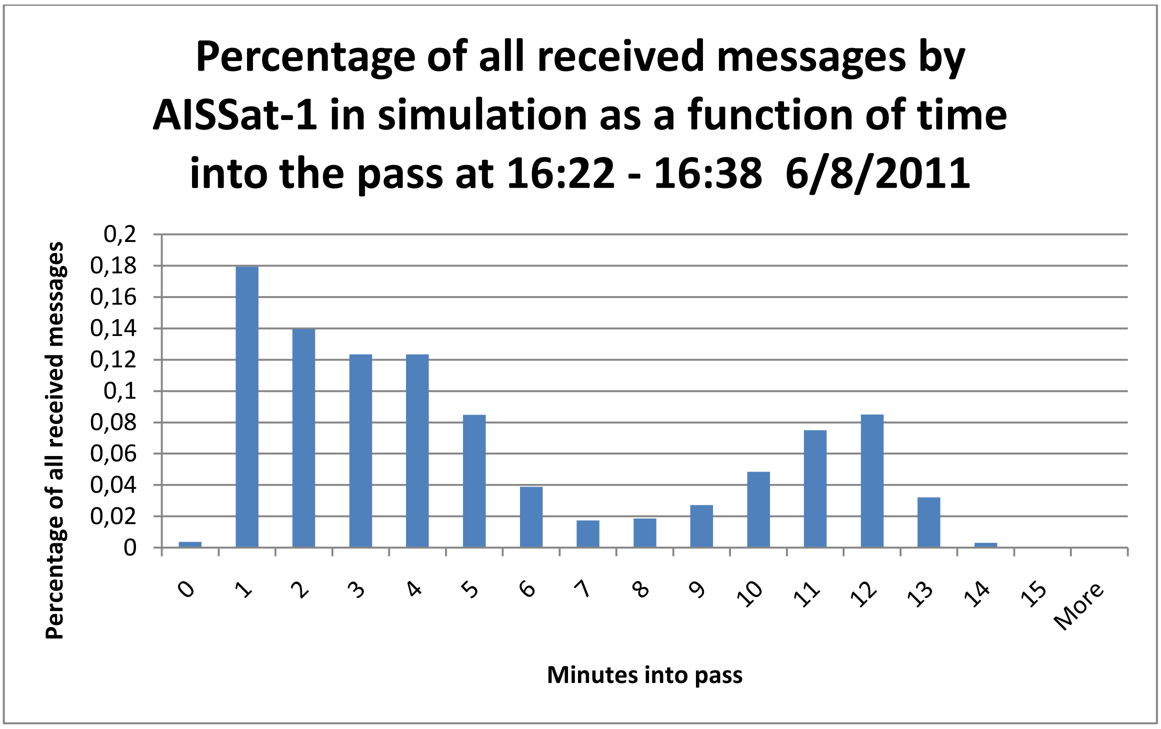


Figure 3.2 *Plot showing the simulated percentage of all received messages by AISSat-1 as a function of time for a pass similar to the ones used in the Malangen trial.*

In addition, several of the ships detected in the SAR imagery for this campaign were identified as AIS class B vessels by aisonline.com. Class B is one of two different classes of AIS equipment carried onboard vessels. The class B AIS transponder was introduced in 2007 to be able to provide low cost AIS transponders, and is for ships not under the rules of the International Maritime Organizations International Convention for the Safety of Life at Sea (SOLAS). As briefly mentioned previously, class B transponders transmit messages with less power, less frequently than class A vessels and in addition, class A messages have priority in areas with many AIS messages being transmitted [13].

Finally, it might be more difficult to pick up AIS signals in space if the AIS equipment is not installed properly onboard the ships.

The sum of all these challenges means that the detection probability in a single pass varies considerably, even in a low traffic area such as the north of Norway. Over time however, the ship detection probability increases greatly as illustrated by the tracking capability discussed in section 2.5. From other analyses performed on AISSat-1 data, the single pass detection probability on the open oceans, with no land within the satellite receiver field of view, is believed to be greater. Other analyses have also shown that the AISSat-1 performance varies with the satellite antenna pointing configuration. During this trial AISSat-1 was still in its commissioning phase with no active antenna control such that somewhat greater performance should be possible for future trials.

Space-based AIS has larger probability to detect ships in the open ocean areas than close to the coast. This is due to the fact that the number of messages from ships increases close to land and there are more ships close to land, thus making the satellite more exposed to interference from land-based re-use of the AIS frequencies. The last point is also valid some distance from land due to the satellite's large field of view.

4 Conclusion

The Malangen area used in the Malangen trial was chosen because it is possible to obtain land-based AIS from aisonline.com. The times are always in the afternoon to be able to get a RADARSAT-2 Standard Quad-Pol image as close as possible in time to an AISSat-1 pass.

How ship detection in high resolution SAR images can be combined with space-based and land-based AIS is shown in this report. Most of the ships reported by aisonline.com are detected in the SAR image as long as the ships are not very close to land, making it difficult to separate land and the ships. Two ships that were not close to land were not detected, where one of them was 10 meters and the other one of unknown length. An example of how it is possible to track a ship using AISSat-1 is also shown.

AIS signals sent from land-based stations have a range of approximately 40 nautical miles. Satellite-based AIS increases this range tremendously to cover larger ocean areas, thus making it easier to monitor the ocean areas north of Norway, which are difficult to monitor with the land-based AIS network that exists today [14].

AISSat-1 was still in the commissioning phase when the data in this study were collected, and it is believed that the performance of the satellite is better when it is possible to control the attitude of the satellite. It should also be noted that AISSat-1 is a first generation technology demonstrator with a main focus on the Norwegian areas in the High North.

FFI is developing capabilities using space borne sensors for monitoring ship traffic in the open ocean. Land-based AIS signals have a range of 40 nautical miles. A satellite-based AIS system will increase this range. This is important for Norway since the ocean areas are large and parts of the areas are far from land and the land-based AIS. Space-based AIS will make it easier to monitor for example the large ocean areas north of Norway.

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Acronyms

AIS	Automatic Identification System
FFI	Forsvarets Forskningsinstitutt
H	Horisontal polarisation
HH	Horisontally transmitted – Horisontally received polarisation
HV	Horisontally transmitted – Vertically received polarisation
IMO	International Maritime Organisation
JRC	Joint Research Centre
KSAT	Kongsberg Satellite Services AS
MDA	MacDonald, Dettwiler and Associates Ltd
MMSI	Maritime Service Mobile Identity
NCA	Norwegian Coastal Administration
Quad-Pol	Quad-Polarisation
SAR	Synthetic Aperture Radar
SOLAS	International Convention for the Safety of Life at Sea
V	Vertical polarisation
VH	Vertically transmitted – Horisontally received polarisation
VMS	Vessel Monitoring System
VV	Vertically transmitted – Vertically received polarisation