ARCTIC MARITIME SURVEILLANCE WITH SENTINEL-1 DATA USING A NORWEGIAN COLLABORATIVE GROUND SEGMENT

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ABSTRACT

The Sentinel-1A and Sentinel-1B C-band Synthetic Aperture Radar (SAR) satellites provide data for European Union's Copernicus program. Norway uses SAR satellites operationally to monitor Norway's maritime areas of interest. Since 2010 satellite AIS (Automatic Identification System) from AISSat-1 and -2 have been used to get additional information about the maritime picture. The paper presents results from trials and early operations with Sentinel-1A and -1B for maritime surveillance in the Norwegian Arctic. System performance from an end user perspective and a Norwegian collaborative ground segment are discussed and analyzed. Use of the Sentinel-1 satellites for ship detection is also addressed. Ship to sea contrast is analyzed, including ways to enhance the contrast to improve vessel detection probability.

Index Terms— Sentinel-1, ship detection, ground segment, polarization, SAR

1. INTRODUCTION

The Sentinel-1 to -5 satellites will provide the EU's (European Union) Copernicus program with data for environmental monitoring and security applications well into the next decade. The satellites have been developed by EU and ESA (European Space Agency) in partnership. Data from the Sentinel-1A (S-1A) and -1B (S-1B) C-band SAR (Synthetic Aperture Radar) satellites are available under a free and open data policy.

Norway uses the SAR satellite RADARSAT-2 operationally for maritime surveillance today, analyzing images from Norwegian waters in the Arctic on a daily basis. S-1A and S-1B provide additional information to the situational picture at sea. AIS (Automatic Identification System) satellites AISSat-1 (2010) and AISSat-2 (2014) have also been included in the daily maritime analysis. Figure 1 shows one year of AIS data from AISSat-1 over the Norwegian Arctic areas. Norway has maritime Areas of Interest (AOI) of over 2 million km^2 (see figure 1), including territorial waters, Exclusive Economic Zone, and Fishery Protection Zones around Spitsbergen and Jan Mayen. The Norwegian AOI is defined as the area inside the rectangle 20°W-60°E, 60°N-83°N. Due to the vast ocean areas it is necessary to utilize all data available in the most efficient way for maritime surveillance. Maritime Situational Awareness is important for Norway because 50 % - 80 % of all vessel traffic above the Arctic Circle (see figure 2) is in the "Norwegian sector". The traffic includes maritime transportation, natural resource exploitation, and tourism, and is expected to increase due to diminishing ice cover in the Northeast Passage and in the Arctic Ocean.

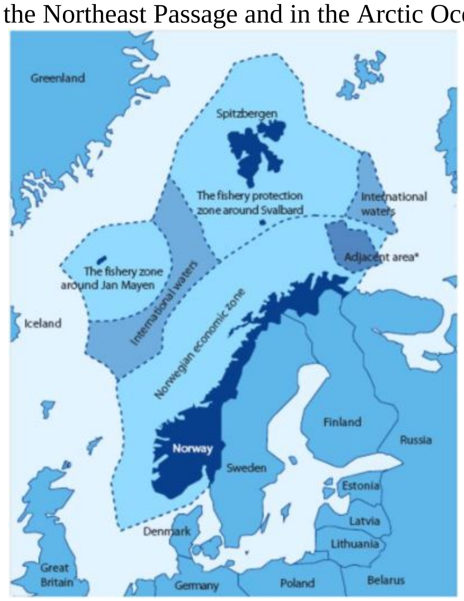

Figure 1. Norway's fishery and protection zones. © fao.org

In order to meet timeliness requirements of Norwegian operational users in the maritime sector, Norway has established a national collaborative ground segment for downloading and processing of Sentinel-1 SAR data. This is facilitated through agreements with ESA and the EU Copernicus program. The Norwegian Defence Research Establishment (FFI) has from November 2014 done an initial evaluation of the Sentinel-1 SAR satellites to determine if the SAR data, the downloading services, the latency, and associated monitoring services are suitable to meet the national operational requirements. Sentinel-1 operations are assessed with respect to mode (Extra Wide

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(EW), Interferometric Wide (IW)), polarization selection, spatial and temporal coverage, and timeliness for both data downlink and subsequent processing. This paper will present results from trials and early operations with S-1A and -1B for maritime surveillance in the Norwegian Arctic.

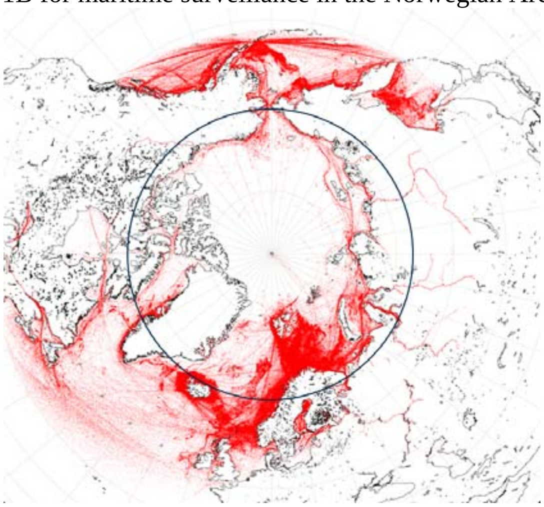

Figure 2. One year of AISSat-1 data.

2. SENTINEL-1 PERFORMANCE

Sentinel-1A and -1B were launched in 2014 and 2016, respectively. The two most suitable modes for open ocean surveillance are the EW mode (400 km swath, 50 m x 50 m range/azimuth resolution) and the IW mode (250 km swath, 20 m x 22 m range/azimuth resolution) [1].

How fast the users can access the satellite data is a crucial point. Early tests showed that the data latency for some test data downloaded from ESA Sentinels Scientific Data Hub had an average latency of 6h23min, while the lowest was 3h4min and the highest was 1d7h27min. This is not good enough for Norway's operational needs. A Norwegian collaborative ground segment dedicated to meet national near real time requirements was necessary due to the time delay. The Norwegian ground stations in Tromsø and Spitsbergen are inside the Norwegian AOI, which enables rapid download and exploitation of the SAR data. The national ground segment for Sentinel-1 data was established October 22nd 2015. This does not provide more images, but the time delay is greatly reduced. Combining the national ground stations with rapid processing and dissemination meets the 1 hour requirement for open sea surveillance, including all steps from acquisition to analysis. An example week, week 15 from 2016, showed an average data latency of 20 min, where the highest was 33 min and the lowest was 14 min. See table 1 for more examples for S-1A and S-1B products in IW mode. The numbers from 2016 are for Sentinel-1A only, while the data from 2017 are from both Sentinel-1 satellites. For week 3 in 2017, the shortest time is 8 minutes, which is fast. The first two images from this week have a high latency, 179 and 202 minutes, respectively. Without these two images, the average time would have been 18 minutes. It is a trend that the average time is going down, making it easier for the operational user to benefit from the information in the data.

Table 1. Data latency for Sentinel-1 SAR data from some example weeks in 2016 and 2017.

Dates (week)	# scenes	Shortest time (min)	Longest time (min)	Average time (min)
18-24/1 2016 (3)	20	14	52	30
15-21/2 2016 (7)	16	31	162	73
14-20/3 2016 (11)	20	14	35	20
11-17/4 2016 (15)	14	14	33	20
16-22/1 2017 (3)	28	8	202	31
13-19/2 2017 (7)	19	8	46	24
13-19/3 2017 (11)	17	7	26	12
10-16/4 2017 (15)	17	7	18	12
8-14/5 2017 (19)	17	7	26	14

Sentinel-1B was introduced into operations during the fall of 2016. The S-1A and S-1B satellites provide potential frequent coverage, although the temporal spacing is an issue. An example of coverage over 24 hours using S-1A and S-1B from October 19th 2016 for EW and IW mode is shown in figure 3. The satellites cover the Norwegian areas of interest quite well. There are 63 products in the EW mode, where 32 (28 HH/HV + 4 HH) are from S-1A and 31 (27 HH/HV + 4 HH) from S-1B. There are 69 products in the IW mode, where 17 (13 VV/VH + 4 HH) are from S-1A and 52 (52 VV/VH) from S-1B. H means horizontal polarization and V means vertical polarization.

Table 2 shows the number of images available inside the Norwegian AOI in September 2016 when only Sentinel-1A was available and in October 2017 when both Sentinel-1A and -1B were available. The number of available images has clearly increased.

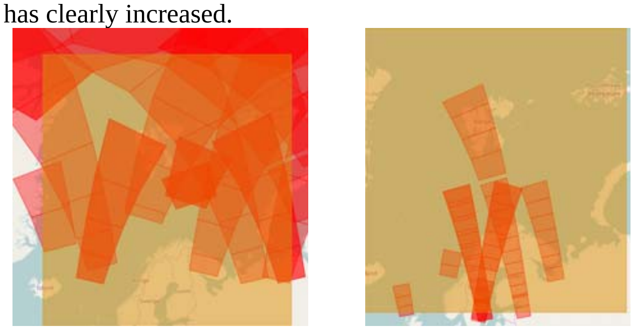

Figure 3. Example of coverage using both S-1 satellites over a 24 hours period for EW (left) and IW (right).

It is shown that the EW mode is used further north over Spitsbergen and over open sea, while the IW mode is used closer to the coast and over land. The HH/HV polarization combination is most often used in the EW mode, and figure 4 shows that most acquisitions are made using HH/HV or HH. The opposite is the case for the IW

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mode (see figure 5). Note that the data presented in these two figures are from January to March 2015. For Norwegian interests, more HH/HV acquisitions in the IW mode would be desirable, as this polarization combination is preferable in automatic ship detection [2]. Expanded use of the IW mode in the fishery protection zone around Spitsbergen, as well as along the continental shelf edge from Spitsbergen down to the Norwegian mainland coast, would give better ship detection performance due to better resolution.

Table 2. Number of Sentinel-1 images available in AOI with only S-1A and with both S-1A and S-1B.

Sentinel-1A		Sentinel-1A + Sentinel-1B	
31/8 - 6/9	IW: 314	28/9 – 4/10	IW: 466
31/8 - 6/9	EW: 575	28/9 – 4/10	EW: 557
7/9 – 13/9	IW: 456	5/10 – 11/10	IW: 671
7/9 – 13/9	EW: 716	5/10 – 11/10	EW: 655
14/9 – 20/9	IW: 313	12/10 – 18/10	IW: 611
14/9 – 20/9	EW: 534	12/10 – 18/10	EW: 844

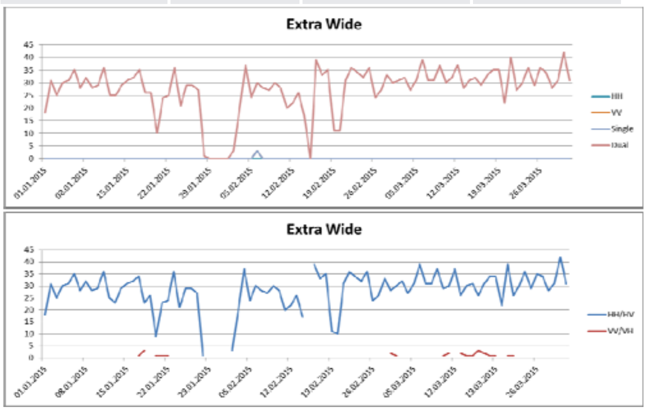

Figure 4. Acquisitions with Sentinel-1A EW mode

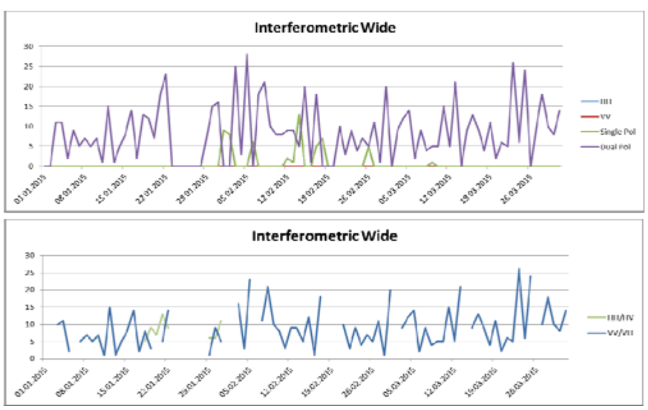

Figure 5. Acquisitions with Sentinel-1A IW mode

3. SHIP DETECTION

Ship detection tests using Sentinel-1 SAR data with different modes have been performed over areas where there are ships of known sizes, small, medium and large. The same vessels are imaged multiple times using different viewing geometries and polarizations. The ship detections from SAR are compared with AIS data (from aisonline.com) as well as satellite AIS (from AISSat-1 and AISSat-2), to validate which vessels are imaged. See figure 6 for an example of Sentinel-1A IW mode VV-polarization on October 6th 2014, where SAR and AIS data are combined for vessel identification.


Figure 6. Early image example from S-1A IW mode VV-polarization combined with AIS data.

The oil production vessel, Norne FPSO (260 m long), is moored to the ocean ground, and has been imaged multiple times with the Sentinel-1 satellites. Ship to sea (peak to clutter) contrast and Target to Clutter (Radar Cross Section to clutter) Ratio (TCR) have been analyzed for the oil production vessel. Figure 7 and figure 8 show TCR for Norne FPSO in 24 S-1A IW VV/VH images for co-polarization and cross-polarization, respectively. Incidence angle values of the vessel are shown on the x-axis. The low TCR value, around 17.5, in figure 7 for high incidence angles is probably due to weather. The TCR for the same image in cross-polarization is 24.0. Cross-polarization shows somewhat better results for high incidence angles compared to co-pol. The same is the case for medium incidence angles, where the values for co-polarization are between 16.3 and 20.7 and for cross-polarization between 21.0 and 23.6. For small incidence angles the TCR results are approximately the same. A similar evaluation done by FFI on ENVISAT data showed a trend where the TCR values increase with increasing incidence angles for co-polarization data, while cross-polarization data did not show a clear trend [3]. Figure 9 and figure 10 show ship to sea contrast as a function of incidence angle for vessels of length 10m - 89m and 90m -175m, respectively, for different polarization combinations.

FFI has also done tests to see how it is possible to improve the ship to sea contrast in Sentinel-1 images. When two polarizations are available, the amplitude values of the respective polarization channels can be multiplied [3]. Figure 11 shows an example of how this method enhances

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the ship to sea contrast. The image segment is from February 12th 2016, and Norne FPSO is imaged at 41.8°.

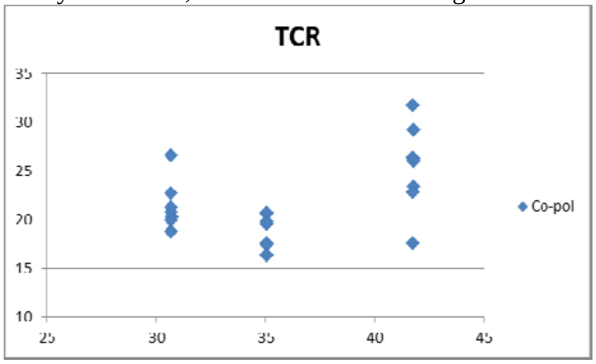

Figure 7. TCR for Norne FPSO for co-polarization.

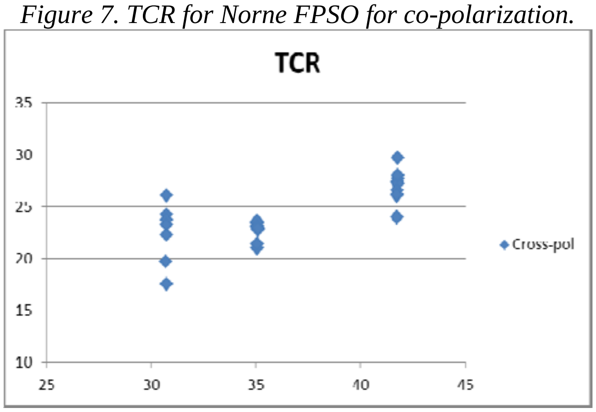

Figure 8. TCR for Norne FPSO for cross-polarization.

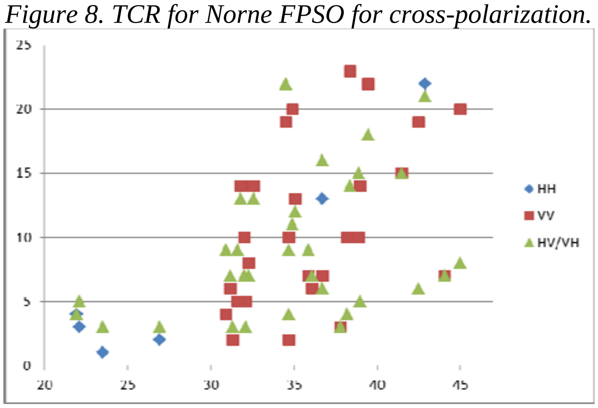

Figure 9. Ship to sea contrast for vessels of length 10-89 m in Sentinel-1A EW and IW images.

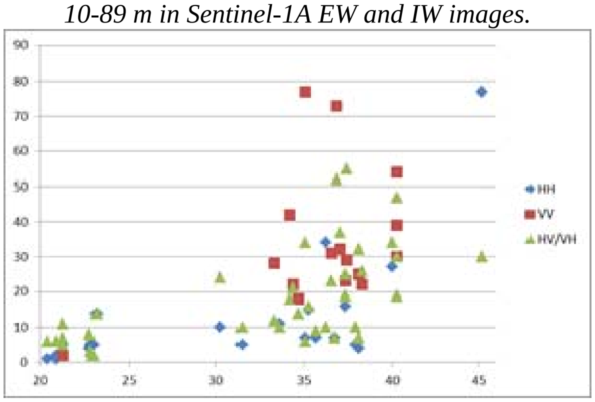

Figure 10. Ship to sea contrast for vessels of length 90-175 m in Sentinel-1A EW and IW images.

The contrast is 16 for VV, 30 for VH (not shown in the figure), and 375 for the combined case. The small vessel, Ocean King (75 m) is not clearly visible in the VV-polarization, but is easier to detect in the combined 3D image segment.

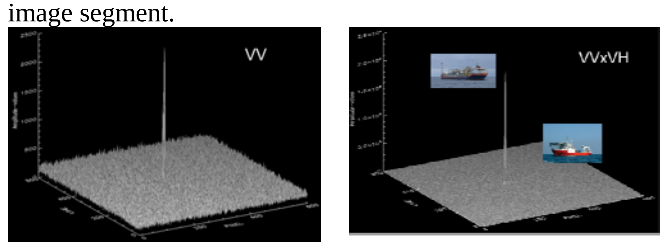

Figure 11. 3D image segments showing contrast enhancement by combining the available polarizations.

3. RECOMMENDATIONS AND CONCLUSIONS

The Sentinel-1 satellites are a great step forward toward an operational ship detection capacity using European SAR satellites. The overall impression is that Sentinel-1A and Sentinel-1B deliver high quality SAR data, compliant with the mission and performance requirements. The satellites have fewer modes than ENVISAT to avoid user conflicts. Sentinel-1 TOPS mode gives better radiometric performance in the along-track direction compared to ENVISAT, RADARSAT-1, and RADARSAT-2, but a marked banding effect and variations in the noise floor can still be seen due to insufficient beam calibration in the SAR processor.

After the launch of Sentinel-1A, timeliness was a key issue when using the ESA scientific data hub. Product availability did not meet timeliness or latency requirements of the Norwegian operational users in the maritime sector. After establishment of a Norwegian collaborative ground segment in October 2015, the data latency for Norwegian users became acceptable.

Geographic distribution of EW and IW acquisitions is as expected. A recommendation from a Norwegian view is to use more HH/HV for ship traffic areas in the Arctic areas, especially for the IW mode. Studies have shown that HH/HV give better ship to sea performance and also better sea ice and iceberg observations.

4. REFERENCES

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