NERSC Technical Report no.305

THE ANALYSIS 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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EXECUTIVE SUMMARY

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

Several satellite images were received for analysis as a part of the Oil in Ice project. The main objectives are: 1- to determine which images cover the activities and 2- what can be seen in these images with regards to ships, oil, and ship tracks through ice. The total number of images received was 26: 10 Envisat ASAR wide swath images, 6 Radarsat-1 images, 7 Radarsat-2 images and 3 Cosmo-Sky-Med images. Only 11 images covered the activity with respect to date and time of the events. Object identification in these images 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 FEX09 field experiments cannot be seen with confidence 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) show most details in the ice. Radarsat-2 (ScanSAR Wide) and Envisat show fewer details due to the lower resolution than Cosmo-Sky-Med. Dual polarization does not seem to have any advantage. In addition, the noise here is high. In order to detect oil in ice by SAR images the ice concentration can't be as high as in this experiment. It is expected that ice concentration must be less than 50% for detection to be possible.

1. INTRODUCTION TO SATELLITE OIL SPILL MONITORING

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 the Pollution Control Authority 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 [2, 3, 4, 5, 6, 7].

The images have been integrated into the 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.

As Human activities in ice-infested waters increases, it is important to investigate if oil spills can be detected also in ice-infested waters, and if so, under what conditions.

2. DETECTION OF OIL SPILLS

The main sources of oil pollution are shipping accidents (Figure 1 illustrates the Prestige accident in 2002 and the extensive area it affected), accidental leakages 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 of both airborne and land based systems, substantial resources must be invested to establish an effective coverage of large 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 start to spill massive amount of oil (dark areas in the image).

2.1. MULTI-NATIONAL OIL SPILL MONITORING SERVICE

EMSA (European Maritime Safety Agency) 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 (Norwegian Clean Seas Association for Operating Companies) also monitors the Norwegian North Sea oil fields for discharges using satellite data. They co-operate with the Norwegian Coastal Authority by sharing with them the information derived from their monitoring activities. This allows the Norwegian Coastal Authority to direct their monitoring operations to other areas of the Norwegian coastline.

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

3. HOW SYNTHETIC APERTURE RADAR DETECTS OIL AT SEA

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 wave lengths 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 illustrate how three different sea states affect the energy reflected and the impact on the ability to detect oil on the surface.

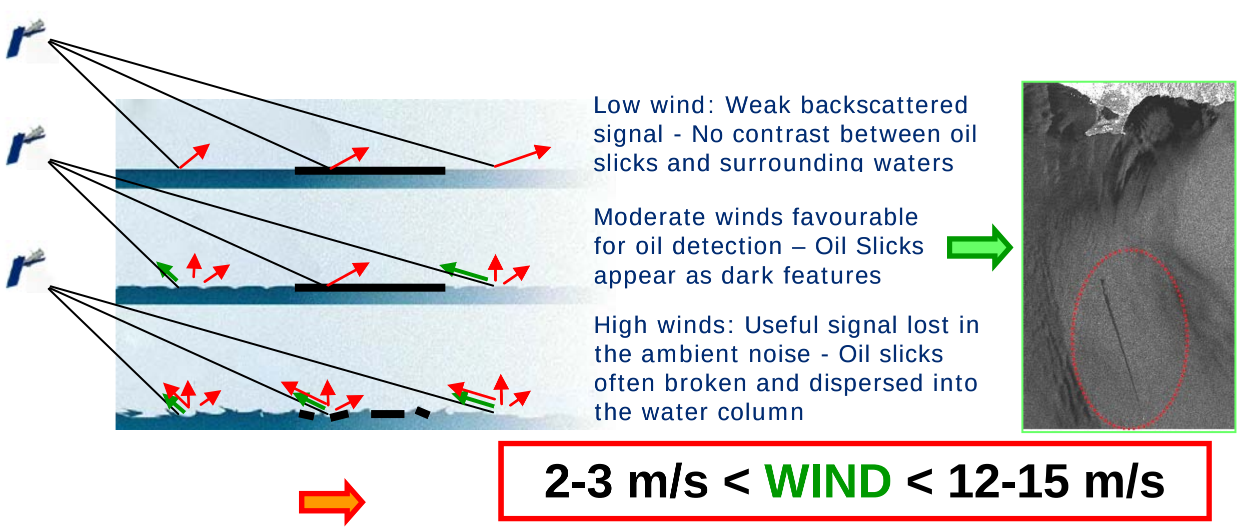


Figure 2: Different wind strengths determine the ease at which oil (black) can be detected.

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.

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. 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 Forland Sundet, and moving in a general easterly direction to Longyearbyen. If an oil spill occurred under similar ice conditions, it may be that the oil-covered area appears as a distinct area.

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 Forland Sundet 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 a 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.

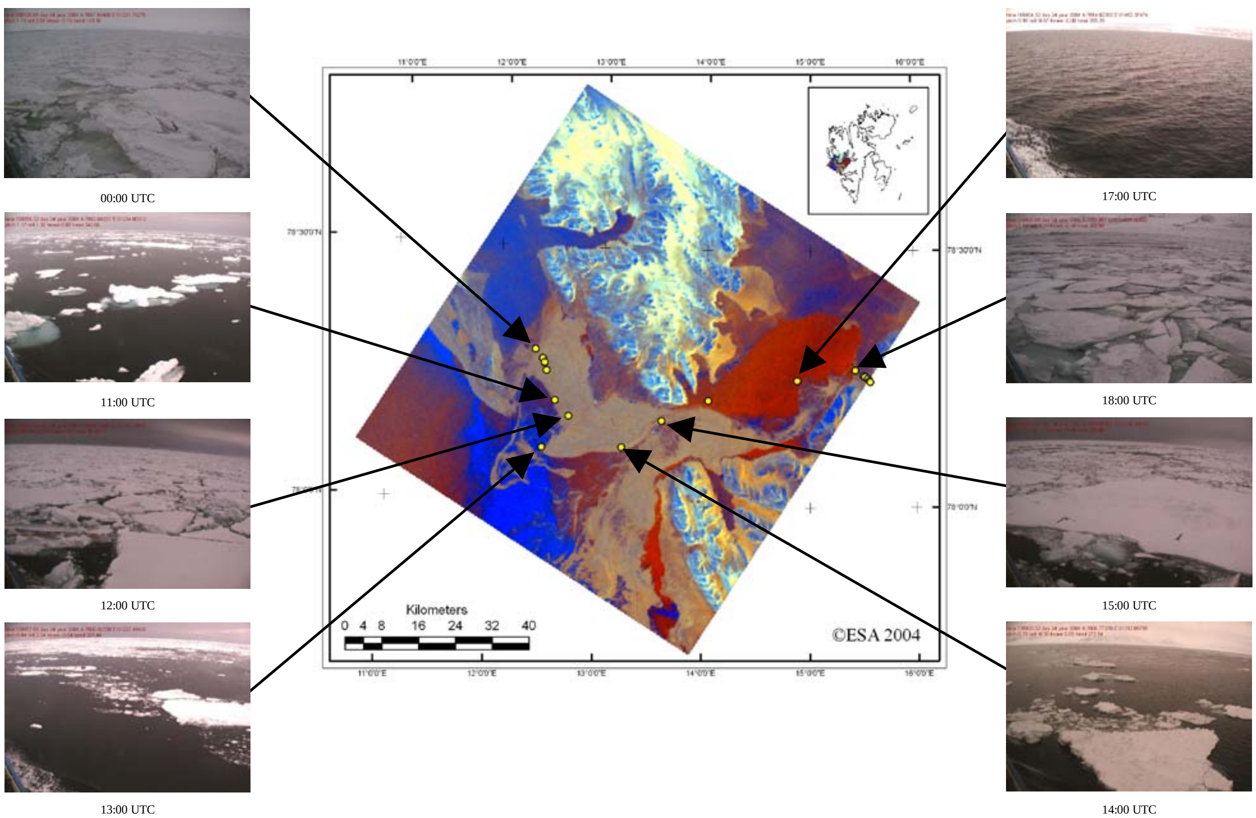


Figure 3: Constructed RGB (R=HH G=HV B=HV – HH) Envisat AP image taken on 24th April 2004, together with geo-located IceCam pictures. The yellow dots are hourly ship positions. © raw data ESA 2004/Processed by Hall/Norwegian Polar Institute

4. 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 to 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.

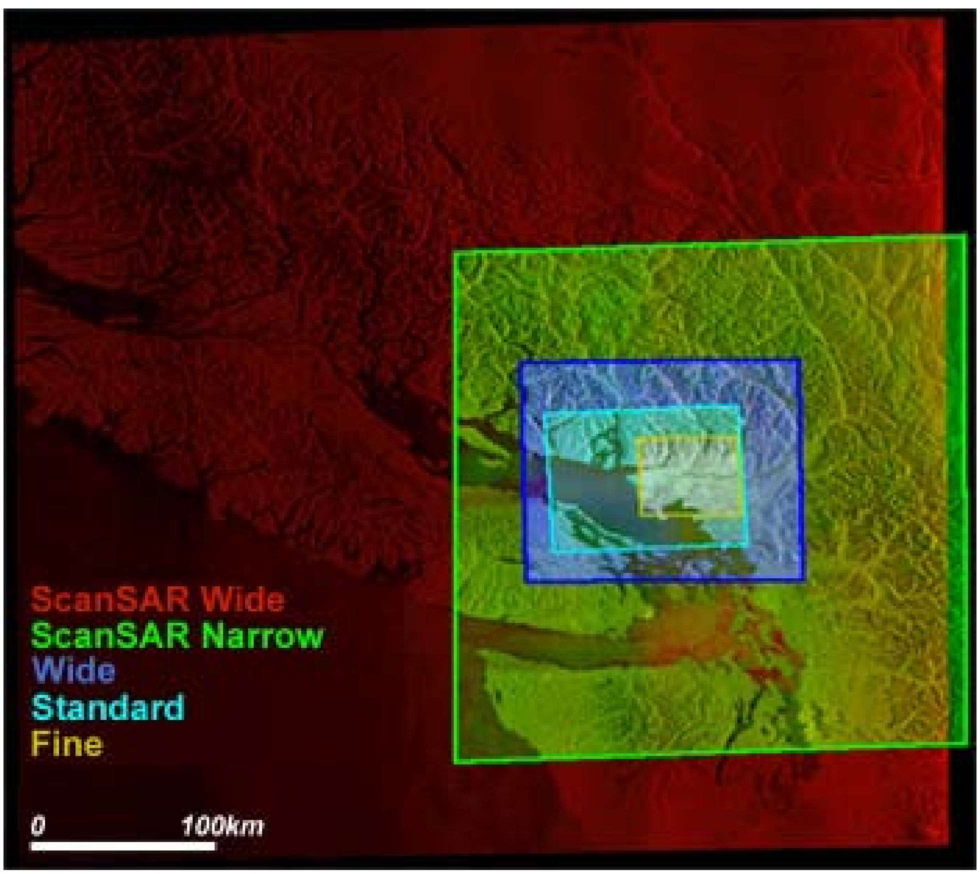


Figure 4. Ground coverage of various Radarsat-1 beam modes.

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).

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

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

4.2. RADARSAT-2

Radarsat-2 is follows on from 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 4 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 are 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 here are currently three identical satellites in the constellation with a fourth planned for launch in the 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.

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	

Table 2: Acquisition modes of Cosmo Sky Med

5. DETECTION OF OIL WITHIN ICE

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.

As stated earlier, grease ice appears very similar to oil on the surface of the water, when both seen by the naked eye and within a SAR image. Within images of oil released in grease ice, it may be possible only to identify areas of wave dampening. 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 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 open water within the pack ice and oil.

6. 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 15-35cm 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-Sky-Med
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
CosmoSkyMed	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-Sky-Med
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)

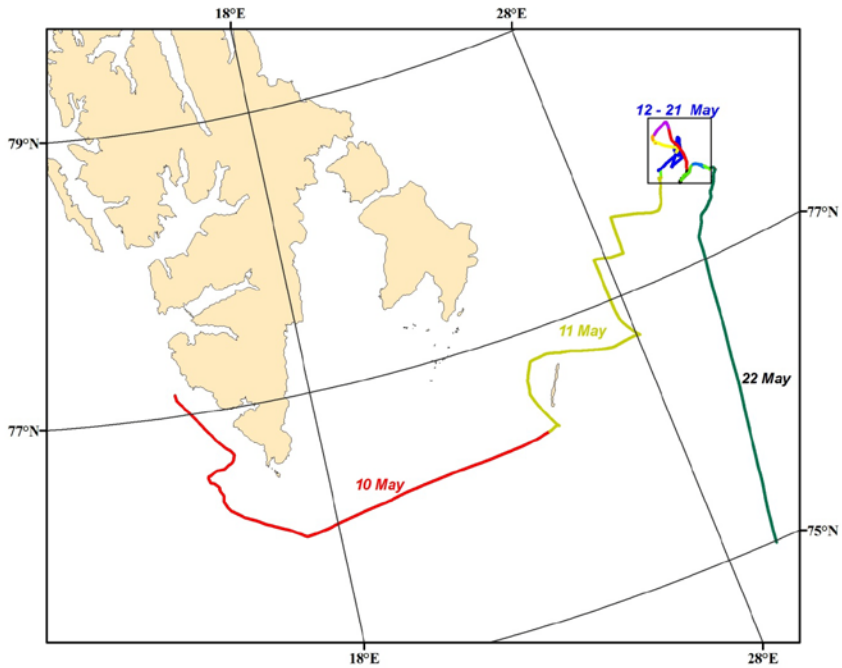
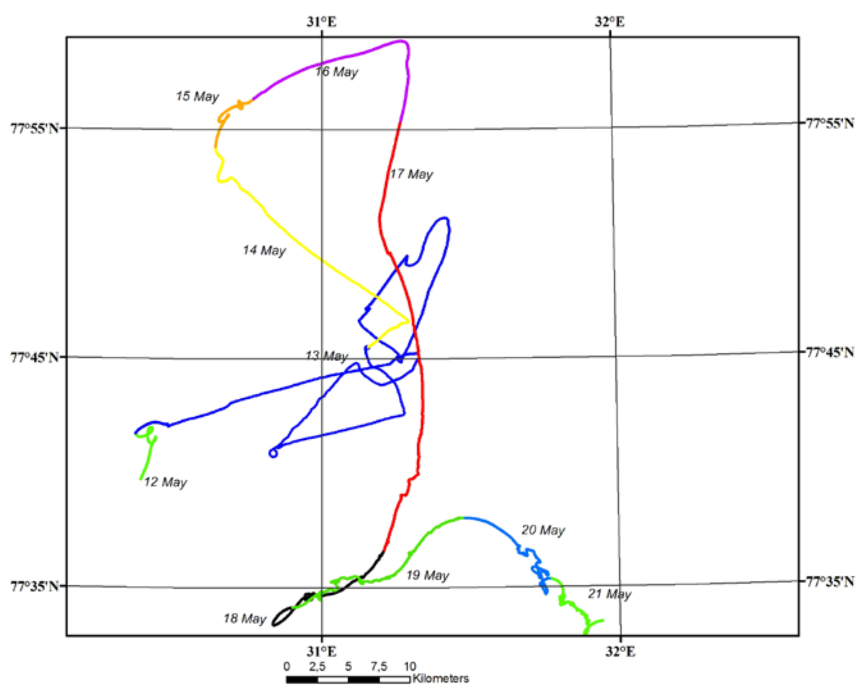


Figure 6: A map shows the Lance route from the 10 of May to the 22 May. The map below shows details route from the 12th May to the 21st May (The different colours indicates the day by day track of the vessel).



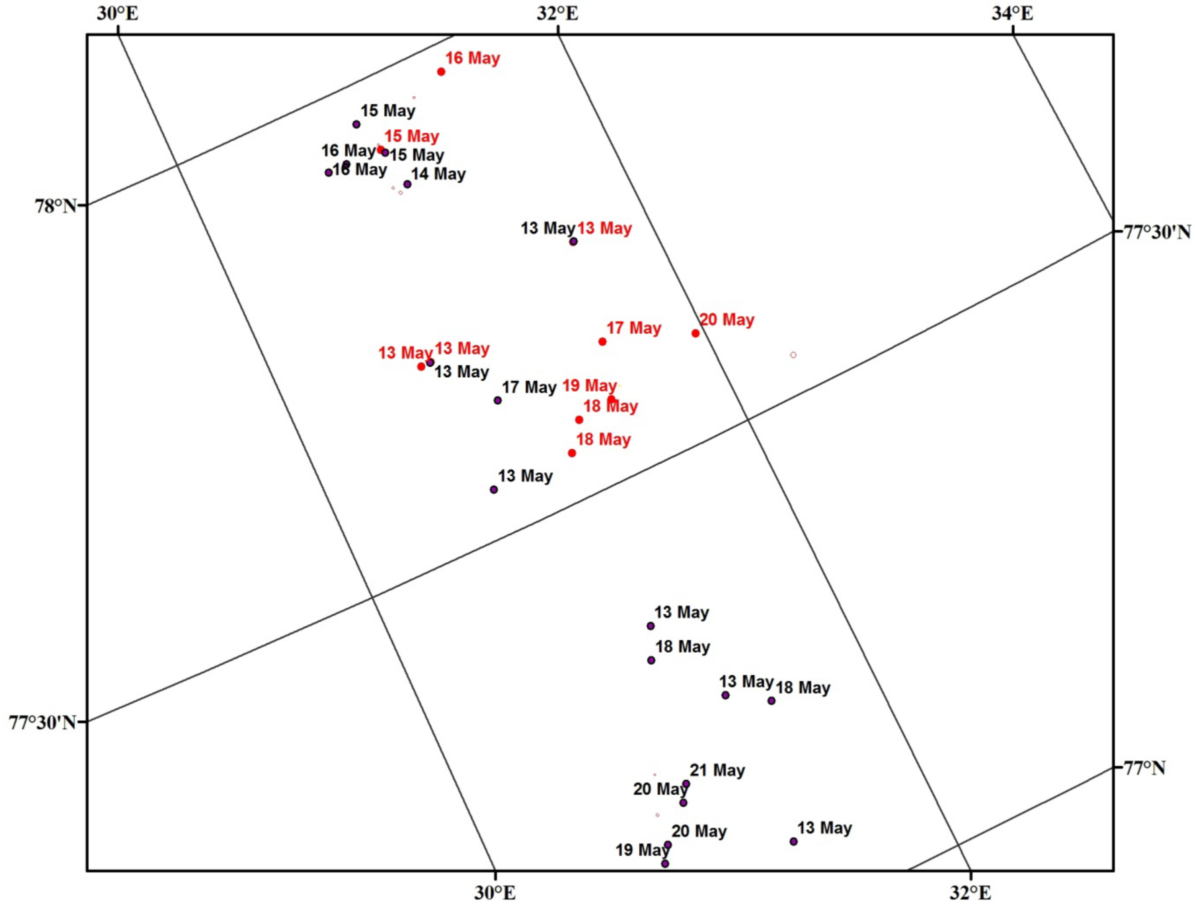


Figure 7 Map shows Lance and Svalbard locations during the experiment, Lance in red and Svalbard in black. Lance is stationary anchored to an ice flow in the ice and its location variation reflects the motion of the ice. Svalbard moves considerably in the ice.

Table 7: **Table shows date and time for the major events during the experiment.**

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

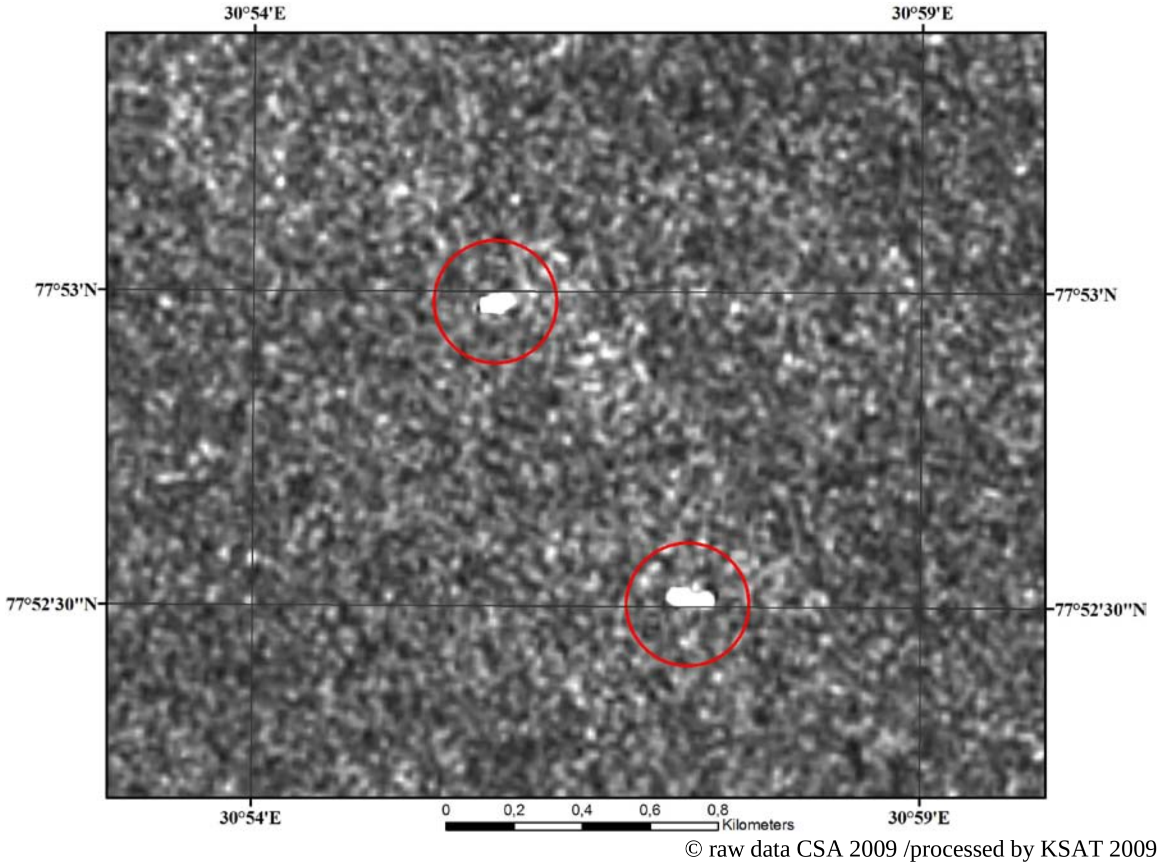


Figure 8 Radarsat-1 image, date 20090514, time 15:18:59. The image shows R/V Lance to the north and K/V Svalbard to the south. The ice edge is about 14 kilometres to the south, the ice situation is very close ice (80-90% concentration) with some leads filled with small ice floes. Small darks areas alongside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

Photo 1

Photo (1) above taken 20 minutes before the satellie image in figure 3. It shows the ice situation with Lance in the distance. There is bright return in a round area alongside 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

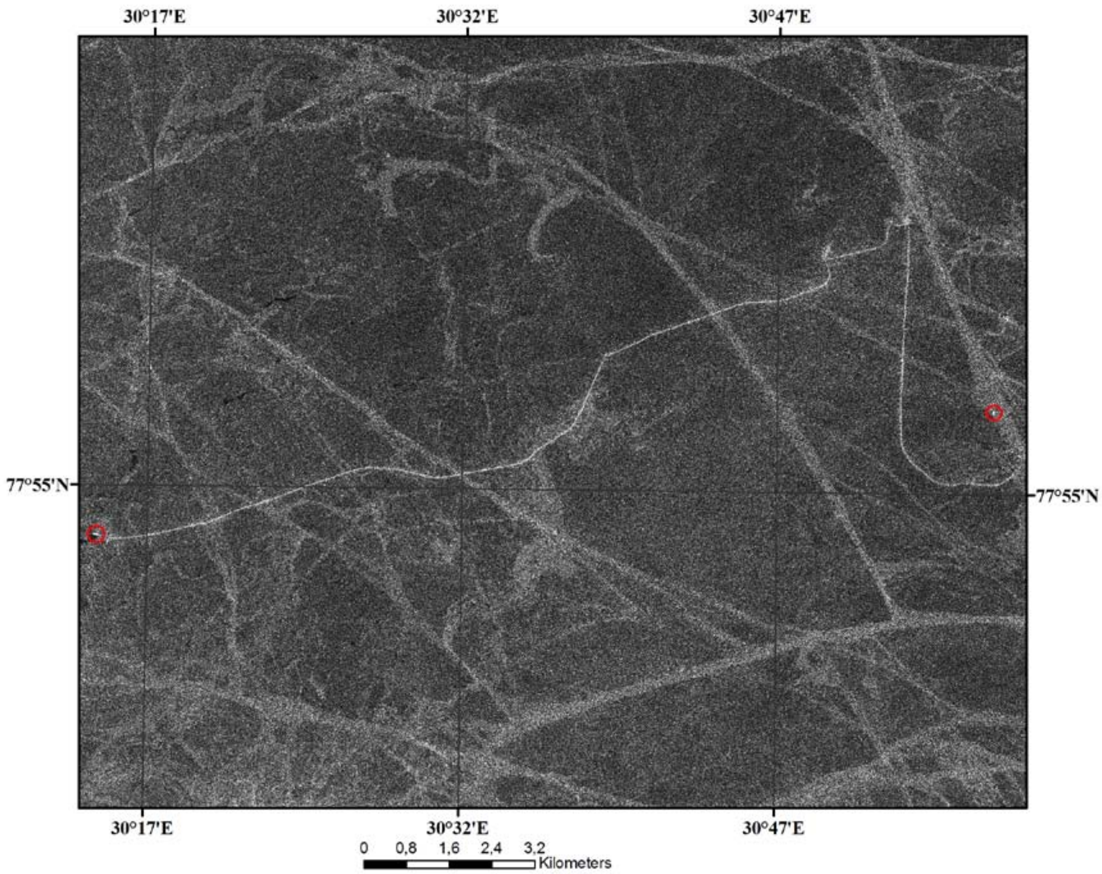


Figure 9 Cosmo-Sky-Med image, date 20090515; time 16:12:45. The image shows Lance within the red circle on the east and K/V Svalbard on the west. The track of K/V Svalbard is clearly visible in the ice.

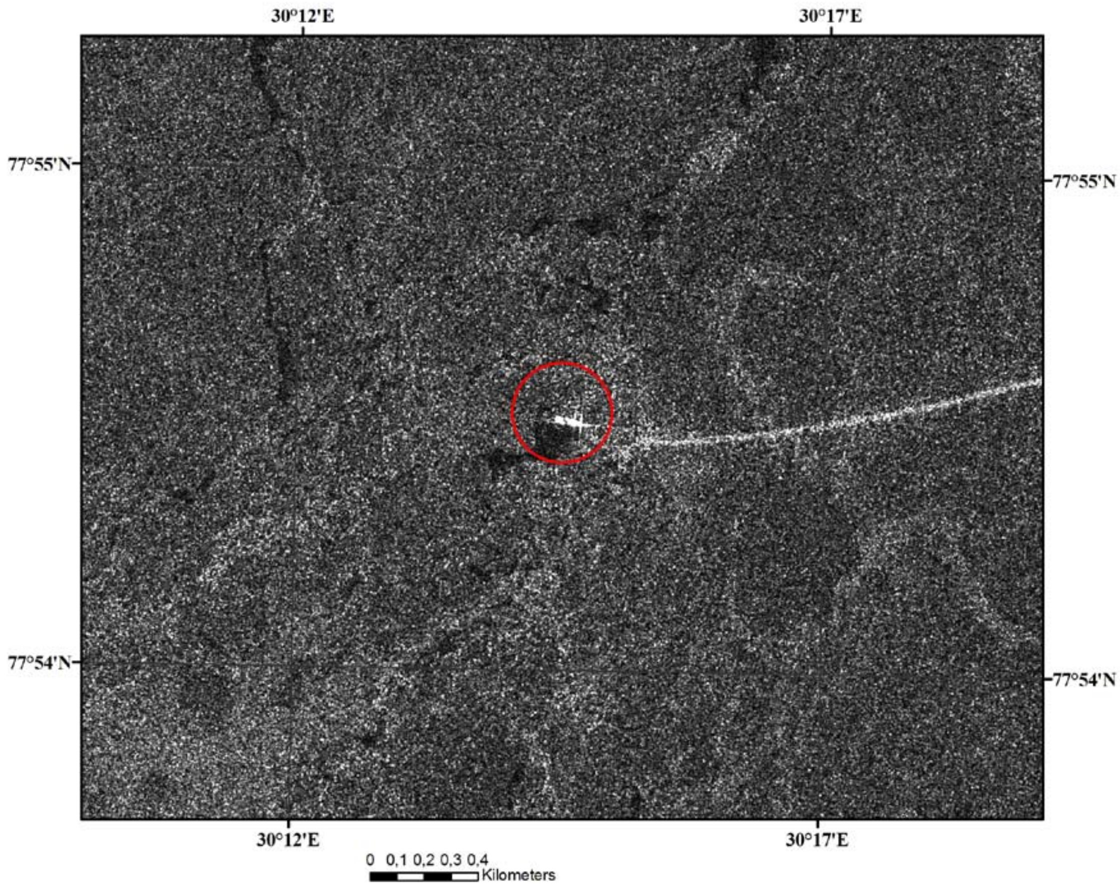


Figure 10 Subset from the previous image (Cosmo-Sky-Med image), date 20090515; time 16:12:45. The image shows K/V Svalbard within the red circle.

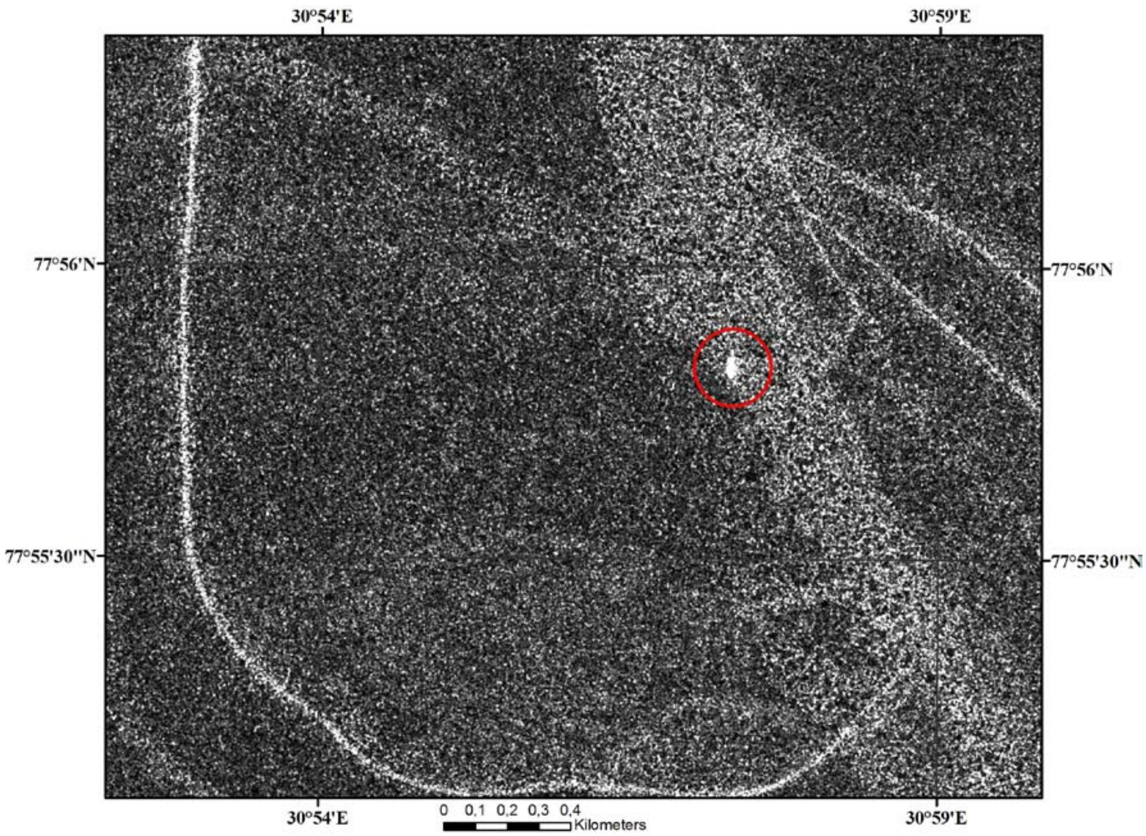


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Figure 11 Cosmo-Sky-Med image, date 20090515; time 16:12:45. The image shows Lance within the red circle, the ice situation is similar to the day before. The track of the ships is clearly visible in the ice. Svalbard is to the west of this sub image. The image is acquired 8 hours after releasing the oil from 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

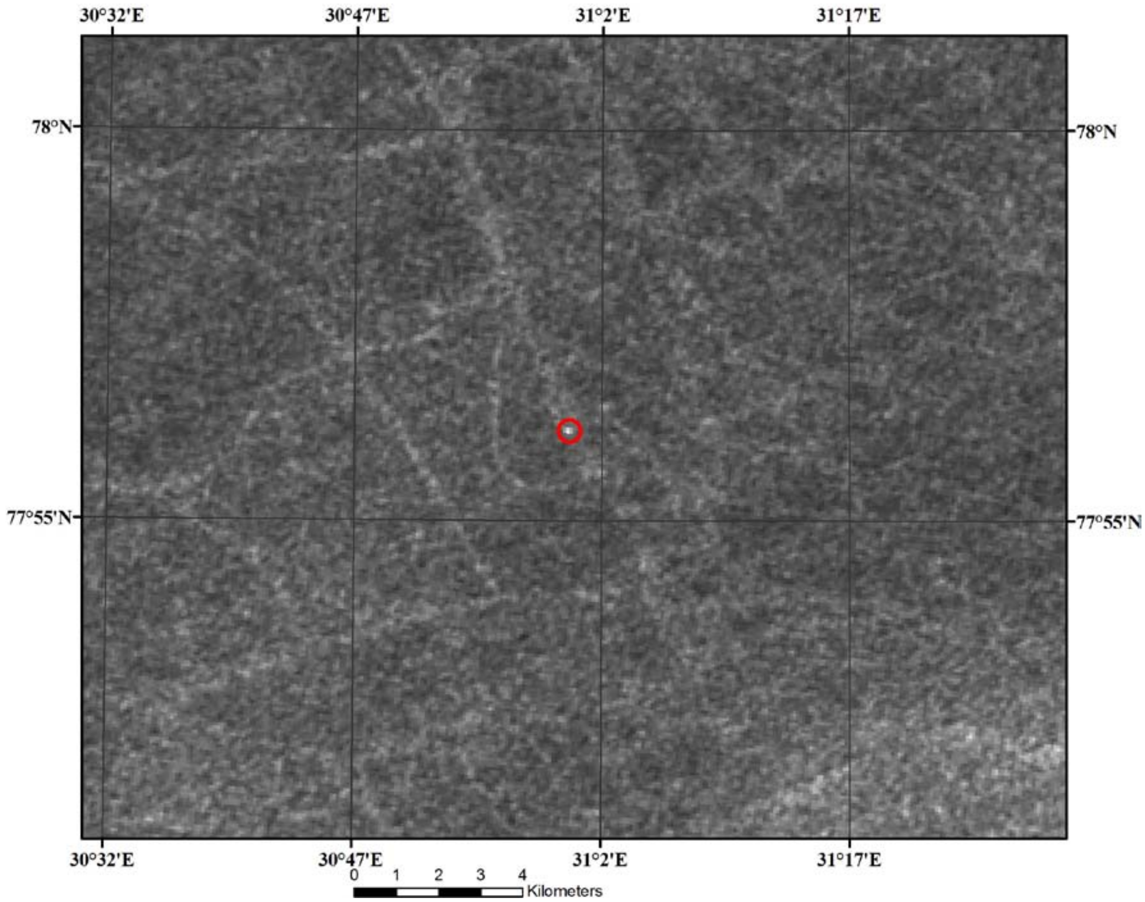

Figure 12 ASAR wide Swath image date 20090515, time 18:33:45. The image show Lance within the red circle. The tracks of the ships in the ice are still visible. The image was acquired more than 10 hours after releasing the oil.

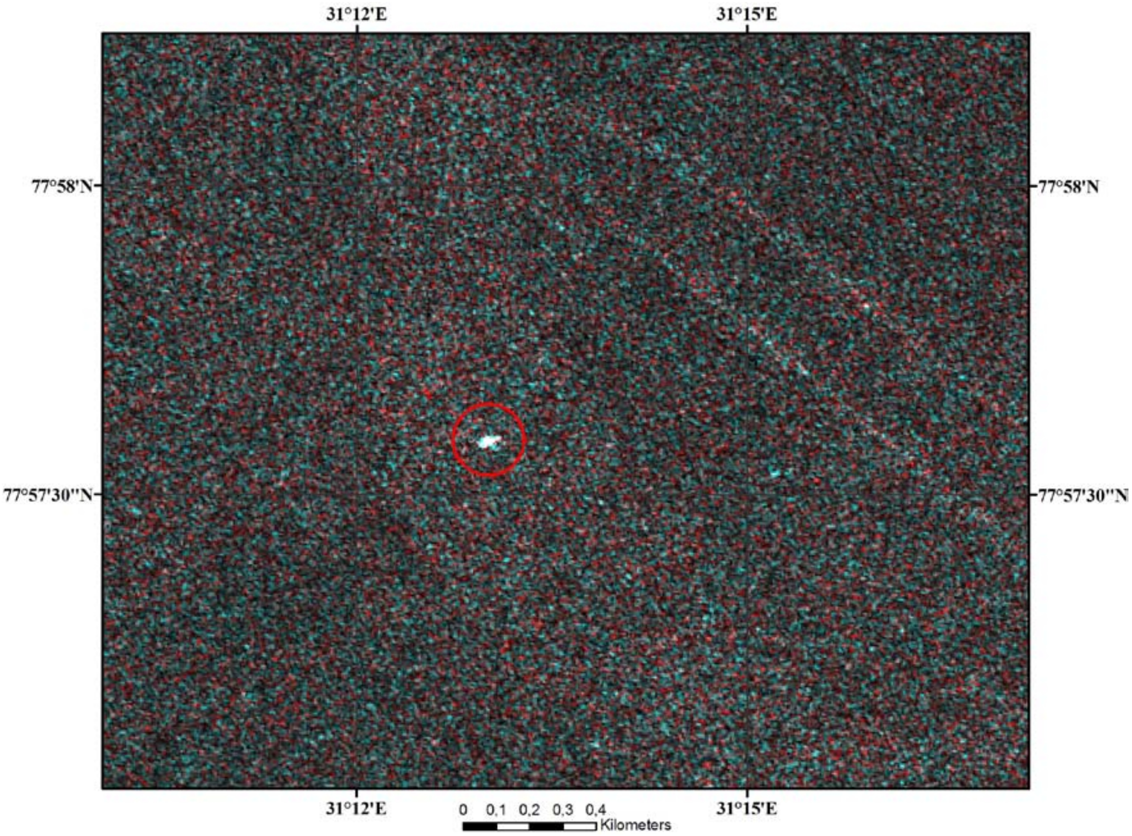

Figure 13 Radarsat-2 image date 20090516, time 05:16:04. The image is a dual polarization RGB composite of VV and VH, Lance appears white in the centre of the image inside the red circle. Two of the ships tracks are still visible in the ice (at upper right). The oil spill, in position within 100 m of Lance is not visible.

Photo (4) below is taken 7 hours after the above image, Taken from the Lance "Crow 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

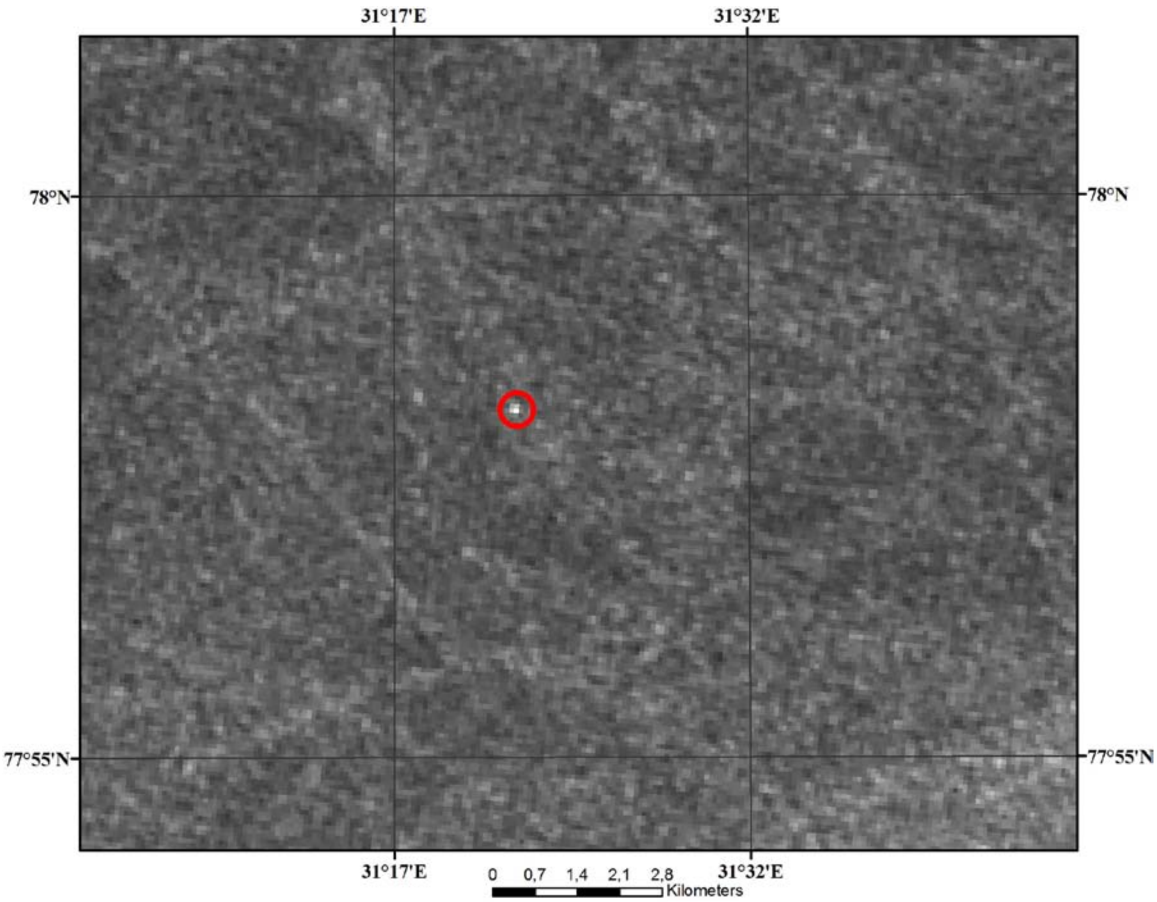

Figure 14 ASAR Wide Swath image date 20090516, time 09:45:31. The image shows Lance at the centre of the image within the red circle. The ships tracks in the ice are still faintly visible.

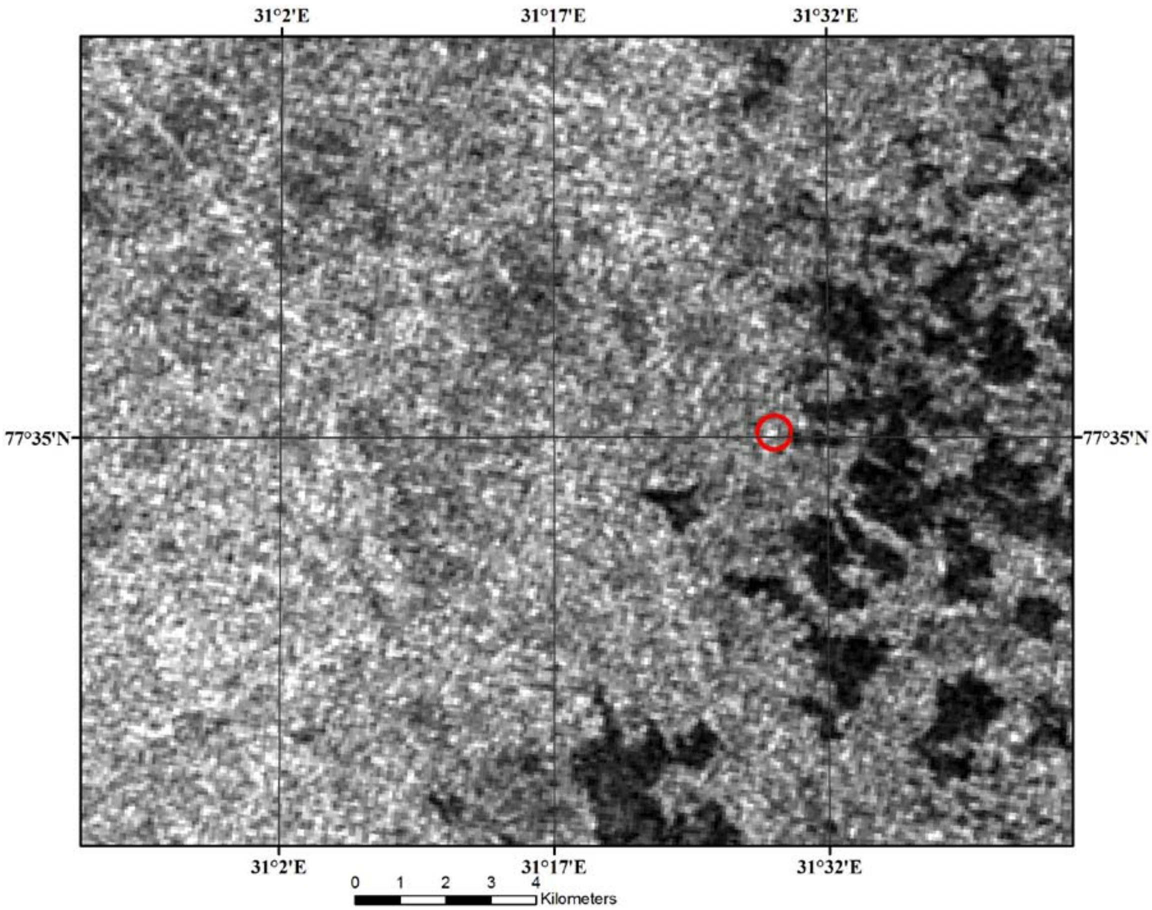

Figure 15 ASAR Wide Swath image, date 20090518, time 18:39:27. Lance is the small white spot inside the red circle. The ice situation is more open (about 50%) than the previous days, with large areas of open water to the east of the ship, indicating that it is closer to the ice edge. The ships tracks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

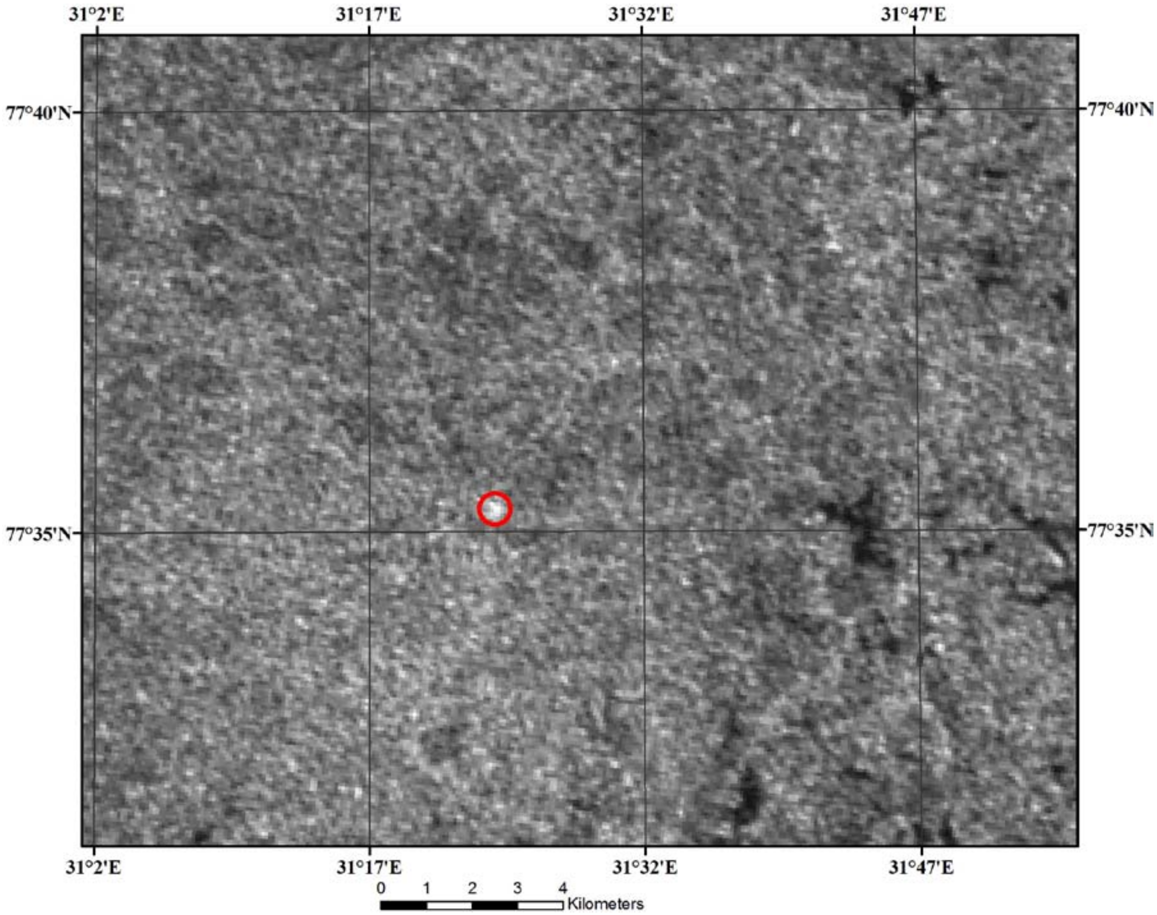

Figure 16 ASAR Wide Swath image, date 20090519, time 09:51.13. Lance appears as white spot inside the red circle. The ice situation is the same as in the previous image.

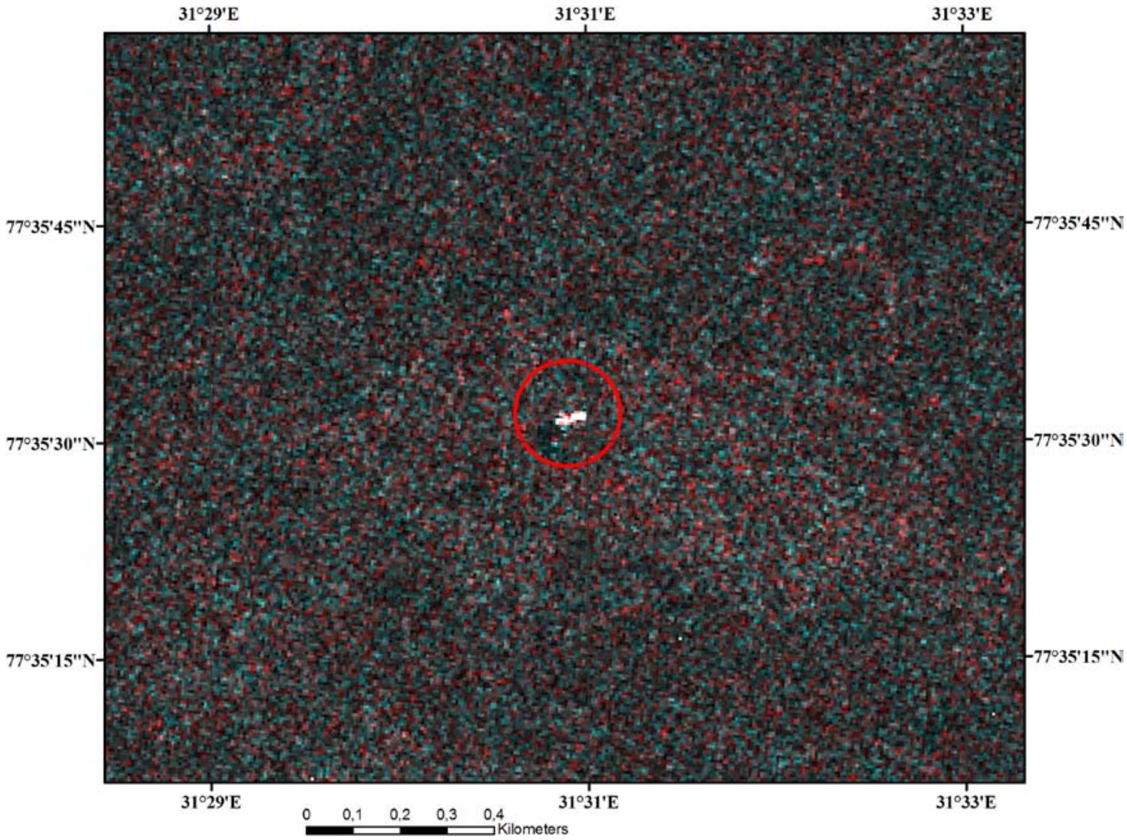

Figure 17 Radarsat-2 image, date 20090519, time 15:26:24. The image is a dual polarization, presented in RGB colour, Lance is clearly visible within the red circle. There is a dark area to the southwest of Lance, this can be either open water or possibly the oil spill. Photo (5) below is taken 3 hours before the image, from the Lance crow's nest showing the oil as brown areas.

Photo 5

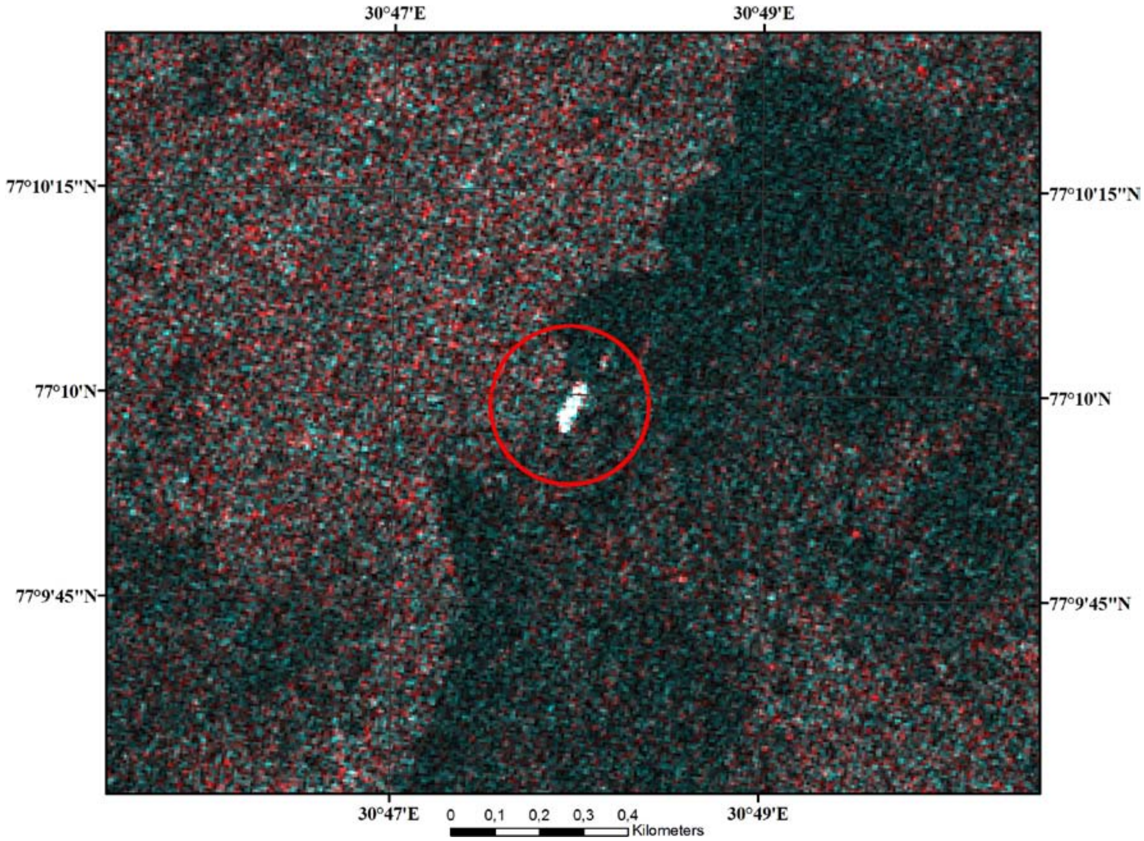

Figure 18 Radarsat-2 image, date 20090520, time 14:57:07. This is a dual polarization RGB coloured image. The ice is now very open (20%). The image shows Svalbard during oil spill burn activity.

Photo (6) below taken one and half hour after the image above shows the ship towing the boom skimmer clearly visible on the satellite image.

Photo 6

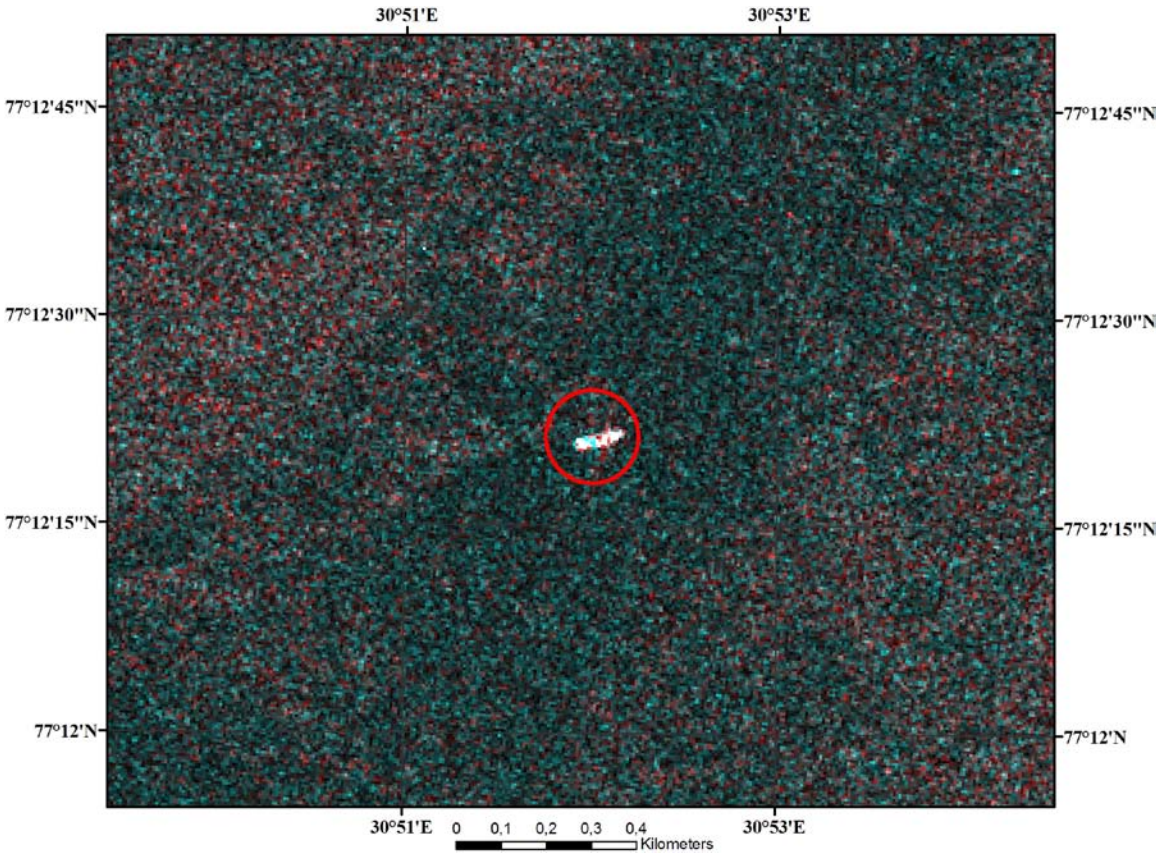

Figure 19 Radarsat-2 image, date 20090521, time 04:30:13. Dual polarization RGB coloured image shows Svalbard within the red circle. The oil has now been recovered.

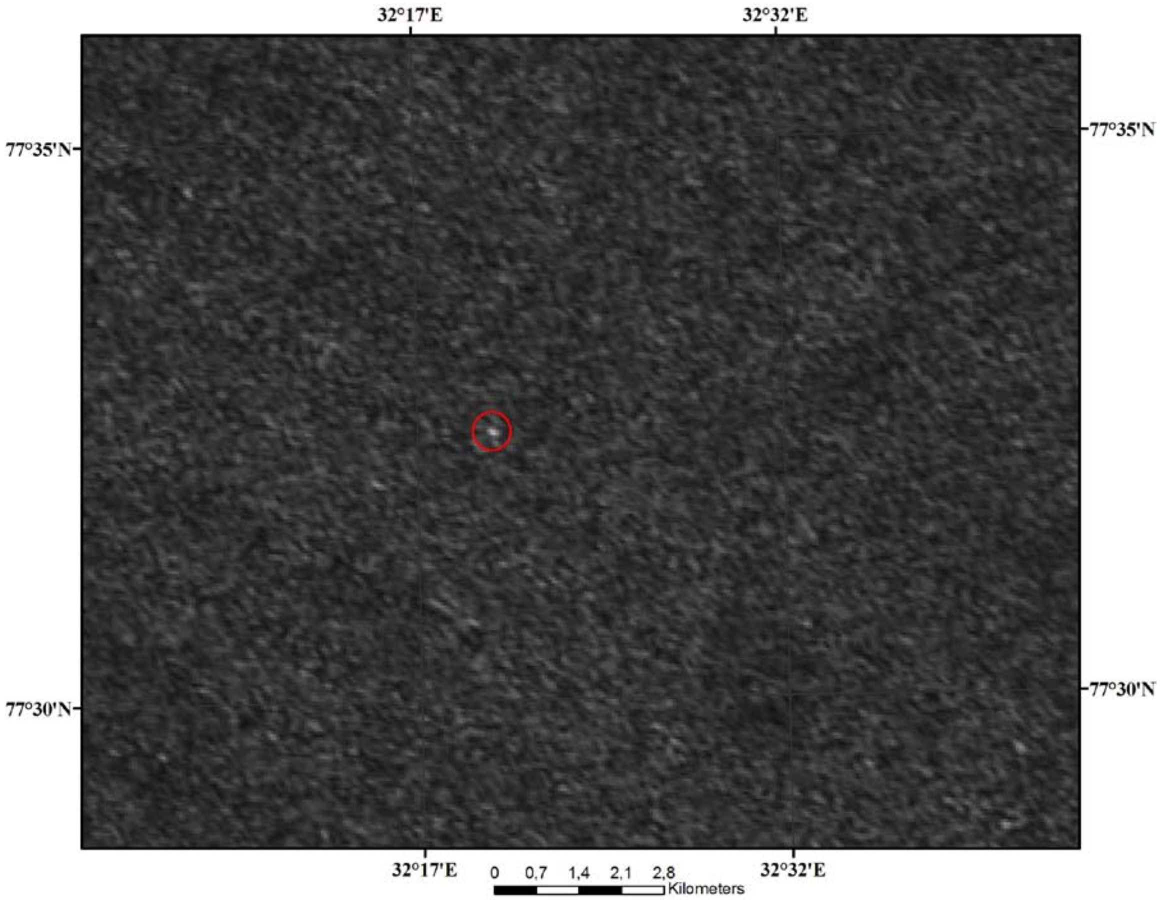

Figure 20 Radarsat -2 image, date 20090522, time 05:40:49. Lance appears as a white spot within the red circle. This is the last day in the ice, the ship left the area later that day.

7. CONCLUSION

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 state within the area of operations, both for ships and oil rigs. If the danger of a possible ice collision is known then hopefully a collision can be avoided.

The aim of the JIP Oil in Ice project was first and foremost to determine whether or not oil released into ice-infested waters can be detected.
However, 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 area uncertainty did bring an element of realism to the experiment in that if this was a real accidental spill then under current practices very high resolution (<10m spatial resolution) would not be planned over the ship's location. Medium resolution (ca. 70m spatial resolution) images covering up to 400 x 400 km, would be available for two reasons: firstly the national ice charting agencies use these images to produce the daily ice charts; and secondly the same set of images are collected to develop a long-term data series for climate studies.

Rapid ordering, defined as within 24 hours notice, 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 resulted in that the projected positions for the following week no longer matched the actual positions. A significant reminder that accidents do not occur first thing on a Monday morning under clear blue skies.

Automatically reported Real-time positioning of the ships before 08:00 UTC each morning might allow more images to be acquired over the site. If the transmission of the position was automatic, then it would remove the reliance on a crew member to send the position, which may be forgotten in stressful conditions.

In answer to the question as to whether or not oil can be detected in ice-infested waters, this experiment has shown that it is probably impossible when the ice concentration is moderate to high. It may be possible in low (1-3/10ths) ice concentrations, particularly in the summer months when new ice does not form. The wind strength and direction are also determining factors.

7.1 RESCUE SCENARIO

If this had been an accident the rescue ship(s) would have access to all available images. The medium-scale images would allow them to identify the quickest, safest route to the incident site. As they approached the site they would also use the very high resolution images to gain detailed information of the surrounding ice pack. At the same time the medium-scale images would be continually used to monitor the changing ice conditions, particularly if a storm centre was passing through the region. The high-resolution images would not provide the same information about the ice pack due to the smaller coverage area.

7.2 THE FUTURE

Currently, there are very few regulations in place for operations in ice-infested waters. However, on-going discussions at multiple levels may change this situation. In particular, regular reporting of a ship's position may become compulsory. Of equal importance is that ships and oil rigs will in the future be required to obtain up-to-date ice and weather information, especially beyond the visible horizon. This though may be voluntarily introduced due to the potential savings in fuel consumption, reduction in damage (both minor and major) due to unnecessary ice breaking, and reduction of risk to sinking. Further, oil rigs may be de-coupled from their connections to the sea floor less frequently due to ice as better ice management practices will be in place due to better 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 which could result in a survey being completed with the minimum number of expeditions. This would be a significant saving to the exploration company and allow more surveys to be completed as ship-time would be maximized.

Currently, it is assumed that if an accident occurs in ice infested waters, extra images will have to be ordered, acquired and delivered at short notice. This will depend on the possibility of ordering images for the specific location at short notice, mainly dependent on satellite configurations and orbit details at the time of accident. This will be expensive, if technically possible. However, if "best practices" mean that daily medium resolution images are acquired to aid ship navigation, together with weekly acquisitions of very high resolution images to aid navigation during specific operations, means that additional images may not have to be acquired and the available images are made available to the rescuers.

In the same way, platforms will also acquire significant amounts of satellite data as part of their ice management system.

There are also questions raised related 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 on-going 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 and is not reporting her position may trigger an inspection by very high resolution satellite imagery to ensure there is no pollution.

7.3 DROP SONDES

There has been development of UAV's (Unmanned Aerial Vehicles) as well as the development of drop sondes which can analyse a suspect oil spill on site and transmit the results back to the operation's centre is on-going. The same transponder can be used as a tracking device for the oil spill. The deployment of a tracker from the air can confirm the presence of a spill safely, and then track the location of the spill even if the ice consequently converges, forcing the oil under the ice pack. In addition the automatic tracking of the ice floes should be operational in the near-future which will consider the ice pack converging, diverging and rotating and allow the affected area to be tracked over time. This could increase the amount of spilled oil that can be recovered.

8 RECOMMENDATIONS:

- One satellite system dedicated to large scale monitoring of the ice conditions. This is particularly important as the biggest user of SAR data are the National Ice Services.
- 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 are needed. The CosmoSkyMed constellation could possibly fill this role.
- Collaboration between different users to ensure request conflicts are minimised. The example of how the north Sea is monitored for oil spills would be a good starting point.
- 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 would allow high resolution images to be acquired over the test in dual-polarization. Both organizations agreed to the request.
- The use of satellite images may be more suited to preventing accidents rather than supporting rescue missions and/or clean-up missions. If ships regularly use satellite images, together with weather forecasts, to determine where the ice conditions are over the horizon, they may avoid accidents, and at the same time save time and money. There is evidence from a variety of sources that indicate using real-time satellite images can reduce both journey time and fuel consumption from up to 20%.

9 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 for (or 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. While it was proved impossible to detect oil in ice, the experience gained in ordering and acquiring the data proved invaluable. In the event of an accident in polar waters, KSAT will make its best effort to make a sufficient number of timely satellite images available to the rescuers.

APPENDIX KONGSBERG SATELLITE SERVICES OIL SPILL SERVICE

The KSAT oil spill and ship detection service chain is based on SAR data from the European Envisat and the Canadian Radarsat satellites. The service chain (figure 19), 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.

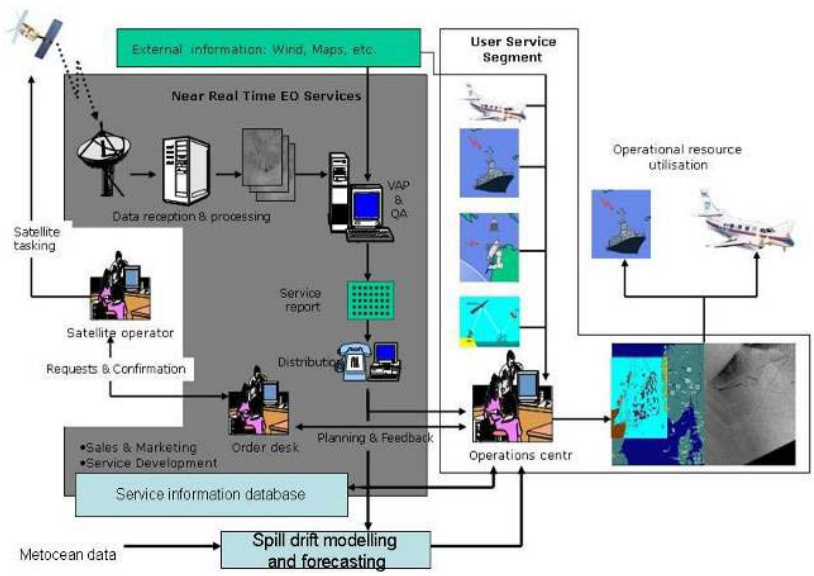

Figure A.1: KSAT oil and ship detection service

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 powerful 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 [3,4,5,6].

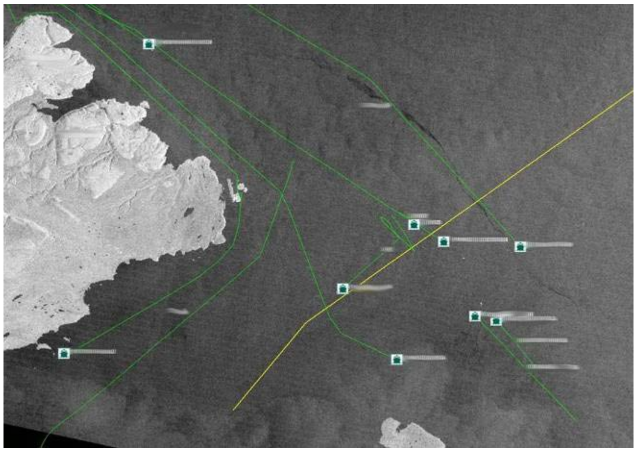

Figure A.2: Example of a SAR image with an oil spill (upper right part), overlaid ship identification from AIS.

Over time users have become more experienced in utilizing satellite 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 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 21).

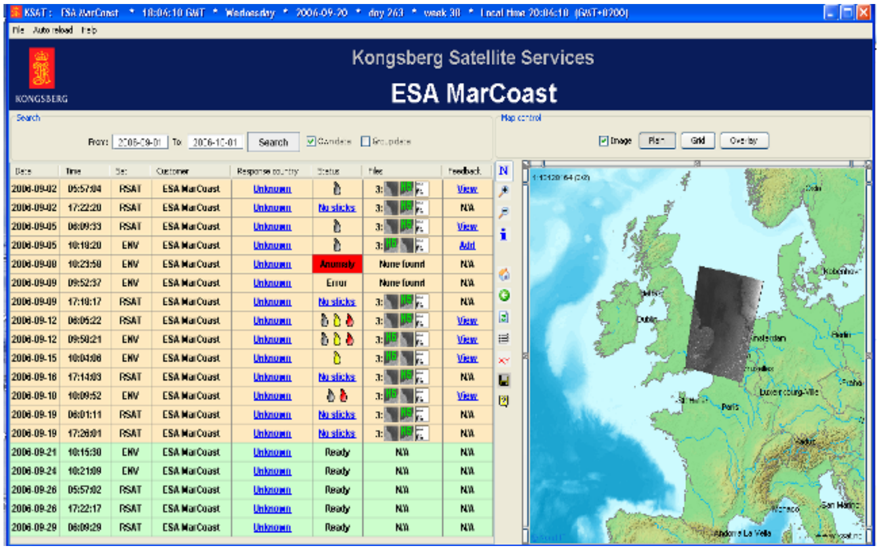

Figure A.3: KSAT service information web-server user interface.

Access to the acquisition plans is important for co-ordination with aerial surveillance The users have an aircraft 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 for KSAT in order to improve service performance.

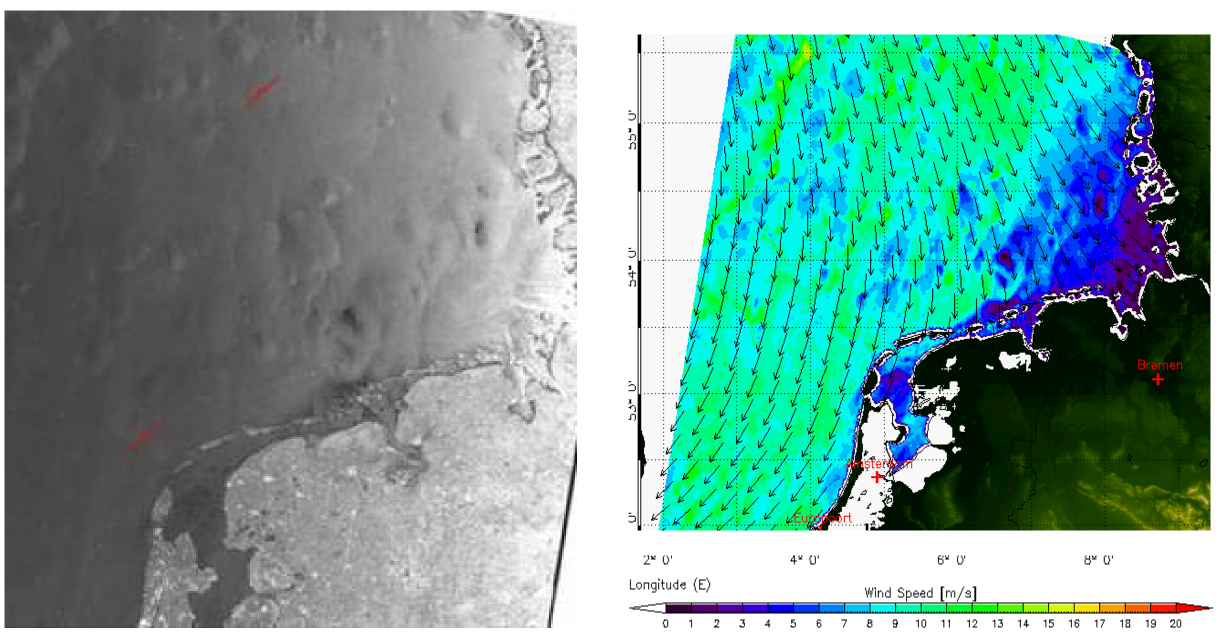

Figure A.4: Example of multiple-use of a SAR scene in the North Sea service area, both for oil spill/ship (red areas, left) and wind information (right).

Verification of the reported spills by the users is based on operational decisions. This consequence is that no user feedback has been obtained for 43 % of the totally reported possible spills. 9 % of the reported spills have been confirmed by user verification. For 13 % of the reported spills could nothing could be observed by the users during the verification activities.

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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. Speckle may be reduced, at the expense of resolution, in SAR processor by using several looks. 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. *Multiple looks* may be generated by averaging over *range* and/or *azimuth* resolution cells. Also the number of looks can be increased by pixel averaging. 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.