Airborne Oil Pollution Observation: Comparison of SLAR and SAR Capabilities together with Other Instruments

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Abstract

Oil spill reconnaissance has an important role in a successful oil recovery operation: locating the thickest part of the oil is the key for efficient response activities. This is vital especially in small and vulnerable sea areas such as the Baltic Sea where mechanical oil recovery has been adopted as the primary response strategy. The oil detection capability of the new sea surveillance radar on board the Finnish patrol aircraft was tested in NOFO Oil on Water 2014 exercise in Norway. During the exercise, several oil discharges were released to the sea and then observed with all of the aircraft instruments. The experiments demonstrated that airborne Synthetic Aperture Radar (SAR) mode in a modern Sea Surveillance Radar has a good capability to detect 0.4-20 m^3 oil spills from at least 20 nautical miles away from the target area. However, there are several operational and scientific considerations that will need further investigation and discussion. In our view, Side-Looking Airborne Radar (SLAR) and Infrared/Ultraviolet (IR/UV) scanner still remain the most important instruments when giving airborne surveillance support to an oil response operation.

Introduction

Maritime patrol aircraft are today used in most European countries for detection, monitoring and documentation of oil spills on the sea surface. The established basic sensor suite traditionally consists of Side-Looking Airborne Radar (SLAR) for wide area coverage, Infrared/Ultraviolet (IR/UV) scanner for detailed mapping of the spill and cameras for documentation of activities on the surface. Satellite images, especially Synthetic Aperture Radar (SAR) images are widely and frequently used to complement airborne oil surveillance.

Maritime patrol aircraft are in many countries also used for monitoring coastal waters for other purposes than oil, for example, border patrol and fishery surveillance. This is why the instrument set has to be designed so that it serves all the multiple functions carried out by the aircraft.

The Air Patrol Squadron of the Finnish Border Guard operates two Dornier 228-212 in their fleet of 14 aircraft. The Dornier 228 is a twin-engine turboprop commercial airplane that has the capacity to carry 19 passengers. The Finnish Border Guard is the only governmental organization in Finland that operates civilian patrol aircraft and, therefore, in addition to its main duties of border surveillance and maritime search-and-rescue, the aircraft also assists other authorities with their tasks. These tasks include maritime environmental surveillance and oil response operations supporting the competent governmental oil pollution response authority, the Finnish Environment Institute (SYKE). The airplanes fly daily from their base in Turku with environmental surveillance in the Baltic Sea region being one of their main tasks.

The Finnish Dorniers have been modified to support the multipurpose flights, however, focusing mainly in maritime surveillance and search-and-rescue. The equipment on board was completely renewed in 2013 and all new state-of-the-art instruments were fitted: a Side Looking Airborne Radar (SLAR), sea surveillance radar with Synthetic Aperture modes (SAR), Infrared/Ultraviolet (IR/UV) scanner, Electro-Optical Infrared camera system (EOIR) and both video and still photo digital cameras along with other instruments designed for border surveillance and communications. The management of missions and the control of all the equipment on board are integrated into a mission system called MSS6000, built by S&T Airborne Systems.

During patrol flights, the tasks are run by two mission operators working from identical consoles in the cabin. The tasks at hand determine how and which instruments are used. In maritime environmental surveillance the SLAR is mainly used to detect spills and calculate their size. The IR/UV can also be used to calculate the area of spills, especially small ones. Because IR is effective in determining the thickest parts of an oil slick, it is used to help guiding the oil response efforts at sea. The sea surveillance radar is mostly used to detect unknown vessels whereas EOIR helps to confirm them visually. As there is no airborne state-of-the-art instrument available to determine the exact amount of oil in a specific spill, visual observation together with the size of the spill are used to calculate an estimate of the volume of oil a spill.

The sea surveillance radar, SELEX Seaspray 5000, on board the surveillance aircraft has an operational mode for producing SAR images ('strip SAR mode', according to the manufacturer). However, experience of using this capability of sea surveillance radar for airborne oil spill detection is not well established in the literature. Therefore, testing surveillance radar's SAR mode was one of the main interests when Finland got the opportunity to fly over real oil spills released to the North Sea.

The Finnish Border Guard Dornier 228 patrol aircraft can be seen in Figure 1. The main instruments for oil spill detection are marked in the image.

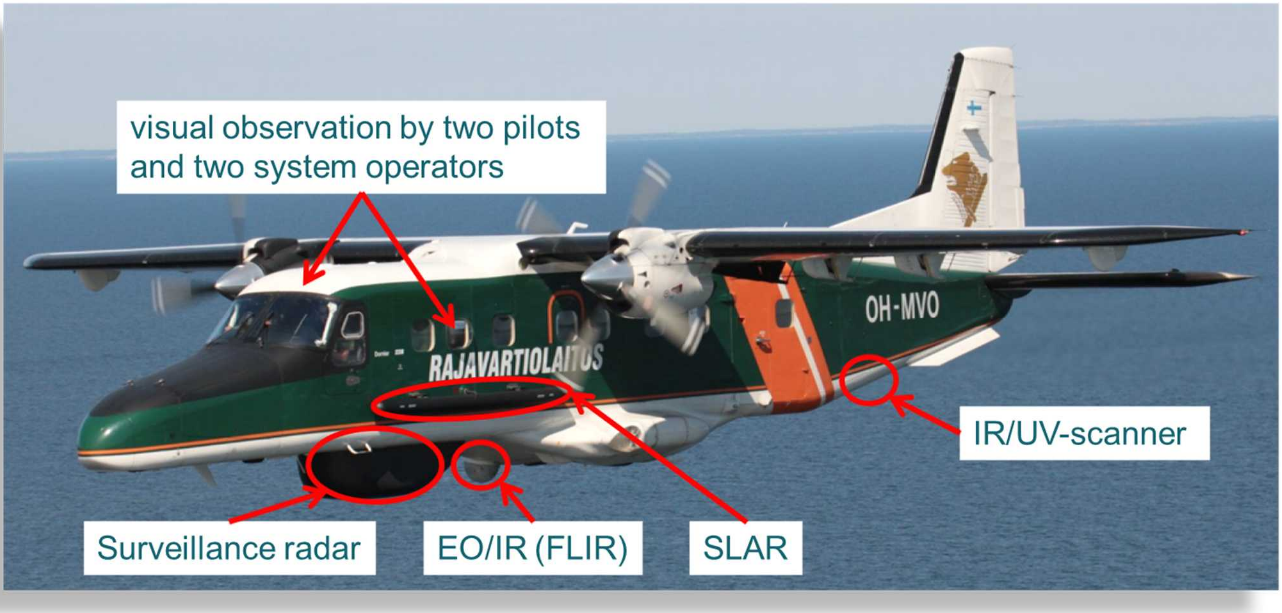

Figure 1. The Finnish Border Guard patrol aircraft Dornier 228-212 and the main instruments for oil detection and documentation.

SAR and SLAR comparison: experience from NOFO OOW 2014 exercise

Overview of NOFO exercise flights

Norwegian Clean Seas Association for Operating Companies (NOFO) organized the annual Oil on Water (OOW) oil response exercise 16-20 June 2014. The purpose of the exercise was to verify new oil response equipment concepts on the open sea with real oil releases. During the exercise, oil pollution aircraft from several countries were documenting the experiments and, also, testing airborne equipment and their capability to detect oil. [*1*]

Finland participated in the exercise with one surveillance aircraft. During the exercise, Finland flew three flights in the exercise area, on 17 and 18 June 2014. The main focus of the Finnish flights was to, in addition to documenting the ongoing exercises on the sea level, also test the SAR mode of the surveillance radar on real oil spills and to compare the results with SLAR images. Table 1 summarizes schedule, oil releases and detailed information on acquired SAR images during the Finnish flights.

Finnish flights in NOFO exercise 2014

Flight Number	Date and Time	SAR	Distance	Altitude	Oil releases
Flight #1	17.6.2014 15:50-17:30z	SAR#1	17 nm	5968 ft	(0,4 m3 palm oil during night - old release) 50 m3 emulsion in different locations, first releasee 12:10z
Flight #2	18.6.2014 09:00-10:35z	SAR#1	20 nm	8344 ft	(5 m3 emulsion during night - old release) 25 m3 emulsion 10:30z
		SAR#2	20 nm	8314 ft	
Flight #3	18.6.2014 15:10-16:30z	SAR#1	20 nm	7309 ft	5 m3 emulsion about 14:00z
		SAR#2	27 nm	7311 ft	
		SAR#3	20 nm	7318 ft	

Table 1. Finnish NOFO 2014 exercise flights.

As indicated in Table 1, there was fresh oil spills on the water only during two of the flights, Flight#1 and Flight#3. One SAR image was taken during Flight #1 and two SAR images during Flight #3. At the end of Flight#2, at 10:30z 25 m3 of oil was released to the water. This was documented with IR/UV scanner but, due to lack of flight time, not with SAR. However, two SAR images were taken in the beginning of Flight #2, documenting the older oil releases from previous experiments still floating on the water surface.

During the 2014 NOFO OOW exercise flights, the SAR and SLAR images of the oil spills were of similar quality, and the SAR was able to detect oil almost as well as the SLAR. In the following section, SAR images taken during the exercise are shown and described.

Flight #1, 17 June 2014

During Flight #1 several SLAR images and one SAR image were taken of the 50 m^3 and old 5 m^3 oil releases on the water surface. On both of the radar instrument images oil was clearly visible, see Figure 2. Both SLAR and SAR images were taken South of the oil release, see Figure 2.

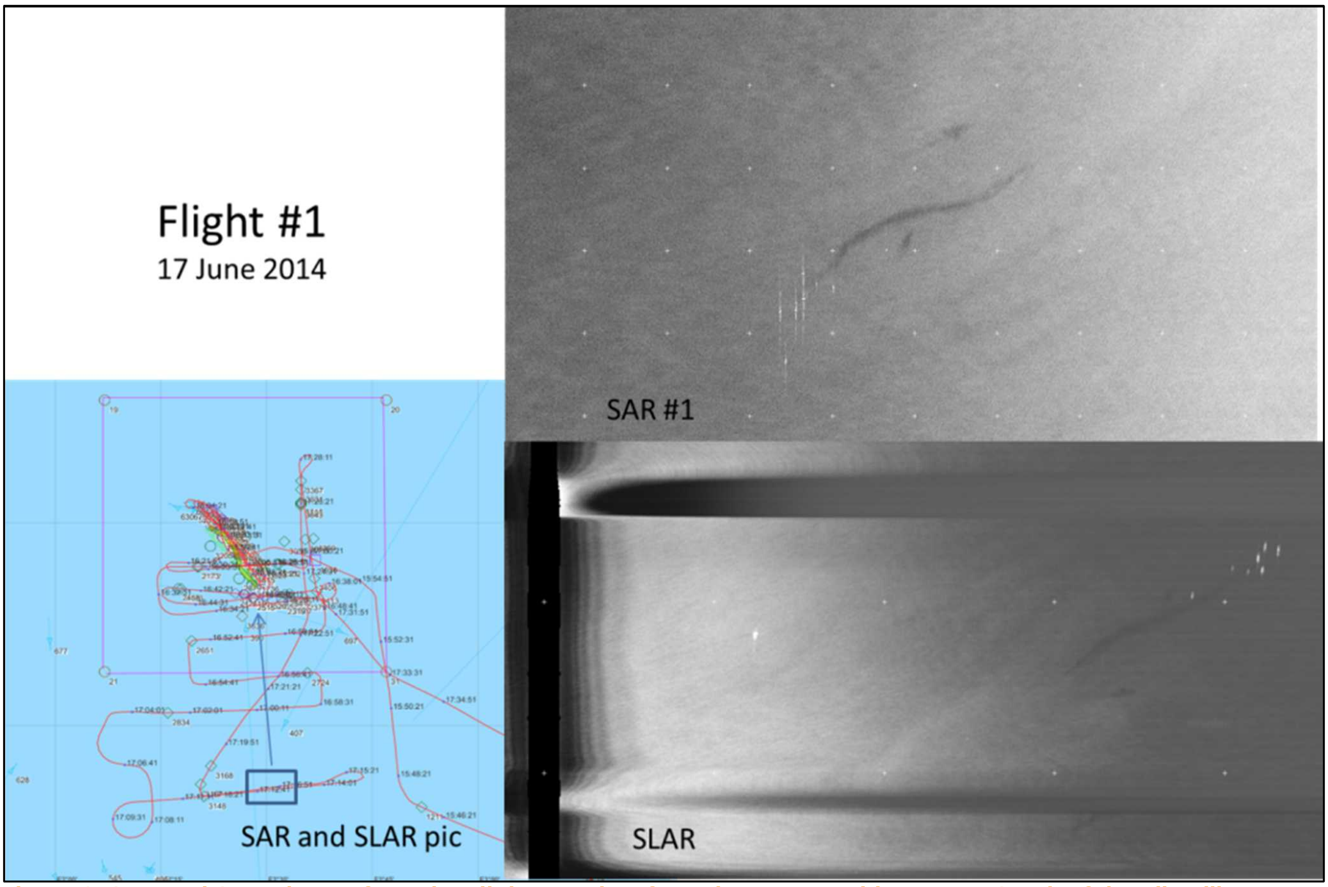

Figure 2. SAR and SLAR image from the Flight #1, taken from the same position 17 nm South of the oil spill.

Flight #2, 18 June 2014

During Flight #2, two SAR images were taken. The first one was taken 20 nm South of the exercise area and the second one 20 nm West from the oil spill. SLAR image shown in Figure 3 was taken much closer than the SAR images. Oil seems to be much more clearly visible on the SAR #1 than in SAR #2 even though the distance and altitude during the image acquisition were about the same. This difference could be explained by wind direction. The forecasted wind direction during the Flight #2 was about 350 degrees. This means that in the SAR image where oil was more clearly visible (SAR #1), the image was taken towards the wind direction.

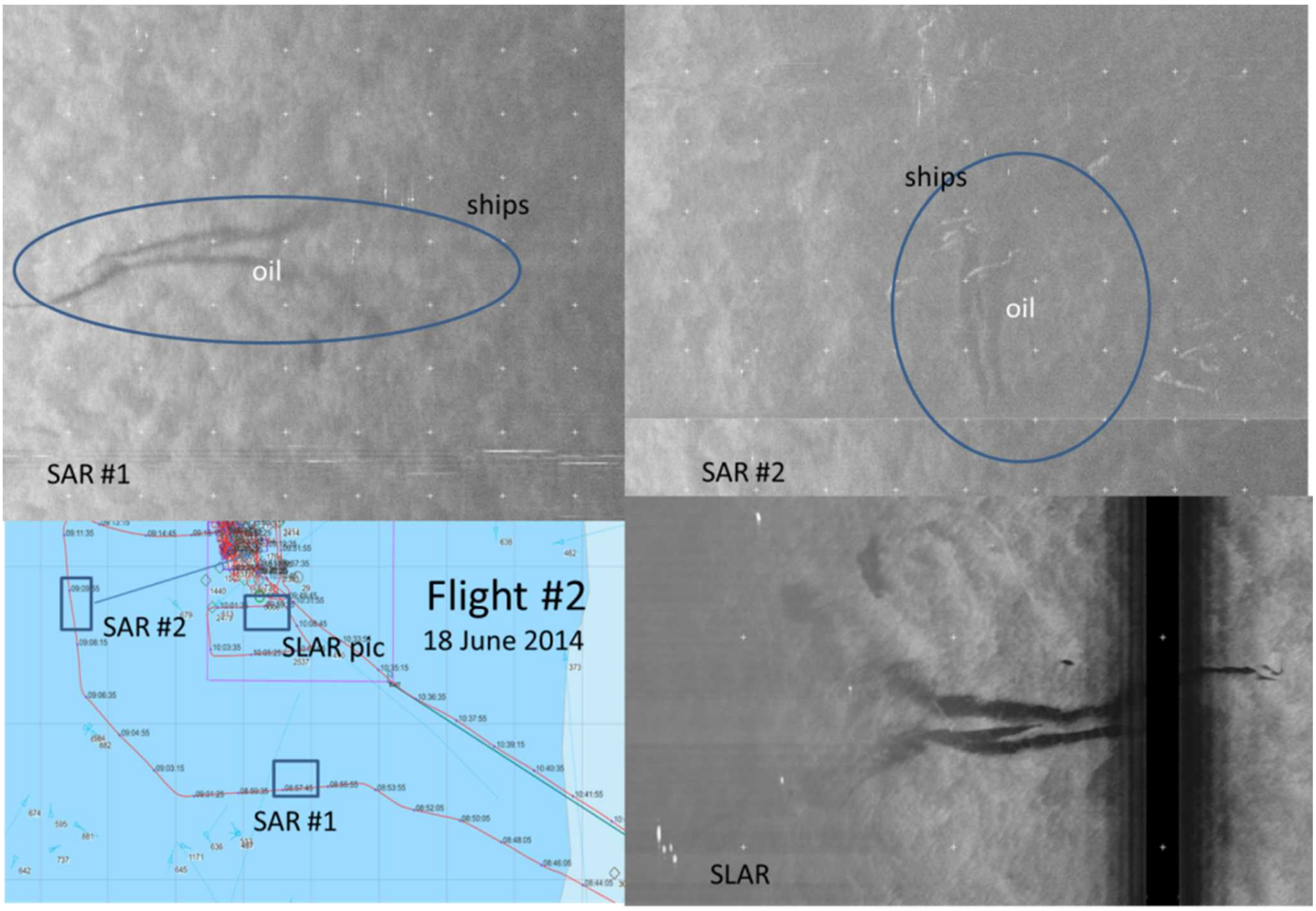

Figure 3. SAR and SLAR image from the Flight #2. The SAR #2 was taken from the West side of the exercise area, 20 nm away while the SAR#1 was taken from the South, 20 nm away. The SLAR image is taken much closer to the oil spill than SAR images.

During Flight #2 a very representative IR/UV scanner image was taken at the end of the flight time, when fresh oil was released to the water, see Figure 4. In this image pair, only the thickest layers of oil are visible on the left hand side IR image whereas the whole oil extent is visible on the UV image on the right. On top of IR/UV image pair, there is day light camera image of the same situation. As seen from this image, the thickest part of the oil cannot be easily distinguished visually from the daylight image. Figure 4 clearly illustrates the usefulness of IR/UV scanner images while guiding the response vessels to the thickest part of the oil floating on the sea surface.

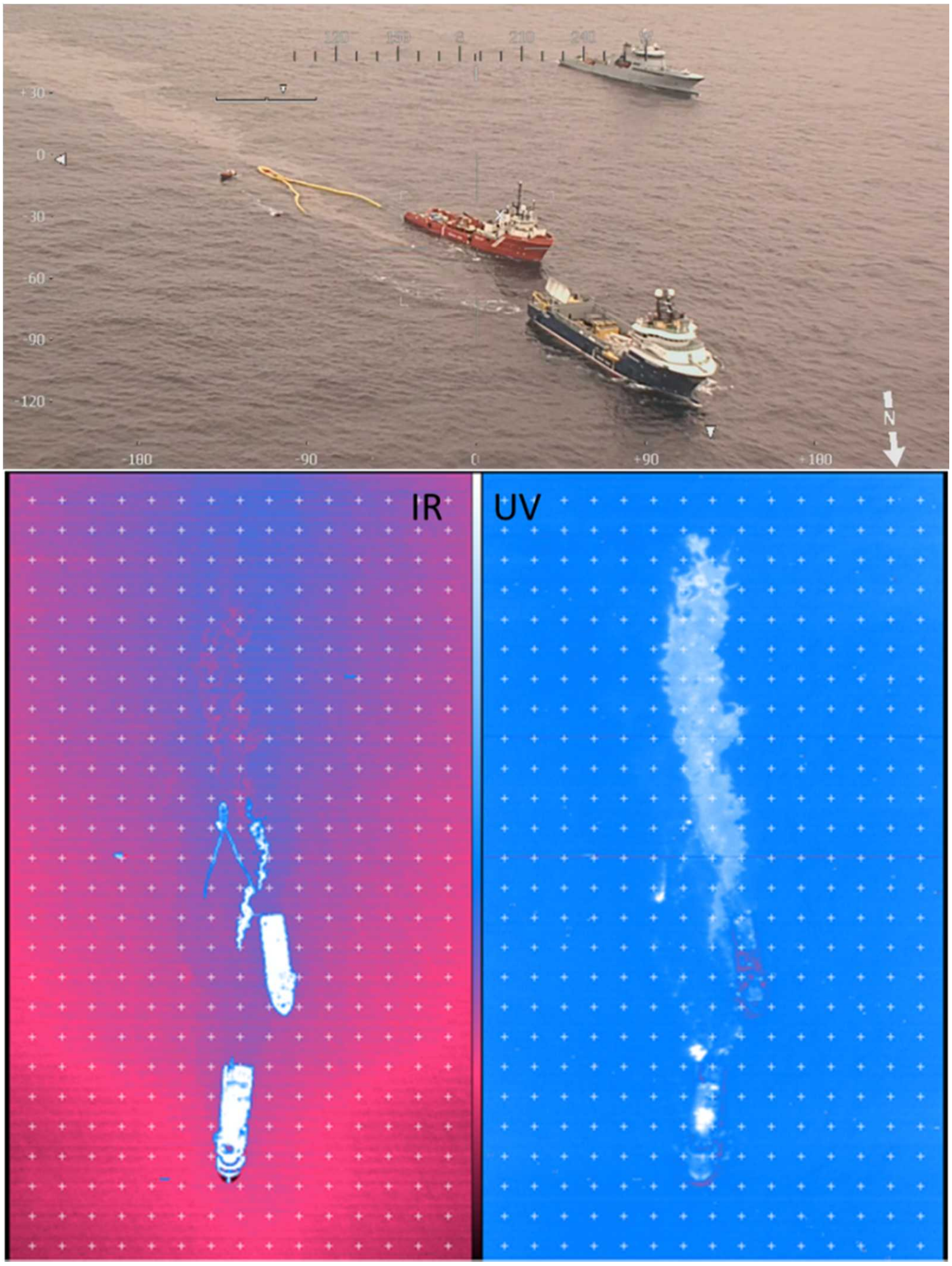

Figure 4. IR/UV scanner image of a fresh oil release at the end of Flight#2. The left image is Infrared (IR) and clearly shows the thickest parts of the oil. The right side of the image, Ultraviolet (UV) image shows the whole extent of the oil.

Flight # 3

During Flight #3, three SAR images were taken, see Figure 5. The oil spills on the sea surface were not as fresh as during the other flights. 5 m^3 of oil was released about an hour before the flight in the area. There was, however old, mostly recovered slick in the sea from the earlier experiment during that day. During Flight #3, 3 SAR images were taken. Two of the images were taken East from the exercise area and one from South-East side of the slicks. The oil was not as clearly visible on any of these SAR images compared to the images taken during Flight #1 or Flight#2. On SLAR image which was taken a lot closer to the exercise area, however, the oil was visible as expected.

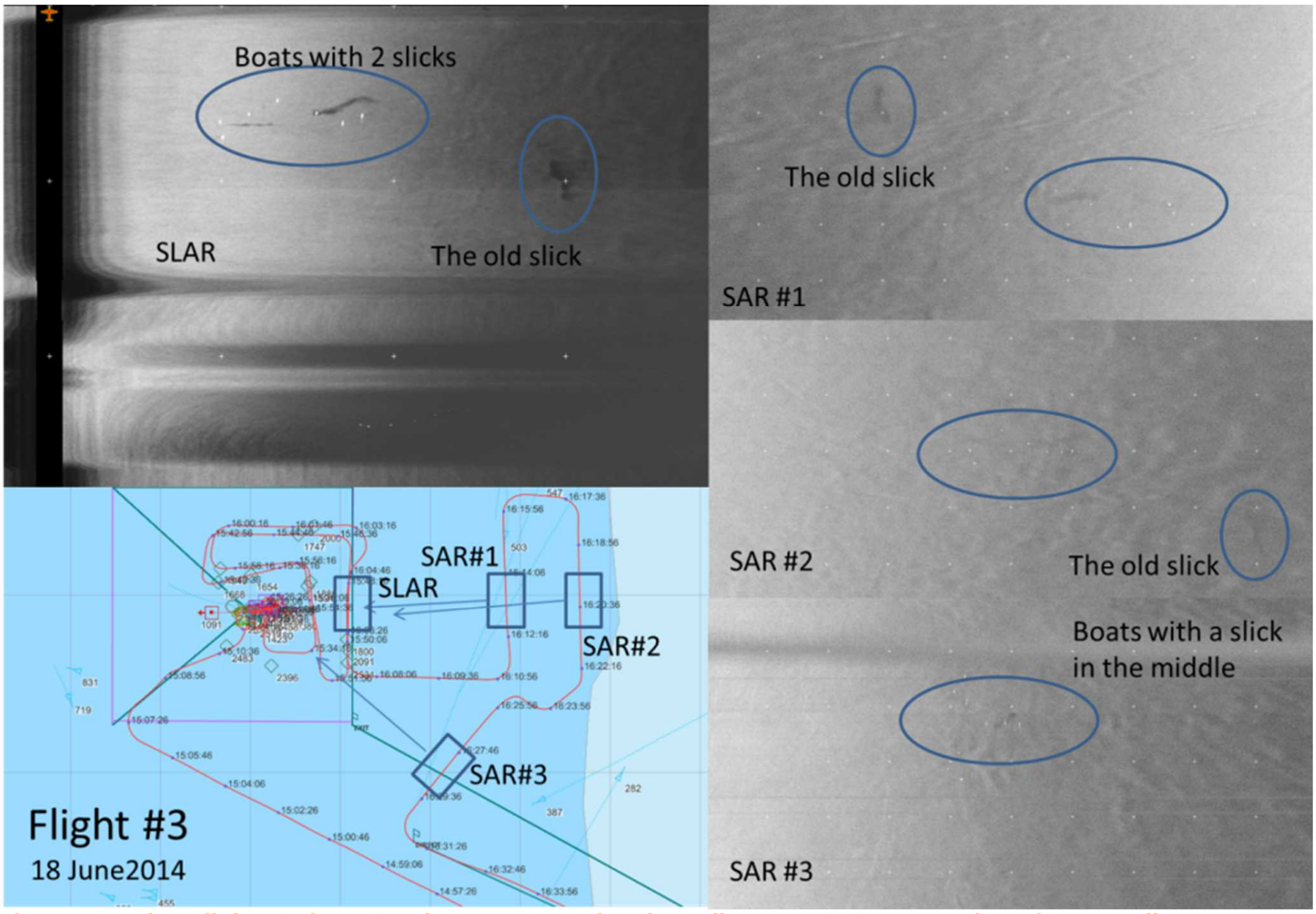

Figure 5. During Flight #3, three SAR images were taken from distances 20-27 nm. In these images, oil was not as clearly visible as in the images taken during the previous flights.

Conclusion of the Finnish NOFO exercise flights

In the NOFO OOW 2014 exercise, the SAR mode of the surveillance radar worked as well as the SLAR for mapping the oil spills on the water. Before the exercise we had seen very little of empirical results showing sea surveillance radar SAR mode's oil detection capability on open sea. Because of the lack of documented evidence, we can say that the SAR capability to detect oil exceeded our expectations.

Two operational notes need to be mentioned: Firstly: The flight profile to acquire SAR images is very different compared to SLAR. SAR images are taken only to one side of the aircraft and further away than SLAR images [2]. Furthermore, our experience is that SAR is more sensitive to the movements of the aircraft. In practice, this means that SAR image acquisition needs a longer straight flight path than SLAR, and a different type of flight profile in order to generate good images. From daily operational oil pollution monitoring point of view this might be a challenge compared to SLAR.

Secondly, the (normal) search mode in the surveillance radar cannot be used at the same time as you use the SAR mode to produce SAR strip maps. It is therefore hardly realistic to use the SAR mode in the surveillance radar for routine oil spill patrols. However, for a defined target area such as accident site, the flight support could be preplanned so that the SAR image could be taken while approaching or leaving the area. Of course, the different flight profile for SAR images may also be an advantage in a situation where you want to monitor an area that you for some reason cannot fly near to.

The IR/UV scanner worked as expected during the NOFO exercise. In order to succeed in oil response operation, the oil response vessels need to get the information on the location of the thickest part of the oil. By guiding the oil recovery vessels there, response activities can be targeted so that the biggest possible amount of oil will be recovered. The ability of the IR to detect the thickest part of oil is essential and this instrument maintains its position as most important when it comes to accidental oil pollution monitoring.

Discussion and topics for further investigation

In the previous chapter, our most obvious findings from the NOFO exercise were explained. However, there are other aspects which would need further investigation and discussion with the operational as well as the science community.

During the exercise, there were relatively big amounts of oil on the sea surface and it was well detected by both SLAR and SAR. However, we had no opportunity to evaluate the capability of the SAR to detect small amounts of oil, say, less than 50 liters. During Flight #3 we observed fresh oil release of 5 m^3 which was better visible on SLAR than SAR. Literature doesn't provide examples of sea surveillance radar SAR mode's ability to detect small amounts of oil. At the same time, SLAR capability to detect also smaller amounts of oil was well documented in a number of national field trials as well as joint Bonn Agreement exercises in the 1980s. The general trend, especially in the Baltic Sea, has been that documented illegal oil pollution cases are reduced both in number and size [3]. The results from the NOFO exercise indicate that the airborne SAR is able to detect large, typically accidental oil spills. However, its ability to detect smaller spills, and thereby potentially be able to replace the SLAR in illegal oil pollution monitoring, needs further investigation.

When doing mapping flights over land the sea surveillance radars SAR mode images give a significantly better resolution than the SLAR. However, over the ocean the impression of the imagery is that the resolution is similar from the two instruments, due to noise from the SAR processing against a background with not much detail but also an unexplained "blurriness" in the image. We believe this could be due to the image generation process of the SAR, which requires looking at the same scene from a number of different angles to create the synthetic image through a mathematical process. The oil spill on the ocean will (unlike fixed targets on the ground) move with the wave motion during the flying time required to capture the data for generating the image. This could possibly account for the somewhat unexpected effect that the edges of the oil spill appear as not very distinct in the SAR images. We would welcome a further research of this assumption.

It should be mentioned that in this work we have only looked at the images visually as they are produced by the system and have made no attempt to analyze raw data. Also, we have only used the standard settings of the radar and have not investigated if there are any modifications that could be made to improve the oil spill mapping capability. In the MSS6000 system it is possible to adjust the contrast and brightness of the images. The contrast adjustment of the SAR images acquired during Flight #3 helped us to better see the oiled area but did not very much improve the indistinct edges of the oil spills in the image.

Another topic for further investigation would be wind and wave direction with respect to flight direction and oil. In Flight #2 the SAR images were taken from different sides of the oil slick, one from the South with the radar instrument pointing into the wind direction and the other from the West, 90 degrees angle with the wind direction. In the image taken towards the wind, oil was a lot better distinguished.

As we know, the reason that oil spills give a visible contrast in the SLAR and SAR images is that oil on the water suppresses the capillary waves, thereby giving a lower radar return from the sea surface covered by oil. We suggest it may be the airborne SAR is more sensitive than the SLAR to the direction of the capillary waves on the surface. This assumption is supported by conversations with US Coast Guard operators who tried the SAR mode of a similar radar over the large spill in the Gulf of Mexico. They also report the impression that the quality of the oil spill contrast in the SAR image is very sensitive to the wind direction; a wind (and wave) direction straight towards the antenna did give a significantly better resulting image.

As a conclusion, it can be said that SLAR and IR/UV scanner were working as expected during the Finnish flights in NOFO OOW 2014 exercise. SAR showed a surprisingly good capability to detect relatively large amounts of oil. However, further experiments and investigation is required before stating that the airborne SAR can fully replace the SLAR in routine oil spill monitoring. As pointed out above, there are also operational advantages for the general sea surveillance mission in being able to use the SLAR and surveillance radar in parallel.

Acknowledgements

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List of references

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