MULTI-CHANNEL AND MULTI-POLARISATION SHIP DETECTION

Tonje Nanette Arnesen Hannevik

Norwegian Defence Research Establishment (FFI), PO Box 25, 2027 Kjeller

ABSTRACT

Norway's large ocean areas in the North require efficient methods to detect vessels in the High North. Radar satellites in orbit today offer dual- or quad-polarised data, which ease the task of detecting vessels in a SAR (Synthetic Aperture Radar) image. FFI has developed an automatic ship detection tool, AEGIR, which uses all polarisation channels to detect vessels. Combining the available channels increases the ship to sea contrast. 19 RADARSAT-2 quad-polarisation images have been run through AEGIR, and it showed that cross-polarisation and (HH-VV)*HV are best for ship detection for all incidence angels. HH-polarisation works well for high incidence angels. RADARSAT-2 offers new high resolution wide modes, which makes it possible to use high resolution and quad-pol images for operational ship detection.

Index Terms**—** Automatic ship detection, SAR, RADARSAT-2, polarisation, AIS.

1. INTRODUCTION

Requirements for monitoring the Norwegian areas in the High North increase, and Norway will therefore be more dependent on being able to have an independent capability to monitor the vast Norwegian interest. To ease the tasks of the maritime monitoring planes, coast guard vessels and helicopters, radar satellites, land-based and space-based AIS (Automatic Identification System) are being used.

RADARSAT-2 delivers SAR (Synthetic Aperture Radar) images to the Norwegian Defence, and these are being used for ship detection and oceanography. Civilian satellites with more advanced sensors, such as TerraSAR-X and RADARSAT-2, give good opportunities to improve the space based ocean surveillance capacity.

2. SAR DATA AND SHIP DETECTION

2.1. Earlier research

Earlier advice for ship detection has been to use large incidence angels and HH-polarisation (Horisontal transmit–Horisontal receive) to detect ships. The ocean backscatter is decreasing with increasing incidence angels for co-polarisation, thus making it easier to detect ships at lager incidence angles. HH-polarisation gives lower ocean backscatter than VV-polarisation (Vertical transmit–Vertical receive). The ENVISAT Alternating Polarisation (AP) mode opened up the possibility to do research on cross-polarised data. It has been shown that cross-polarised data can be used for ship detection at low incidence angels[3];[4]. Research has also indicated that it is easier to estimate more accurate ship lengths in cross-polarised data compared to co-polarised data [5].

2.2. Multi-polarised SAR data

The information content in multi-polarised SAR data is superior to the more traditional single-polarised SAR data from ERS, ENVISAT Wide Swath mode and RADARSAT-1. Several systems now in orbit (RADARSAT-2, TerraSAR-X and Cosmo-SkyMed) can now provide at least dual-polarised data. Recent work shows that significant improvements may be made to detect and classify ships by using the channels that give one image in co-polarisation and one image in cross-polarisation. It may also be possible to discriminate between ships and icebergs in areas where both are present. Ocean backscatter in co-polarised data is dependent on imaging geometry and wind conditions. Co-polarised data are suitable for detecting vessels at large incidence angles, when ship to sea contrast is maximised. Ocean backscatter in cross-polarised data is much weaker than in co-polarised data, and is observed to be much less dependent on imaging geometry and wind conditions. Ship signatures are also weaker, but the reduction is not as significant as for the ocean surface backscatter. This means that ship detection can be done at smaller incidence angles than in the co-polarised case.

2.3. SAR and AIS

AIS will be used to verify and identify the vessels in the SAR images. AIS data from aisonline.com [1] and Statoil/VisSIM AS [7] have be used. Operationally, vessel tracking based on SAR and AIS will give a good picture of the vessels in the area of interest. 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.

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3. AUTOMATIC SHIP DETECTION

3.1. AEGIR

AEGIR is an automatic ship detection tool developed at FFI. The software tool automatically detects bright objects in all polarisation channels in SAR images. Figure 3.1 shows the work flow of AEGIR. Two different thresholding algorithms are used, N-sigma algorithm and K-distribution algorithm. First the image is divided into overlapping frames of M pixels x M pixels. The N-sigma method is a simple method where the threshold value is set to N sigma above the expected value:

$$T = \mu + N\sigma \tag{3.1}$$

The second method is more advanced based on Probability Density Function (PDF). Threshold value and model parameters are estimated for each frame. The three main parameters are the L (Equivalent Number of Looks), the order parameter, ν, of the K-distribution and the Constant False Alarm Rate (CFAR) [5].

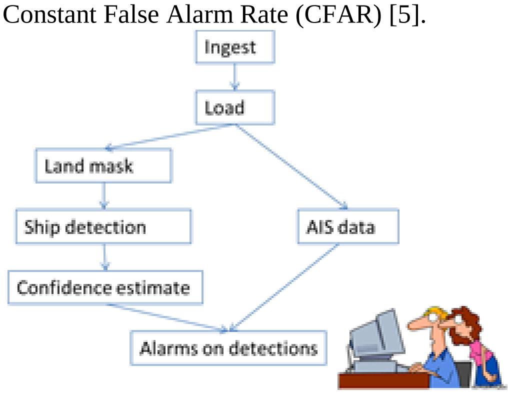

Figure 3.1 Work flow of the automatic ship detection tool AEGIR.

3.1. AEGIR and polarisation

The paper will look at optimizing the use of different polarisations, and how to best combine them to achieve the best ship detection results. Dual and quad-polarisation data from RADARSAT-2 have been used. Examples of fusion of the available polarisation channels before the ship detection is done in a Vessel Detection System (VDS) at FFI will be shown. The individual multi-channel ship detection outputs, for example HH-polarisation and HV-polarisation (Horisontal transmit–Vertical receive) can also be fused after the ship detector is run.

33 RADARSAT-2 ScanSAR dual-polarisation and 19 RADARSAT-2 Quad-Pol images have been analyzed. Some of the results are shown here.

3.1. Dual-polarised SAR data

Dual-polarised data are in the combination HH/VV, HH/HV or VV/VH. Dual-polarised data have less information than quad-polarisation data, but is better for operational use due to better temporal coverage. It is possible to do the ship detection in two ways: 1) Look at the polarisation channels separately and combine the ship detection results afterwards, or 2) Combine the two channels before the ship detection is done by multiplying the amplitude of the two channels and dividing by a constant. The constant is the average value of a typical sea scene. The second method is developed by Eldhuset [6]:

$$\frac{|co - pol| \cdot |cross - pol|}{const} \tag{3.2}$$

Figure 3.2 shows signatures of three vessels on the Norne Field outside the west coast of Norway on March 31st 2010. The vessels are shown in a 600 pixels x 600 pixels 3D presentation in VV-, VH-polarisation and the combined case (VVxVH/const). The contrast is best when combining the two polarisation channels. Table 3.1 shows the contrast between the oil production vessel Norne FPSO's maximum amplitude and the mean sea. The contrast is 8.7 for VV-polarisation, 34.7 for VH-polarisation and 39.7 for the combined case.

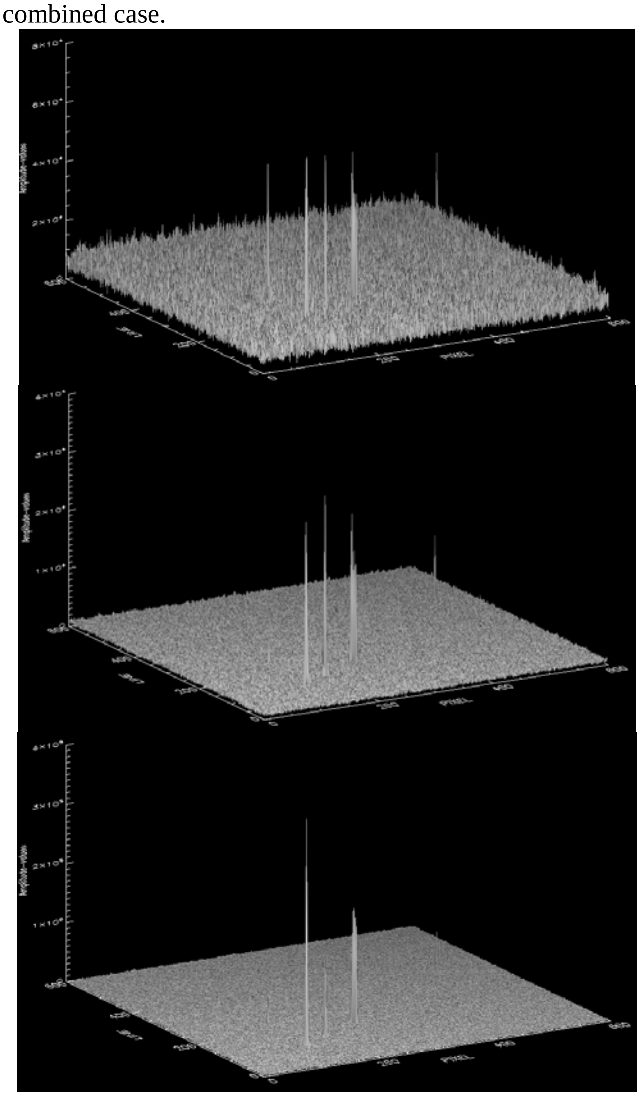

Figure 3.2 Signatures of three vessels on the Norne Field shown in segments of 600 pixels x 600 pixels. The VV-channel is shown at the top, VH-channel in the middle and the combined case at the bottom.

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Channel	Max ampl.	Mean sea	R = Max ampl. / mean sea
VV	57799	6611	8.7
VH	26693	770	34.7
VVxVH/const	2.01875 * 10^8	5087237.9	39.7

Table 3.1 Maximum amplitude, mean sea and the contrast between the maximum amplitude and the mean sea for Norne FPSO.

3.1. Quad-polarised SAR data

All four polarisation channels can be combined when doing the analysis when quad-polarisation data are available. Quad-polarisation data give more complete information about the vessels and the surroundings. The scattering matrix can be used to decompose the data in many different ways. The Pauli decomposition method gives components of surface scattering (HH+VV), volume scattering (HV or VH) and double bounce (HH-VV). Another decomposition method is the Circular Basis decomposition:

$$\begin{bmatrix} S_{RR} & S_{RL} \\ S_{LR} & S_{LL} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & -i \\ -i & 1 \end{bmatrix}\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}\begin{bmatrix} 1 & i \\ i & 1 \end{bmatrix} \quad (3.3)$$

The S_{RL} and S_{LR} elements contain the double bounce HH-VV and the sum of the volume scattering HV+VH. The S_{RR} and S_{LL} elements contain surface scattering HH+VV. The double bounce case is expected to be best for ship detection since the ocean surface scattering is suppressed. Surface waves, oceanographic phenomena and ship wakes may be visible in the surface scattering channels. Combining the double bounce and the volume scattering ((HH-VV)*HV) will give even stronger contrast between vessels and sea.

Figure 3.3 shows an example from December 1st 2009. The enhancement is evident when combining the double bounce and the volume scattering.

Figure 3.4 shows an example from the Norne Field on December 9th 2009 of polarimetric combination of (HH-VV)*HV. The HH-channel is shown to the left and the quad-polarimetric fusion image is shown to the right. The vessels are a lot more prominent in the fused polarimetric image.

Table 3.2 shows the results from running AEGIR on 19 quad-polarisation RADARSAT-2 images from November 2009 to March 2010. The table presents first the results from images with low, then medium and last large incidence angle (θ). HH- and VV-polarisation are shown in two columns, while HV-, VH-polarisation and (HH-VV)*HV (combined case) are shown in same columns since the results from these are the same with respect to how many of the vessels that were detected. The last column shows how many vessels that are expected to be detected in each SAR image. These numbers are based on AIS data from [1] and [8]. If two vessels are completely side by side, then one only detection is expected. The smallest AIS reported vessel is 65 m long and the longest is 264 m long.

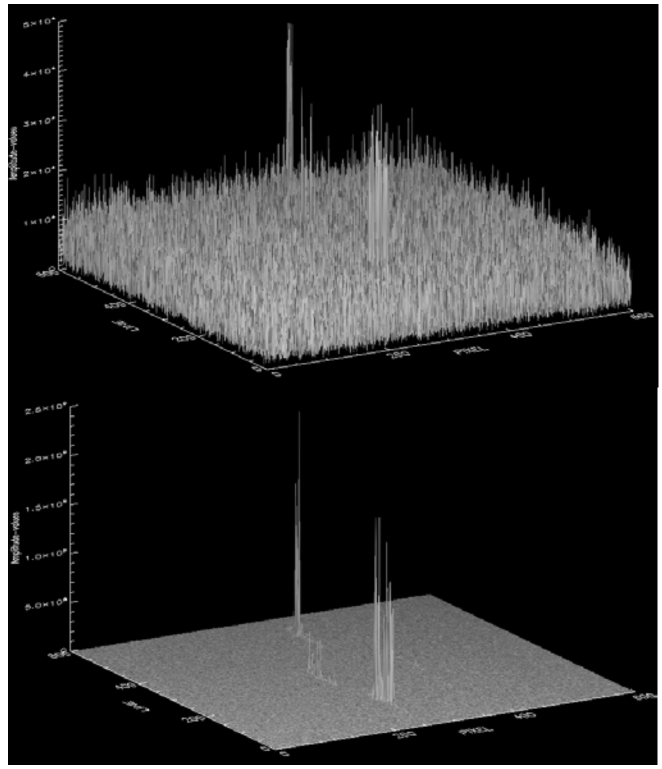

*Figure 3.3 Three detections in HH (top) and (HH-VV)*HV (bottom). Norne FPSO is shown at the bottom right.*

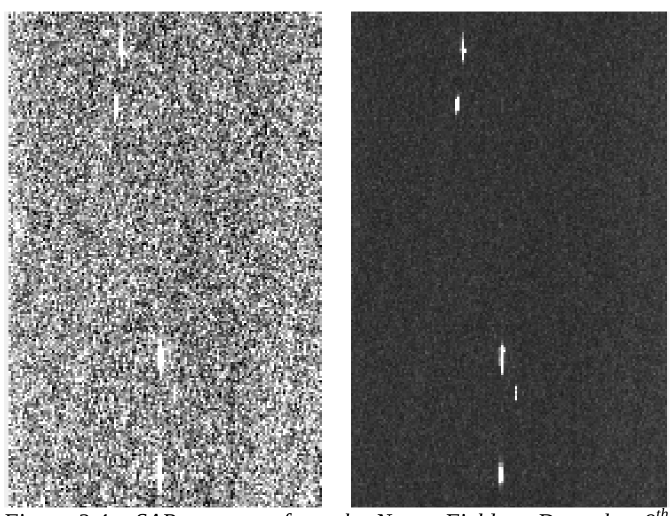

Figure 3.4 SAR segments from the Norne Field on December 9th 2009. The HV-channel is shown to the left and the quad-polarimetric fusion image is shown to the right. The contrast enhancement between ship and sea is evident.

The cross-polarisation channels and the fused case perform very well when using AEGIR for automatic ship detection. All vessels are detected except in one image with high θ on December 10th 2009 where there are strong

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surface waves in the SAR image. The co-polarisation channels miss one or more vessels in many images for all incidence angels. The co-polarisation channels perform better for higher incidence angels as expected, especially for HH-polarisation, but not as good as the performance of cross-polarisation and when combining the channels. The performace is poor for low and medium incidence angles for both of the co-polarisation channels.

Date	**θ**	**HH**	**VV**	**HV, VH & Comb.**	**Exp. det.**
29/11-09	L	-2	-1	OK	6
9/12-09	L	-5	-5	OK	5
15/12-09	L	-5	-5	OK	5
22/12-09	L	-1	-1	OK	3
21/3-10	L	-4	-4	OK	4
22/3-10	L	0	0	OK	7
29/3-10	L	OK	OK	OK	6
28/3-12	L	-3	-3	OK	4
1/12-09	M	-4	-7	OK	7
17/3-10	M	-1	-1	OK	6
19/3-10	M	-1	-1	OK	5
10/12-09	H	OK	-1	-1	6
21/12-09	H	0	0	0	0
16/3-10	H	-1	OK	OK	6
20/3-10	H	OK	OK	OK	5
23/3-10	H	OK	OK	OK	5
26/3-10	H	-1	-3	OK	4
22/3-12	H	OK	OK	OK	4
29/3-12	H	OK	-1	OK	5

Table 3.2 Results from automatic ship detection with AEGIR on 19 quad-polarisation images. L = low, M = medium and H = high incidence angle.

6. CONCLUSION

Norway has large ocean areas in the North that require good methods for surveillance of vessel traffic, fishing and smuggling. Radar satellites have been used operationally for ship detection and oceanography since 1998. To ease the tasks of monitoring the vast ocean areas, efficient ship detection methods are desirable.

New and more advanced radar satellites that offer dual- or quad-polarised data ease the task of detecting vessels in SAR imagea. Extensive research has been done the last years on how to best use and combine the different polarisation channels.

FFI has developed and automatic ship detection tool, AEGIR, that detects vessels in all polarisation channels. It is also possible to do extra polarimetric analysis manually. Combining the available channels increases the ship to sea contrast. When dual-polarisation data are available the co- and cross-polarisation channels are multiplied and then divided by a constant. By multiplying the double bounce and the volume scattering (HH-VV)*HV, when quad-polarisation data are available, gives evident enhancement of the ship to sea contrast.

Using AEGIR to do automatic ship detection on 19 RADARSAT-2 quad-polarisation images showed that cross-polarisation and (HH-VV)*HV are best for ship detection for all incidence angels. HH-polarisation works well for high incidence angels, but not for low and medium incidence angels.

Before high resolution and/or quad-polarisation (quad-pol) images only covered small areas, and were mainly useful in harbor areas or over a known small area of interest. To be able to image vessels of interest in the open ocean with high resolution and/or quad-polarisation before, information in advance was necessary to locate where the images should be acquired. From 2011 RADARSAT-2 has offered new wide modes, thus opening up new opportunities to use high resolution and quad-polarisation images for operational ship detection due to increased coverage area.

11. REFERENCES

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