DeCOP: Detection and characterisation of organic pollution in the coastal environment – a synergistic approach

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Abstract – DeCOP addresses the problem of detecting smaller oil spills and wastewater discharges through improved understanding of processes that control the formation and movement of oil and other organic films, and factors that determine the appearance of oil in SAR images. DeCOP aims to do this through synergistic use of satellite data, experimental studies of marine pollutant films, and mathematical modelling of wave damping by films and the scattering of electromagnetic waves at radar frequencies. Here the project philosophy is demonstrated through first results from the analyses of satellite data, and experiments with natural and artificial surface films.**

Keywords: oil pollution, remote sensing, environmental monitoring, wave damping, synthetic aperture radar.

1. INTRODUCTION

Public interest in the problem of oil pollution arises mainly during dramatic tanker catastrophes such as the Sea Empress (Wales, 1996), Erica (France, 1999) and Prestige (Spain, 2002). However, tanker catastrophes are only one among many causes of oil pollution. The International Tanker Owners Pollution Federation (ITOPF) estimates that over the period 1974-2001 spillages resulting from collisions, groundings, tanker holes and fires amounted to 52% of total leakages during tanker loading, unloading and bunkering operations. Discharge of wastewater containing oil products is another important source, by pollutant volume comparable to offshore oil extraction and damaged underwater pipelines. The greatest, but hardest-to-estimate oil inputs come from domestic and industrial discharges, direct or via rivers, and from natural hydrocarbon seeps. The long-term effects of this chronic pollution are arguably more harmful to the coastal environment than any single, large-scale accident.

The best way of monitoring this chronic oil pollution would be a constant satellite-based system, combining data from active and passive sensors working at microwave, infrared, and optical frequencies. Of these sensors synthetic aperture radar (SAR) is already routinely used for the monitoring of offshore activities in different parts of the world. Oil slicks appear as dark patches on SAR images because of the damping effect of the oil on the backscattered signals from the radar instrument. Nevertheless, automatic detection based only on radar images is still problematic because it is difficult to distinguish oil from other phenomena, especially at low wind speeds. Natural organic films, areas shadowed by the coast, rain cells, zones of upwelling, and oceanic or atmospheric fronts and internal gravity waves have all on occasion been mistaken for oil slicks in SAR images. The ability to distinguish such oil 'look-alikes' from real oil pollution would be an essential feature of a continuous satellite based system. However, this can only be achieved through careful consideration of available background information and better understanding of the processes controlling the formation of oil and other organic films and the factors that determine the appearance of different slick-like features in SAR images.

1.1 The DeCOP Project

DeCOP and its sister project SIMP (Slicks as Indicators for Marine Processes) bring together expertise from five European countries, Germany, Portugal, Russia, Ukraine and United Kingdom. The aim of DeCOP is to create reliable algorithms for detecting small scale oil spills and waste-water discharges. This will be done by combining satellite data at optical, infrared and microwave frequencies to monitor water quality, give information on parameters controlling the formation, transport and evolution of oil slicks, and provide more general background information that will help to identify potential oil look-alikes. The project combines satellite information with field and laboratory studies of marine pollutant films and their physical characteristics, which influence their wave-damping capacity. This is combined with mathematical modelling of wave damping by organic films, and of the scattering of electromagnetic waves at radar frequencies. The project is still in its early stages, but preliminary results presented here demonstrate the multi-sensor, multidisciplinary approach through examples from some of the study areas - all regions where marine traffic, off-shore oil fields, tanker operations or waste-water discharges have been the cause of oil pollution in the past, and still remain a risk to the marine environment.

2. FIELD WORK IN THE BLACK SEA

In August–September 2004 field work was carried out in the Black Sea to develop methods for the use of ERS-2 and Envisat ASAR data to detect sources of pollution in the open sea (Lavrova *et a*l. 2004a). Field observations included optical imaging from vantage points on the shore, optical imaging from a helicopter and the collection of hydro-meteorological data. Analysis of 5 ERS

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SAR and 7 Envisat ASAR images from the period has revealed two main sources of pollution in the study area: oil and oil product spillages in the port of Novorossiisk, and waste water discharges from vessels on anchorage sites and in the open sea. Waste-water discharges containing oil products are frequent, both close the shore and far from it. Analysis of available satellite data reveals dark patches due to oil films in data from August 10, 20, 23, 26 and September 5, 8, 11, 27 (figure 1). When such events occur far from shore, they can only be detected by satellite radar.

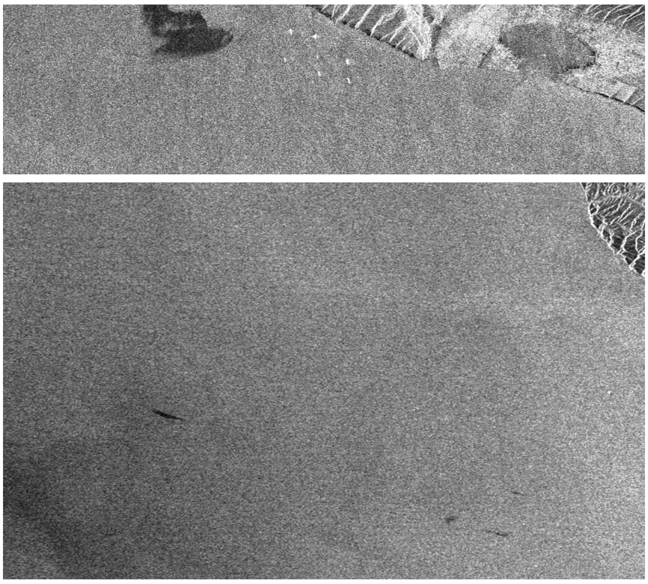

Figure 1. Examples of minor oil spills. ERS-2 SAR from 20 August 2004 (top) shows a dark patch representing waste water discharge on the anchorage site near Cape Doob. Below: Envisat ASAR data from 23 Aug. 2004 show pollution 65 km offshore.

2.1 Environmental conditions favourable to oil spill detection

In addition to detecting oil pollution sources and identifying areas of frequent pollution, oil pollution manifestation in radar images was investigated in relation to wave parameters, wind speed and direction and the state of near-surface layer of the atmosphere. The most favorable conditions for detecting pollution are wind speeds of 3-7 m/s, waves up to 3 points, and stable atmospheric stratification near the sea surface (Lavrova *et al.*2004b, Mityagina *et al.*2004a). Under weaker winds and in the absence of waves, radar images often show numerous slick bands created by the presence of natural surfactants, which resemble oil pollution. During unstable atmospheric stratification convective processes can disguise oil patches in radar images, particularly older spills, where films have been thinned by the impact of waves and wind. Near the coast wind direction is an important consideration, as oil look-alikes may occur when off-shore winds interact with the coastal relief to cause wind shadows.

2.2 The Georgios III oil spill

An oil spill from the Greek tanker Georgios III occurred in the study area on August 7 (figure 2). The tail of oil products was detected by an optical camera on board the helicopter, and the degree of pollution was estimated from visual observation, using a method of oil slick classification by density evaluated on a scale of 1-5 (Litovchenko and Lavrova, 2005). Large amounts of oil was also seen in Envisat ASAR data 12 hours later. Fortunately, pollution events of this scale are rare. This case was unique for two months of observations following the fate of the spill.

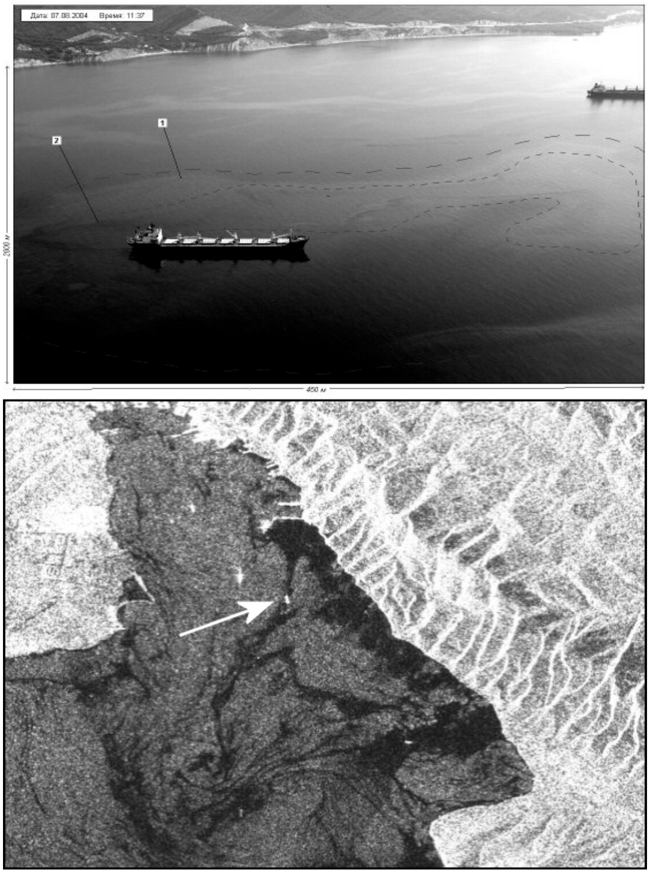

Figure 2. The Georgios III oil spill on 7 August 2004. Top: aerial photograph of the spill. Bottom: Envisat ASAR image of oil in Tsemesskaya Bay 12 hours later. Arrow shows the tanker position.

3. OIL SPILLS IN THE CASPIAN SEA

Deterioration of facilities of the old sea drilling platform over Neftyanye Kamni oil deposit in the Caspian Sea is the cause of almost everyday spillages of oil. Figure 3 shows examples of how such spills may be observed in images from Envisat ASAR as they are spread over areas of tens of kilometers by winds and currents.

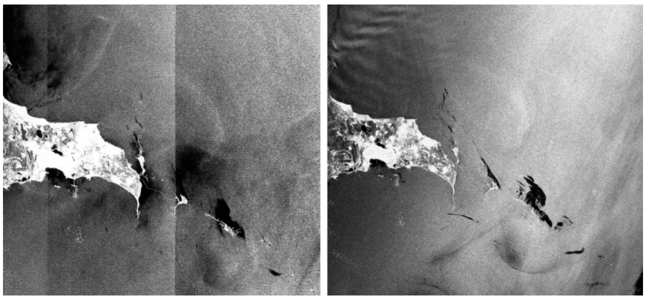

Figure 3. Envisat ASAR images of oil pollution in the Caspian Sea on 9-10 August 2004, obtained 12 hours apart.

3.1 Modelling of radar backscatter from thick oil films

Oil spills in the Caspian Sea study area include areas of the sea surface covered by films with a thickness reaching several millimeters. Such films do not include surfactants forming a monomolecular layer on the surface, and bistatic scattering by the films may be modelled using a three-layer medium of atmosphere, film and water divided by two statistically rough interfaces. In the middle layer, the film, multiple reflections are allowed. Scattering is described using geometrical optics. Multiple scattering in the middle layer leads to interference between electromagnetic waves reflected in different directions. An analytical solution is obtained for the amplitude of the scattered field at a small fragment of sea surface as function of frequency and polarization of the incident electromagnetic wave, incidence angle and film thickness. Computed dependencies of scattering intensity on film thickness have an oscillating character, and small variations in thickness may correspond to a very wide range of scattering intensities. Preliminary results also reveal qualitative differences in the angular dependencies of scattering at two polarizations for films of different thickness (Mityagina *et al.* 2004b).

4. OIL SPILLS IN THE JAPAN SEA

Oil refineries are concentrated on the southeast coast of Japan, the south of South Korea, and China along the Bo Hai and Shanghai. There is heavy oil tanker traffic in the East Asian Seas from the Persian Gulf to Japan, Taiwan, and South Korea. Development of new oil fields in the Okhotsk and Yellow Seas, construction of a new oil-pipe-line from Angarsk (Eastern Siberia) to the Japan Sea coast, and continuing releases of petroleum hydrocarbons into rivers all contribute to an increase in marine pollution, making continuous monitoring essential. High resolution observations by satellite SARs have a significant contribution to make to routine pollution monitoring in this area, and is a main objective of the cooperation between China, Japan, Korea and Russia in the Northwestern Pacific Action Plan. A web site on oil spill monitoring has recently opened at the Coastal Environmental Assessment Regional Activity Centre (NOWPAP 2004).

Figure 4 reveals how data from instruments such as ERS-1/2 SAR may be analyzed to reveal essential information. The image shown was acquired at 02:00 UTC on 22 September 1997, and shows several dark features in Peter the Great Bay, Japan Sea. These were defined as illegal oil spills from ships due to their simple shape and structure. The dark patches seen in this image east of the Muraviev-Amurskiy Peninsula, east of the Russkiy Island and southwest of the Gamov Peninsula are likely due to weak winds. The thin lines near a dark patch east of the large oil spill are example of natural biogenic slicks resulting from enhanced biological activity. Based on data from this image wind speed in the area of the extended dark spill was estimated with the usage of the CMOD4 model to be 3 m/s. Wind direction was determined by the orientation of dark stripes in the oil spill area. Oil begins to spread as soon as it is spilled but it does not spread uniformly. Any shear in the surface current will cause stretching and even a slight wind will cause a thickening of the slick in the downwind direction (figure 4a). Windward side looks like dark stripes that stretch on wind direction. Estimated wind direction was about 220° in the spill area (figure 4b). over the whole image. Method of interactive adaptive slicing of the clusters was used to determine the oil spill area. An accuracy of this method is estimated as 2-3%. The area of the large spill is 32.3x106m^2 and the volume of the spilled oil is 6.5 m^3 providing the oil film thickness is 0.2 micron.

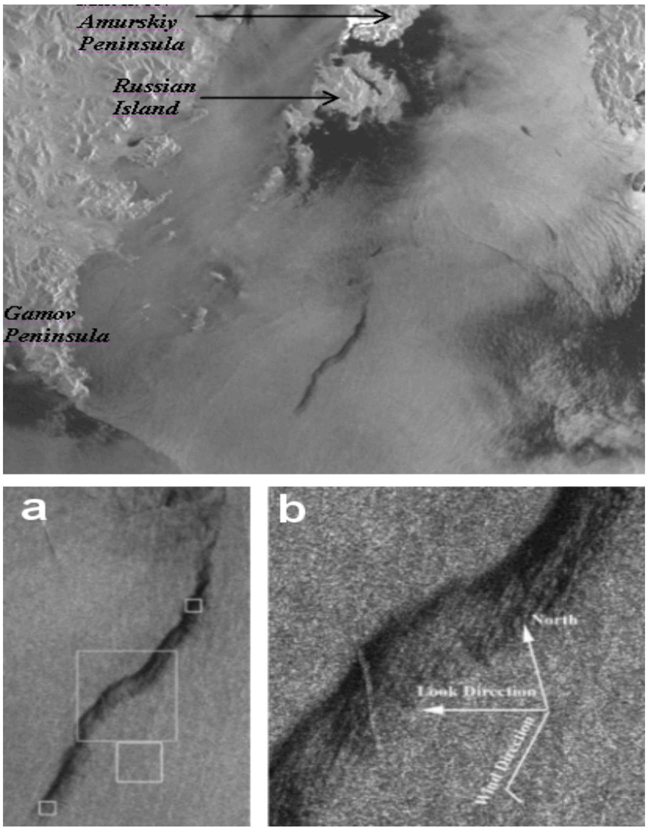

Figure 4. ERS-2 SAR image from 22 September 1997 at 02:00 UTC showing oil pollution in Peter the Great Bay, Japan Sea. Below this (a) shows an enlarged fragment of oil spill (large white rectangle) used for estimating the wind direction (b).

5. A SYNERGISTIC APPROACH TO OIL LOOK-ALIKES

An important aim of DeCOP is to develop algorithms that will improve the discrimination between oil pollution and natural look-alikes in SAR images. This is a complex task, often requiring a multidisciplinary approach. An example is shown in figure 5 where phenomena associated with an atmospheric front and internal waves give rise to slick-like features extending from Aveiro Lagoon north along the Portuguese coast. At first glance these may be taken for oil, but further analysis using available background information reveals that this is unlikely to be correct.

Aveiro is a regional port, where pollution from port activities, tourism development and local industry pose a potential threat to the ecosystem of the coastal lagoon, and routine monitoring using satellite data would be a useful management tool. The ERS-2 SAR scene in figure 5a shows a plume with reduced radar intensity extending from the mouth of the lagoon northward along the coast for more than 20 km. At first glance this feature may seem to represent an organic surface film, possibly oil pollution. However, several oceanic or atmospheric phenomena are known to give rise to oil look-alikes, and could also cause the low back-scatter features seen here. Analysis of the backscatter patterns reveals that the dark plume is bounded to the west by a sharp front characterized by a slick-like signature with a 4 dB drop in normalised radar cross section, followed by wavelike features with enhanced and reduced radar backscatter intensity of about 1 dB.

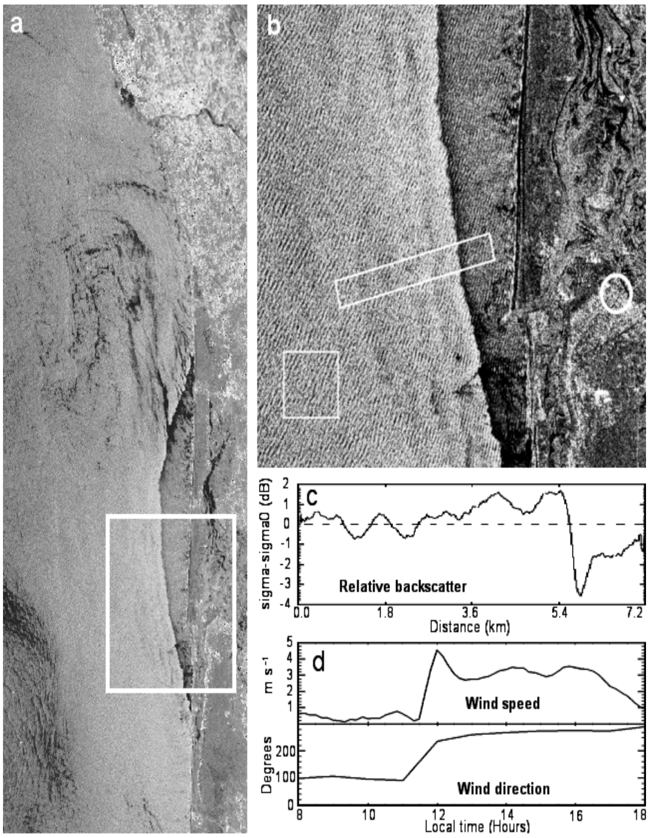

Figure 5. Oil look-alike caused by atmospheric internal waves. a) ERS-2 SAR scene from the west coast of Portugal on 26 September 2001 at 11:19:57 UTC. b) Extract from the image showing wavelike features. c) Relative backscatter profile obtained from the area of the long rectangle in b. d) Wind speed and direction recorded at the meteorological station near Aveiro indicated by a circle in b.

A calibrated backscatter profile performed across the front, revealed at least 4 waves of approximately 1.5 km wavelength (figure 1c), likely to be caused by atmospheric gravity waves. Records from the meteorological station of the University of Aveiro nearby show periodic wind speed oscillations, preceded by a sharp change in wind speed and direction, consistent with the propagation of internal waves and internal bores in the atmosphere, provided the necessary stratification is present. No atmospheric soundings are available from the Aveiro, but typical end of summer conditions in the study region indicate the existence of a temperature inversion, and data from La Coruna, 300 km North of Aveiro, shows an inversion at 1500m altitude, which could trap the wave energy at low atmospheric levels. Thermal infra-red data from NOAA AVHRR reveals cooler areas likely to be connected with low clouds or thick fog. The thermal pattern show a spatial similarity with the slick-like features observed in the SAR image, further supporting the conclusion that these are caused by atmospheric phenomena associated with an atmospheric front.

The ability to distinguish organic slick from small scale changes in the wind-field requires accurate meteorological data from the area at the time of the SAR overpass. Often this is not available, but analysis of other satellite data may yield the necessary information. For example, to establish the potential presence of atmospheric internal waves the Scorer parameter (Scorer 1949) could be obtained from temperature data and the profile of wind speed and direction. Such information could potentially be obtained from satellite information on cloud-top heights and temperatures, combined with meteorological radar information.

Internal gravity waves can propagate both in the ocean and the atmosphere, provided stratification is appropriate. Both are commonly observed on SAR images of the sea surface, and have been interpreted in terms of models describing the radar imaging and the dynamics of these two types of waves (Alpers, 1996). The Scorer parameter indicates conditions when energy can be trapped at low atmospheric levels and give rise to internal wave signatures in SAR data. A comparison between the Scorer parameter profile and the wavenumber of wave-like features observed in SAR data should reveal whether conditions are right for atmospheric internal wave propagation, and thus used to classify SAR internal wave signatures as atmospheric.

Other synergistic approaches under investigation include the use of data from various radar sensors to establish the spectral damping characteristics of biogenic surface films and to establish their spatial extent on a global scale. In combination with radar, ocean colour data are used to study biophysical indicators for the generation and decay processes of biogenic surface films.

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