Polarimetric Maritime Surveillance Radar With Electronically Steered Antenna

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Abstract: *The paper presents the ISPAS dual-polarized Ku-band radar with electronically steered antennas for maritime surveillance. The radar is designed to measure the sea surface for detection and mapping of oil spill around oil producing platforms on both coarse and quiet sea while at the same time be able to measure sea wave heights, sea currents and vessel traffic. The radar has also been tested for sea ice detection.*

1. Introduction

For offshore oil production it is important to detect an oil-spill as early as possible to reduce damage to the environment and wildlife. The activities of petroleum companies operating offshore on the Norwegian continental shelf producing oil are regulated by law and monitored by The Norwegian Environment Agency. One of the regulations relates to oil-spills on the sea and states “Be able, independently of visibility, light conditions and weather, to detect and map position, area, amount and properties of immediate pollution” [1]. Especially the requirement that an oil-spill must be detected and mapped independently of weather conditions has not been met for the lower sea states, i.e. 0-1, that corresponds to wind velocities below 2 m/s. Oil-spill on the sea surface is normally detected indirectly as a dampening of the wind generated capillary waves. However, for the lower sea states with wind velocities less than about 2 m/s the capillary waves are too small to indirectly detect oil on the sea surface [2].

In 2009 NOFO (The Norwegian Clean Seas Association For Operating Companies) announced a technology development program, “Oljevern 2010”, asking for solutions to detect oil on quiet seas. After some initial studies and tests, the Norwegian oil company Statoil Petroleum AS (now Equinor) signed contract in 2012 with the Norwegian radar company ISPAS AS to develop a radar that could detect and map oil on quiet seas. In 2014 the Norwegian oil company Lundin Norway AS granted ISPAS the funds to develop four operational radars and install them on the Edvard Grieg platform for testing. In 2015 the companies Statoil (Equinor), Lundin and ISPAS made an agreement under the auspices of The Research Council of Norway, DEMO 2000, for full scale testing of the radar system.

The radar system is installed on the Edvard Grieg platform and has logged more than 50.000 operational hours. 6 more radars have been delivered for installation on the new Johan Sverdrup Field Centre operated by Equinor. The ISPAS OSD radar has been presented at Interspill 2018 in London and IGARSS 2018 [3] as well as the IRS 2018 [4].

2. The Radar

The radar is polarimetric, coherent and with Ku-band frequency and electronically steered antennas. The pulse modulation is Frequency Modulated Continuous Wave (FMCW) with a maximum bandwidth of 300 MHz. The radar has the following main parameters.

Frequency	15.7 – 16.0 GHz
Power	1 W
Polarization	Vertical and horizontal, co – and cross polarization
Range resolution	0,5, 1, 2, 4 and 6 m.
Antenna lobe horizontal	0.8 degrees
Weight of two radars in enclosure	less than 200 kg

Horizontal scanning of 100 degrees in 0.2 seconds.

The fast scanning, electronically steered, antennas makes it possible to do several simultaneous tasks in real-time. As an example the radar can be used for both vessel traffic monitoring, wave and current measurements and oil-spill detection at the same time.
The enclosure is made according to strict maritime offshore requirements (NORSOK standard) and designed to stand on an offshore platform in a harsh maritime environment with very little maintenance for minimum 10 years and operated remotely from land based centers. The radar enclosure is presented in Fig. 1.

Figure 1. Enclosure for two radars covering 190 degrees.

3. Oil on Quiet Water

Detection of oil on a sea surface is normally done by observing the dampening of the oil of the capillary waves [1]. For oil on a quiet sea surface this is not possible and the oil has to be measured directly as a change in the reflection of the sea surface or in combination with polarimetry.

The Fresnel polarization dependent complex reflection coefficients are

$$\Gamma_H = \frac{Sin(\alpha) - \sqrt{\varepsilon - Cos^2(\alpha)}}{Sin(\alpha) + \sqrt{\varepsilon - Cos^2(\alpha)}} \tag{1}$$

$$\Gamma_V = \frac{\varepsilon \cdot Sin(\alpha) - \sqrt{\varepsilon - Cos^2(\alpha)}}{\varepsilon \cdot Sin(\alpha) + \sqrt{\varepsilon - Cos^2(\alpha)}} \tag{2}$$

where Γ_V is the complex reflection coefficient for vertical polarization and Γ_H the reflection coefficient for the horizontal polarization. α is the grazing angle and ε is the complex dielectric constant. By measuring the complex relation Γ_V / Γ_H over a surface with and without oil this relation will change according to the complex dielectric constant of the surface.

4. Oil on Sea Water Trials

During 4 days in September 2013 ISPAS was given the permission to release raw oil inside a fjord on the West coast of Norway at Kollsnes. The distance from the radar to the oil was approximately 85 m and the radar antenna height 4 m above the sea surface. The wind velocity was 2 m/s with a sea temperature of 14.9 degrees. The thickness of the oil during the measurements was estimated to be approximately 0.1 mm. Fig. 2 shows a picture of the actual sea surface during the measurements of the oil spill.

Figure 2. The sea surface during the experiment at Kollsnes

The radar measured the sea surface with pulse – pulse polarization change VV and HH and the results are presented in Fig. 3. Fig. 3 presents the amplitude of the two polarization horizontal (HH) and vertical (VV) measurements and the coherent division of the two (i.e. abs (VV/HH)). The plotted data are the results of the summation of approximately 65 seconds of measurements data.

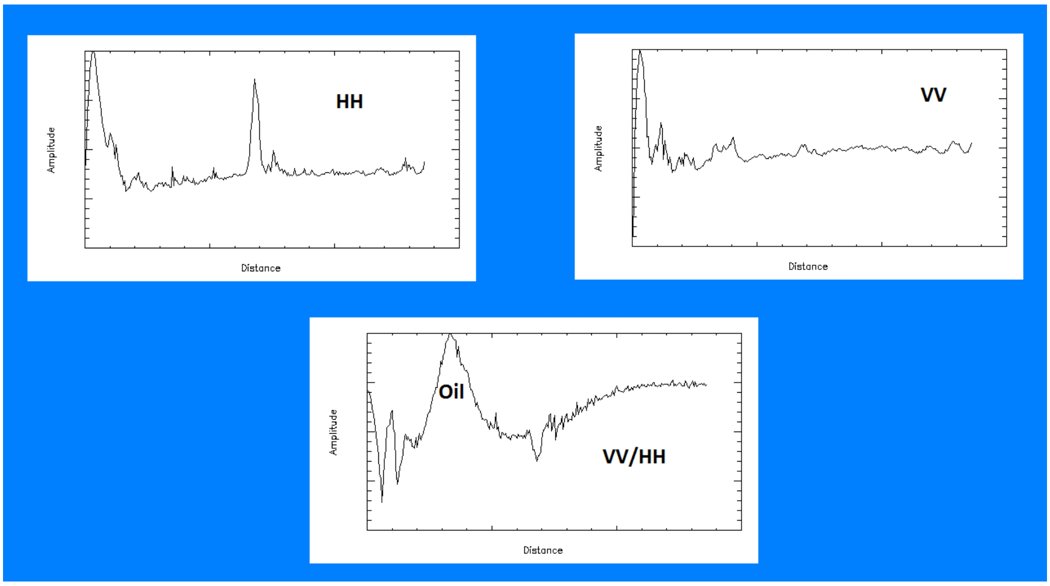

Figure 3. The results of polarimetric measurements of oil on quiet sea surface.

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As Fig. 3 shows, there is amplification at the same distance where the oil is on the surface.

In November 2015 a new trial was performed at Ohmsett – The National Oil Spill Response Test Facility in Leonardo, New Jersey, USA. The water tank is 203 x 20 m and the facility have different oils for testing purposes. The oil was poured on the surface from an oil tank on a bridge that was spanning across the water tank while the bridge itself was moving to a new location further away. The radar was located on the bridge so that oil could be measured on the water surface with different grazing angles. Fig. 4 shows the bridge with the radar antennas in front of the small hut at the start of the release of oil on the surface. The height of the center of the antennas is 3.4 m above the water surface.

Figure 4. The bridge at the Ohmsett facility. The antennas can be seen on the bridge.

Fig. 5 shows the results of one of the polarimetric measurements of oil on a quiet water surface in the Ohmsett water tank. The thickness of the oil was estimated to be about 1 mm.

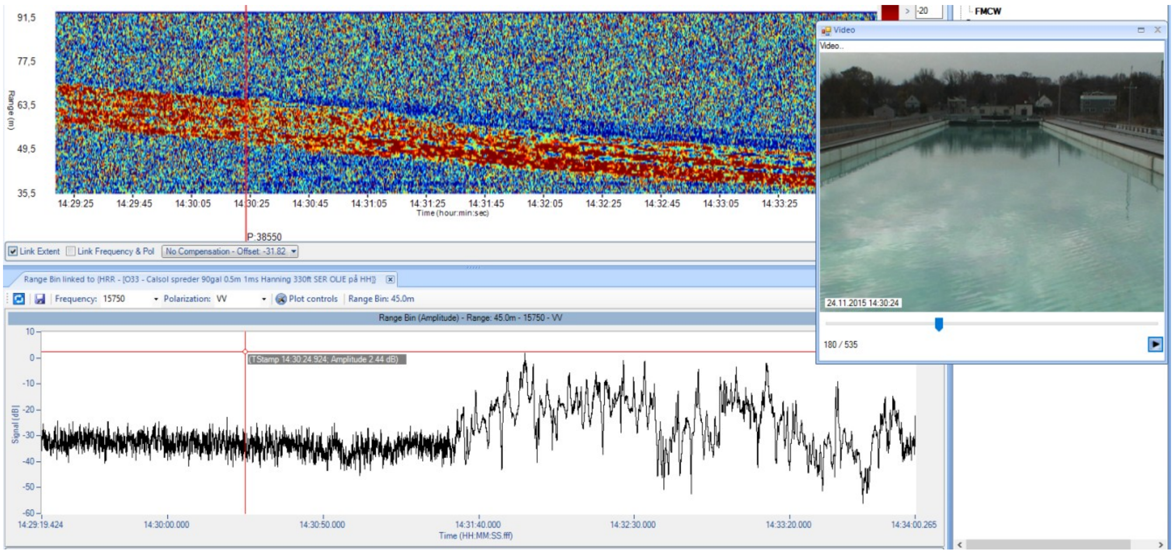

Figure 5. Polarimetric measurements of oil on quiet water surface.

The plot shows the relation VV/HH in the upper left part of Fig. 5 during approximately 3 minutes while the oil is drifting towards the radar. The corresponding visual image to the right shows the water tank at the time of the vertical line in the plot. As can be seen in the image the oil is not visual on the water surface in the picture. The lower plot shows the actual difference in the amplitude indicating a difference of up to 30 dB between the polarimetric measurements of the water and oil. The distance from the radar antenna to the oil was between 40 and 70 m.

When the wind is below 2 m/s there may be waves not supported by the wind, i.e. swell, but without capillary waves. Due to relatively high grazing angle with respect to the radar when the oil is on the front of the wave facing the radar, the reflection coefficient of the oil is higher, especially for vertical polarization. Fig. 6 presents the VV measurements of oil on swell generated by the Ohmsett wave generator. The distance was about 55 m and the amplitude of the generated waves was 30 cm from top to bottom.

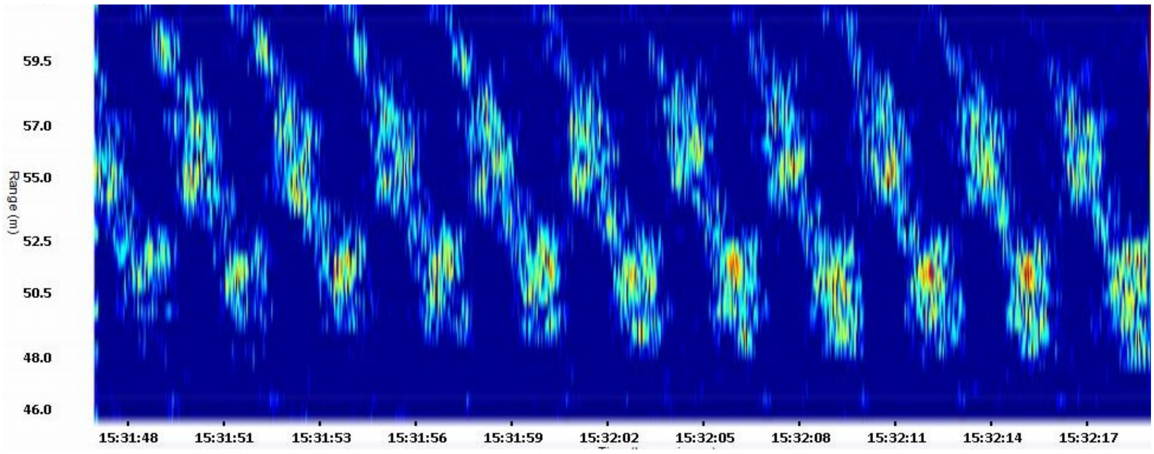

Figure 6. Oil on swell waves, vertical polarization.

In June 2018 ISPAS participated in the annual “Oil on Water” exercise organized by NOFO where oil is released on the sea surface testing oil spill recovery equipment. A reduced version of the ISPAS polarimetric radar was installed onboard the Norwegian Coast Guard ship KV Sortland, see Fig. 7. The height of the antenna was approximately 20 m above sea level.

Figure 7. The ISPAS maritime surveillance radar onboard the KV Sortland. The radar is seen in the inset in the lower right part of the picture.

The purpose was to test the algorithm for OSD from ship and also test a new adaptive threshold algorithm for vessel detection. Fig. 8 shows a print screen of the real time radar and video display. As the figure shows the algorithm detects and maps the oil on the sea surface very well. The sea state during the measurements was approximately 5 with wind velocities around 10 m/s.

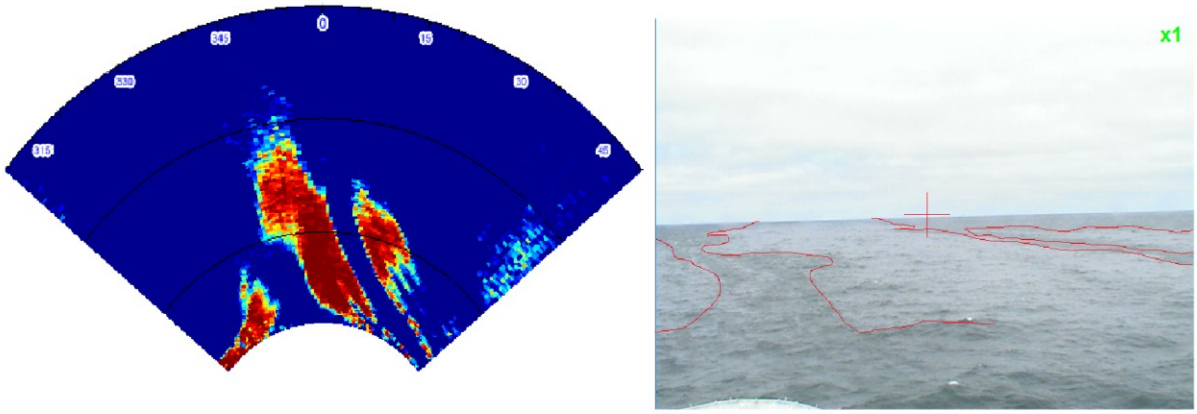

Figure 8. Mapping of oil on sea using the small radar onboard KV Sortland

5. Platform Installation

Four radars, each covering up to 100 degrees in azimuth, have been installed on the offshore platform Edvard Grieg in the North Sea for oil-spill detection and mapping. The height of the radars is about 55 m above sea level and 2 and 2 radars are combined in one enclosure, each radar covering about 90 degrees see Fig. 9.

Figure 9. Installation of the ISPAS radars on the Edvard Grieg platform. The traditional X-band radar is seen behind the ISPAS radar enclosure.

The output of the four radars are combined into one 360 degrees picture, see Fig. 10.

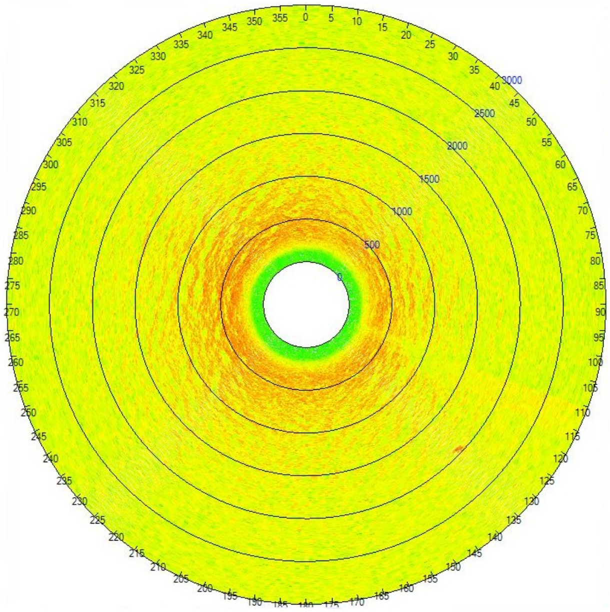

Figure 10. Combined presentation of 4 scanning radars

The radar data are presented to the operator on land and the operator can focus on the area of interest that has a possible oil-spill and inspect the raw data using either or both VV or HH polarization or as the relation VV/HH. Fig. 11 shows an example where a dampening of the sea is marked with a polygon and the corresponding VV and HH polarization measurements of the area is presented on the lower right-hand side of the display.

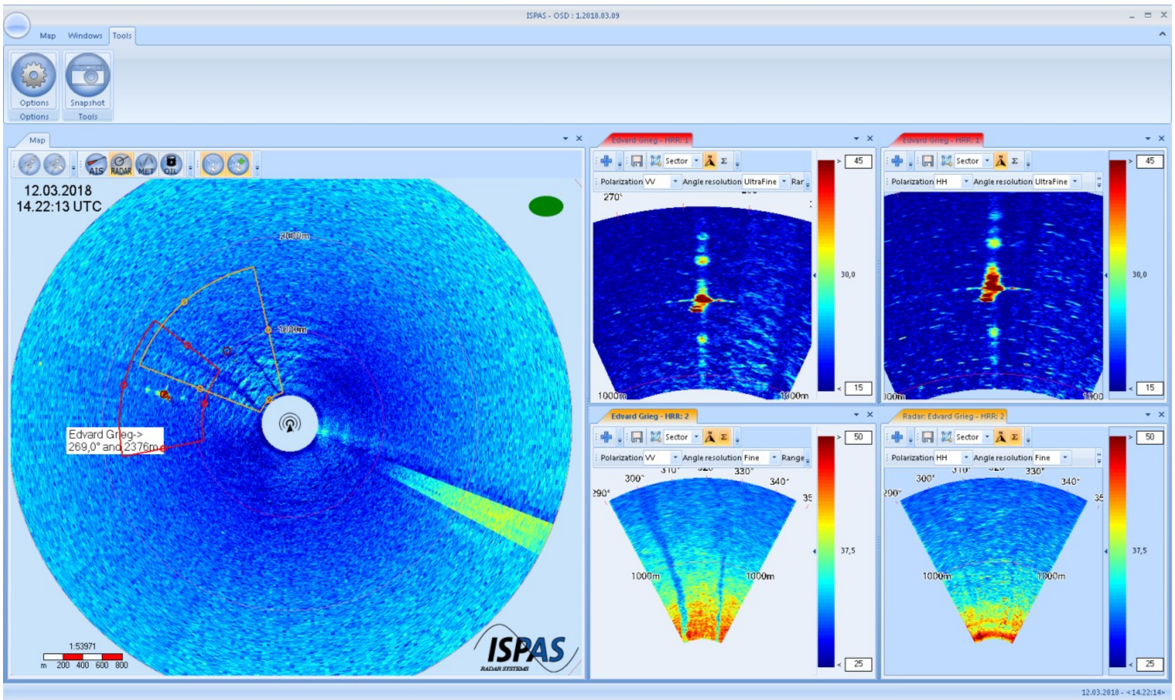

Figure 11. User interface for OSD operation.

Due to the multifunction capabilities of the radar, different settings of the radar can be used simultaneously. Fig. 12 presents a possible example of different settings for detection of oil using different range resolutions and polarizations. In the event of a positiv detection of oil on the sea, that particular setting will change the colour to red representative of an alarm, see the example with HH, 1 m rangeresolution in Fig. 12. In the event that a possible oilspill is detected, the colour may be yellow just as a indication of warning.

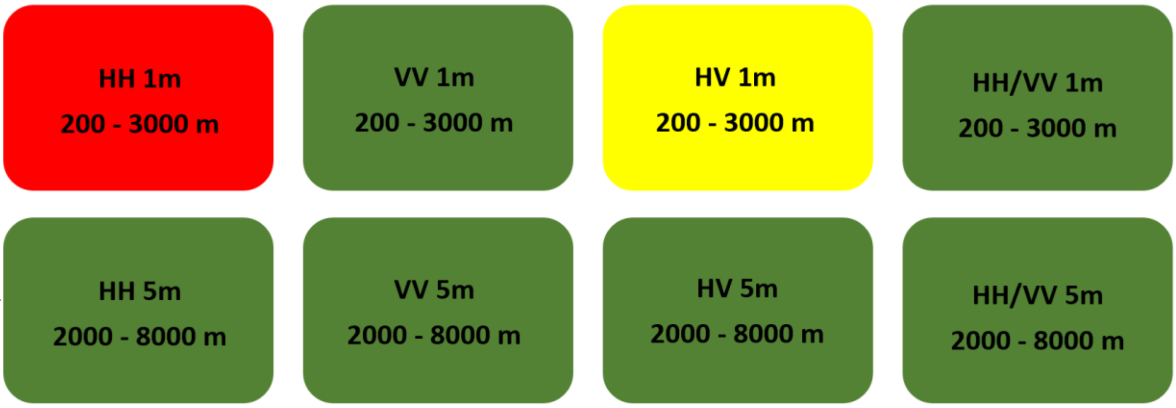

Figure 12. Example showing multiple simulateous settings of the multifunction radar

Initially the purpose of the development of the radar was to be able to detect oil on quiet sea. However, most of the time there is wind above 2 m/s with capillary winds generated on the sea surface. Detection of oil spill for sea states 2-5 is based on the detection of the negative contrast between capillary waves and dampened waves due to oil film on the sea surface. An example is presented in Fig. 13 using the algorithm for mapping oil on the sea.

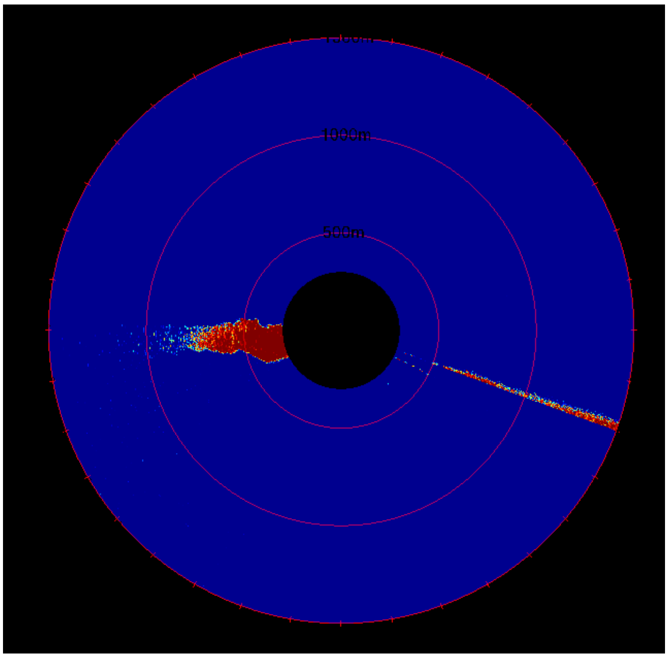

Figure 13. Mapping of sea surface dampened by a planned discharge of production water

Within this range dampening of the capillary sea waves is relatively easily observed. An example is presented in Fig. 14 that shows dampening of the capillary waves due to planned discharge of production water out to about 3 km for seastate 1-2. The range resolution was 1 m.

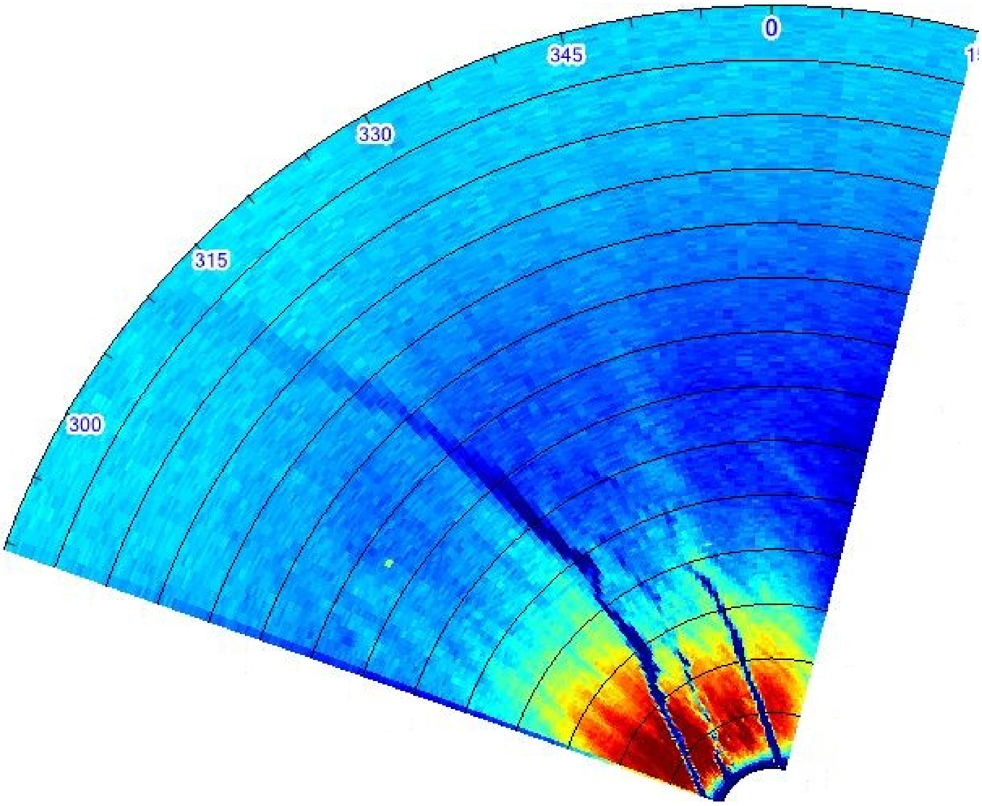

Figure 14. Measurements of planned discharge of production water,sea state 1-2. Each distance marker is 200 m

As part of a qualification procedure the radar was tested with crude oil on water. The following example shows an example with detection and mapping of oil on the sea, see Fig. 15. The release of oil consists of two times 1 m^3 oil. The oil was detected shortly after it was on the sea and was tracked for several hours during seastate 5.

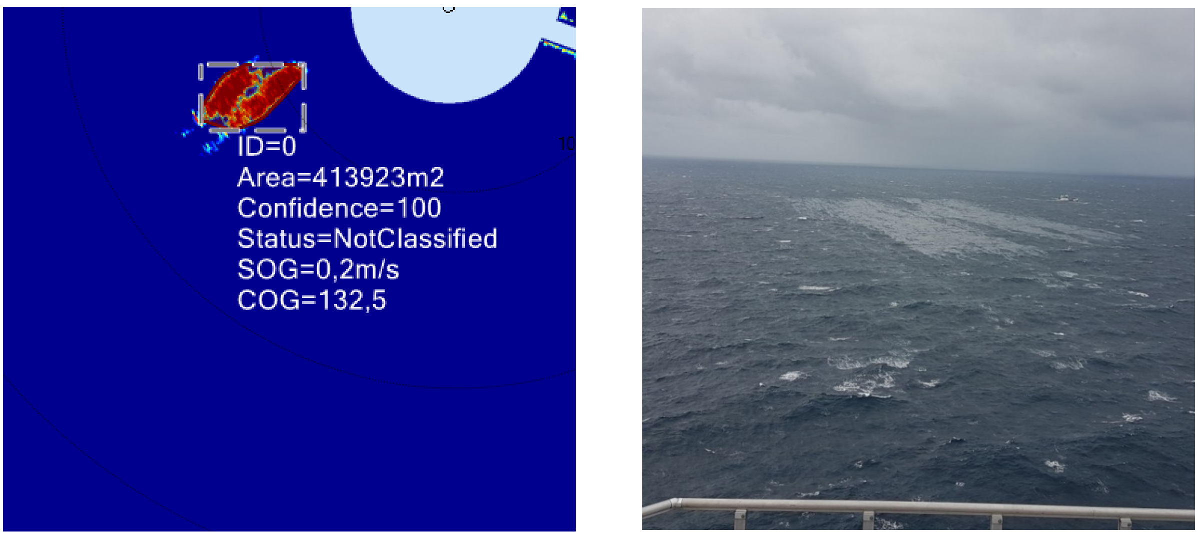

Figure 15. Qualification tests of the ISPAS OSD radar with crude oil on the sea

5. Estimation of Sea Wave Height

Out to a distance equivalent to about 1 degree grazing angle the individual waves can be tracked due to the high scanning rate. Fig. 16 shows an example of measurements of sea waves over 90 degrees and out to a range of 3 km.

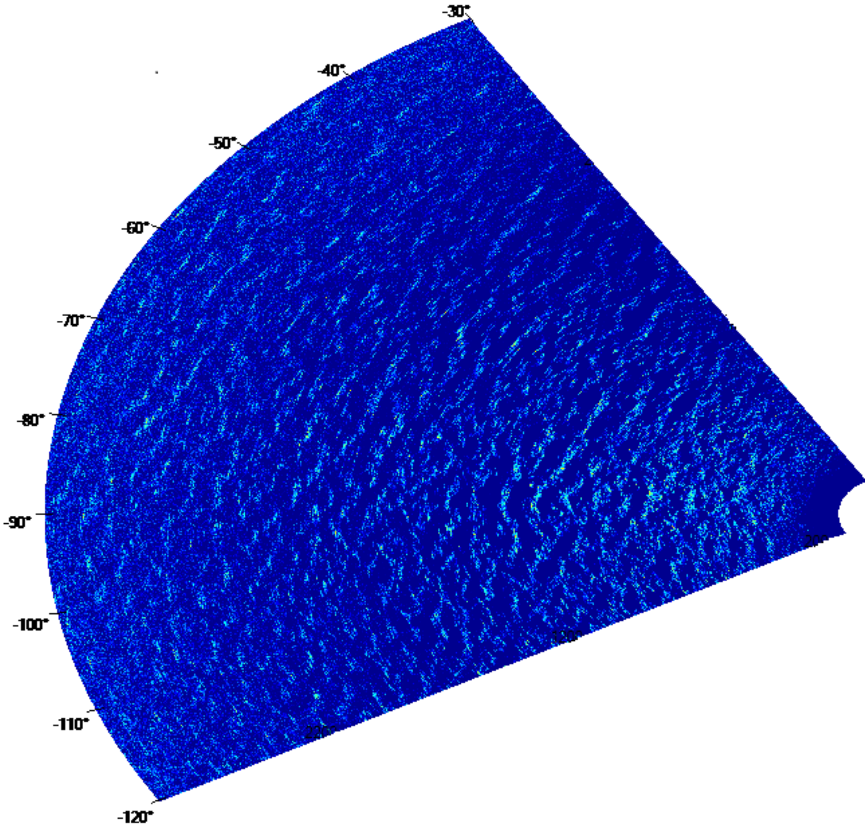

Figure 16. Measurements of sea waves, vertical polarization

Depending on the sea state, sea waves can be measured at longer distances than 3 km if required.

6. Vessel Traffic Monitoring

Due to fast scanning electronically steered antenna and the radar multifunction capability, vessel traffic can be monitored simultaneously with OSD and wave height estimation. The vessel traffic is correlated with AIS for vessel identification. An example is presented in Fig. 17. The target list is presented on the right hand side of the presentation.

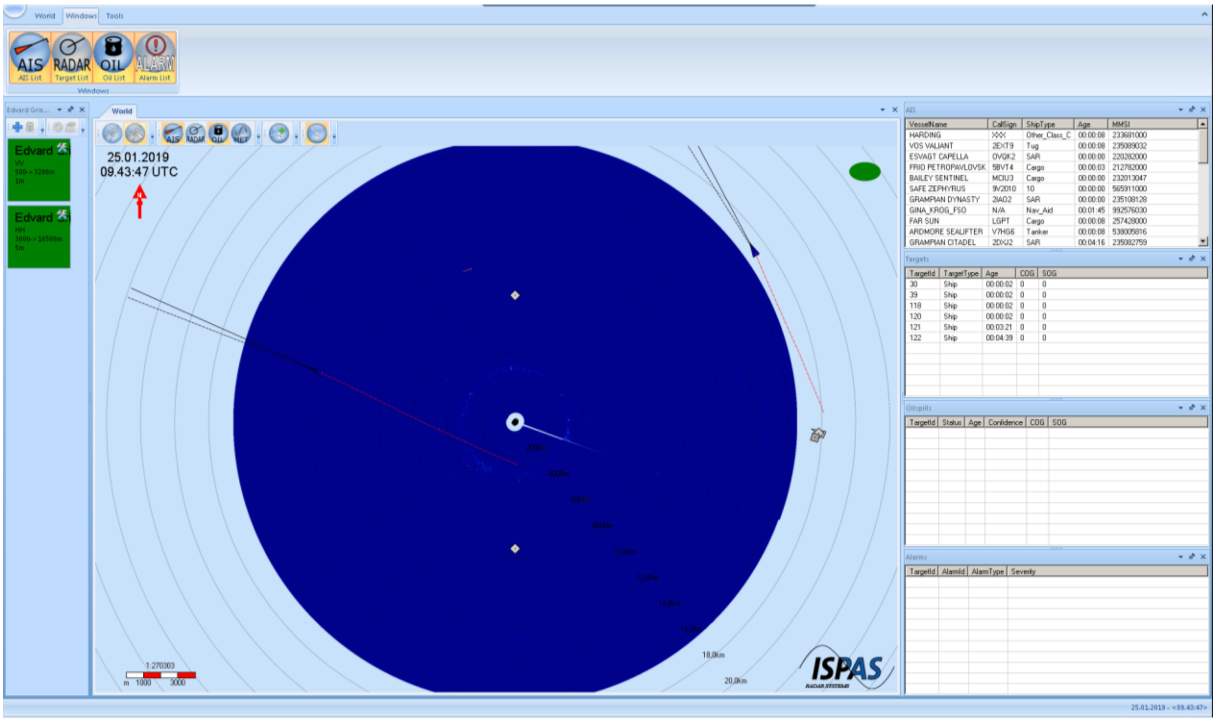

Figure 17. Simultaneous OSD and vessel traffic monitoring.

7. Conclusion

A Ku-band coherent radar system with dual polarized electronically scanning antennas for oil-spill detection, wave height estimation and vessel traffic monitoring has been presented. Using polarimetry, the radar is able to measure oil on a quiet sea surface and thereby extending the detection of oil-spill to also include sea state 0 and 1, i.e. wind velocities below approximately 2 m/s. Qualification tests with crude oil on the water has demonstrated that the radar can also detect and map oil on sea during heavy sea. The ISPAS radar is thus the only sensor that can detect and map oil on sea during most weather conditions.

Acknowledgement

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References

[1] Guidelines to Aktivitetsforskriften § 57

[2] B. Jones, “A comparison of visual observations of surface oil with Synthetic Aperture Radar imagery of the Sea Empress oil spill”, International Journal of Remote Sensing. 2001

[3] R.Norland, “A Ku-band radar with dual-polarized phase steered antenna for maritime environmental surveillance”, The 19th International Radar Symposium IRS 2018, June 20-22, 2018, Bonn, Germany

[4] R.Norland, “A new radar for detection of oil-spills on quiet seas”, International Geoscience and Remote Sensing Symposium, Valencia, Spain, 2018