TOWARDS THE DEVELOPMENT OF AN OPERATIONAL STRATEGY FOR OIL SPILL DETECTION AND MONITORING IN THE CASPIAN SEA BASED UPON A TECHNICAL EVALUATION OF SATELLITE SAR OBSERVATIONS IN SOUTHEAST ASIA

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ABSTRACT

A short assessment of the oil spill occurrences in the Strait of Malacca, Gulf of Thailand and Brunei Bay, based on interpretation of the low-resolution images, was carried out. The results indicate that most detected slicks are small in size but this is insignificant compared to the total covered area by the bigger slicks. Moreover, the most polluted waters are found along the major international shipping routes as well as in those areas with intensive oil exploitation activities. Using a similar approach, a mapping of oil spills in the Caspian Sea around Baku/Azerbaijan was carried out based on an example of analysis of ERS SAR imagery. Some preliminary conclusions are focused on an intense monitoring and ideas on the generation of an appropriate database for policy making and development planning in the region.

1   INTRODUCTION

One of the most relevant pollution is concerned with the effects of oil on marine and coastal ecosystems. As long as there is a global demand on petroleum products, however, oil spilling will continue to occur, making the improvement of monitoring very necessary.

Oil spill can occur both in the open sea and in coastal waters. There have already been several spectacular accidents, involving the spilling of very large quantifies of crude oil from supertankers. For instance, the grounding of the Sea Empress in February 1996 caused one of the largest and most environmentally damaging oil spills in European history. About 72,000 tonnes of crude oil were released into the seas around the coast of southwest Wales (Clemento-Colon *et al.,* 1996).

In the Southeast Asia region the growth of human activities has had a significant impact to nature. Among these, accidental and chronic oil pollution of the marine environment is one of the most important issue. In this domain, it is expected that significant improvements may result from the use of space borne remote sensing technology. In particular, freely available low-resolution Synthetic Aperture Radar (SAR) images can be used to provide a spatial distribution map. The aim of such a map is to collect all of the relevant information to assist end users in setting-up emergency plans and organizing pollution response operations (Gadimova, 1998).

In addition, the aim of such a study in this region is to establish the techniques and tools along with necessary expertise to monitor oil spills. In general, such experience can be applied also in a number of key test sites in other threatened areas such as the Caspian Sea, for instance in the coastal zone of Baku/Azerbaijan.

The Caspian Sea is probably unique in the world when it comes to the environmental impact of oil pollution. Considering the technology used in marine oil production, we are faced with a variety of pollutants. As a result, the Caspian Sea is polluted by petroleum, chemicals as well as by waste waters from industries. Also accidental oil spills occur. They are rather frequent during oil exploration, extraction and transportation (Mekhtiev *et al.,* 1997).

This paper describes the results of these two studies and examines some of the issues related to the development of an operational strategy for oil spill detection and monitoring based on satellite observations.

2   SATELLITE SAR OBSERVATIONS IN SOUTHEAST ASIAN WATERS CENTRED UPON SINGAPORE

For the period of September 1995 through June 1998, 1400 ERS-1/2 SAR scenes of the part of the Southeast Asian waters centred upon Singapore were used in this study. These data were freely available through the standard World Wide Web (WWW) catalogue-browse system of the Centre for Remote Imaging, Sensing and Processing (CRISP) of the National University of Singapore (NUS) at spatial resolution of about 400 m. From these low-resolution images assumed oil slicks were mapped by means of visual interpretation. In addition to ERS images RADARSAT data (a set of 40 images) has been used as well. This satellite has the capability to cover a larger swath (500 km) than the ERS satellite (100 km), and its SAR can also operate in various modes. This was specially useful for mapping oil slicks. Improvements in terms of temporal coverage was achieved through images obtained during the ERS-1 and ERS-2 Tandem Mission period. In order to check the performance of the oil spill detection method some full resolution ERS SAR Precision images (PRI) were also used from selected areas. The interpretation of SAR data was supported by meteorological and geographical information.

In SAR images, the brightness of the sea surface is a measure of the sea surface roughness. Surface roughness is induced by wind and current but can be reduced by an alteration of the surface tension due to a top layer of very thin natural or spilled oil. Low wind speed, typically below 2-3 m/s (Hamre et al., 1996), will not produce sufficient roughness to be visible in SAR images, while in high wind the increased microwave backscattering from a spill area can be appreciated. If the wind speed is too high, typically above 12m/s (Johanessen et al., 1994), certain types of oil are quickly mixed or dispersed into the water column, becoming invisible for SAR, although it can re-appear at the surface during subsequent calm weather. Hence, oil spill monitoring using SAR data is optimal at moderate wind speed (3-10 m/s), but it is problematic at low and high wind speeds.

The main problem in the detection procedure is to distinguish oil slicks (man-made) from natural slicks, because they have very similar radar backscatter signatures. Both types of slicks are seen as dark patches in the radar image and under certain conditions it can be very difficult, or impossible, to separate them.

The analysis of SAR images for oil slick detection was performed in two steps in order to identify possible key sites for further investigations at higher spatial resolution. First, possible oil slicks in each SAR scene were visually identified and discriminated from others, so-called look-alikes. Second, the identified oil slicks were further classified into "spill like", "oil spills" and "spilling ships" in order to provide a confidence level for each oil spill alarm to end-users.

		Number of slicks	Percentage, %
	Total slicks	1107	100.0
Slick types	Spill-likes	641	57.9
	Oil spills	458	41.37
	Spilling ships	8	0.72
Slick area	< 1 km^2	162	14.63
	1 – 5 km^2	259	23.39
	5 – 10 km^2	39	3.52
	≥ 10 km^2	11	0.99

Table 1. Statistics of possible (oil) slicks in Southeast Asian waters centred upon Singapore

The oil slicks statistics derived from the analysis of ERS-1and 2 and RADARSAT quick-look images are summarized in Table 1. Natural slicks are very common in three areas (Strait of Malacca, Gulf of Thailand and Brunei Bay) and in most cases they can be discriminated from oil spills by their size and shape. The form of the majority of man-made spills was found to be either as elongated segments collocated with shape wakes, or short zigzag stripes. Obviously such appearances indicate, either leakage on the course of the ship, or bilge water discharging during tank cleaning operations. Nevertheless, the large number of spill-likes (57.9% of the total number of slicks) indicates that there was a problem to discriminate between natural sea surface slicks and oil spills. A total of 458 oil slicks were identified. However none of these identified oil spills have been confirmed by *in situ* observations, but the evidence of spills indicate that oil pollution is a significant impact an environmental problem in the Southeast Asian waters.

More specifically, the average size of all detected slicks was 1.2 km². The area covered by a slick on the SAR images was only calculated by multiplying mean length and width of the slick. The pixel sizes of 400 m and 600 m for ERS and RADARSAT, respectively, were taken into account. Most detected slicks are small in size, but their total surface is significant compared to the covered area by the bigger slicks.

In summary, it is important to note, the most polluted waters are found along the coast of East Malaysia and Brunei Bay where intensive oil exploitation activities exist causing chronic pollution to these regions. Another heavily polluted area lies in the Gulf of Thailand. The pollution in this area is probably due to deliberate oil discharges from ships.

Obviously, we can point out that the use of the WWW is regarded as the suitable source for quick-look images for the detection of possible (oil) slicks. By comparing them to the full-resolution images, the quick-look data are most cost effective since they are free of charge, or available for the cost of a phone call. Further, the high-resolution SAR data and, in particular, multitemporal SAR data can provide good delineation of features and should allow for accurate estimates of the slick drifts. Drilling platforms can be surveyed perfectly by radar satellites since their positions are fixed and well known. However the satellite data cannot fully replace other monitoring means such as aircraft when it comes to the identification of polluting ships. Using satellite data, aircraft operations can be made more efficient and therefore cost effective.

3 MONITORING OF THE CASPIAN SEA WITH ERS SAR

Using a similar approach, an area in the Caspian Sea off the coast of Baku/Azerbaijan was chosen as the test site for ERS SAR surveillance. The Caspian Sea, a saltwater lake in southeastern Europe and southwestern Asia, is the largest inland water body in the world. It has a surface of 371,000 km² (143,000 mi²). The Caspian Sea is about 28 m (about 92 ft) below sea level. This level changes from year to year.

All Caspian states (Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan) have highly developed industries and agriculture. All these human activities have a substantial impact to the coastal ecosystems. Among these are accidental and deliberate oil pollution. It is to be noted that a certain amount of pollution is due to oil seepage.

In this study, a set of 6 ERS SAR scenes, acquired between 1996 and 1999 were analysed for oil spill occurrences. Each image covers an area of 100km by 100km; the pixel spacing is 12.5m x 12.5m. One example is included here. On 12-13 May 1996, an ERS tandem pair was obtained in the coastal zone of Baku/Caspian Sea near 40.1^0 N and 50.5^0 E (Figure 1).

| ERS-1, 12 May 1996 | ERS-2, 13 May 1996 |
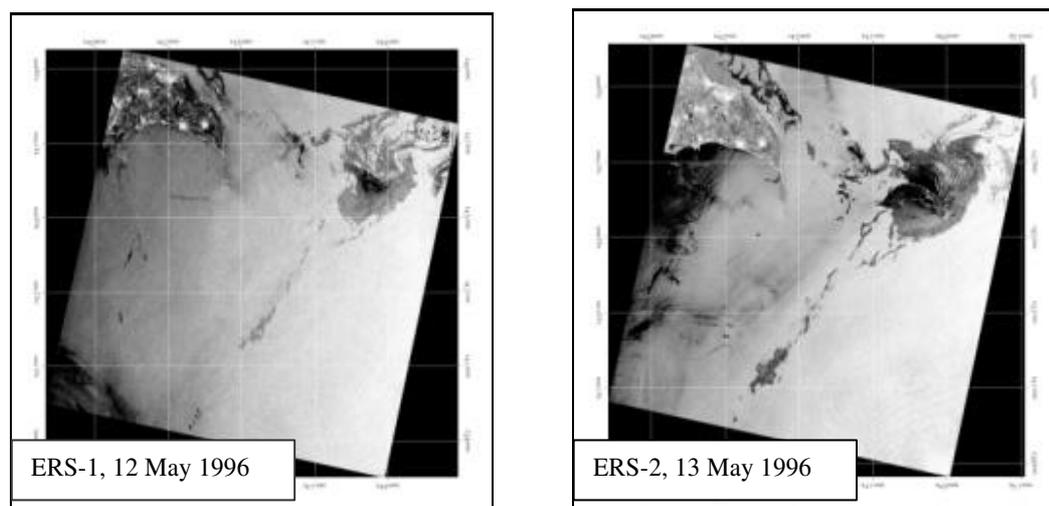
Figure 1. ERS SAR images acquired on 12-13 May1996 over the coastal zone of Baku/Caspian Sea

3.1 Preliminary Interpretation

The comparison of the two images indicates that there are visually more dark areas in the ERS-2 scene while the image of the day before seems to have fewer slicks. As weather maps were not available the wind history had to be taken from backscatter value and the model CMOD4 (Lecomte, 1993). The overall mean backscatter values (Table 2), about –5.8 dB (May 12, 1996) and –7.4 dB (May 13, 1996) respectively, suggested that there was moderate wind in the area of interest. It might range from about 3 m/s through 8 m/s . These are ideal conditions for detecting any type of oil films.

In fact, both scenes show dark linear features in connection with almost every very bright spot representing oil platforms and/or ships. Platforms can be surveyed perfectly by radar satellites since their positions are fixed and well known.

		ERS SAR 12 May 1996	ERS SAR 13 May 1996
Overall mean backscatter value		-5.8 dB	-7.4 dB
Sea surface	Brightest area	-5.38 dB	-5.75 dB
	Darkest area	-10.99 dB	-15.65 dB
"Oil slick"	Very dark area	-20.83 dB	- 23.80 dB
	Less dark area	-10.05 dB	-13.78 dB
	Grey area	-8.34 dB	-9.07 dB
Ship		-	-6.49 dB
Platform		-5.2 dB	-5.79 dB

Table 2. The comparison of different gray levels of the objects in ERS SAR images acquired on 12-13 May 1996

A huge large oil spill of about 81.3 km^2 can be observed in the area of the "Neft Dashlari" oil field (top right corner of the images presented in Figure 1). On the image the spill appears in very dark tones. The slick extends to the northeast and southwest in both images. A profile from clean to oil covered surface is shown in Figure 2. The oil causes a 12 dB decrease in backscatter value. Within 24 hours some large detached oil slick has drifted southwestward
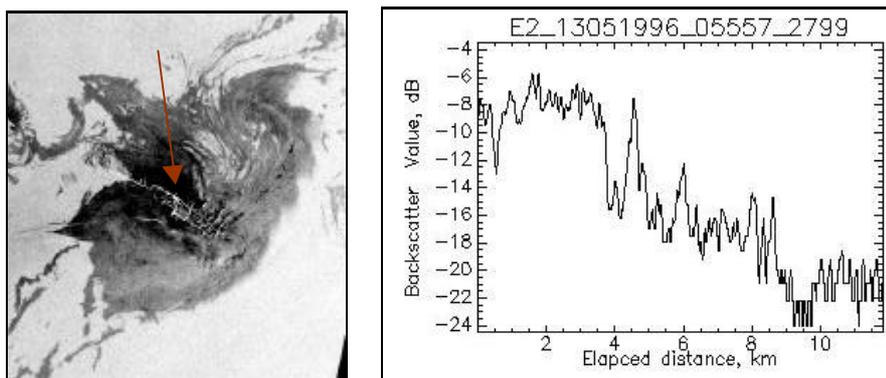
Figure 2. An enlarged subsection of the "Neft Dashlari" oil field and a profile of radar backscatter across edge of oil spill

We observe also a large dark area in the western part (coastal zone south of Baku) of the May 13 image and a bright region in the same area of the May12 image. This dark area must be a low wind area of less than 3 m/s and most probably not linked to a polluted zone.

In the enlarged subsection of the ERS-2 scene (Figure 3) a ship can be seen as a bright point and a spill appears as a dark band behind the ship. This slick, about 22 km long, is thin near to the source and becomes broader at the end where the slick has been affected by wind. It can be deduced as well that the ship discharged this slick while heading towards the southwest direction which correlates very well with major shipping route via Baku Bay. This demonstrates that this pollution was caused by the ships, since on May 12 this area was clean.

ERS-2 SAR, 13 May 1996 (orbit: 05557; frame :2799)

Possible oil spill, $39^0 54^{'}$N, $50^0 11^{'}$E
Length: 22 km
Slick Area: -14.62 dB
Ship: -6.49 dB
Area outside of slick: -10.48 dB (corresponding to a wind speed of 3.5 m/s in NE-wind)
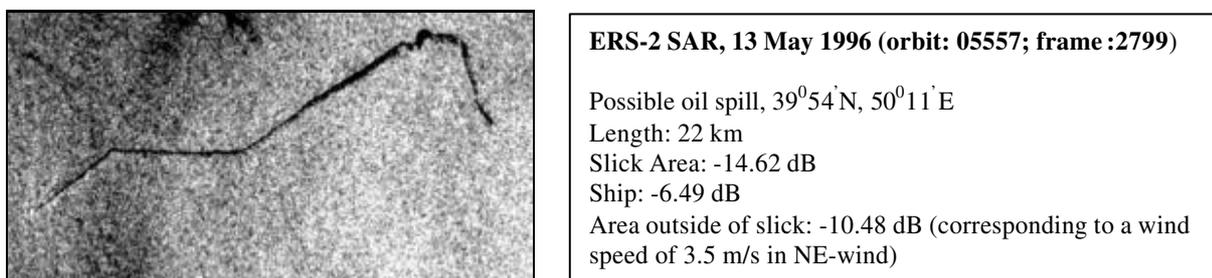
Figure 3. An enlarged sections of the image from 13 May 1996

Only two samples of ERS SAR images must be regarded as small, but already now some preliminary conclusion can be drawn. The measurements indicate that the area affected by a film of oil is approximately 143.6 km^2. The spilling seems to be consistent but in variable quantities. Assuming the "Neft Dashlari"oil field as a main source of pollution the alignment of the slicks in northeast/southwest direction in our samples is caused by winds in the days before data acquisition. The displacement in 24 hours is estimated to be 6 km (wind speed 3m/s). Supposing a constant northeast wind over the past day, the detected large slick would have traveled for 4-5 days. Oil films reaching that age need to be rather thick at their origin.

4 CONSIDERATIONS FOR THE DEVELOPMENT OF AN OPERATIONAL STRATEGY

This study of the Caspian Sea reveals the problem of oil spill pollution in its full dimension. We have to consider to monitor repeatedly the state and condition of the sea surface over a manageable number of test sites and to build up an archive of satellite and *in-situ* derived observations. This will enable the compilation of key signatures and characteristics of naturally occurring surface phenomena in the area as well as the pollution incident. To assess the reliability of the satellite observations, sea truth needs to be obtained from a number of sources, such as aircraft and ship observations.

Data generated from the ERS missions will make a substantial contribution to the database for the region. The aim should be the compile spatial and non-spatial information into a geographic information system (GIS). Such a database could serve for policy making and development planning in the region. The database can be used as an inventory that provides thematic data on coastal and marine environment. It will improve the capacity of the littoral countries and concerned agencies to acquire information in order to develop policies and strategies for the management in the Caspian Sea.

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