The use of spaceborne SAR imagery for oil slick detection on the North Sea

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ABSTRACT

Recent studies have shown the potential of ERS-1 SAR imagery for oil slick detection at sea. To explore the potential of spaceborne SAR a project has been carried out in the framework of the ESA ERS-1 pilot projects, with financial funding from the Netherlands Remote Sensing Board (BCRS). During 1993 a total of 171 ERS-1 SAR images, made available as so called Fast Delivery Products, were received and processed. The remote sensing aircraft has covered simultaneously ten ERS-1 passes. Due to the limited number of simultaneously covered frames the dataset for inter-comparison is limited. The percentage of correctly classified spills is estimated to be 85% and the false alarm rate is 32%. Using low resolution SAR imagery slicks larger than 0.3 km^2 can be detected. The SAR will be a valuable system for an operational authority when it is attuned to specifications. Therefor the user requirements are discussed and in addition to this a proposal for an operational system is presented. Although these requirements are not met by ERS-1 SAR the results of the project are promising for the operational oil spill detection from space.

1. INTRODUCTION

All countries bounded by the North Sea are faced with an increase of pollution of the sea. The Netherlands Continental Shelf area extends over 57,065 km^2, about 420,000 ship movements are recorded yearly and about 160 oil and gas platforms are productive. The North Sea is an important economic and ecological area. A considerable amount of the pollution is caused by operational discharges from ships and offshore installations.

For more then one decade the Rijkswaterstaat, North Sea Directorate operates a remote sensing aircraft for monitoring the marine environment. Airborne surveillance is very well attuned to the requirements for operational use. Airborne platforms i) can be directed on a very short notice to inspect locations of interest, ii) can be used for operational guidance of the oil combating ship(s) and iii) the flight schedule can be highly random over the year. The aircraft is equipped with SLAR, IR/UV sensors, a photo camera and since several years, also with a night vision camera. The flights are scheduled randomly in time and area. Nowadays, in one year over 1200 flight hours are being made. Sometimes polluters are caught red-handed, reported and consequently being prosecuted in court.

As a result of the Third North Sea Ministers Conference, the North Sea Directorate was given the task to intensify the airborne surveillance. One way to intensify the surveillance is to increase the number of flying hours. However to cover the Netherlands Continental Shelf daily requires an enormous effort in manpower and flight time. Therefore additional systems for oil spill detection are of interest to the North Sea Directorate. The ERS-1 SAR might be such a system provided that the operational requirements are met. The next section will discuss the requirements as proposed by the North Sea Directorate.

Recent studies (Bern et al. 1992a, b) and (Okamoto, 1992) have shown that the ERS-1 satellite equipped with Synthetic Aperture Radar (SAR) can be used for oil spill detection at sea. In 1992 (Pellemans et al. 1993a) have been able to detect an intentional spill.

This paper reports on the continuation of the work of (Pellemans et al. 1993 and 1994) with respect to the inter-comparison of airborne SLAR and spaceborne SAR. In addition to this a set-up for an operational system is discussed.

The work has been done in close co-operation by the remote sensing group of the Survey Department, Rijkswaterstaat, the operational service group of the North Sea Directorate Rijkswaterstaat and the remote sensing section of the Netherlands National Aerospace Laboratory (NLR).

2. USER REQUIREMENTS

The main objectives for a system that detects oil spills are twofold:

- an early warning system thus providing the authorities with information on accidental or illegal oil spills and in addition to this support in combating spills.
- to collect data for statistical use e.g. to evaluate pollution policies or aerial surveillance strategies.

Both objectives put different requirement to a system. Disregarding costs and manpower it can be put that requirements can be translated to:

data availability

time delay — elapsed time between acquisition and images ready to be interpreted at the operational services

coverage — area covered by the spaceborne SAR

frequency — repeat interval of satellite passes

data quality

resolution — the smallest spill to be detected

data validity

success rate — required percentage correctly classified, errors of omission and commission that can be tolerated.

In **Table 1** the requirements are specified quantitatively. For the airborne SLAR system it is clear that the these requirements are difficult to meet. As the airborne SLAR system is a real time system the time delay is essentially zero. The airborne system is a flexible tool therefor the coverage of the area is sufficient but the repeat cycle of the airborne system is on the average less then ones a day. No resolution problems are met. However when an airborne SAR is be operated the SAR processing will cause a time delay which depends on the characteristics of the system.

Table 1 - User requirements for different tasks.

user requirements	early warning	statistics
time delay (hours)	0 - 1	few days
coverage	traffic lanes and coastal zone	Netherlands Continental Shelf
repeat cycle (hours)	0 - 12	12
success rate	>75%	>95%
resolution (km^2)	>.01	>.01

3. DESCRIPTION OF THE EXPERIMENT

In 1993 a pilot project has been carried out of which (Pellemans et al. 1993a, b) have extensively described the goals and experiments. In short the objectives have been:

i) to demonstrate the operational capabilities of ERS-1 SAR imagery for oil spill detection,

ii) to determine the value of the ERS-1 SAR imagery for oil slick detection and

iii) to propose an operational system for oil slick detection by means of the ERS-1 SAR imagery.

Twelve simultaneous flights with the remote sensing aircraft of Rijkswaterstaat (PH-MNZ) have been scheduled during ERS-1 passes in orbits 194 and 466, see **Figure 1**. To cover three ERS-1 frames will take four hours of flight time which is actually the maximum possible operational flight time of the remote sensing aircraft. Therefore priority has been given to cover the area of interest as best as possible. A drawback is that a lot of SLAR detected slicks have not been identified.

In **Figure 2** the initially achieved transmission path is presented. SAR imagery is downlinked to the ERS-1 ground segment where SAR processing is performed, after that the BDDN network was used for transmission to the NLR in the Netherlands where low resolution imagery was created. The low resolution imagery has been transmitted to the Survey Department where further processing, interpretation and archiving of the imagery was done. When necessary the watchman at the Hydro Meteo Centre of the North Sea Directorate (HMR) has been informed when a serious spill was detected.

In cooperating with Tromsø Satellite Station (TSS) a second transmission path, shown in **Fig. 3**, has been rea-

Figure 1 - Tracks flown by the PH-MNZ during the orbits 194 and 466

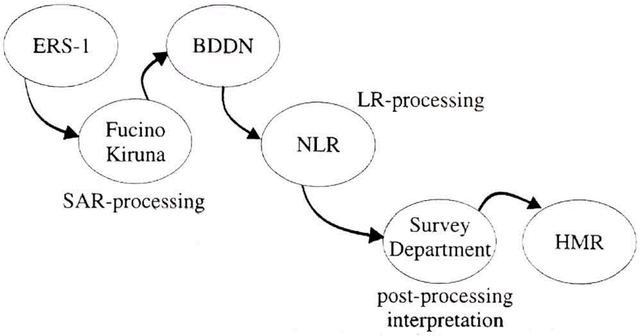

Figure 2 - Transmission route of ERS-1 data

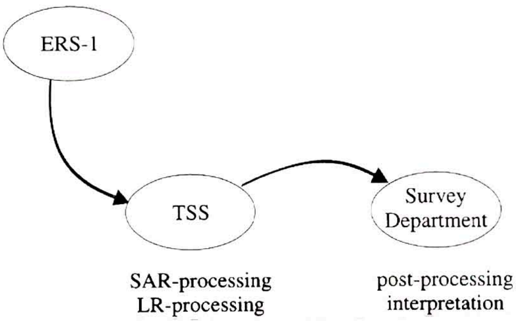

Figure 3 - High speed transmission route bypassing the ESA ground segment

lised. TSS provided low resolution imagery on a disc accessible by Internet.

The SAR images have been interpreted visually. A graphic workstation was used to perform some basic image manipulations but no special algorithms have been used to detect oil spills automatically. Points of attention during the project have been time delay between data acquisition and interpretation, data yield, environmental conditions, ground truth and comparison with the conventional SLAR system.

4. RESULTS

The project period during which images have been received was from 1 June 1993 to 31 December 1993. (Pellemans et al. 1993, 1994) have given extensive discussion on the results of the project. Additionally the results of the ERS-1 and the remote sensing aircraft will be compared.

During the project 191 frames have been assigned of which 171 were received in good order and used for interpretation.

Initially, the 171 images were analysed by an operator with little experience in slick detection. In a later stage all slicks have been checked with the aid of the North Sea Directorate where a lot of experience is available in interpreting radar imagery. This resulted in 48 new slicks and 63 rejected slicks. The images have all been inspected visually. Apart from experience and knowledge of the area (bottom topography and frontal zones), important criteria for qualifying an observed patch as an oil slicks are contrast, structure of the patch in relation to the area surrounding the patch and meteorological conditions (showers, wind direction).

The above mentioned numbers show that a 32% false alarm rate has been met and 25% of existing slicks have not been detected. After a double check, a total of 192 slicks were detected in 171 images, which corresponds to an average of 1.1 slicks per frame.

In **Figure 4** a compilation of about 192 detected slicks on the Netherlands Continental Shelf are presented. Many slicks are well within the ship traffic lanes which are located along the Dutch coast. In Dutch waters there is no correlation found between the observed slicks and the existing oil platforms.

Figure 4 - All slicks detected by SAR in the period from 6-Jun-93 till 31-Dec-93. Mark the significant correlation of the slicks position and shape to the existing shipping lanes

It should be mentioned that the nature of most slicks is not known because no ground truth data could be collected for all ERS-1 passes due to the restraint in available flight hours. The SAR is not an instrument that is strictly selective for oil slicks. As (Pellemans et al., 1994) have discussed, SAR is receptive for reflectivity variations which is influenced by a lot of factors. However at this moment we are confident that slicks, although of unknown origin (oil, other pollutants or algae), can be detected.

An overview of the results of the airborne SLAR and ERS-1 SAR images are given in **Tab. 2**. The average of slicks per unit area as detected by ERS-1 SAR is 22% higher than the average detected by SLAR. The coverage of the Netherlands Continental Shelf by ERS-1 frame is such the coastal zone and the main shipping routes (Pellemans et al. 1993) are covered more frequent then remote areas. The airborne missions however cover the Netherlands Continental shelve more equal which means that parts with on the average less slicks are observed more frequent by the airborne SLAR. This may be an explanation to the difference in the average slick density.

Table 2 - Results from airborne and spaceborne systems for all missions during project period from June to December 1993

all flights / passes	airborne SLAR	ERS-1 SAR
number of slicks	244	192
operational coverage	272 hours (corrected for ferry times)	171 images
covered area	2.720.000 km²	1,710,000 km²
number of slicks /10,000 km²	0.89	1.12

Table 3 - Results from nine simultaneous missions of ERS-1 and the remote sensing aircraft.

simultaneous missions	airborne SLAR	ERS-1 SAR
number of slicks	36	34
operational coverage	29 hours (corrected for ferry times)	34 frames
covered area (km²)	290,000	270,000
number of slicks /10,000 km²	1.24	1.26

In **Figure 5** the average number of detected slicks is compared with the wind speed. It can be added that a decrease in size has been observed at higher wind speeds. An explanation for this effect is the fact that oil slicks disappear more rapidly at high wind speeds. It can also mean that the slicks are less visible at high wind speeds. Important to notice is that at wind speeds from 2 m/s up to 13 m/s, oil slicks have been identified. These limits range beyond the limits of 3 to 10 m/s according to (Bern et al., 1992, and Wahl et al., 1993).

Twelve flights have been scheduled to collect ground truth data for the ERS-1. Due to circumstances both platforms failed on two occasions therefore leaving only nine simultaneous flights. **Tab. 3** shows the subset of data that was collected during the simultaneous flights of ERS-1 and the remote sensing aircraft. During the simultaneous coverage the average number of slicks per unit area is almost equal for both systems. Actually the average number of slicks detected by both systems is higher during simultaneous missions than the average over the whole project period. This can be explained by the fact that the area of interest has been the traffic lanes and the coastal zone where on the average more slicks are detected. The airborne SLAR equals the ERS-1 average results because no time was lost by slick identification and therefore a larger area is covered with an increased chance of detecting slicks.

Figure 6 compares the estimated sizes of slicks detected by SAR and SLAR. The dataset of simultaneously detected slicks by SAR and SLAR is limited. Although **Fig. 6** shows a reasonable correlation, deviations of up to a maximum of 30% in observed sizes. A larger number of classified slicks may give a stronger support to the reliability of ERS-1 SAR oil slick detection.

Table 4 shows the number of slicks detected by both instruments. Only eleven slicks have been detected by both instruments. During simultaneous coverage the remote sensing aircraft has been able to verify 14 slicks of which

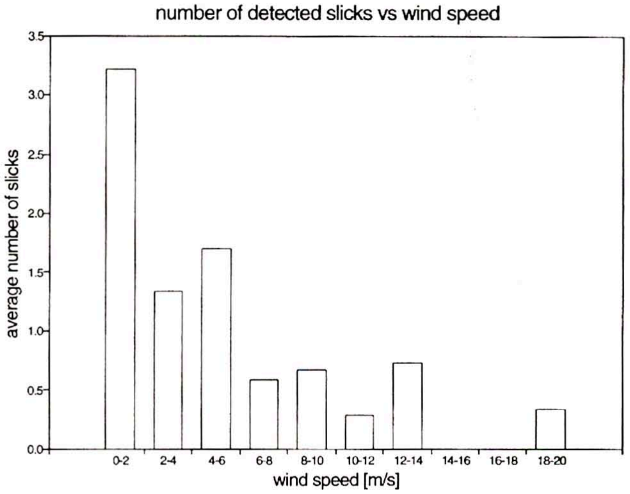

Figure 5 - The average number of slicks as a function of the wind speed

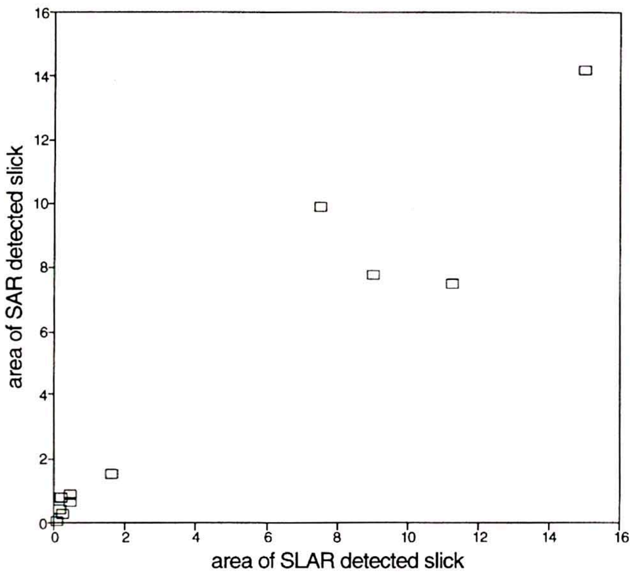

Figure 6 - Sizes of SLAR detected slicks vs. sizes of SAR detected slicks

11 were oil slicks. Six of these verified slicks have been detected by SAR. The size of the verified slicks detected by SAR varies between 0.3 and 15 km^2. Of the verified slicks not detected by SAR, 4 were slicks smaller than 0.2 km^2 and one slick of 1.5 km^2 had a relative large time difference (1hr:28m) between SLAR detection and SAR passage. For slicks larger than 0.3 km^2 the success rate is 85% (6 of 7).

Statistics from the airborne SLAR shows that 91% of identified slicks consist of some type of oil.

At this moment the ERS-1 database has not been combined with the flight records of the airborne platform to remove 'out of range slicks' for the SLAR. This may reduce the number of SAR detected slicks in **Tab. 4**.

Table 4 - The slicks detected during nine simultaneous missions, categorised to size

size	all slicks observed by ERS-1	all slicks observed by aircraft	slicks observed by both instruments
< 1 km^2	16	31	6
1 - 2 km^2	9	1	1
2 - 5 km^2	4	0	0
5 - 10 km^2	3	3	3
> 10 km^2	2	1	1
Total	34	36	11

5. DISCUSSION

With respect to the user requirements it can be mentioned that provided that a satellite ground station can generate low resolution SAR images with high priority and that modern digital communication are used a time delay of less than one hour between acquisition and interpretation can be achieved.

Due to the processing capacity in the ESA ground segment the coverage for one pass of the ERS-1 is now limited to three frames. With respect to the airborne SLAR this a comparable coverage. However when other users around the North Sea are interested then more frames per pass may be required. Important is that the weather conditions do not prevent data acquisition.

The repeat cycle of the ERS-1 is currently once per three days. This is a limitation of the ERS-1 system. Another drawback of the ERS-1 satellite is the commitment to a wide user community that strongly influences the orbit scenario which means that sometimes the orbit scenario is switched into another mode. At this point the ERS-1 does not meet the above requirements. However this point may be in future less cumbersome because more satellite mission are planned with SAR. Combining different sources can contribute to a reasonable coverage. A well defined orbit scenario may provide a good coverage and an acceptable frequency of acquisition. Improvement can be made when different spaceborne SAR systems can be used simultaneously, like ERS-1, ERS-2, Envisat and RADARSAT.

It can be put that, depending on weather conditions, slicks larger than 0.1 to .03 km^2 can be detected with the low resolution ERS-1 SAR data. Slicks smaller than 0.1 km^2 can probably be detected by using advanced image processing techniques and/or less data reduction.

A success rate of 85% seems feasible. However this success rate is estimated on a small number of verified slicks. This number is comparable to a recent study by (Wahl et al., 1994). It is advisable for validating SAR data to increase the number of identified slicks to enlarge the possibility for statistical validation.

6. CONCLUDING REMARKS

This study shows that ERS-1 SAR data have a large potential for detecting oil slicks on the North Sea on a regular basis. User requirements for an operational oil slick detection by spaceborne SAR are made explicit. Although these requirements are not achieved by ERS-1, the use of SAR data may contribute to a better coverage of the North Sea.

The benefits for a spaceborne SAR system for oil slick can be summarised as follows:

- low resolution data can be available within one hour;
- easy data handling and interpretation;
- it takes relatively small investments;
- large degree of semi-automatic processing possible (only inspection is visually);
- limited manpower is needed;
- it provides size and geographical position of a slick;
- the percentage of oil spills correctly classified is in the order of 85%;

When compared with airborne SLAR the limitations of using spaceborne SAR data are:

- coverage is fixed due to orbital scenarios;
- overpass time is fixed due to orbital scenarios;
- only slicks larger than 0.1-0.3 km^2 can be detected;
- detected slicks cannot be identified;
- monitoring of the evolution of individual slicks in time is impossible;

It is recommended that the user community for operational oil slick detection make their requirements known to ESA and others.

Furthermore it is recommended to collect a larger dataset of verified slicks during ERS-1 passes in order to get a more statistical validation of SAR data.

An operational system will have to guarantee limited time delays, it must be robust, easy to use, reliable and preferably continuous. Operational use of an early warning system may be as follows:

- surveillance flights are scheduled after reception and interpretation of SAR images;
- surveillance flight can cover other areas and be redirected in case of emergency;
- reducing the number of flights e.g. when statistics are of more importance than enforcement.

A system set up for oil slick detection based on spaceborne SAR systems consists of four sections. The Satellite section is the most essential part of the system but at this moment its specifications are actually boundary conditions.

Satellite ground station

The ground station receives SAR data, perform SAR processing and generate low resolution images. The ground station distributes the results to the user community. Requirements for such a station is that fast delivery (near real time) low resolution imagery is made available which means that sufficient computing capacity with high priority is available. Besides the ESA ground station Fucino and Kiruna, also a commercially operated satellite station such as TSS can be used.

Data transmission

The transmission of low resolution data to the HMR can be done by the digital computer network Internet or with the digital telephone network ISDN.

Processing

The different processing steps needed for image interpretation are described by (Pellemans et al., 1993). Commercial available image processing software with an application layer on top is in favour. Most steps can be done automatically and the operator will be led through the processing steps.

Interpretation

During the project good results have been obtained by visual inspection of SAR images. Although development of automatic slick detection are in progress algorithms for oil slick detection are not yet suitable for operational use. Therefore visual inspection is the best option for this moment. The interpretation station should be equipped with data base facilities for easy access of all slicks for statistical analysis and data presentation.

The costs will be one of the issues that play a role in the decision to set up a ground system containing data transmission, processing and interpretation segments. The total cost is estimated to range from 175 to 300 kfl. ESA will charge DFL 500 for a low resolution image. The manpower needed for a maximum of 400 images a year will be about 50 - 100 hours for image processing and interpretation.

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