REPORT

Oil in Ice - JIP

Report no.: 29

The Utilisation of Satellite Images for the Oil in Ice Experiment in the Barents Sea, May 2009

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SINTEF Materials and Chemistry
Marine Environmental Technology

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Preface

SINTEF has in cooperation with SL Ross Environmental Research Ltd and DF Dickins Associates LLC on behalf of the oil companies AGIP KCO, Chevron, ConocoPhillips, Shell, Statoil and Total initiated an extensive R&D program; *Joint industry program on oil spill contingency for Arctic and ice covered waters.* This program was a 3-year program initiated in September 2006 and finalized in December 2009.

The objectives of the program were;

- To improve our ability to protect the Arctic environment against oil spills.
- To provide improved basis for oil spill related decision-making:
- To advance the state-of-the-art in Arctic oil spill response.

The program consisted of the following projects:

- P 1: Fate and Behaviour of Oil Spills in Ice
- P 2: In Situ Burning of Oil Spills in Ice
- P 3: Mechanical Recovery of Oil Spills in Ice
- P 4: Use of Dispersants on Oil Spills in Ice
- P 5: Remote Sensing of Oil Spills in Ice
- P 6: Oil Spill Response Guide
- P 7: Program Administration
- P 8: Field Experiments, Large-Scale Field Experiments in the Barents Sea
- P 9: Oil Distribution and Bioavailability

The program has received additional financial support from the Norwegian Research Council related to technology development (ending December 2010) and financial in kind support from a number of cooperating partners that are presented below. This report presents results from one of the activities under this program.

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Funding Partners

R&D Partners

Cooperating Partners

NERSC Technical Report no.305

THE UTILISATION OF SATELLITE IMAGES FOR THE OIL IN ICE EXPERIMENT IN THE BARENTS SEA IN MAY 2009

A report by Nansen Environmental and Remote Sensing Centre (NERSC) and Kongsberg Satellite Services (KSAT)

Photograph of RV Lance during the oil in ice experiment

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Final Report

Edited in response to JIP Steering Committee review comments

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EXECUTIVE SUMMARY

In support of the Oil in Ice JIP (Joint Industry Project), satellite images were acquired to monitor the experimental site to determine if the technology used to successfully detect oil spills in open water is applicable to oil spills in ice-covered water. Images were planned and acquired based on the expedition plan and up-to-date information from the field.

Twenty-six satellite images were received for analysis as a part of the Oil in Ice project: 10 Envisat ASAR wide swath images, 6 Radarsat-1 images, 7 Radarsat-2 images and 3 COSMO-SkyMed. The main objectives were to determine: which images cover the activities, and what can be seen in these images with regards to ships, oil, and ship tracks through ice. Object identification is dependent mainly on image resolution and radar speckle noise. Ships can be clearly seen in all images as strong backscattering targets. Although an expansive slick in less dense ice concentrations may be detectable, the small surface area covered by oil spills in the 2009 offshore field experiments cannot be seen in any of the images. The main reasons for this are: 1- the size of the oil spill was small (few tens of metres), and 2- the ice concentration was high (80%-90%) where the oil was located. Ship tracks through the ice can be seen for some days after the ship has passed, depending on the ice motion. COSMO-SkyMed with high resolution (5m) shows the most details in the ice. Radarsat-2 (ScanSAR Wide) and Envisat show fewer details due to the lower resolution. Dual polarization does not seem to have any advantage. In order to detect oil in ice by SAR images the ice concentration cannot be as high as in this experiment. It is expected that ice concentration must be less than approximately 40% for detection to be possible. The main utility of SAR imagery in future Arctic spill incidents could be to reduce the risks associated with marine operations in ice during spill response operations by providing close to real time ice information.

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1. INTRODUCTION AND OBJECTIVES

The overall objective of the satellite project within the overall oil-in-ice JIP was to assess the capabilities of the latest generation SAR satellites in detecting oil spills in ice and monitoring the ice conditions at the spill site on both local and regional scales.

Marine surveillance is important for environmental protection and sustainable management of the Exclusive Economic Zone (EEZ) of coastal nations. National legislation and international agreements exist to prevent illegal activities such as oil pollution, fisheries incursion and smuggling. The majority of European coastal nations have dedicated marine surveillance programmes, which are based on a combination of coastal radar, airborne, space-borne and vessel surveillance systems.

Since 1994, Kongsberg Satellite Services (KSAT) has developed an oil spill detection service utilising satellite Synthetic Aperture Radar (SAR) in close co-operation with key end users such as Norwegian Clean Seas Association for operating Companies (NOFO) and the Norwegian Coastal Administration in Norway. The capabilities to use the SAR data for oil spill and ship detection have been documented during the last ten years, and the operational capabilities have been established [1, 2, 3, 4, 5, 6].

Imagery is now integrated into national marine surveillance programmes, which combine the satellite images with aircraft surveillance operations to produce a cost-effective solution for large area surveillance. Today, the European Maritime Safety Agency (EMSA) uses this service to provide pan-European coverage for its member states. See 2.1 below and the Appendix for more details.

As exploration, development and marine transportation increases in ice-covered waters, it is important to investigate if oil spills in ice can be detected and if so, under what conditions.

2. DETECTION OF OIL SPILLS AT SEA WITH SATELLITE MONITORING

The main sources of oil pollution are shipping accidents (Figure 1 illustrates the Prestige accident in 2002 and the extensive ocean areas affected), accidental spills from offshore oil production platforms and - of most concern - illegal cleaning and discharges from ships. Implementation of policy legislation, environmental protection and law enforcement requires systematic surveillance of large ocean areas. A combination of coastal radar, airborne surveillance and patrol ships has been the traditional marine surveillance system. With the limited coverage and operational constraints of both airborne and ship-based systems, satellite surveillance was implemented to establish an effective, strategic and continuous multi-purpose surveillance of large and remote areas.

Satellite-based SAR can offer wide area surveillance coverage day and night, independent of cloud cover and weather conditions. A combination of aerial and satellite surveillance has proven to be the most effective system for large area monitoring, and satellite surveillance is now an important part of the marine surveillance system both for European national agencies and oil companies in northern Europe.

Figure 1: The ASAR Wide Swath image above was acquired over the Galician coast in Spain on 17th November 2002, i.e. few days after the Prestige tanker started to spill massive amounts of oil (dark areas in the image).

2.1. Multi-national Oil Spill Monitoring Service

The European Marine Safety Agency (EMSA) established the oil spill detection service in 2007. The service provides pan-European coverage for the European seas and allows neighbouring countries to share satellite coverage and therefore make the use of satellite data more cost-effective. The sharing of satellite data has also encouraged cross-border co-operation with regards the planning of aerial surveillance and the investigation of any suspect oil spills.

In addition, NOFO also monitors the Norwegian North Sea oil fields for discharges using satellite data. They co-operate with the Norwegian Coastal Administration (NCA) by sharing the information derived from their monitoring activities. This allows the NCA to optimize their airborne and ship-based monitoring operations in Norwegian waters.

The result of the co-operation in both Norway and Europe is that the European seas are monitored in an efficient way, and the operational utilization of satellite data are maximised.

The process of using satellites imagery to monitor and screen spills is discussed in the Appendix.

3. HOW SYNTHETIC APERTURE RADAR DETECTS OIL AT SEA

SAR sensors can provide large area coverage of the Earth's surface independent of weather and light conditions. As a result SAR has evolved to become one of the most important sensors for operational monitoring of the marine environment.

The image brightness in a SAR image is dependent upon material properties and surface geometry. For this reason SAR data is extremely useful for observing the surface features of the ocean. The C-band radar backscatter (as in Radarsat and Envisat SAR sensors) is caused by Bragg scattering by interaction of the incident radar waves with short gravity waves with wavelengths in the range of 5-7 cm. The capillary waves and short gravity waves are generated by winds blowing over the ocean surface. Under low wind conditions, the energy content in this part of the wave spectrum is low or almost zero, resulting in low radar backscatter and in dark patches in the SAR imagery. Surface film of high-viscosity material such as oil present on the sea surface will dampen the Bragg waves, and give rise to dark signatures.

Therefore the image is dark where the slicks occur not due to the colour of the oil, but because the oil damps down small surface waves and the smoother surface reflects more of the transmitted signal away from the satellite. Figure 2 illustrates how three different sea states affect the energy reflected and the impact on the ability to detect oil on the surface.

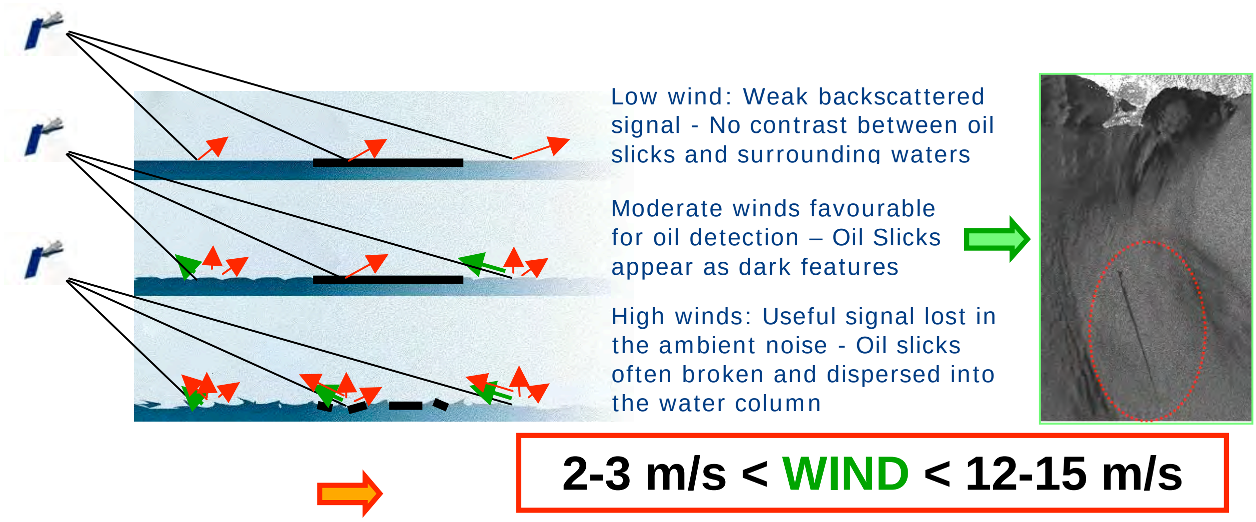


Figure 2: Different wind strengths determine the ease at which oil (black) can be detected.

Currently, the detection of oil on the surface of the ocean is limited to the presence of oil, and not the type of oil. There have been examples where fish oil (from a ship), whale oil (from a whale carcass being towed to deep water) have been detected in the operational oil spill service.

The same techniques to detect oil spills are also used to detect natural oil seeps from the sea-bed, even though the seep oil has passed through the water column to reach the surface and therefore has had chance to dissipate.

However, detecting oil in ice-infested waters is complicated. When the formation of new ice starts, it begins with a soupy layer of frazil crystals, which is named grease ice due to the likeness of oil on the water surface to the observer. The grease ice also dampens down the waves and therefore it can appear very similar to oil in SAR images, especially in single-band SAR images. Within images of oil released in grease ice, it may be possible only to identify areas of wave dampening regardless of whether this effect is caused by the ice or oil. Another limiting factor may be that the wind speed may be low and the sea state at the location of the experiment is calm. In most rough ice, to have any chance of success in detecting oil between the floes, the ice concentration should be less than 5/10ths. A greater ice concentration would mean limited open water areas, which could make it difficult to discriminate between the relatively calm open water within the pack ice and oil.

In Figure 3, a colour image produced from multiple polarization Envisat AP (Alternating Polarization) SAR data is shown. It can be seen that the regions with different open water or ice cover characteristics can be identified, especially when supported by *in situ* observations. The yellow dots show the hourly positions of the ship, starting in the west at the edge of the fast ice in Forlandsundet, and moving in a general easterly direction to Longyearbyen on Spitsbergen. If an oil spill occurred under a similar mix of ice conditions, it is possible that the oil-covered area will appear as a distinct area in the imagery but this will depend on a combination of factors such as the ice concentration, floe size and sea conditions including wind and waves.

In Figure 3, the ice belt (brown) is made up of first year and multi-year floes that have been pushed northward by wind and ocean currents. The calm open water in Isfjorden appears bright red. The fast ice in Forlandsundet appears blue, while in Isfjorden the fast ice is a red-blue colour mixture. In the west, the open ocean region is split into two distinct regions, a bright blue region located immediately next to the ice edge. This is calm open ocean as the wind direction at the time of overpass was northerly, and the dark red region further out which is open ocean exposed to the wind (speed 6m/s-1). Calm water with ice floes, as illustrated by IceCam pictures 13:00 and 14:00 has a dark red/blue appearance in the constructed RGB (Red, Blue Green) satellite image.

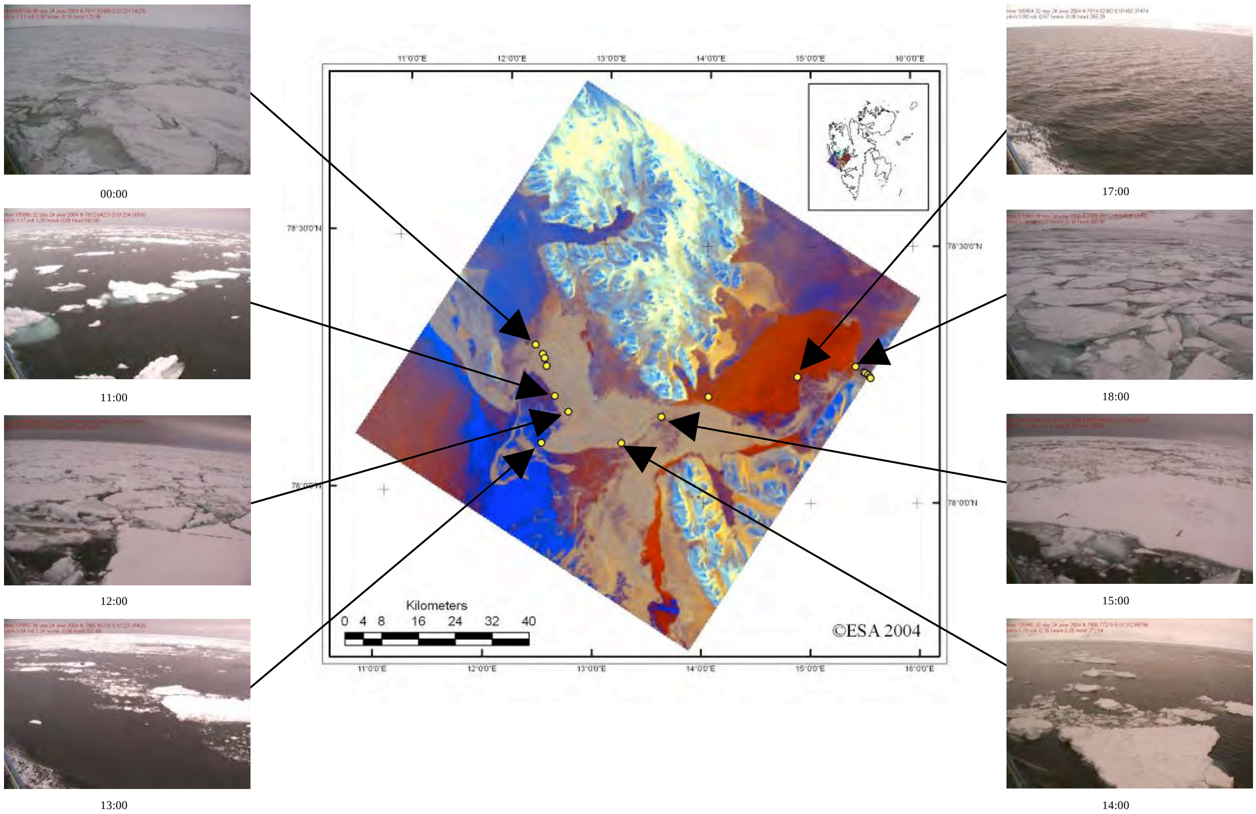


Figure 3: Constructed RGB image (R=HH G=HV B=HV – HH) Envisat AP image taken on 24th April 2004 off the West coast of Spitsbergen, together with geo-located IceCam pictures. The yellow dots are hourly ship positions. © raw data ESA 2004/Processed by Hall/Norwegian Polar Institute

4. METHODOLOGY: 2009 ACQUISITION PROGRAM

Four SAR satellite systems were employed to monitor the 2009 Oil in Ice experiment. All have the capability to operate at different modes, ranging from narrow swaths with high spatial resolution, to wide swath with reduced spatial resolution. This is the trade-off that has to be made when deciding which mode to use. Figure 4 illustrates the different area coverage of the Radarsat-1 modes, but the illustration is applicable to all SAR satellites. The wide swath modes, also named ScanSAR, are generally used to monitor ocean and ice as they cover the greatest area, which is currently the strongest weighting factor when choosing a mode. These satellites systems are briefly described below.

Due to the small amount of oil planned to be released, it was decided to obtain the highest possible pixel resolution while ensuring the image area is large enough to account for expected uncertainty in the planned location of the experiment. Each satellite was assigned a task to provide a certain set of images based on these requirements and the sensor capabilities. Envisat and Radarsat-1 were assigned the task to obtain images that show the general ice conditions. This also ensured that the national ice agencies also had suitable data available for the production of their ice charts. COSMO-SkyMed was programmed to obtain the highest resolution images in single polarization mode. Finally Radarsat-2 was programmed to obtain high-resolution images in dual-polarization mode.

4.1. RADARSAT-1

Radarsat-1 is a Canadian SAR satellite and was the first fully operational SAR imaging satellite. Although nearing the end of its life, it still provides useful information to both commercial and scientific users in such fields as disaster management, interferometry, agriculture, cartography, hydrology, forestry, oceanography, ice studies and coastal monitoring.

Launched in 1995, the C-band (5.3 GHz frequency) SAR instrument operates in a number of modes acquired with HH polarization, a Fine mode with a swath width of 50 km at 10 m resolution, a standard mode with a swath width at 100 km and 30 m resolution, and the ScanSAR modes respectively at 300 km (ScanSAR Narrow) and 500 km (ScanSAR Wide) swath widths (Figure 4 and Table 1).

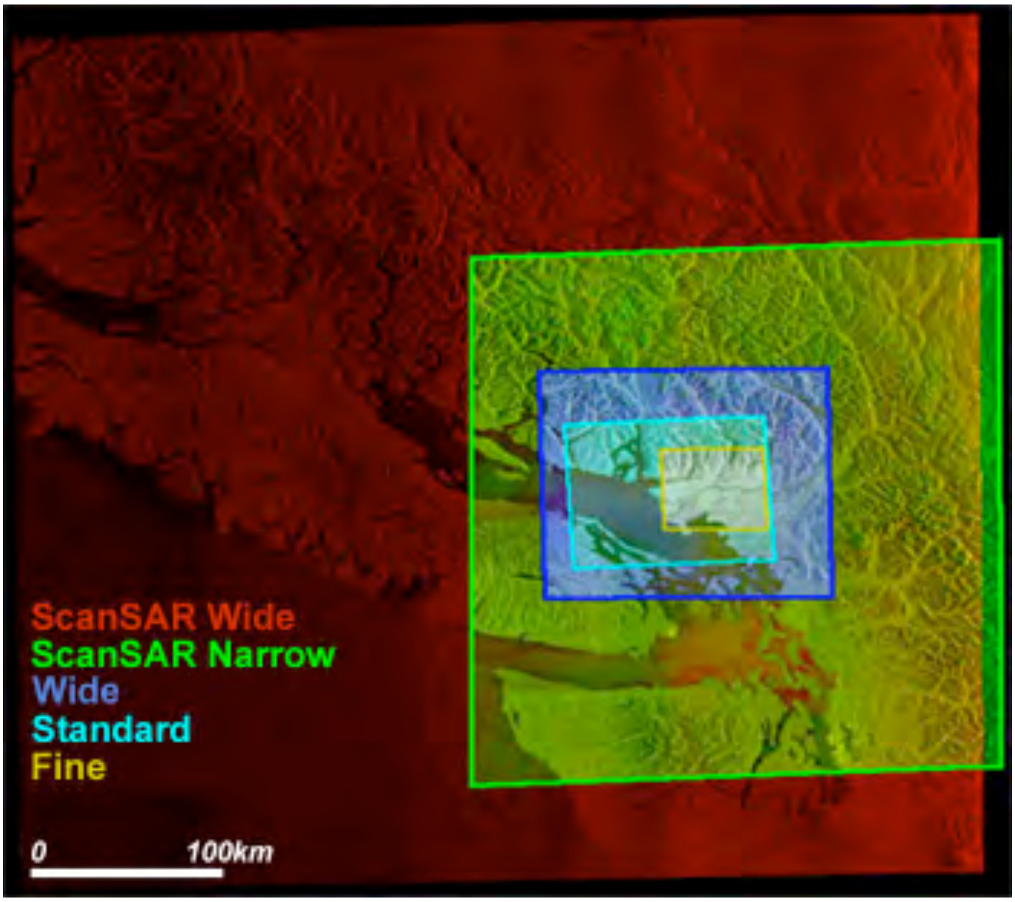


Figure 4. Ground coverage of various Radarsat-1 beam modes.

Table 1: Main characteristics of Radarsat-1's imaging modes.

Imaging modes				
Mode	Nominal Resolution (m)	No. of Positions / Beams	Swath Width (km)	Incidence Angles (degrees)
Fine	8	15	45	37 – 47
Standard	30	7	100	20 – 49
Wide	30	3	150	20 – 45
ScanSAR narrow	50	2	300	20 – 49
ScanSAR wide	100	2	500	20 – 49
Extended high	18 – 27	3	75	52 – 58
Extended low	30	1	170	10 – 22

4.2. RADARSAT-2

Radarsat-2 follows Radarsat-1, and offers all Radarsat-1 image modes as well as modes with multi-polarization and higher resolution. Like its predecessor it is a C-Band SAR, chosen for optimum atmospheric penetration to guarantee cloud and haze-free images. The system has been designed with maritime surveillance as a key application. Coverage options range from very high-resolution spotlight mode to very broad area ScanSAR modes at lower resolution. This flexibility allows operational programs to alter image acquisition modes routinely, with wider swath modes providing regional surveillance and higher resolution modes being used for target analysis and classification.

Although capable of acquiring four polarizations simultaneously, most maritime surveillance is conducted using dual polarized acquisitions, in this case combining HH and HV. The co-polarized (HH) channel is known to provide well-known ocean surface scattering characteristics and hence is useful to measure wind conditions, locate oil or other contaminants, and to observe wave and current patterns. The cross polarized channel (HV) is much less sensitive to ocean surface scattering and may therefore provide better target detection capability e.g. ships and ice floes.

4.3. ENVISAT

Envisat, launched by the European Space Agency (ESA) in 2002 carries 10 instruments. Its largest single instrument is the Advanced Synthetic Aperture Radar (ASAR), operating at C-band. As well as operating in the same band as the Radarsat series, it offers other similar capabilities in terms of capability, coverage, range of incidence angles, polarisation, and modes of operation. The ASAR is a high-resolution, wide-swath radar-imaging instrument that can be used for site-specific investigations as well as land, sea, ice, and ocean monitoring and surveillance.

There are 3 main modes available from Envisat ASAR sensor: Image Mode, Alternating Polarisation Mode and Wide Swath Mode. These beam modes have 8 beam positions (incidence angles). The 400 km Wide Swath mode is the primary mode for the operational services, and in particular for oceanographic-based observations such as oil spill detection and ice mapping. Occasionally the higher resolution (25m), but narrower Image Modes (app. 75 km swath) are used, mainly for ship detection.

The new Alternating Polarisation Mode is also used. It offers the same spatial resolution as Image Mode and may increase the detection capabilities for a range of incidence angles. However the radar noise (speckle) is higher than for Image Mode.

4.4. COSMO-SKYMED

COSMO-SkyMed is an Italian SAR constellation mission dedicated for dual (military and civil) use. This mission is funded by the Italian Space Agency and the Ministry of Defence, and operates in X-band (9.6 GHz), with shorter wavelength than C-band. The first satellite was launched in June 2007 and there are currently three identical satellites in the constellation with a fourth planned for launch in the 1st quarter 2010. The main mission objective is the provision of data and derived services relevant for monitoring applications.

An important factor in the constellation is that the four satellites are identical. This has a particular impact on the repeat coverage. With the fourth satellite the constellation will be able to repeat the coverage with the same image characteristics of any position in the world within 12 hours. This is very significant for monitoring situations that change rapidly over time.

Table 2: Acquisition modes of COSMO-SkyMed

Mode	Name	Resolution	Coverage	Polarization
Spotlight	Mode 2	1m	10 x 10 km	HH or VV
Stripmap	Hi image	3m	40 Km swath	HH or VV or VH or VV
	Ping Pong	15m	30 Km swath	HH+HV or HH+HV or VV+VH
ScanSAR	Wide Region	30m	100 x 100 km	HH or VV or VH or VV
	Huge Region	100m	200 x 200 km	

5. RESULTS

In total, 26 images from the four satellite systems were acquired, and of these 11 were used for the project. The images are listed in Tables 4 and 6, together with major events in Table 7. Table 5 lists some important SAR image parameters. The images used are shown in Figs 8 through 20.

The actual ice conditions where the experiment took place had a higher ice concentration than planned. Ice concentration was 7-9/10ths with the ice pack made up of floes ranging from 5 to 30 m in size with 15-35 cm snow cover. The location of the oil spill site was within the Marginal Ice Zone (MIZ) and due to meteorological conditions the ice in the MIZ was converging. This made it extremely difficult to find a suitable site to perform the experiment, and this is evident in the satellite images. It is also notable that in the 2009 set of images it is difficult to distinguish individual floes compared to the images in 2008.

Table 4: Satellite data available

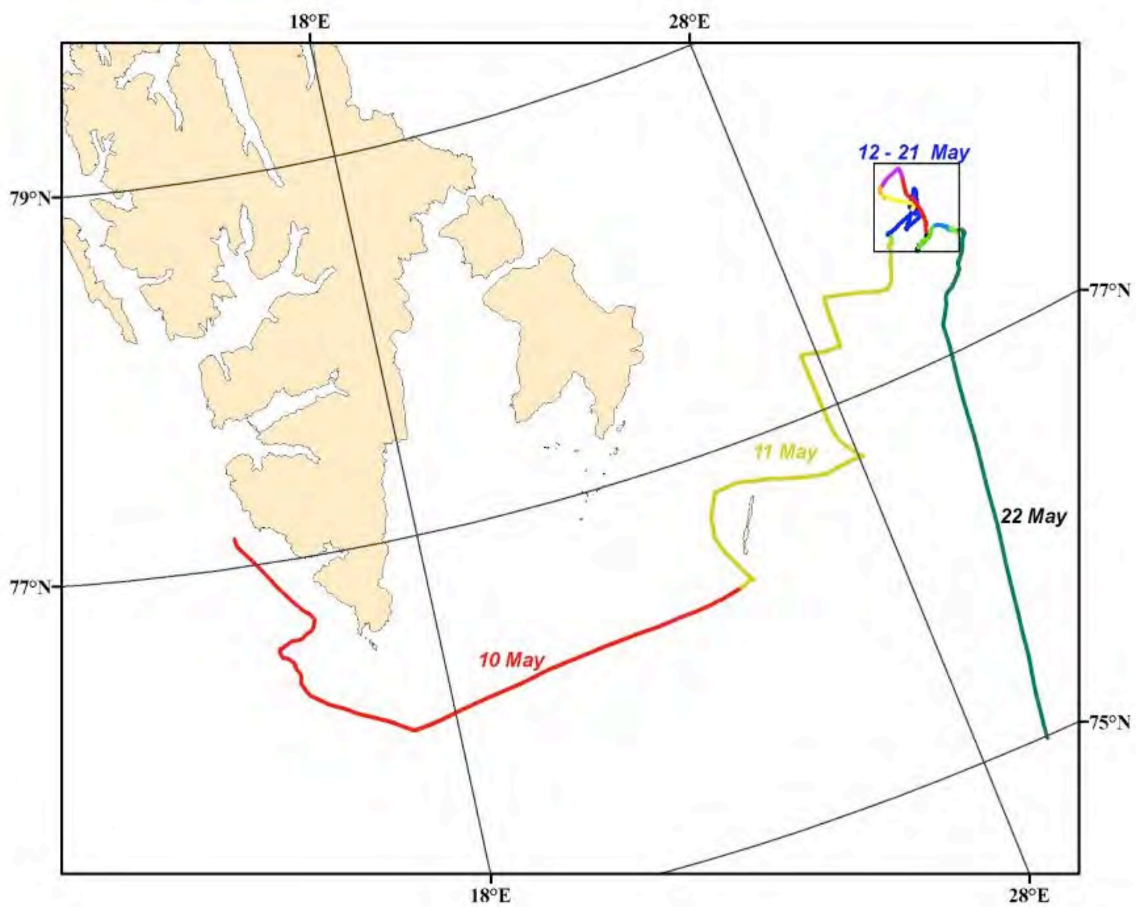
ENVISAT ASAR Wide Swath	**Radarsat 1**	**Radarsat 2**	**COSMO-SkyMed**
14 May 2009	11 May 2009	12 May 2009	15 May 2009
15 May 2009	14 May 2009	16 May 2009	19 May 2009
16 May 2009	14 May 2009	17 May 2009	20 May 2009
18 may 2009	15 May 2009	19 May 2009	
19 May 2009	15 May 2009	20 May 2009	
20 May 2009	15 May 2009	21 May 2009	
21 May 2009		22 May 2009 (ScanSAR Wide)	
22 May 2009			
23 May 2009			
24 May 2009			

Table 5: Technical specification of the satellites used
(See glossary for definition of technical terms.)

Satellite	**Swath**	**Polarization**	**Resolution**	**Pixel size**	**Number of looks / Noise**
ENVISAT ASAR Wide Swath	400 km	HH	150 m	75 m	12 / ±1.1 dB
Radarsat 1 (Standard)	100 km	HH	25 m	12,5 m	4 / ±1.8 dB
Radarsat 2 (Standard)	50 km	VV+VH	10 m	6,25	1 / ±3dB
Radarsat 2 (ScanSAR Wide)	500 km	HH	100 m	50	8 / ±1.3dB
COSMO-SkyMed	40 Km	VV	~ 5m	2,5	1 /±3dB

Table 6: Chronological order of the image used.

Date	Time (UTC)	Oil Spill status	Satellite
14 May 2009	15:18:59	Before oil spill	Radarsat-1
15 May 2009	16:12:45	After oil spill	COSMO-SkyMed
15 May 2009	18:33:45		ENVISAT
16 May 2009	05:16:04		Radarsat-2
16 May 2009	09:45:31		ENVISAT
18 May 2009	18:39:27		ENVISAT
19 May 2009	09:51:13		ENVISAT
19 May 2009	15:26:24		Radarsat-2
20 May 2009	14:57:07	Oil burn	Radarsat-2
21 May 2009	04.30:13	Oil burn	Radarsat-2
22 May 2009	05:40:49	After oil recovery	Radarsat-2 (ScanSAR Wide)



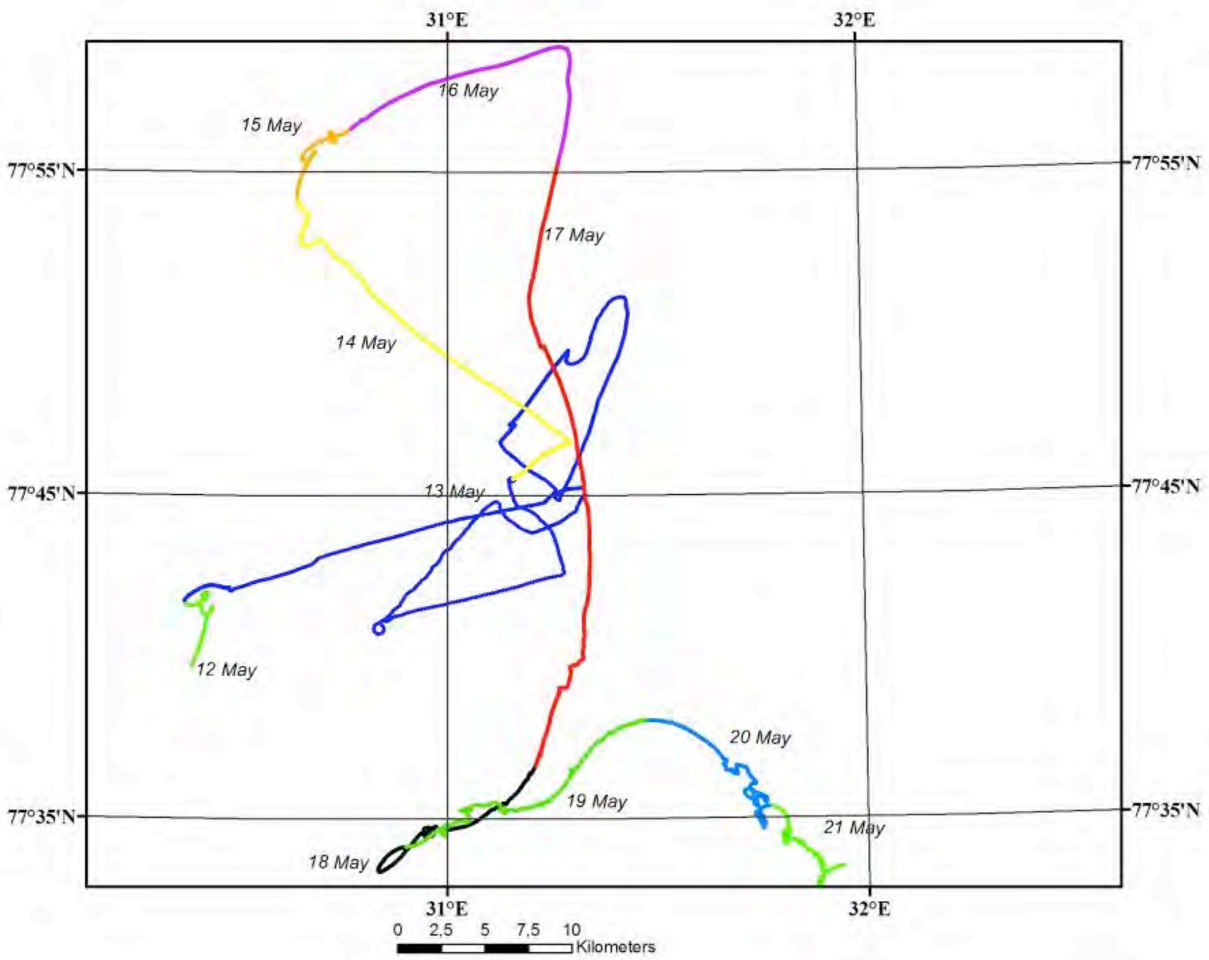


Figure 6: The top map shows the R/V Lance route from the 10th May to the 22nd May. The bottom map shows details route from the 12th May to 21st May (The different colours indicates the day by day track of the vessel).

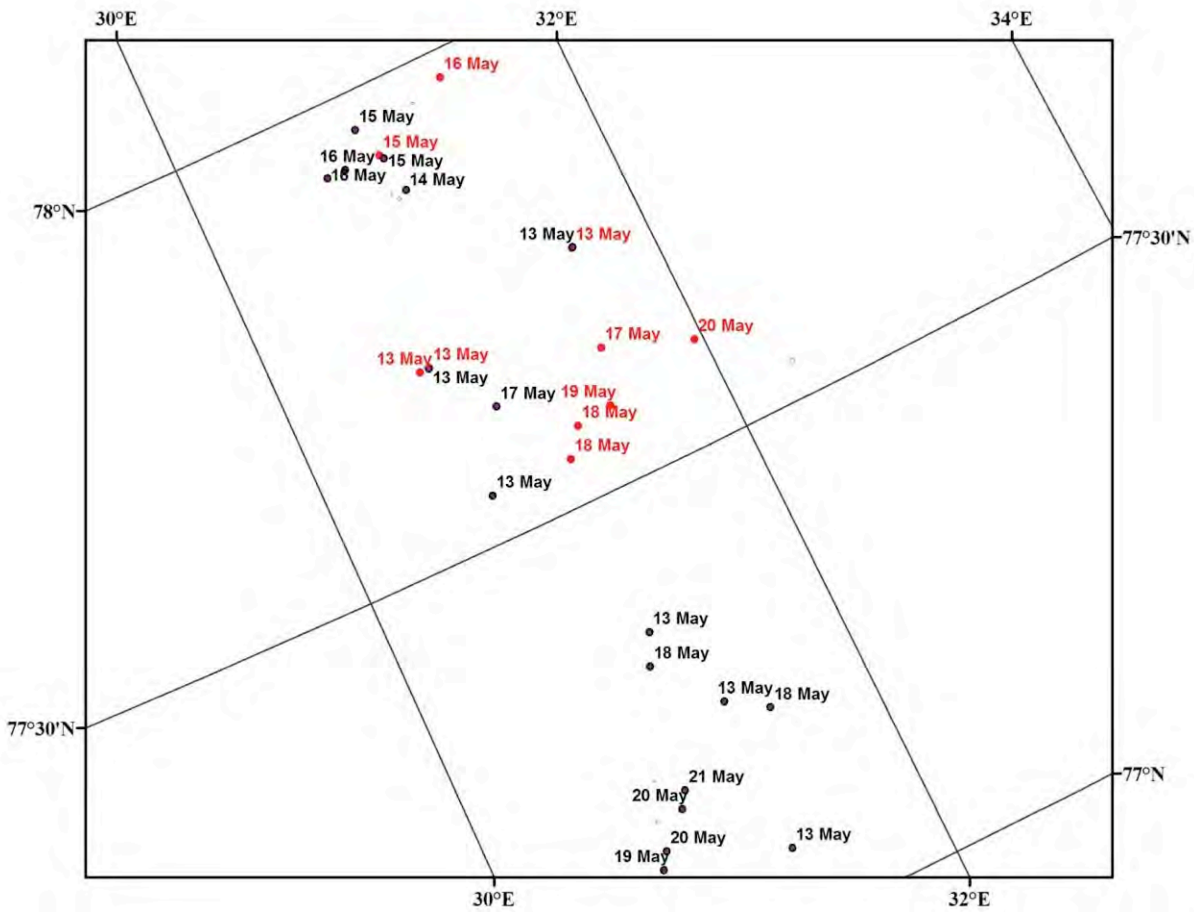


Figure 7: Map shows R/V Lance (red) and K/V Svalbard (black) locations during the experiment, R/V Lance in red and K/V Svalbard in black. R/V Lance is stationary anchored to an ice flow in the ice and its location variation reflects the motion of the ice, while K/V Svalbard moves considerably in the ice.

Table 7: Date and time for the major events during the experiment.

Date	Time	Comments
13.May	05:30	Entered ice 1-3/10
	06:00	5-6/10 floes with 1-2/10 slush and cakes
	06:30	Open water
	07:53	Second ice edge
	08:13	At site with other vessels
	12:30	M/S Nordsyssel departs for Longyearbyen
14.May	11:45	K/V Svalbard moved early morning to new site for skimmer tests
	15:00 to 22:00	Oil in boom alongside K/V Svalbard - sheen on water in vicinity.
15.May	06:45	Ice drift approx 3 n miles past 12 hours to the NW
	08:10	Pumping 7 cubic m spill from R/V Lance started
	09:00	All oil out from R/V Lance - very little spreading
	11:55	Swedish Coast Guard overhead for 35 min
16.May	10:00	
	13:30	R/V Lance maintaining position within 100 m of the large spill
	13:00 to 20:00	Oil in boom alongside K/V Svalbard - surrounding rainbow sheen visible on water outside
17.May	Aft	Small 0.5 cubic m spill over the side of the R/V Lance - contained by ice within 50 m. Not a remote sensing target
	21:00	
18.May	08:00	K/V Svalbard moved to ice edge to prepare for fire boom towing
		R/V Lance still drifting with the main spill
	20:00	Ice drift 5 n mi SSW past 12 hours
19.May	08:00	Ice drift 6 n mi last 12 hours
	15:00	R/V Lance conducted two 2 cubic m spills close by main spill - no details on area. Oil on surface for less than 4 hours
20.May	10:50	K/V Svalbard setting up for Burn 1
	19:30	Oil burning in fire boom - extensive uncontained sheen spreading for up to 1 km downwind behind vessel
21.May	08:30	K/V Svalbard moved overnight to recover helicopter from R/V Lance
	All Afternoon	Burn 2 with extensive sheen in open water and light ice 1-3/10 behind K/V Svalbard for several km
		R/V Lance crew removes/recovers main spill by dispersal mainly
	21:00	K/V Svalbard moves back to solid ice to take on helicopter for trip back to Tromsø
	23:00	K/V Svalbard out of the ice heading for Tromsø
22.May	12:00 approx	R/V Lance departs for Tromsø

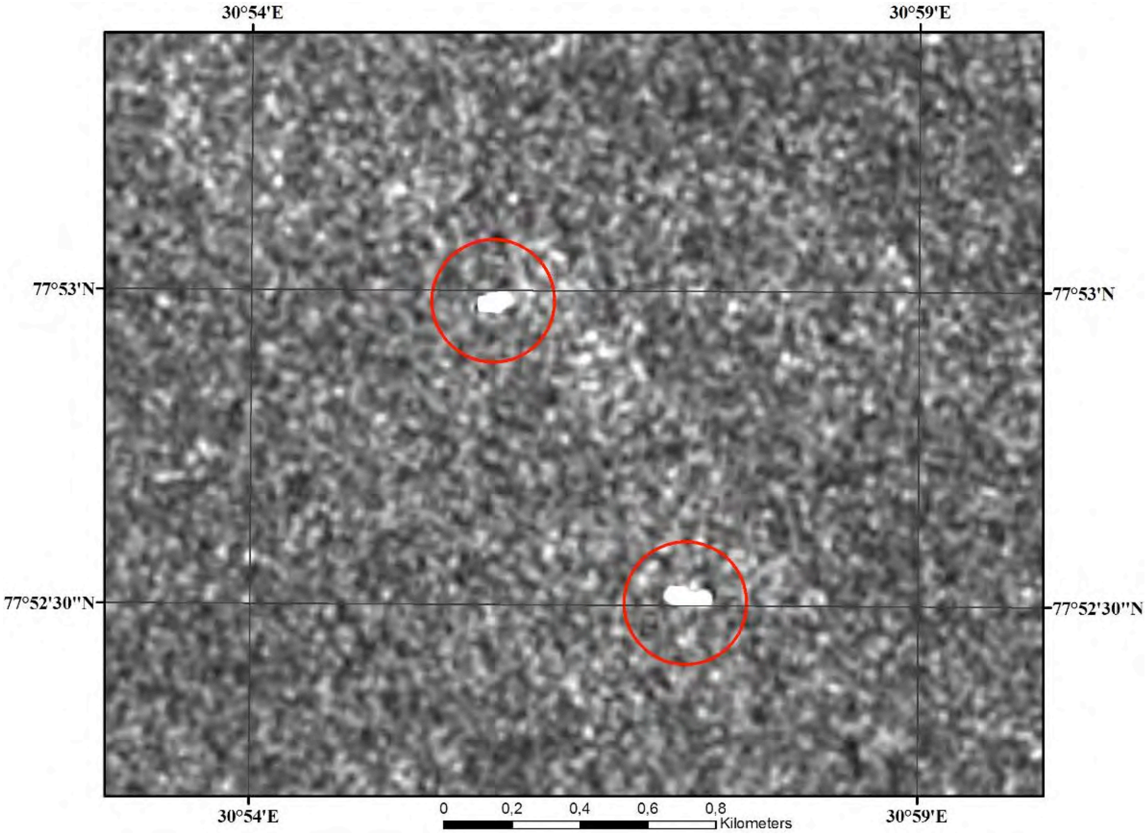


Figure 8: Radarsat-1 image, date 20090514, time 15:18:59. The image shows R/V Lance to the north and K/V Svalbard to the south. The ice edge is about 14 kilometres to the south; the ice situation is very close ice (80-90% concentration) with some leads filled with small ice floes. Small darks areas alongside the ships may be open water. Photo (1) was taken 20 minutes after the image. It shows the ice situation with R/V Lance in the distance.

Photo 1

Photo (1) above taken 20 minutes before the satellite image in figure 3. It shows the ice situation with R/V Lance in the distance. There is bright return in a round area alongside K/V Svalbard (figure 3). This corresponds with the time there was an ice filled circular oil boom tethered to the ship. It looks like the ice pieces concentrated in the boom are creating a bright return alongside the ship. (See photo (2) below taken 26 minutes before the satellite image in figure 3) Photos: D. Dickins.

Photo 2

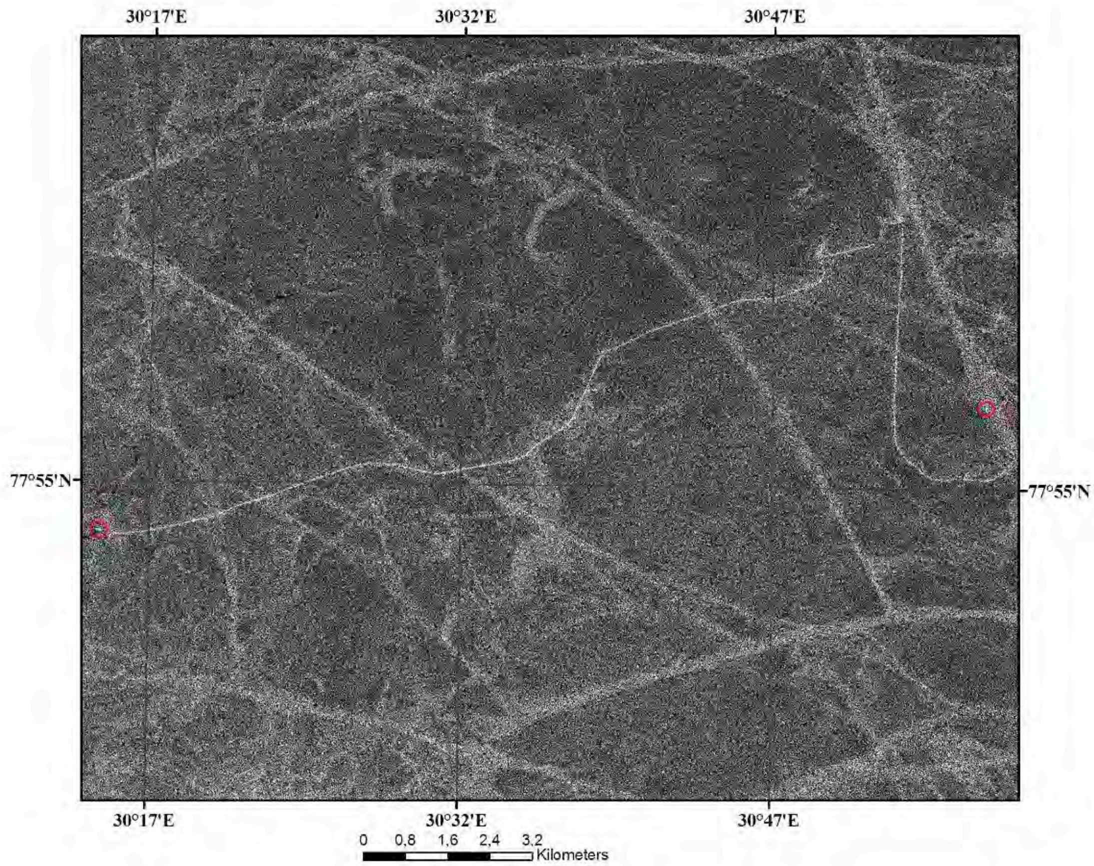


Figure 9: COSMO-SkyMed image, date 20090515; time 16:12:45. The image shows R/V Lance within the red circle on the east and K/V Svalbard on the west. The track of K/V Svalbard is clearly visible in the ice.

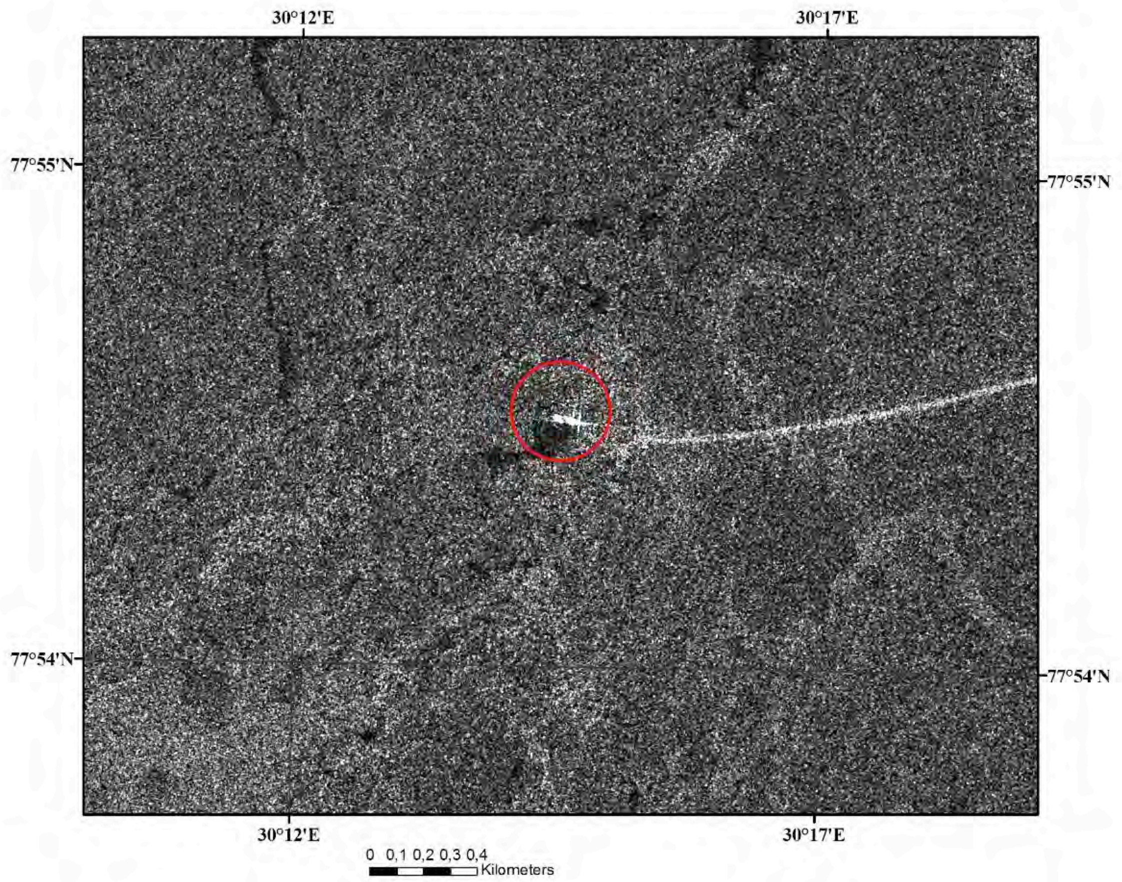


Figure 10: Subset from the previous image (COSMO-SkyMed image), date 20090515; time 16:12:45. The image shows K/V Svalbard within the red circle.

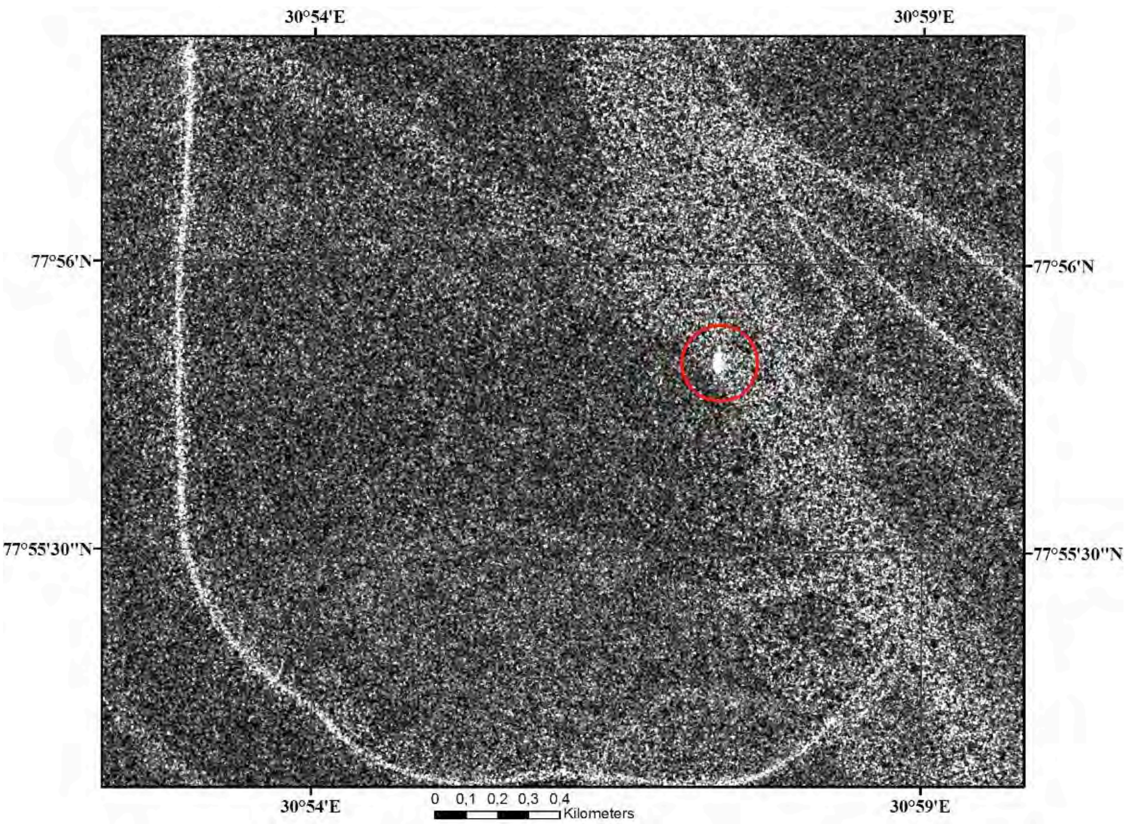


Figure 11: COSMO-SkyMed image, date 20090515; time 16:12:45. The image shows R/V Lance within the red circle, the ice situation is similar to the day before. The track of the ships is clearly visible in the ice. K/V Svalbard is to the west of this sub image. The image is acquired 8 hours after releasing the oil from R/V Lance. No oil signature is visible (the small dark patches are ambiguous signatures). This is to be expected, given the concentrated and fragmented nature of the oil distribution with thick patches confined by the close pack ice. The lack of any defined oil slick that could provide an unambiguous target on radar imagery is clearly shown in photo (3) below.

Photo 3

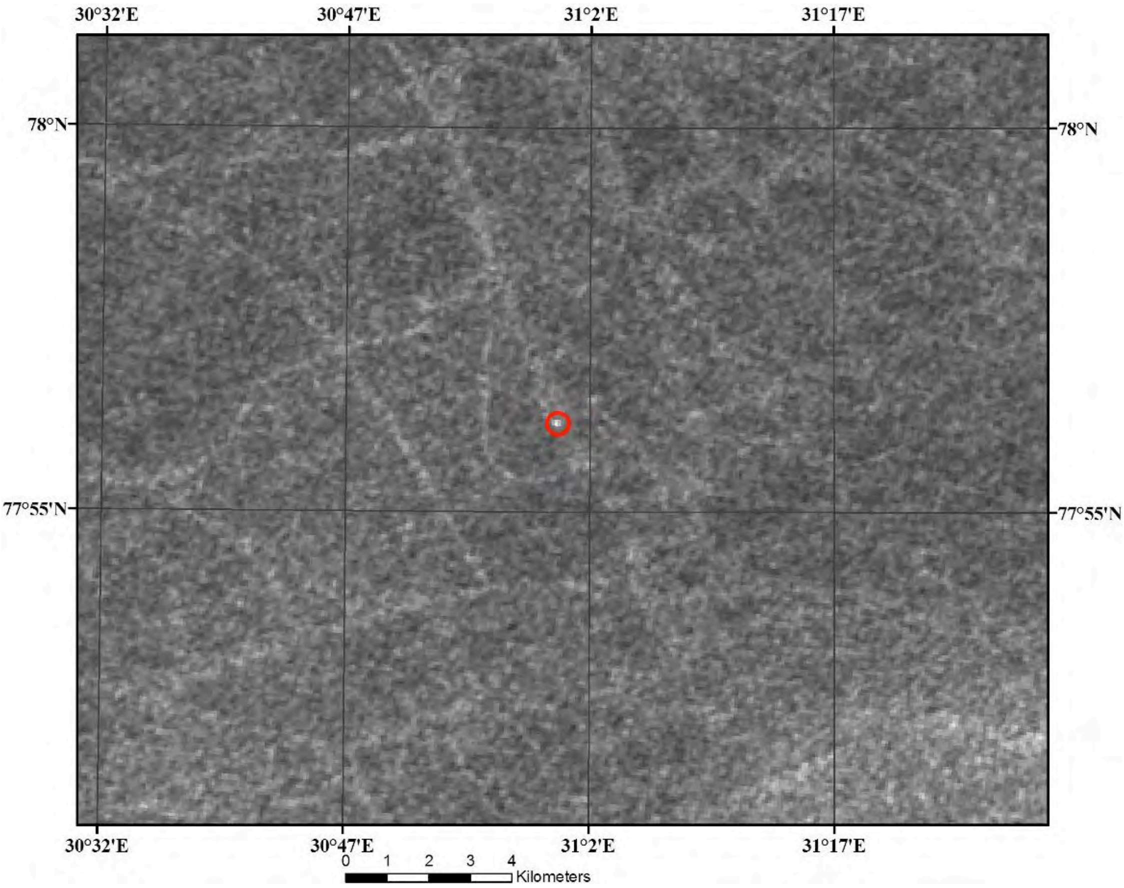


Figure 12: ASAR wide Swath image date 20090515, time 18:33:45. The image shows R/V Lance within the red circle. The tracks of the ships in the ice are still visible. The image was acquired more than 10 hours after releasing the oil.

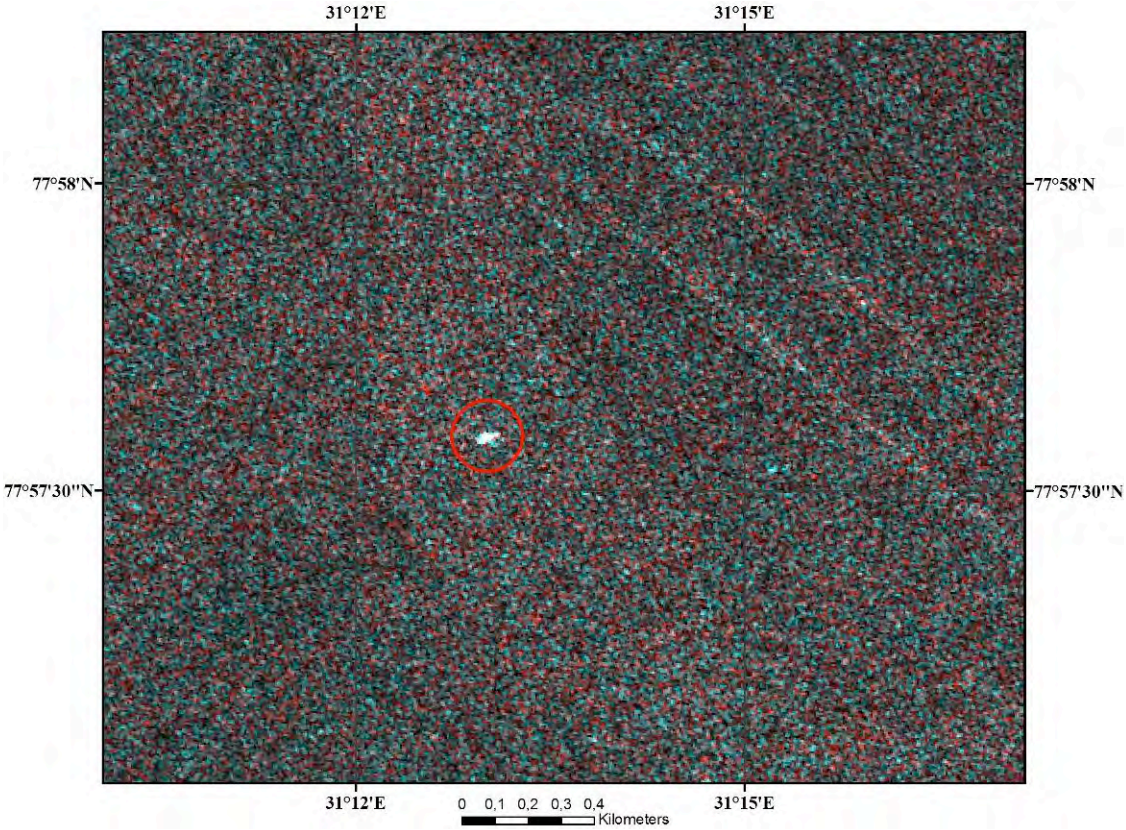


Figure 13: Radarsat-2 image date 20090516, time 05:16:04. The image is a dual polarization RGB composite of VV and VH, R/V Lance appears white in the centre of the image inside the red circle. Two of the ships tracks are still visible in the ice (at upper right). The oil spill, in position within 100 m of R/V Lance is not visible. Photo (4) below is taken 7 hours after the above image from the R/V Lance's crows nest. The oil was released the day before. The separated small brown areas just above the centre of the picture are the released oil.

Photo 4

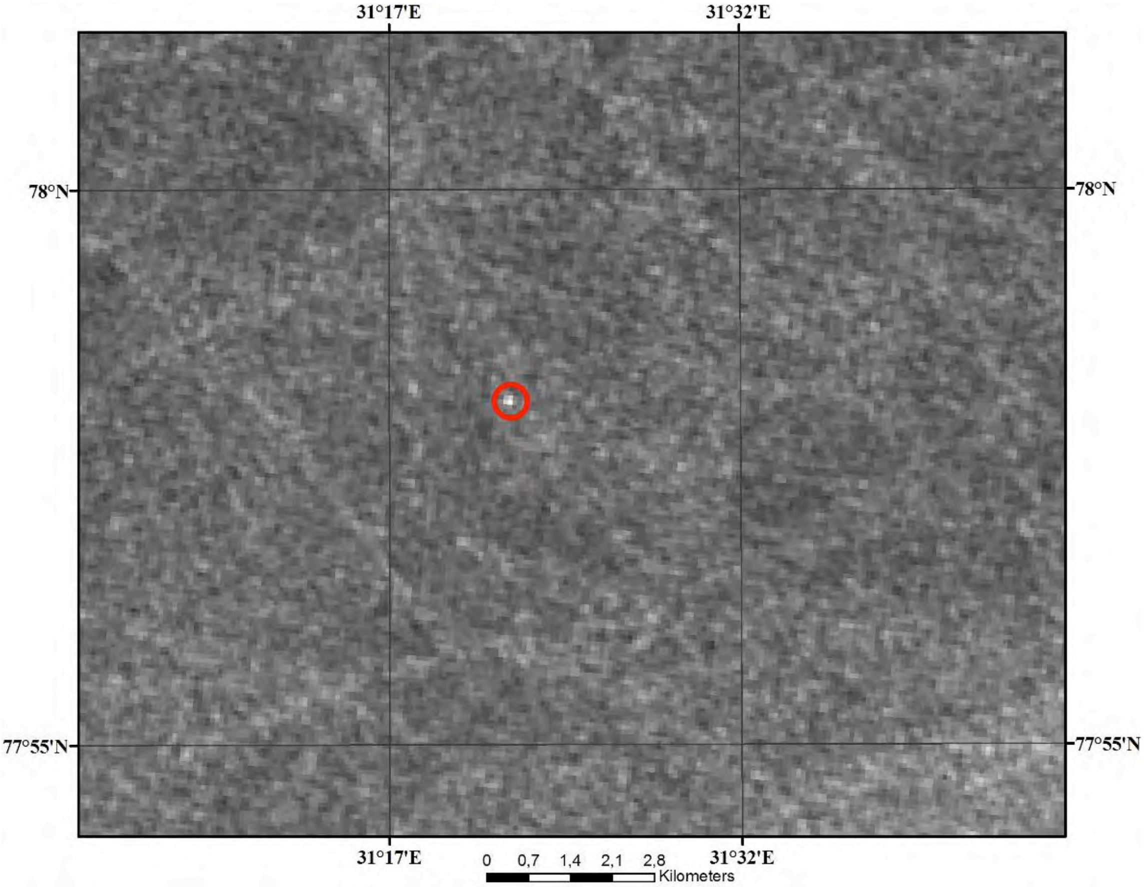


Figure 14: ASAR Wide Swath image date 20090516, time 09:45:31. The image shows R/V Lance at the centre of the image within the red circle. The ships tracks in the ice are still faintly visible.

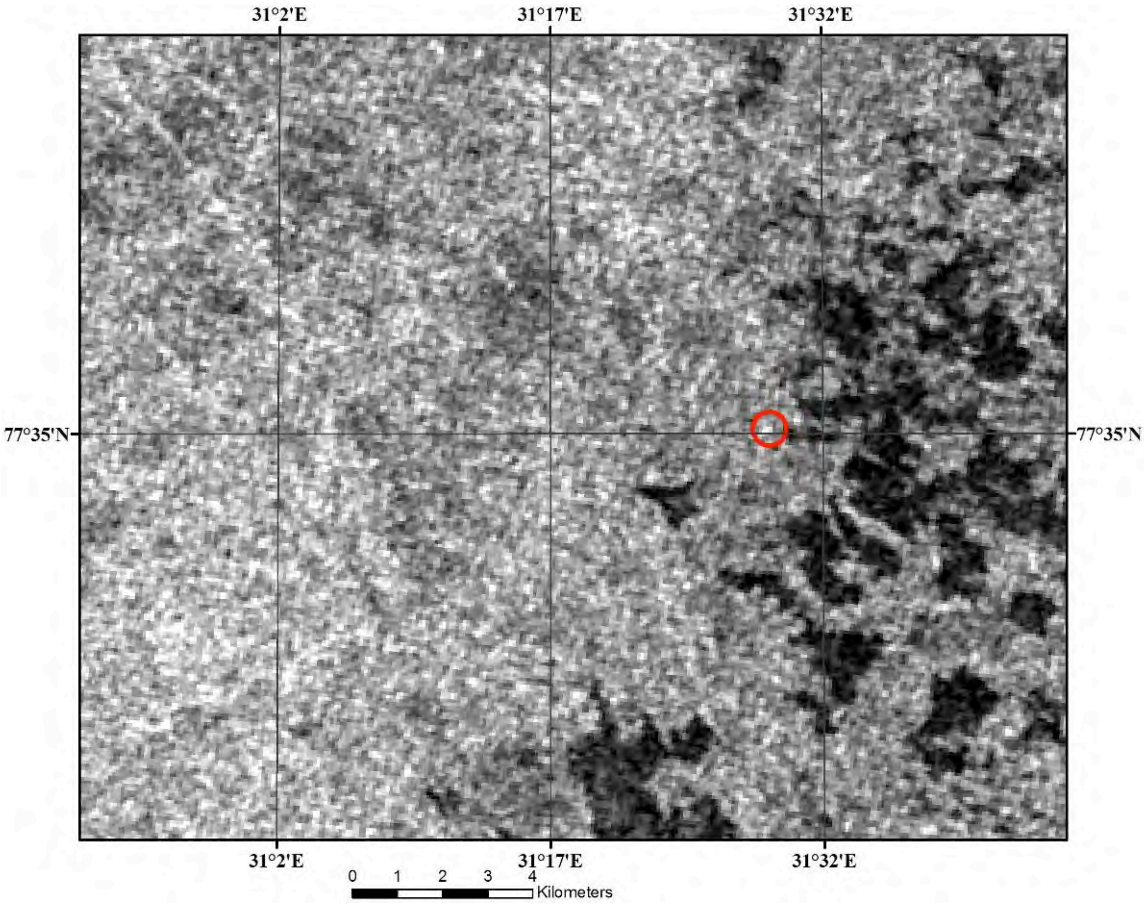


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Figure 15: ASAR Wide Swath image, date 20090518, time 18:39:27. R/V Lance is the small white spot inside the red circle. The ice situation is more open (about 50%) than the previous days, with large areas of open water to the east of the ship, indicating that it is closer to the ice edge. The ships tracks are no longer visible.

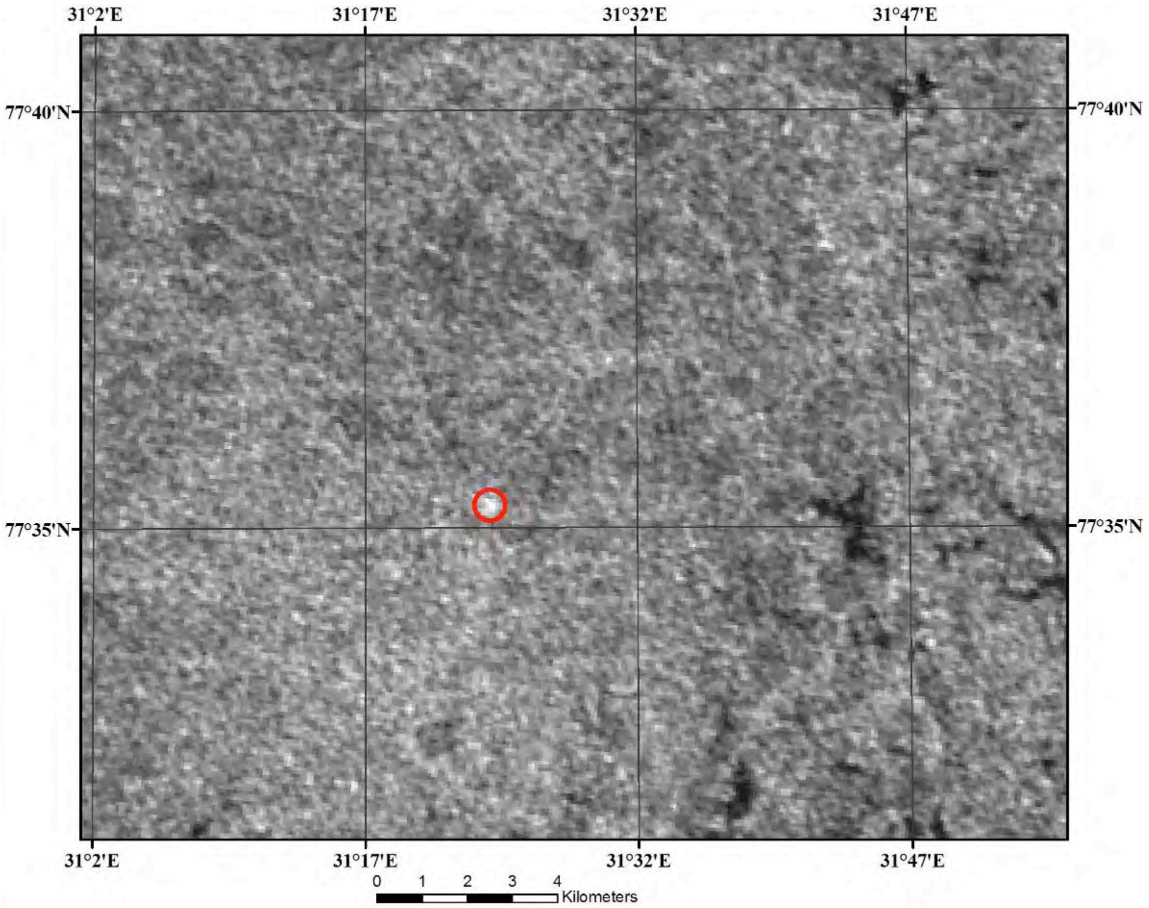

Figure 16: ASAR Wide Swath image, date 20090519, time 09:51.13. R/V Lance appears as white spot inside the red circle. The ice situation is the same as in the previous image.

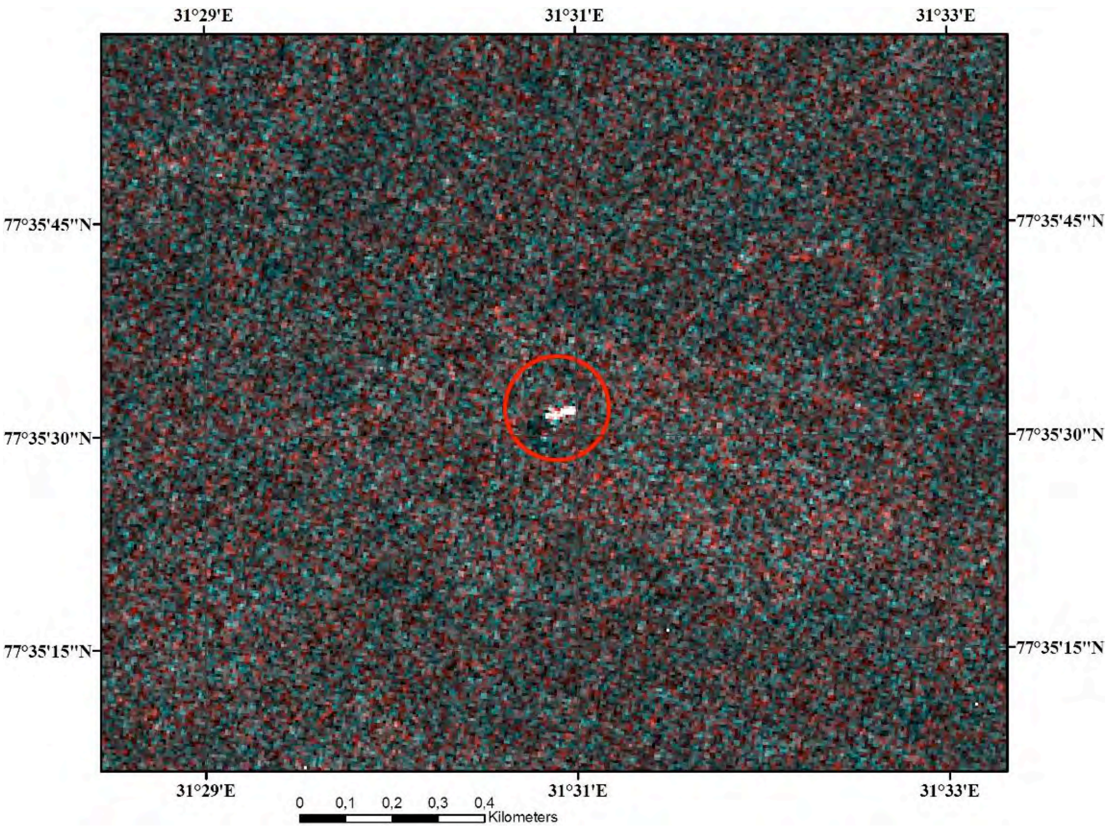

Figure 17: Radarsat-2 image, date 20090519, time 15:26:24. The image is a dual polarization, presented in RGB colour; R/V Lance is clearly visible within the red circle. There is a dark area to the southwest of R/V Lance, which can be either open water or possibly the oil spill. Photo (5) below is taken 3 hours before the image, from the R/V Lance crow's nest showing the oil as brown areas. The linear bright return showing on the starboard side of the vessel is likely the articulated metal arm used to apply dispersants – Photo 6

Photos 5 & 6

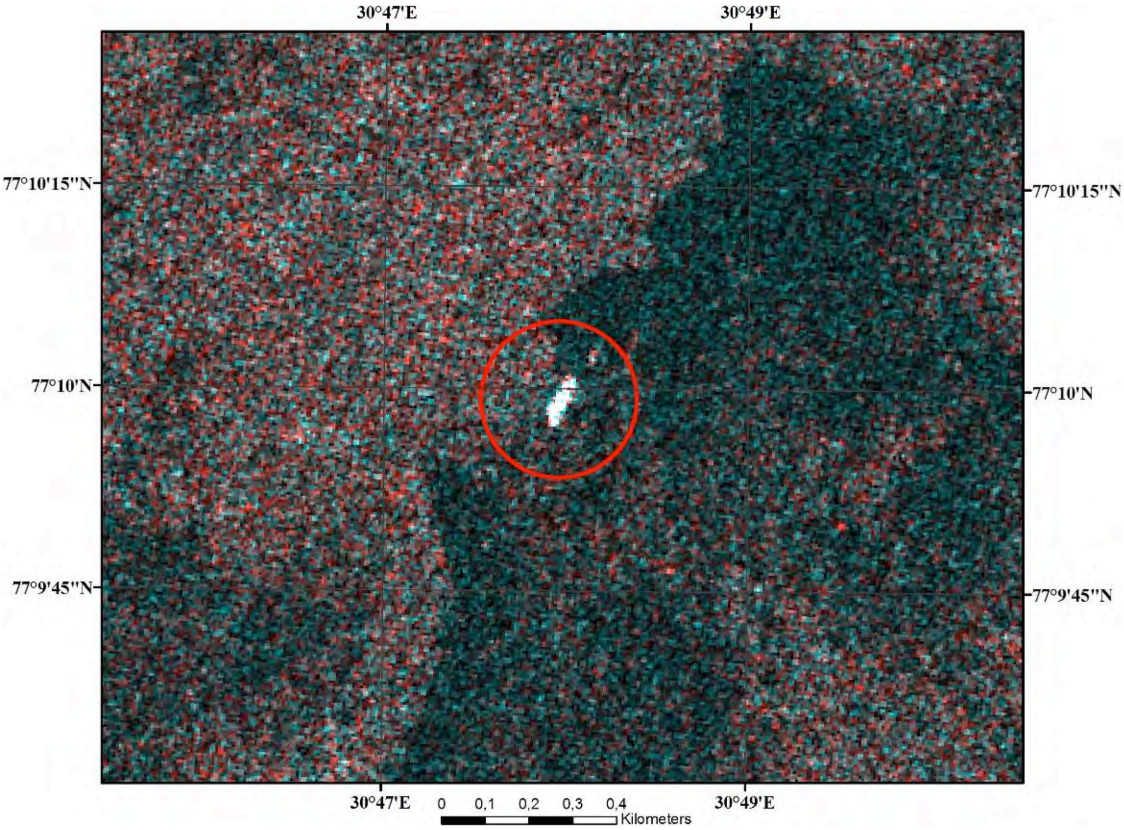

Figure 18: Radarsat-2 image, date 20090520, time 14:57:07. This is a dual polarization RGB coloured image. The ice is now very open (20%). The image shows K/V Svalbard during oil spill burn activity. Photo (7) below taken one and half hour after the image above shows the Svalbard towing the ice-filled fire resistant boom, visible as a separate bright return.

Photo 7

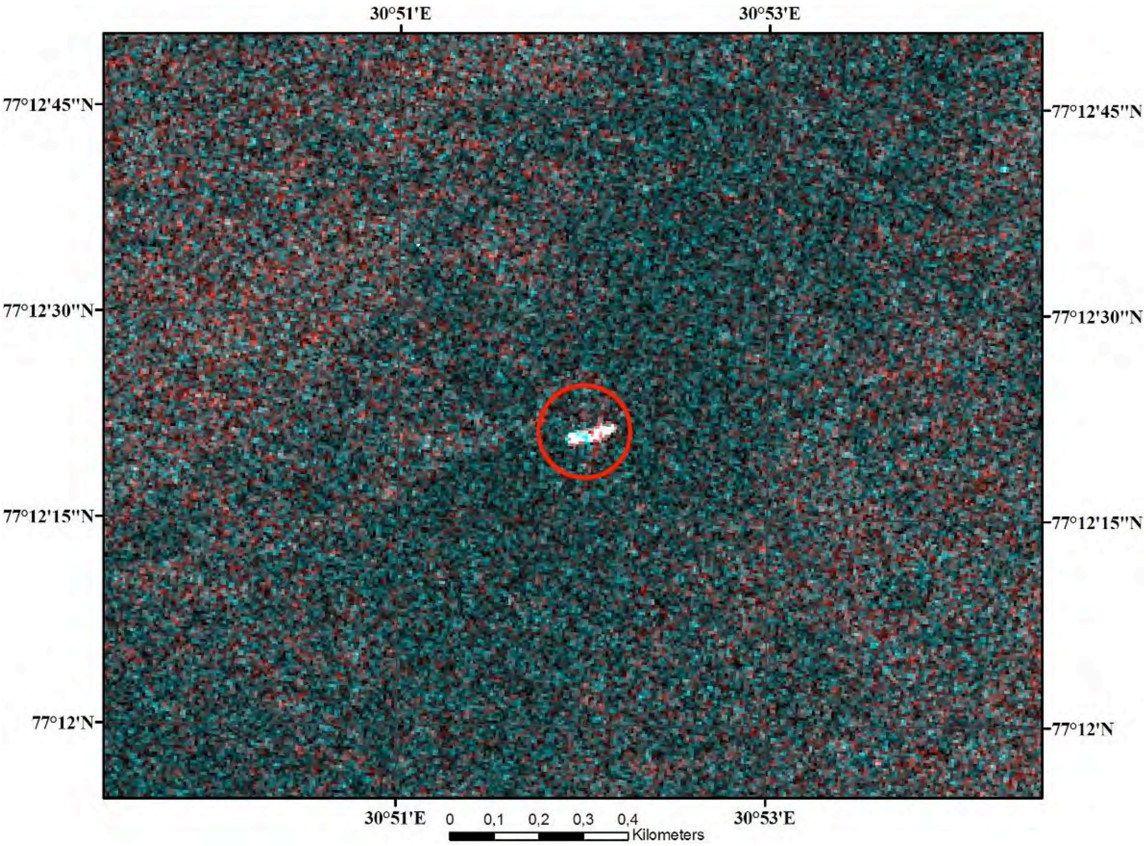

Figure 19: Radarsat-2 image, date 20090521, time 04:30:13. Dual polarization RGB coloured image shows K/V Svalbard within the red circle. The oil has now been recovered.

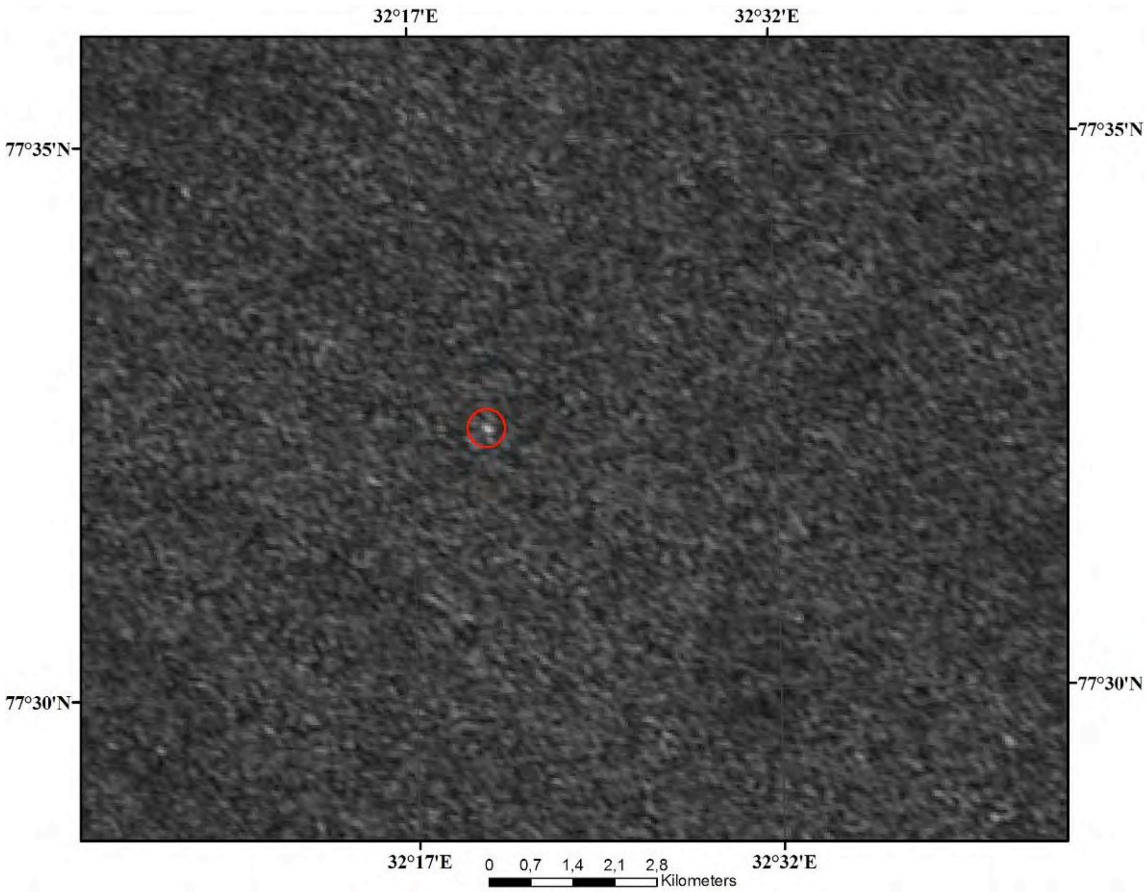

Figure 20: Radarsat -2 image, date 20090522, time 05:40:49. R/V Lance appears as a white spot within the red circle. This is the last day in the ice; the ship left the area later that day.

7 CONCLUSIONS

The aim of the JIP Oil in Ice project was first and foremost to determine whether or not oil released into ice-infested waters could be detected. The results show that small spills contained from spreading in close pack ice cannot be detected with satellite imagery. Without the contrast in surface roughness offered by an adjoining area of open water, there is no means to differentiate the presence of the oil from its surroundings. Direct satellite observations of oil in ice were not possible in this JIP because of the ice conditions controlling the spreading behaviour of the oil. This outcome was not related to the technical specifications or settings chosen for the satellites.

Although this experiment showed that detection it is probably impossible when the ice concentration is moderate to high (considered as 4/10 or more) it may be feasible in low (1-3/10ths) ice concentrations, particularly in the summer months when there is no interference from new ice. Scenarios that could satisfy these conditions include: when a major spill drifts into areas of low ice concentration during the melt season, or when winds temporarily disperse the ice pack, leading to low ice concentrations at the spill site.

During the planning stage of the experiment it became clear that it would be difficult to pre-define a suitable area or transect where the experiment could take place. The reason for this was that the location would be within the dynamic Marginal Ice Zone (MIZ) where the ice conditions can change rapidly during May. A location further into the ice pack was also rejected, as it may not be possible to reach the location due to the ice conditions. The uncertainty with respect to the area did bring an element of realism to the experiment. If this were a real accidental spill then under current practices very high resolution (<10m spatial resolution) would not be routinely planned in advance over the ship's location. Medium resolution (ca. 70m spatial resolution) images covering up to 400 x 400 km, would be immediately available for two reasons: firstly the national ice services use these images to produce daily ice charts; and secondly the same set of images are routinely collected as part of ongoing ice climate studies.

During the experiment, rapid ordering - defined as within 24 hours notice - and repositioning of the image centres, was successfully achieved when a reliable position was received before 06:00 UTC. Images were successfully acquired at the beginning of the oil spill experiment on 15th and 16th May. Unfortunately, a storm hit the area on 17th May. As a result, the projected positions for the following week no longer matched the actual positions. This experience demonstrated the need for maximum flexibility at all times and the need to plan for the unexpected such as another marine emergency coinciding with the spill – as happened in both 2008 and 2009 offshore field experiments.

If an accident occurs during an Arctic oil recovery operation (*e.g.* salvage), the rescue ship(s) would have access to all available satellite images. The medium-scale images immediately accessible through routine sources would allow crews to identify the quickest, safest route to the incident site. As the ships approached the site they could then use specially ordered very high-resolution images to gain detailed information on the surrounding ice pack. At the same time the medium-scale images would be continually used to monitor the changing ice conditions over a broad area, particularly if a storm was passing through the region. The high-resolution images cannot provide the same information about the overall ice pack dynamics due to the smaller coverage area.

Human activity in the Arctic and especially in ice-infested waters carries a certain amount of risk. This risk can be minimised if certain precautions are taken. One of the most important considerations to take into account is the monitoring of ice conditions within the area of operations, both for ships and oil rigs. If the potential of a possible collision with and extreme ice feature is known then a safer course can be selected to avoid being beset or damaged. SAR imagery is an important monitoring tool that can be used to reduce the risks associated with marine operations in ice during spill response operation.

8 RECOMMENDATIONS:

A number of advanced planning steps can be taken to facilitate the emergency application of satellite imagery in support of future Arctic spill response:

- Dedicate one satellite system to large scale monitoring of the ice conditions around the spill site. This is particularly important, as the biggest users of SAR data, the National Ice Services, have established long-term standing orders with the major satellite providers.
- Secure access to a second complimentary satellite series that can be quickly programmed to cover the ship's position in near real-time with very high-resolution images. The COSMO-SkyMed constellation could possibly fill this role.
- Collaborate between different users to ensure that conflicting requests for satellite data conflicts can be reconciled, using the example of how the North Sea is monitored for oil spills as a good starting point.
    - For example, in 2009, KSAT sent requests both to the United States National Ice Center and the Norwegian Meteorological Office (Met.No) who regularly order wide swath images over the Barents Sea, to not request any Radarsat medium resolution images over the test site during the experiment period. This allowed high-resolution images to be acquired over the test site in dual-polarization. Both organizations agreed to the request at the time, but it is important to recognize that this may not always be possible, depending on ongoing priorities or other emergencies in the same general area.

The greatest value of satellite images may be in the area of preventing marine accidents that could lead to spills. If ships regularly use satellite images, together with weather forecasts, to determine how the ice conditions are over the horizon, they are able to choose safer and more efficient routes through the ice.

9 THE FUTURE

Currently, there are large disparities between national regulations governing Arctic marine operations. However, on-going discussions at multiple levels may change this situation. In particular, regular reporting of a ship's position may become compulsory. Regardless of the national regulatory framework, ships and offshore installations will always require detailed and current ice and weather information. High quality ice information, including all-weather satellite coverage, is considered essential by most Arctic operators due to the potential savings in fuel consumption, reduction in damage risk (both minor and major) due to unnecessary ice breaking. Further, with regular satellite surveillance the need for floating rigs to disconnect the riser and drill string in response to advancing ice features may occur less frequently, thereby reducing spill risk. Better ice management practices will result from more detailed knowledge of the ice conditions upstream of the location. In addition, seismic surveys may be completed more efficiently by tactical planning of the survey transect by taking into consideration the surrounding ice conditions. As a result, surveys could be completed with fewer expeditions, thereby minimizing environmental impact and maximizing ship time.

Currently, it is assumed that if an accident occurs in ice-infested waters, additional high-resolution images will have to be ordered, acquired and delivered at short notice. The availability of these images for the specific location at short notice will depend mainly on satellite configurations and orbit details at the time of accident. This process will be expensive, and not always technically possible. However, if "best practices" mean that daily medium resolution images are routinely acquired to aid ship navigation, together with weekly acquisitions of very high-resolution images to aid navigation during specific operations such as ice management, then at least a basic level of necessary coverage will always be available to support an accident in the first week and beyond.

Questions are sometimes raised as to whether or not a ship is reporting her position. It has been illustrated in this report that ships can be identified in ice, and research is ongoing to improve the automatic detection of ships in ice. If, in the future, ships will have to report their positions regularly even when operating in the open seas, then any ship detected in a satellite image that is not reporting her position may trigger an inspection to ensure there is no pollution, illegal activity or negligent operating procedures.

In future incidents, automatic reporting of real-time ship positions before 08:00 UTC each morning might allow more images to be acquired over a spill site and would remove the reliance on a crew member to send the position, an action that may be forgotten in stressful conditions.

10 ACKNOWLEDGEMENTS

We greatly acknowledge the reception of a unique collection of 26 images (at minimal data cost) during an 11 day-period over a dynamic target area. This was only possible due to the good support from the satellite owners. In addition, support from the national ice centres was crucial ensuring that we had sufficient control over the satellites to obtain the most suitable imagery over the target.

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APPENDIX OIL SPILL MONITORING AND SCREENING

This Appendix explains the process by which satellite imagery is being routinely used as a screening tool for spills in the EU – this has direct applications to future monitoring of Arctic areas, especially in the summer period. The example presented here is the KSAT oil spill and ship detection service chain based on SAR data from the European Envisat and the Canadian Radarsat satellites. The service chain (figure A.1) includes a dialogue with the users to harmonise the coverage requirements, which are being used for satellite tasking requests and aircraft operations coordination. The other service chain elements include SAR data acquisition and processing, reception and integration of non-space data into the analysis process, image analysis and interpretation, followed by early warning alert to the customer as well as information ingestion into the service web-server.

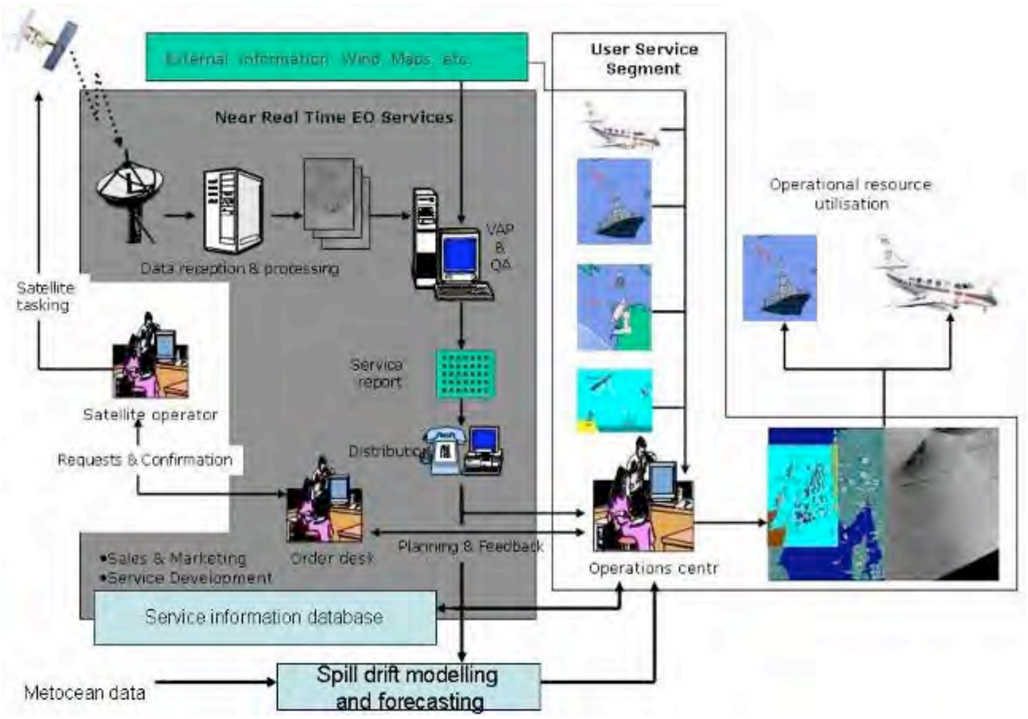

Figure A.1: KSAT oil and ship detection service

A dedicated service workstation is employed to control the multi-source data ingestion and integration, information extraction, presentation and distribution. The operator utilizes SAR data integrated with meteorological data and geographical information during the analysis and interpretation process. The oil spill analysis still relies upon interactive human interpretation, while the ship detection is done automatically. KSAT operating engineers have analysed several thousands of SAR images, and therefore have developed their experience and knowledge on interpretation of SAR images in terms of identifying possible oil spills. Automatic oil spill detection algorithms are being developed with encouraging reliability, and KSAT has initiated a process for integrating these into the operational service chain.

The basis for the near real-time service capability to provide the information to the customer within 30 minutes after acquisition, are the Radarsat and ENVISAT SAR processors capable of generating ScanSAR images in less than 10 minutes. It has been documented that radar images with a spatial resolution of 100 meters is very suitable for detecting oil spill and ships at the sea surface [2,3,4,5].

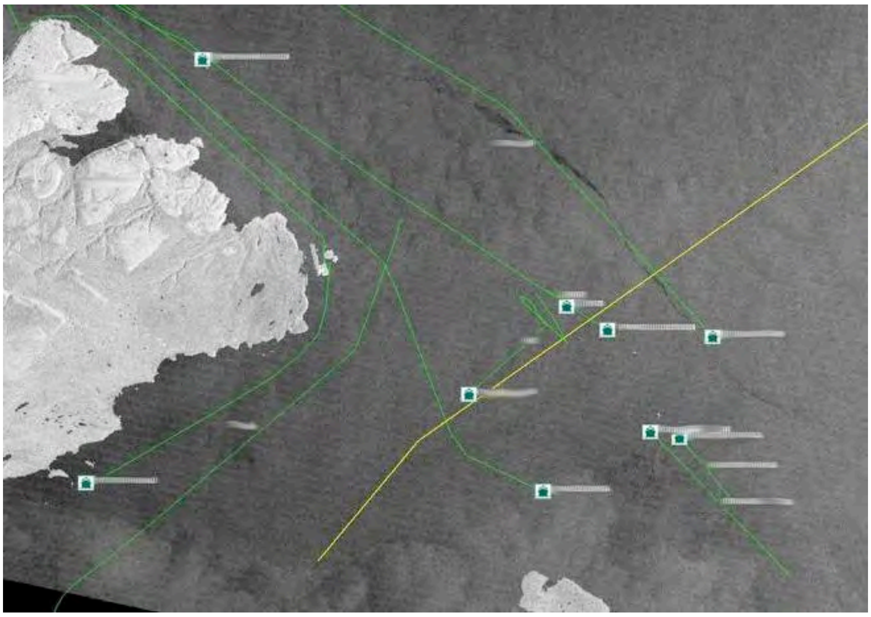

Figure A.2: Example of a SAR image with an oil spill (upper right part), and overlaid ship identification from AIS.

Over time, users have become more experienced in utilizing satellite Earth Observation (EO) services; their demand has developed from simple feature or object detection into more detailed information and identification. The service now provides extended information on oil spills, including a source notification and identification if present. Identification on fixed targets such as offshore installations is derived from a database updated regularly, while ship identification is derived from operationally accessing the AIS database via the Norwegian Coastal Directorate. The identification information is provided to the users as a graphical layer via the web-server and in the service source reports.

As part of the European Maritime Safety Agency's (EMSA's) CleanSeaNet service, users are informed about possible oil spills within 30 minutes after data acquisition. EMSA receives both the image data and the service information, while other users receive only the email report with the results from the analysis. The complete service information is also made available on the customer's web-page, which also contains information on planned satellite passes (Figure A.3).

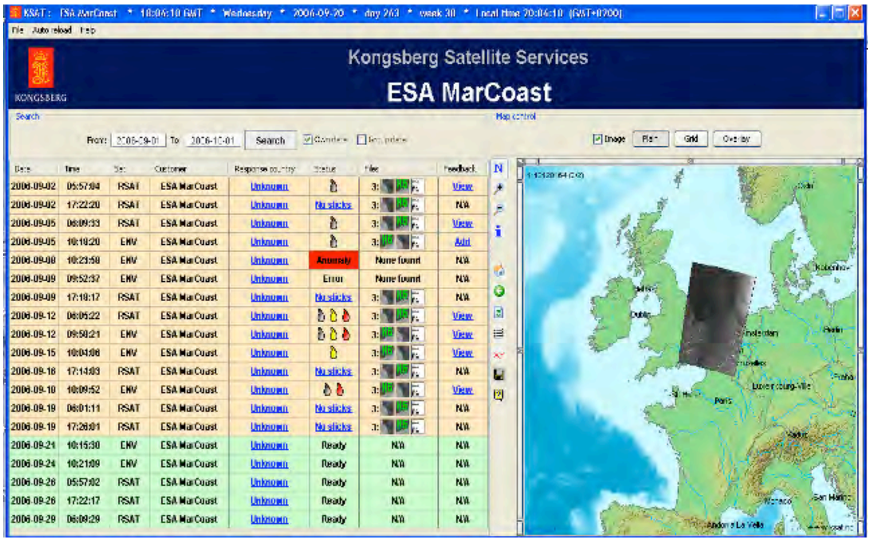

Figure A.3: Service information web-server user interface.

Access to the acquisition plans is important for co-ordination with aerial surveillance whereby the users have an aircraft on stand-by or already flying in the area to check reported oil spills. The delivery time is therefore crucial for this integrated service. The requested delivery time is <30 minutes. A user feedback function has also been implemented on the web-page, and the users now provide KSAT with results (text and images) from verifying flights. This feedback is essential in order to improve service performance.

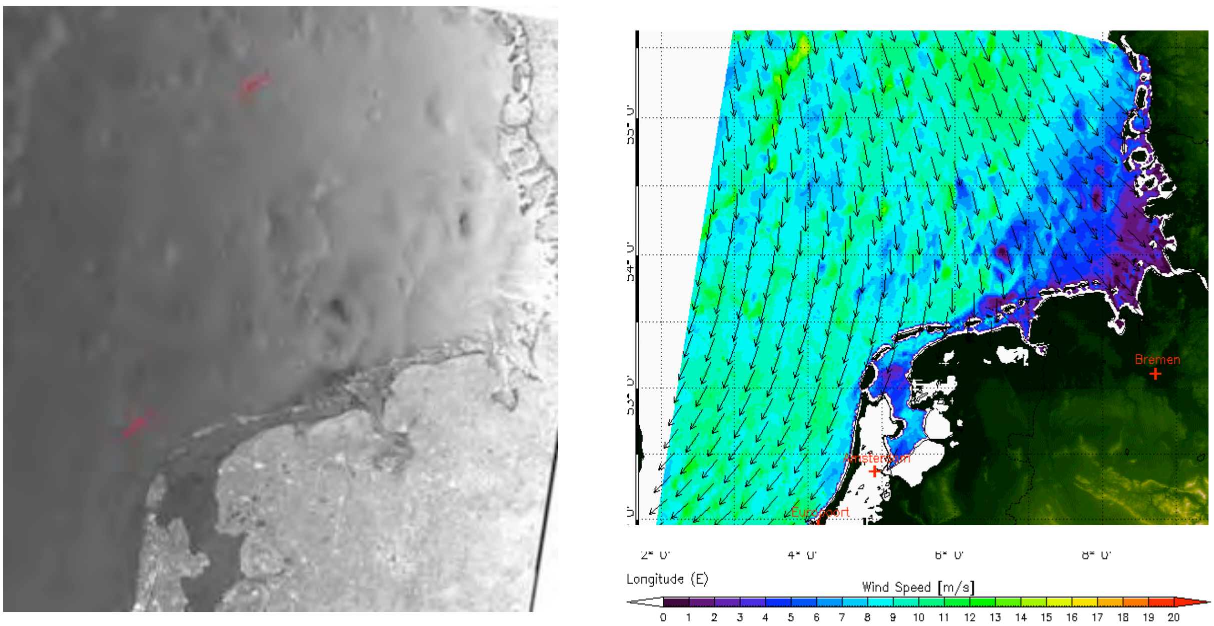

Figure A.4: Example of multiple-use of a SAR scene in the North Sea service area, both for oil spill/ship (red areas, left) and wind information (right).

Verification of the reported spills by the users is based on operational decisions as to what is possible with the air and marine resources available. As a consequence, 43 % of the totally reported possible spills received no user verification or feedback. Nine per cent of the reported spills were confirmed by user verification. For 13 % of the reported spills, the users observed nothing during the verification activities.

GLOSSARY:

Polarisation: Radars are usually designed to transmit either vertically polarised or horizontally polarised radiation. This means that the electric field of the wave is in a vertical plane or a horizontal plane. Likewise, the radar can receive either vertically or horizontally polarised radiation, and sometimes both. The planes of transmitted and received polarisation are designated by the letters H for Horizontal and V for Vertical. Thus the polarisation of a radar image can be *HH*, for horizontal transmit, horizontal receive, *VV* for vertical transmit, vertical receive, *HV* for horizontal transmit vertical receive, and vice versa (*VH*).
Resolution: The minimum separation between two objects of equal reflectivity that enables them to appear individually in a processed *radar image*. Also referred to as spatial resolution. Resolution in a radar system differs in two directions: the *azimuth* (or *along-track* direction) and the *range* (or *across-track*) direction.
Noise: Any unwanted or contaminating signal competing with the desired signal. In a SAR, two common kinds of noise are additive (receiver) noise, which is independent of signal level, and signal dependant noise, usually multiplicative. The relative amount of noise is described by the signal to noise ratio. Signal dependent noise, arise from system imperfections, and are dependent on the strength of the signal itself.
Speckle: Statistical fluctuation or uncertainty associated with the brightness of each pixel in the image of a scene. A single look SAR system achieves one estimate of the reflectivity of each resolution cell in the image. Using several looks may reduce speckle. Speckle appears as multiplicative random process whose variance and spatial correlation are determined primarily by the SAR system.
Looks: Refers to individual looks as groups of signal samples in a *SAR* processor that splits the full synthetic aperture into several sub-apertures, each representing an independent look of the identical scene. The resulting image formed by incoherent summing of these looks is characterised by reduced *speckle* and degraded spatial resolution. The SAR signal processor can use the full synthetic aperture and the complete signal data history in order to produce the highest possible resolution, albeit very speckled, *single-look complex (SLC)* SAR image product. *Averaging over range and/or azimuth resolution cells may generate multiple looks*. Also pixel averaging can increase the number of looks. For an improvement in radiometric resolution using multiple looks there is an associated degradation in spatial resolution. Note that there is a difference between the number of looks physically implemented in a processor, and the effective number of looks as determined by the statistics of the image data.