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SPILL SCIENCE & TECHNOLOGY BULLETIN

Oils • Chemicals • Land • Marine

SPECIAL ISSUE

ERS SAR Contribution to Oil Pollution Monitoring in the Mediterranean

Guest Editor: Gianna Calabresi, ESA-ESRIN

PERGAMON

SPILL SCIENCE & TECHNOLOGY BULLETIN

Oils • Chemicals • Land • Marine

Aims and Scope

An international, peer-reviewed journal on oil and chemical spill science and technology focusing on the effects and control of discharges of oil, oil products and other hazardous substances. It includes *Research* papers, *Review* papers, *Viewpoint articles, Technical Notes* and *Technical Product News*, as well as sections for *Book Reviews* and *Announcement of Conferences* of general interest to the spill community. Subjects treated are engineering developments, including equipment performance assessments, as well as scientific issues, and physical, chemical and biological research findings. Both land and water spill issues are addressed and papers linking science and technology with policy and management matters (including economics) are also considered appropriate. The unique aspect of the journal is its focus on solutions, rather than identification of the impacts of oil and chemical spills, derived through enhancements in basic knowledge and development of new methodologies and advanced technologies.

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PREFACE

ERS Thematic Workshop. Oil Pollution Monitoring In The Mediterranean. 25–26 March, 1996, ESRIN, Frascati, Italy

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On 25 and 26 March, 1996, ESRIN organised and held at their premises in Frascati an ERS Thematic Workshop on "Oil Pollution Monitoring in the Mediterranean". It was the second in a series of Thematic Workshops started in March 1995 with the "First ERS Thematic Working Group Meeting on Flood Monitoring". © 1997 Published by Elsevier Science Ltd

Introduction

The ERS mission is a European Earth Observation mission with two satellites (ERS-1 launched in 1991, ERS-2 launched in 1995). Each satellite carries a suite of instruments (for the most part operating in the microwave region of the electromagnetic spectrum) which provide information regarding a variety of Earth system processes both off-line and in near real time. In particular, both platforms are equipped with a Synthetic Aperture Radar (SAR) which acquires information about the Earth surface (ocean and land) in all weather conditions and at any time, day or night.

As one of a number of actions relating to the exploitation of the data acquired by the SAR, ESA-ESRIN have organised thematic workshops dedicated to particular uses of the SAR data. These are intended to bring together satellite operators, information service providers and the end customers within the relevant business and application domains.

Given that the operating characteristics of the SAR make it very suitable for the detection of oil slicks, a thematic workshop was organised to focus on the issues related to the prevention and control of illegal and accidental oil discharges in the Mediterranean area.

The attendance of the 1996 Workshop on Oil Pollution consisted of over 65 participants from entities such as national Pollution Control Authorities, scientific and research institutions, Universities, Ministries of Environment and Transportation, Space Industries, private Consultancy/Value Adding Companies, specialised Press Representatives, national Meteorological Institutes and National Remote Sensing Centres.

The following Countries were represented: Cyprus; France; Germany; Greece; Italy; Malta; the Netherlands; Norway; Spain; Sweden; and the United Kingdom. Participants from international programmes/organisations like Joint Research Centre, SACLANT, Mediterranean Action Plan/UNEP, REMPEC (regional Marine Pollution Emergency Response Centre for the Mediterranean Sea), EUR-IMAGE Consortium, and SPOTIMAGE were also present.

Workshop Scope

As for the previous Thematic Workshop (focused on "Floods"), the decision to hold a second Workshop on a different but challenging subject like "Oil Pollution" was inspired by the innovative concept in ESA to ensure, whenever possible, that the Earth Observation Programme's objectives by pursued not only in the scientific but also in the application and operational/ commercial domains.

Several considerations led to the selection of oil pollution in the Mediterranean as a theme for the workshop. These were:

- the uniqueness and fragility of the Mediterranean ecosystem;
- the high risk of both intentional and accidental pollution from the extensive levels of shipping traffic (among the highest in the World);
- the need to identify how best to use available surveillance technology within the context on national, international and multi-lateral agreements and legislation (e.g. the Mediterranean Action Plan) to provide an adequate monitoring and early warning service;
- the opportunity the workshop would provide to bring together the various parties interested in the use of satellite derived information for pollution monitoring within the Mediterranean region.

A selection of papers from the workshop is presented here, illustrating the diversity in organisations involved with the problems of the Mediterranean and also the level of development that has already been achieved with regard to implementation of an operational monitoring system.

A summary of the main points and conclusions arising from the workshop is included at the end of this special issue.

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VIEWPOINT

The Use of Satellites to Detect Oil Slicks at Sea

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Oil pollution from ships (and offshore installations) poses a threat to the marine environment in two ways:

- **the loss of crude oil due to accidents which can range in size from a few tens of tonnes to some hundreds of thousands of tonnes; and**
- **the deliberate illegal discharge of oil, which can vary from a few litres to a few tonnes.**

The effects of major spills have been well studied and the acute effects of the oil on the environment are fairly well understood. Illegal discharges pose a chronic threat and should be considered along with the other (greater) source of oil pollution which is land based, entering the marine environment via rivers.

This paper will concentrate on illegal discharges from ships and offshore installations and how we in the UK consider satellites might be of value in detecting and deterring illegal discharges. © 1997 Elsevier Science Ltd

The Role and Responsibilities of the Marine Pollution Control Unit

The Marine Pollution Control Unit (MPCU) was established to provide the UK Government's response to an oil or chemical spill from a ship at sea. It also provides assistance to Local Authorities who are responsible for cleaning oil from the coastline. The MPCU develops and implements the UK's National Contingency Plan for dealing with oil spills.

In order to conduct an effective at sea clean up operation it is necessary to have aircraft which are capable of directing the response into the thicker part of the oil. As a rule of thumb 90% of the oil will be located in 10% of the slick area and it is not possible for a ship based observer to determine where the thicker parts of the slick are located.

For this reason the MPCU has developed the use of aircraft remote sensing equipment. As this equipment is available on standby to respond to the relatively rare event of an oil spill it has been decided that this resource can provide a cost effective way of monitoring UK waters to detect illegal discharges of oil from ships.

Current Aerial Surveillance

The MPCU has two Cessna 404 aircraft (Fig. 1) on contract fitted with side-way looking airborne radar, ultraviolet and infrared detectors, a still camera and video.

Side-way looking airborne radar (SLAR)

This is an active device which measures the roughness of the sea surface. The surface is illuminated with microwaves with a wavelength in the region of 3 cm, and the reflection is used to build up a radar

Fig. 1 Cessna 404 remote sensing aircraft.

picture on both sides of the aircraft. Capillary waves on the sea surface will give a strong echo, and unusually smooth areas such as those caused by an oil slick, where the capillary waves have been damped, will show up against the background.

SLAR can provide an image of an oil slick from a distance of up to 24 km, even when the oil layer is thin. By scanning continuously to either side of the aircraft large areas of the sea can be checked for the presence of oil very quickly.

The main disadvantage of SLAR is that it responds to any phenomena that suppresses capillary waves. For example, certain current patterns, ice, and surface slicks associated with biological activity can all produce false targets. It is important, therefore, that SLAR targets be confirmed as oil by other means.

Ultraviolet Line Scanner (UV)

Oil is a good reflector of the ultraviolet component of sunlight. The UV is a passive device which detects reflected ultraviolet with a wavelength of about 0.3 μm. It is mounted vertically beneath the aircraft, and can build up a continuous picture of an entire oil slick, even the extremely thin areas, as the aircraft passes over the oil. It cannot, though, distinguish between oil layers of different thickness.

Infrared Line Scanner (IR)

The IR is very similar in operation to the UV, and the two are normally operated together. It detects infrared radiation with a wavelength of about 10 μm emitted from the oil. Thin layers of oil radiate more slowly than the sea and show up as black patches on the display. Thicker layers (greater than about 0.5 mm) will warm up more rapidly than the surrounding sea and show up white on the display.

IR can therefore give some limited information about the relative thickness of the oil on the water surface (the MPCU is currently funding research into this aspect). It is not as sensitive to oil as UV and so comparison of the outputs from the two sensors will show the position of those thicker parts of the slick where combating efforts should be concentrated. Infrared systems can be misled by other temperature effects, such as cooling-water discharges and should therefore always be used in conjunction with other sensors.

Photographic Camera

Conventional photography will not normally provide a clear and unambiguous image of an oil slick, but it can be valuable as a simple and readily understood record of the scene of an incident. When used to augment imagery from more sophisticated sensors, photographs can provide an on-scene commander with a better idea of the operations in progress around him. Also, in general, the public and the courts tend to be more receptive to photographic evidence than to imagery from less common devices.

Video Camera

Much the same applies to video recordings as to photography. The advantage of video is that it provides a more instant record and of course a moving picture. It does not have the same degree of resolution or clarity as a photograph and presentation is less convenient.

Cameras can be fitted either with a conventional data back, which will record date and time on the negatives, or with a data back which will accept information such as latitude and longitude from the remote sensing system computer.

Systems

The imagery from the remote sensors must be processed on board the aircraft if a display is to be available to the operator. This is done by means of a dedicated computer which accepts as input signals from the various sensors and information from the aircraft's navigation system, and presents it to the operator in the form of an annotated video display. If more than one sensor is operating, the operator can switch between the different images.

The computer can also provide some limited in-flight processing facilities, typically expanded views of areas of the screen, and facilities for selecting targets to provide navigational instructions for moving the aircraft to the target.

Output from the computer is recorded for future reference. There are several ways in which this is done. The raw information from the sensors and the navigation system are recorded digitally onto tape for further processing on the ground. The operator's display is recorded on to conventional video tape and it has been found useful in addition to provide an audio track on the video tape to record the operator's comments. The computer also provides navigational information (position, heading, altitude, time) to photographic and video cameras to be superimposed onto the pictures.

As data from the sensors are recorded digitally, it is necessary to have a ground-based computer system for further processing. This might simply be the production of hard copies—it has been found useful to augment flight reports by telefaxing hard copies of imagery from the operational airfield to the command post and to other appropriate centres. In addition, a ground-based computer provides digital video image enhancement to permit more accurate measurements of the slick, and false colour displays to assist visualisation of the scene.

Some systems allow for the direct transmission of imagery from the aircraft to the ground station, using either fast but short-range VHF or slower but long-range HF radio, this has not been done in the UK.

Operational procedures

UK waters are divided into a number of patrol areas of roughly equal size (Fig. 2). These areas are patrolled on a random basis but with more patrols in the areas of known activity, such as area M where most of the UK's oil production platforms are located and areas C, D, and E which cover the busy shipping lanes in the English Channel and Southern North Sea.

When on patrol the aircraft proceed at 290 km h^{-1} at a height of 1000 m using SLAR only. When an image is detected the aircraft drops to 300 m and investigates the slick using UV and IR. If a vessel is associated with the slick the aircraft drops to 100 m to identify the vessel and obtain pictures/video.

Possible offenders are imaged and photographed using the techniques set out in Chapter 23 of the Bonn Agreement Counter-Pollution Manual. It is important that the photographs and the imagery show that the vessel is the only possible source of the oil. The vessel's name is photographed, if possible, in a way which identifies it unambiguously as the offender and recorded in the log. The master is contacted and invited to explain the discharge. His response is noted precisely, and if possible recorded on the remote sensing tape.

On return to base, the evidence from the offence is treated as evidence to court and all precautions required by the law are applied in securing it and transferring it to the responsible authorities. After each mission, routine tapes and logs (that is, those showing oil-like targets but with no potential as evidence) are taken for interpretation and statistical analysis and the results recorded in a database for use in periodic reports and future planning.

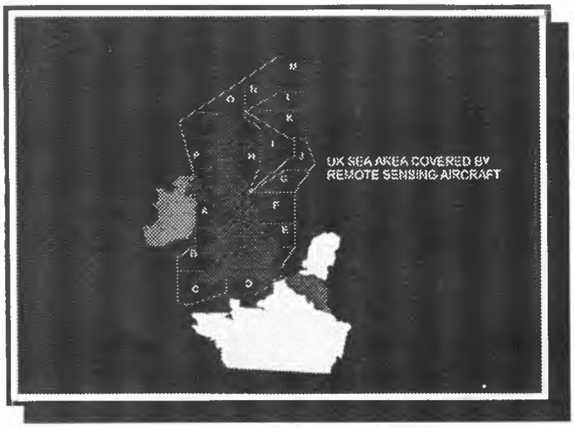


Fig. 2 UK sea area covered by remote sensing aircraft.

A SLAR image will give the location and area of the slick but UV will confirm that the slick is mineral oil and IR will show the thicker parts. The two images shown in Fig. 3 are of a test spill of approximately 10 t, the IR shows the 'structure' of the slick which has started to break down into windrows (wind is bottom right to top left).

BONN Agreement

The primary objective in routine patrolling is to encounter ships in the act of discharging oil illegally, and to gather sufficient evidence for a prosecution. Contracting parties to the Bonn Agreement (Fig. 4) have agreed a co-operative approach to aerial surveillance, and this is set out in Chapter 4 of the Bonn Agreement Counter-Pollution Manual.

Over the years a large body of data has been collected for aerial surveillance in the North Sea. The charts in Fig. 5 show the data for individual Bonn Agreement countries for 1994 and the total data for 1986–1994 (the data for 1995 have been compiled and are awaiting agreement from Bonn Agreement countries before being made available for wider circulation).

Perceived Weaknesses

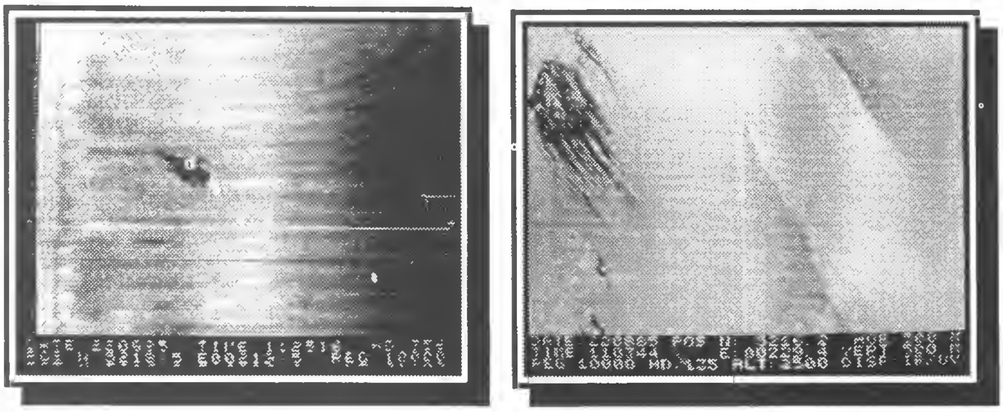
Weather/visibility

Weather and visibility will affect the ability of the remote sensing aircraft to detect slicks for two reasons (Table 1).

- Bad weather will restrict the ability of the aircraft to fly. Although the waters around the UK can experience severe weather the percentage of times when the aircraft cannot fly is quite small.
- Weather conditions will affect the ability of the sensors to detect slicks and to identify offenders.

Table 1 Table of the number of times the use of a particular sensor was reported by Bonn Agreement countries for 1994

Wind speed	Visual	SLAR	UV	IR
Less than 3 knots	43	33	8	10
3–30 knots	148	454	190	189
Greater than 30 knots	6	3	2	2



SLAR IMAGE IR UV

Fig. 3 SLAR image; UV, IR.

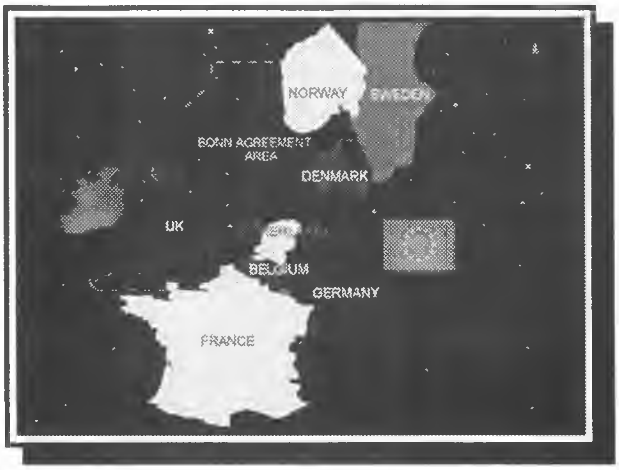


Fig. 4 Bonn Agreement area.

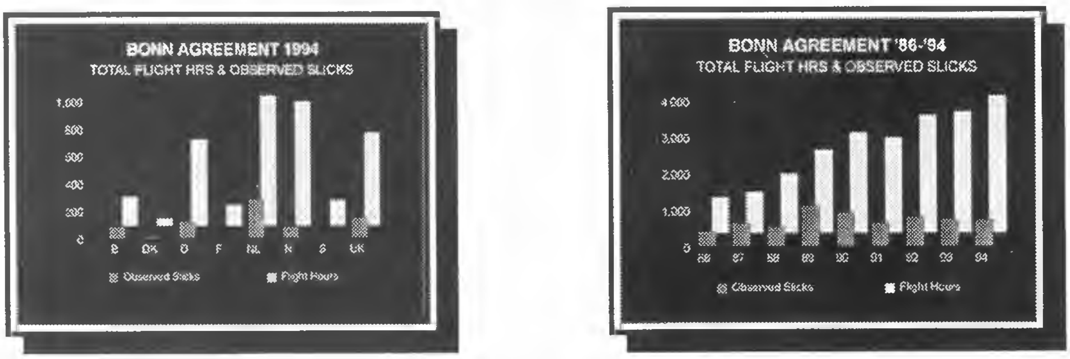
Detection by SLAR is limited by very low and very high wind conditions. In near calm weather there are no capillary waves to be dampened by oil and in very high wind conditions any surface slick will be broken up and rapidly dispersed.

IR will detect slicks for a few hours after sunset, and the UV can not be used during the hours of darkness, which is when many illegal discharges occur. Work is being carried out to develop a low light camera which can be used to identify the offender at night without the aircraft descending to an unsafe altitude.

Number of hours flown

The UK waters currently patrolled cover some 360 000 km^2. When on patrol the aircraft flies at 290 km h^{-1} and covers 24 km on each side using SLAR. Therefore the aircraft can survey some 14 000 km^2 h^{-1}. Assuming a slick will persist for 24 h, then to ensure that all slicks are detected would require 26 h to be flown each day—assuming 6 h patrols this would require some four aircraft.

The total yearly hours required would be some 9400 h. In fact we fly some 800 h (500 on ship patrols and 300 on offshore installation patrols). This represents around 10% of the requirement. It should be remembered that a form of 'stratified sampling' is



BY COUNTRY TREND

Fig. 5 Bonn agreement data by country and trend.

employed with more hours flown in some areas than in others.

The current cost of the 800 h is £320 000 and to give full coverage would require an expenditure in excess of £3.5m.

Possible Uses of Satellite Mounted SAR

Collection of statistical data

A regular, thorough coverage of UK waters would give sufficient data to show where slicks occur and when. Thus patrol flights could be focused in critical areas and at critical times. This would ensure that the aircraft had the maximum possibility of encountering an offender.

More interestingly it could indicate temporal trends which could be used to assess the effectiveness of new regulations such as special area status.

During major oil spills

It is unlikely that a major oil spill would occur without the relevant national authorities being aware (not least because of the search and rescue element which accompanies collisions, groundings, explosions etc). Therefore satellites will not help in the alerting process.

During a major incident remote sensing aircraft will be used to assess the spill and direct response operations. It is unlikely that satellites limited to SAR will assist. Indeed it is possible that a satellite image, which contains no internal structure showing where the thicker parts of the oil are located, could mislead and distract those carrying out clean-up operations.

During the recent *Sea Empress* incident in Wales (15 February 1996) SAR images were obtained but were not used to direct response operations. Interestingly the image in Fig. 6 does not indicate the main location of the slick and no significant oil was observed in the area shown as black on the image.

Other images (Figs 7–9) showed a mixture of 'dark' areas where no significant oil had been detected and 'dark' areas where oil could have been.

Detection of illegal discharges

Satellites can detect slicks at sea, but they cannot confirm that the slick is due to oil, nor can they identify any vessel causing the slick. It is unlikely that at present courts would prosecute on the evidence of

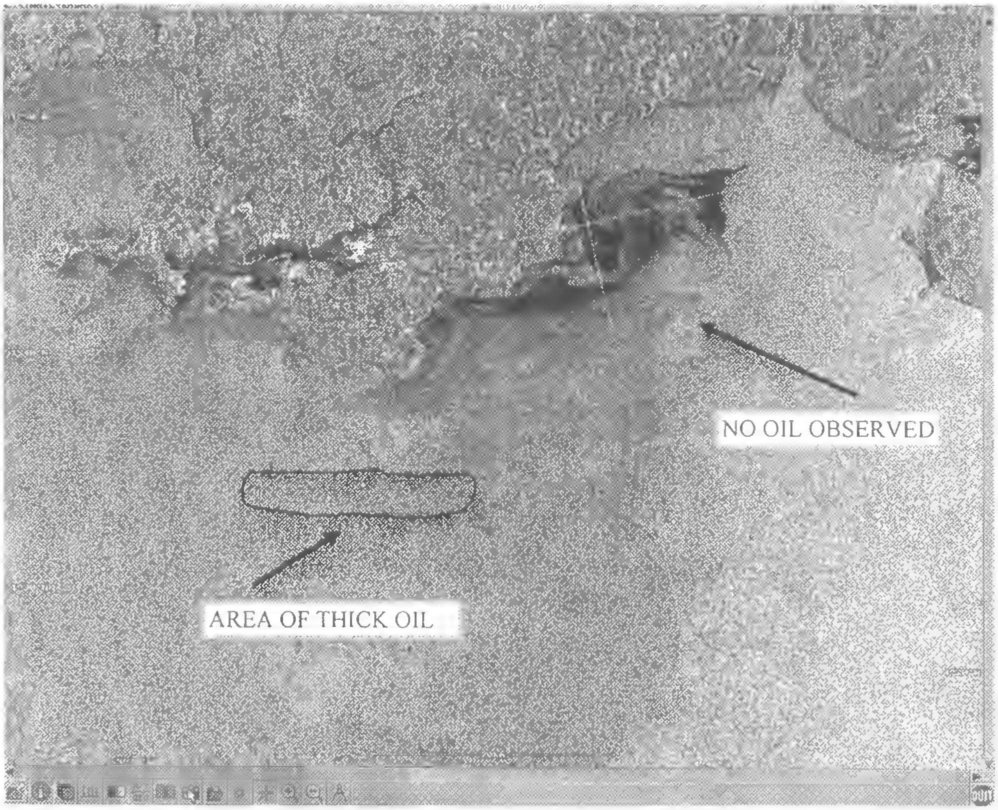


Fig. 6 Image from Radarsat February 21st 1996 at 06:45 UTC (wind 5–8 m s^{-1}, Northerly).

IMAGE FROM ERS-1 25th February 1996 at 22:23 UTC (wind 7 to 10 m/s Easterly)

Fig. 7 Image from ERS-1 25th February 1996 at 22:23 UTC (wind 7–10 m s^{-1} Easterly).

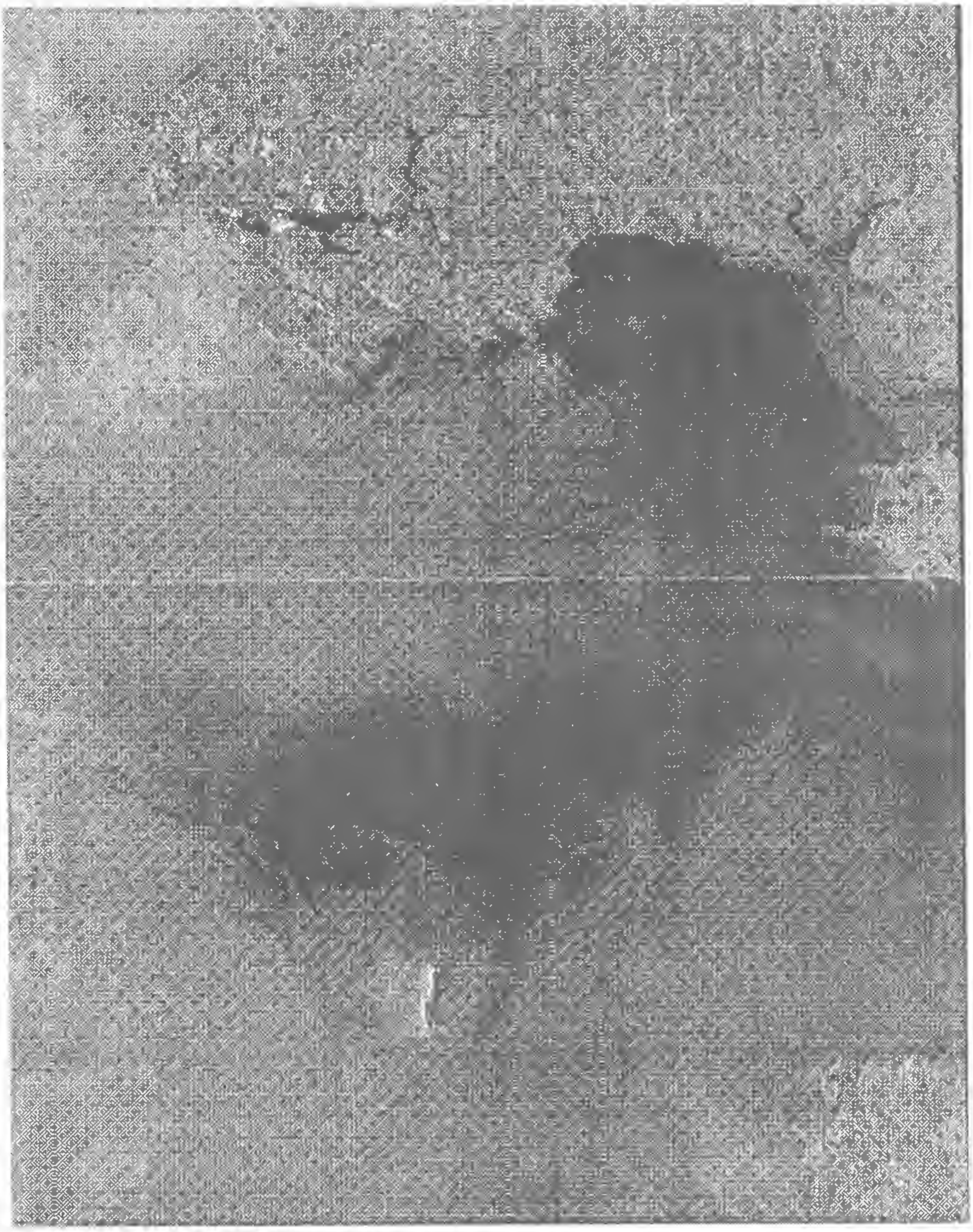


IMAGE FROM ERS-2 FEBRUARY 26th 1996 at 22:23 UTC
(wind 4 m/s Southerly)

Fig. 8 Image from ERS-2 February 26th 1996 at 22:23 UTC (wind 4 m s^{-1} Southerly).

satellite imagery alone. However, it is possible that satellites could prove a useful way of using remote sensing aircraft more effectively. This is currently being carried out in Norway.

From the data on number of hours flown, it can be seen that the probability of an aircraft encountering a ship discharging illegally is relatively low. If satellites could be used to direct the aircraft to probable offenders this would increase the detection rate and possibly the number of prosecutions. The increase in prosecutions, combined with the knowledge that satellites are being used, could increase the deterrent effect of the aircraft patrols and therefore reduce the total quantity of oil discharged.

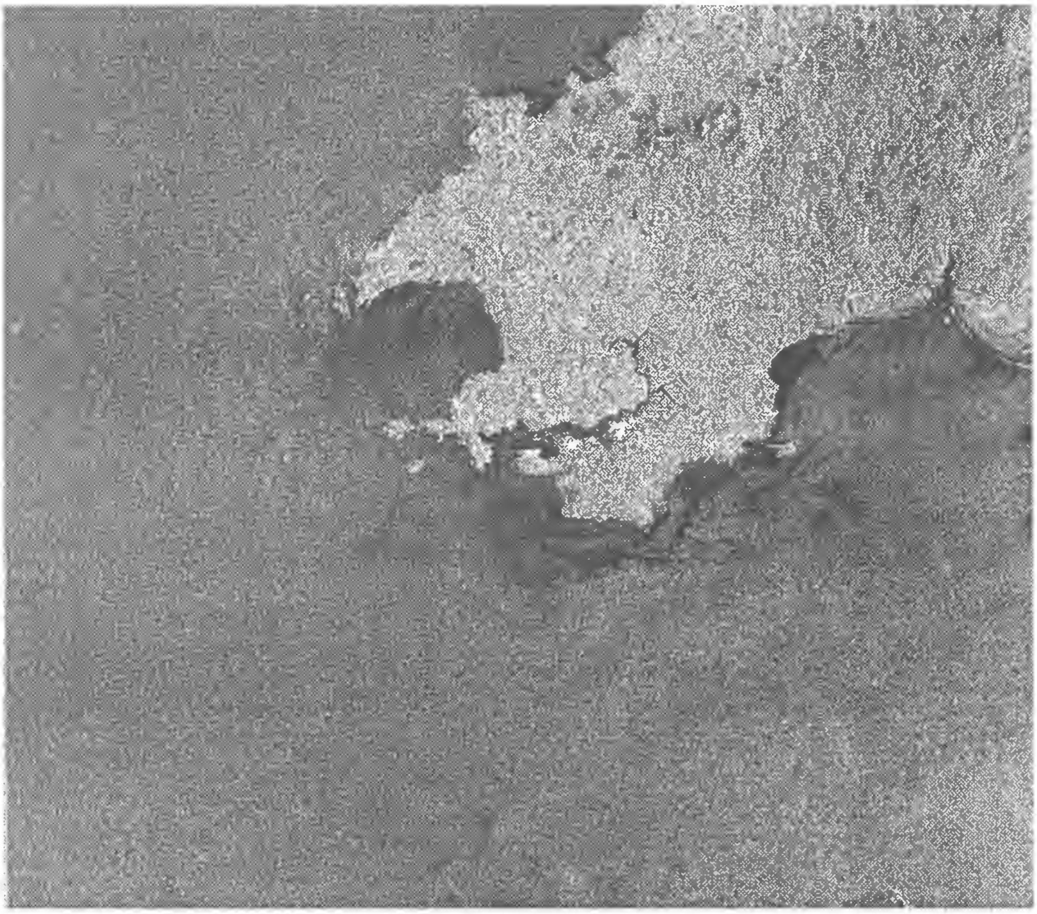


IMAGE FROM RADARSAT FEBRUARY 29th 1996 (time unknown)
(wind 5 m/s Northerly)

Fig. 9 Image from Radarsat February 29th 1996 (time unknown) (wind 5 m s^{-1} Northerly).

User Requirements

For the aircraft to be directed to a possible offender in good time to ensure that the ship can be identified it will be necessary to receive notification from the satellite within 1 h (it may take the aircraft up to 2 h to arrive on the scene depending on distance from base). In order to avoid wasted effort the satellite should be correct in its identification of an oil slick at least 90% of the time.

It is not necessary to send detailed imagery in the first hour; this can follow in slower time and can be used in conjunction with data collected by the aircraft.

As mentioned earlier, the UK currently spends some £320 000 each year on aircraft remote sensing. In order to improve the effectiveness perhaps some 20% of the budget could be directed to satellite detection. However, £60 000 will not buy much satellite time. It would appear that the best way forward would be some form of multi-user agreement based on a regional agreement such as the Bonn Agreement, or through a wider user group such as the EU.

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VIEWPOINT

CEO Proof-of-Concept Study on Oil Spill Detection Services: User Requirements and Feedback

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During the Pathfinder Phase of the Centre for Earth Observation (CEO) Programme, a number of studies were launched in Europe to demonstrate how application projects could be fostered within the CEO framework and to experimentally test elements of the Programme. Actual projects and applications were used as a practical demonstration towards achieving the high level objectives of the CEO project. Therefore, the primary purpose of the applications proof-of-concept studies were as a test of the CEO concept.

The applications proof-of-concept studies contributed to the user requirements capture by providing input from expert users in the scientific and operational domains. They also contributed to the testing of the services exchange model named the European Wide Service Exchange (EWSE, internet address: http://ewse.ceo.org/.). The EWSE was implemented as test-bed during the CEO Pathfinder Phase and is currently operational in maintaining feedback with the Earth Observation (EO) community. Additionally, the studies helped to assess the capability of the selected projects and applications to broaden the range of users of EO data and services.

Two issues were of particular interest in the frame of the CEO activities:

- ***Thematic issues.* The type of data, information and services required from the user(s) or furnished by the provider(s) for a given application area, including related policy, costing, etc. issues.**
- ***Technical issues.* The practical usefulness of infrastructure elements, such as user interface, network access, etc. and including an assessment of the effort required to achieve the CEO objectives.**

This paper describes the user requirements and feedback collected by one CEO application proof-of-concept study conducted by the Tromsø Satellite Station in Norway and dealing with the detection of oil spill at sea. © 1997 Elsevier Science Ltd

***Keywords:* Oil spill, pollution, SEA, SAR, CEO, user requirements.**

During the Pathfinder Phase of the Centre for Earth Observation (CEO) Programme, a number of studies were launched to promote and foster the use and dissemination of data, products and services developed by application-oriented projects. These studies were called 'CEO application proof-of-concept studies'.

An application proof-of-concept study on utilization of ERS SAR data for near real-time detection of oil spills at sea was performed using the pre-operational oil spill detection service provided by Tromsø Satellite Station (TSS) as a test probe. The service operated by TSS is a result of a project that was started in 1991 as part of the Norwegian Space Centre's (NSC) national ERS-1 application programme.

The project consortium was composed by Tromsø Satellite Station (TSS, Norway), Telenor Research and

Development (TNR, Norway), Swedish Space Corporation (SSC, Sweden).

The main objectives of the study were the improvement of the interaction with current users and the capture of new customers for the oil detection service.

In addition to existing users in the North Sea area (i.e. Norwegian Pollution Control Authority (Norway), Rijkswaterstaat (The Netherlands), National Remote Sensing Centre (UK), Norwegian Defense Research Establishment (Norway)), new users were identified and contacted. This new group of users included:

- Baltic Sea countries;
- other Bonn Agreement countries; and
- value adding companies.

The users can be divided into three main categories: national pollution control authorities (NPCA), value adding industry (VA) and research and development (R&D) users. NPCA users have three main purposes concerning oil spill detection: early warning, legal prosecution and off-line applications (documentation, statistics, planning and long-term environmental planning). VA users are interested in data for studies on natural oil seepage and data for operating an oil spill detection service. Oil companies belong to the VA group. R&D users are interested in data for science applications.

The study has focused on the users, and extensive user interactions have been performed. Through the means of oil spill service experiments and service information exchange, the dialogue with the users was established and the user requirements and feedback assessed. This paper presents the user feedback obtained during the study.

User Description

The users currently interacting with the service can be divided into three main categories:

The end users interacting directly with the service by receiving the final information about identified possible oil spills at sea, e.g. NCPA and oil companies. The requirements of the pollution control authorities are to obtain information in near real-time, i.e. in less than 1 h, about possible oil spills in their territorial waters. The oil companies requirements are generally off-line, but could also be near real-time for monitoring and operational purposes during larger accidents.

The value adding users receiving standard SAR images from TSS, performing an analysis by themselves, and informing their end users directly. These users (could) also have a near real-time requirement. This is especially critical to the total data throughput since transmission of larger amounts of data is required.

The R and D users requiring limited but representative amounts of data containing specific features for development and verification tasks. This type of user normally have an off-line delivery requirement, but a requirement for on-line archive and catalogue search and browse. The concept of the service–user interaction is illustrated in Fig. 1.

The interaction frequencies with the users varies from weekly with the pollution control authorities, to only a few times annually with the R and D institutions and the oil companies. From an average analysis of approximately 350 scenes per month, alarms are forwarded to the pollution control authorities for approximately 2.5% of the data, i.e. one alarm every fourth day. A study is undertaken in order to evaluate the quality of satellite based oil spill detection vs aircraft based oil spill detection. Preliminary results shows a good correlation between the two observation methods. The amount of false alarms from satellite based oil spill detection is probably less than 5%.

The interactions with the oil companies mainly results from a requirement for detection of natural oil seepage from the sea floor off the coast of Norway. More than 150 ERS-1 SAR images have been analysed and ten seepage candidates have been identified. None of these candidates have, however, been confirmed by any *in situ* observations. Eight of the candidates were detected at very favourable wind conditions (i.e. wind speed less than approx. $5\,\mathrm{m\,s^{-1}}$). Comparison of the observed candidates with wind speed and direction estimates shows a reasonable good match between observed slick direction and wind speed direction.

The current service can be characterized as a pre-operational service. The coverage area in combination with the near real-time capabilities of Tromsø Satellite Station represent important advantages of the current service. The overall objective is within three years to develop an operational service utilising satellite based information in combination with aircraft. The results obtained so far have demonstrated that there is still a need for continuous service improvements. Both shorter term activities dealing with improvements of existing algorithms, products and systems, and longer term activities dealing with new developments and improvements are required. These requirements are planned to be taken care of under the service R and D activities.

User Feedback Analysis

This section presents the user feedback in terms of products issues, service issues and communication issues, obtained during the study.

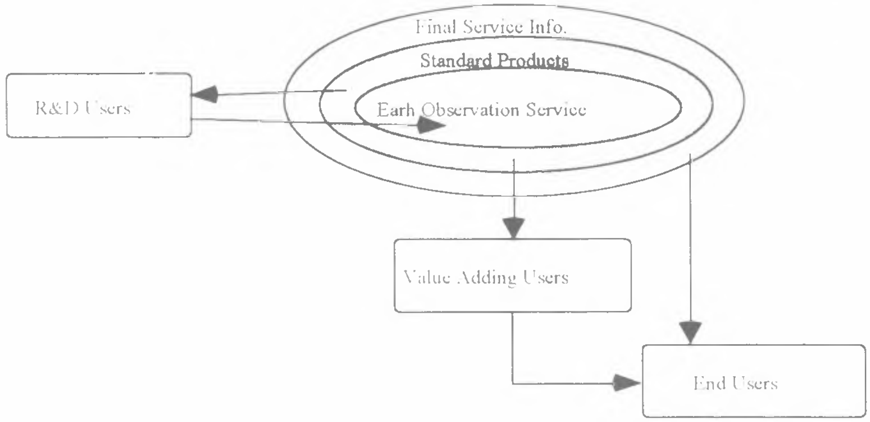

Fig. 1 Relationship between the oil spill service and the existing main user groups.

Product issues

This section discusses various user requirements that have or may have implications for the products delivered by the Oil Spill Detection Service.

Requirements. The following list of requirements have been obtained during the study, especially through the user workshop, user visits, and other contacts with the users.

- Information on the time and position of observed slick should be contained in the alert.
- An estimate of the slick extent and volume.
- Avoid information about thin slicks.
- Classification of oil types and discharge samples. A classification of the oil spill, i.e. to assess crude oil type either by remote sensing or from discharge samples taken in the sea and onboard the ship.
- An estimate of the probability that the detected feature is real pollution, e.g. different from natural slicks/algae blooms.
- Illegal discharge detection. To distinguish legal from illegal discharges. Legal discharges may be of two kinds. Authorized discharges as defined by the International Convention MARPOL 73/78 and the other kind are e.g. sewage pipes, natural seepage areas, leaking wrecks etc.
- Identification of the discharge source. Either to identify an illegal discharging ship or a potential source known a priori to exist at the slick position.
- Off-line need for images (hard copies or digital) for documentation purposes.
- Statistics on location and frequency of occurrences of illegal discharges.
- Statistics for long-term environmental impact monitoring.
- Raw data off-line or in near real-time.
- Detection of natural seepage, time, location, extent.

Problems. The NPCA users in general emphasize that their main problem is not to detect oil spills but to obtain evidence that can be accepted in court. This may require a change in court evidence rules concerning illegal discharging from ships. None of the prosecutions based on aircraft oil spill detection led to a conviction in the HELCOM area during 1994.

Satellite data alone are not regarded as sufficient evidence in court. Other sources of information will always be needed, e.g. infrared scanner data, photographs and possibly also samples.

Assessment of the satellite capabilities and limitations is one of the key issues in order to develop a dialogue with the users. A listing of the limitations in terms of the previously presented requirements has been produced.

- Volume cannot be estimated from SAR data.
- Discrimination between thin and thick slicks is not possible from analysis of SAR data. It can be used for detection of oil spills but the technology currently does not allow a reliable discrimination between thick and thin slicks.
- Classification such as determination of the crude oil type cannot be made from SAR data.
- Discrimination between different kinds of natural slicks is very difficult without having collateral data.
- Only detection of oil spills or other surfactants is possible by means of SAR data.
- It is generally not possible to identify the discharge source from SAR data alone, especially for moving targets such as ships. However, for fixed targets such as off-shore oil rigs identification is possible.

Solutions. The two previous sections have presented user product requirements and problems related to these requirements. This section discusses possible solutions.

- Estimation of pollution volume is regarded as one of the important issues. This can hardly be done by satellite. An indication of a possible solution is discussed in the next point. The satellite information can be used as a guide for an aircraft to map out the thickness of an oil slick, e.g. by use of an IR scanner or microwave radiometer. Additional volume estimates can be obtained from samples taken from a boat.
- Crude oil type determination may possibly be a potential of an aircraft equipped with a laser fluorosensor (LSF). The normal procedure is to take samples in the sea and onboard the ship. The probability of getting high quality samples will increase with shorter time between satellite acquisition and delivery of indication to the end user.
- The Oil Spill Detection Service may aid in identification of a discharge source in two ways:
  - by giving an alert with delivery time very close to real time and with a ship detected in the image so that an available airplane or vessel can identify the culprit; and
  - by using a GIS to identify a possible source, e.g. when the position of a discharge indicates that it comes from a previously known source giving pollution/pollution-like features. Any other slicks not explained by the analysis have to be inspected and investigated by other available means.

Service issues

Requirements

- *Service flexibility.* The service provider must be able to provide the users with the product or set of products they require. We have identified three different user groups: (1) those who require only information about possible oil spills; (2) those who require images for their own interpretation and analysis; and (3) those who require both information and images.
- *Additional source of information.* Existing oil spill monitoring systems are based on use of aircraft and/or other observation means. Satellite based information will in an operational system represent an additional source of information, primarily contributing to the development of a more efficient and cost-effective operational system. Use of aircraft will be important for observation verifications, identification of polluting source and for classification of pollution type. Aircraft are also more flexible to operate than a satellite, and a combined use of satellites and aircraft are therefore the most likely operational scenario.
- *Legal prosecution.* Pollution control authorities requires evidence of the oil spill in order to identify and catch illegal polluting sources for legal prosecution. Satellites cannot be used for providing direct evidence in court. Additional sources of information are required, e.g. aircraft and *in situ* measurements.
- *Data continuity.* In order to develop the use of satellite data for operational applications, a continuity of satellite data is required. This means that satellites with SAR instruments are required also in the future. Gaps in data availability are unacceptable to the users.
- *Near real-time aspect.* The time between satellite observation and information provided to the end user is a critical factor. It has been expressed that even a one hour time delay is too long for this kind of service. A very short time delay will increase the possibilities of identifying the pollutant. The time aspect is also important for combat planning and monitoring e.g. during larger accidents. Some users have expressed requirements for information about possible spill less than 30 min after satellite overpass.
- *Acquisition planning information.* The available planned acquisition period for ERS-1 and ERS-2 is currently 3 weeks. To aid the planning of aircraft operations, especially for co-ordination of aircraft with satellite overpasses, this information should be available earlier. For planning purposes some of the end users require information about planned acquisition at a minimum 6 weeks in advance. Provision of acquisition planning information is, however, a satellite operator responsibility outside the control of the service provider TSS.
- *Data archive.* Both R&D users and VAI require a data archive for off-line analysis, science and statistical purposes.
- *Presentation tool.* A low-cost, add-on, easy-to-use presentation tool is required by users receiving images. PCs are available in most offices and are widely used, and it should therefore be possible for a new oil spill service user to avoid installing new hardware. Distribution and presentation tools should therefore be based on existing hardware and systems at user premises.
- *Extended coverage of existing low priority areas.* Satellites can provide data from areas not covered by other surveillance systems. In this way an area not covered by aerial surveillance due to low priority or lack of resources, could be monitored by satellite.
- *Monitoring special areas.* During special occasions like major accidents, disasters and offshore activities a selected area should be regularly monitored for a limited time period.
- *International cooperation.* The operations of satellite based systems for pollution monitoring are seen as an international community responsibility, especially

by some of the national pollution control authorities and the R&D users.

- *User support.* The service utilising satellite data for oil spill detection is a new service. Many of the users dealt with during this study, especially those located in the Baltic Sea countries, have little experience of interacting with the service. It is therefore strongly required that TSS provide support to the users. This mainly includes information about service capabilities and limitations, training on image interpretation, installation and training of the service communication tool, SARA.

Other service requirements specified by the users are:

- proven service confidence (90% true alarms);
- daily coverage of priority national waters;
- satellite data may be used for early warning during night-time (when aircraft do not fly);
- additional information about images in data archive (meteorological data, *in situ* observations etc.); and
- highest priority, many users want to be the first one served.

Problems. Use of satellite SAR for detection of oil spills at sea is a new application, and many of the users are unconvinced about the cost effectiveness and about the information reliability and quality. In addition, concerns about the uncertainty of satellite operations in the future have been expressed.

An operational monitoring service based on utilization of satellite data alone do not provide the end users with all the information they require. A final identification of the pollution type and source is not possible, and the satellite based information cannot be used for legal prosecution. The satellite is hence considered to be one of several means of providing an operational service for early warning of oil spills.

In the following a list of the most important problems are provided.

The users must be convinced about the *cost-effectiveness* and the benefits of the service. In the first instance the satellite application costs appear higher than the users normally deals with, and the benefits versus the costs are not addressed.

The current *near real-time aspect* is not satisfactory for all users. The service provided by TSS offers an alert of a possible oil spill within 2 h after acquisition. Many users state that this alert time is too long for their application.

The most experienced users already make efforts to coordinate aircraft operations with satellite coverage. For this purpose information about satellite acquisition plans is needed in advance. The current final acquisition plans including timing information provided by ESA is available 2 weeks in advance. For some of the users this period is too short since the aircraft operations are planned for a longer period.

The users' ultimate requirement for operational purposes is *daily coverage* of their national areas. At present it is not possible to offer a service with daily satellite coverage over a given area.

In general, use of WWW is regarded as the future operational tool. The experiences obtained during this study do, however, show that an information exchange process involving use of *WWW is not available to all users*. The WWW is also too slow for some users. Especially presentation graphics and images are too time-consuming to retrieve and to display.

From some users' point of view, management of an all-European oil spill detection service should be a *responsibility of an international organization*, in addition to national activities. The main problem is, however, that currently there exists no international institute or organization that has taken the responsibility for managing such a monitoring service.

An important requirement for a further development of a user community is a guarantee of *continued access to satellite data*. There is, however, no commitment from any satellite operators about a future, operational SAR satellite programme.

Solutions. A fully operational monitoring service that best can meet the user requirements should be based upon a *combination of satellite and aircraft (and other means)*. During the study the best results in terms of user satisfaction have been obtained for those already utilising these combined sources into a joint service.

The *alert time* can be improved with a minimum of investments, both technical and through optimization of the TSS service routines. An immediately applied solution has been to send the information about a possible oil spill first by a telephone and fax alert to the user, and then send the image electronically.

As regards the timing of *acquisition planning* TSS, which has daily/weekly contact with ESA, should put pressure upon ESA and try to convince them that this is an important requirement from the users.

Telephone and/or fax have, through practical applications, demonstrated their usefulness as an alternative and/or additional means for information transmission. These means can be hence used instead of WWW for providing all kinds of service information to the users.

During the *design of WWW pages*, a trade-off between applicability and advanced designs need to be taken into account. Timely, effective, but informative, designs need to be developed in order to make it more operationally convenient for those users that have a low speed connection with Internet.

Cost benefit analysis are needed in order to convince the users about the real benefits versus total service costs. A cost–benefit analysis based upon Norwegian user requirements has been carried out and the results show that for monitoring of illegal oil spills it is more cost-effective to use a combination of satellite and aircraft than aircraft alone. Similar studies based upon broader all-European user requirements are needed for further market development.

Feedback from the users involved in the project regarding their interpretation and/or verification of the alarms issued from TSS should be strengthened in order to improve the service reliability. This should in turn be applied as a means for convincing other/new users about the service reliability and confidence.

Communications issues

Distribution of service information to the users is another important task dealt with during this study. Service information in this context means both information about planned acquisitions, historical data from the service archive, processed image data itself, and information about possible oil spills, or combination of all these. This section deals with the communication solutions applied for the oil spill detection service during this study.

Requirements. The requirements for access to information both about oil spills and image data in near real-time is the most critical one. This implies that a communication link has to be available whenever needed, and the link must in addition satisfy the transmission capacity requirements. The basic assumption is hence that fulfillment of these requirements will meet additional service communication requirements.

The complete list of requirements include the following.

- The communication solutions between TSS and the different users must be based on communication systems or means currently available at the user sites.
- TSS as a service provider has to deal with a multilevel communication system.
- Information to the users requiring only information about oil spills is provided by means of a telephone (early warning alert) and a telefax.
- For transmission of images for interpretation locally at the users sites, communication requirements are met by means of e-mail (directly from SARA) and/or a ftp-solution (presentation made in SARA).
- Distribution of both information and images means that the combination of both solutions has to be available.
- Network capacity, reliability, and availability are important criteria due to the importance of the delivery time of information and data. Since some of the users need to be served within a maximum delivery time of two hours, only minor delays due to the communication network can be accepted.

Problems. Establishment of the communication means for distribution of service information to the different users has been one of the most important challenges experienced during the project period. An electronic link for data and information distribution from TSS to an end user is not necessarily straightforward. Some users do not have technical facilities nor operational routines that allows implementation and use of SARA. The list of problems experienced include the following.

- Existing communication systems differ from user to user. Available communication services include:
  - telephone;
  - fax;
  - e-mail;
  - World Wide Web (internet); and
  - ftp (on-line service).The electronic mail system available at some of the users has not been compatible with the standard applied by SARA (MIME). It has therefore not been possible to apply SARA directly for distribution of service information to some of the users.
- System unreliability has been experienced in some cases. Phone/fax messages to some of the users in Eastern Europe have been very delayed or even missed.
- The TSS mail system is based on the internet. Because of this configuration it is not possible for TSS to control it, or to receive an automatic receipt confirming that the collections distributed via SARA arrive at the users. A manual confirmation from the recipient is therefore needed. This is one disadvantage for the e-mail configuration, e.g. compared with the use of ftp or complete X.400 based mail systems for data distribution.
- For security reasons, some users provide very limited external access to their internal, operational networks. Therefore, setting up an electronic link from TSS to such a user has required flexibility to adapt to special user systems.
- Network capacity is variable, and does not meet the requirements of the near real-time users. A delivery time of several hours has been experienced by one user while others have been able to receive images

within acceptable delivery times. The delivery time is also depending on the size of the collections being sent as an attachment to the e-mail message.

Solutions. In order to provide service information to the users, efforts has been made to solve the communication problems experienced during the study. The solutions to some of the main problems include the following.

- To cope with the different systems available among the users alternative means of communication solutions have been implemented. In addition to the already existing communication means (phone, fax and e-mail by internet), use of remote e-mail over modem and ftp have been implemented and applied.
- Instead of sending the SARA collections using e-mail, they are copied to a local ftp server where the user has an ftp account. TSS informs the users when the relevant data has been processed and made available at the server, and the users log on to the ftp account and retrieve the collections.
- For external access to the computer networks among the users applying limited external access, a remote e-mail client was implemented at TSS. This e-mail client is connected to the computer network via a modem placed at the SARA-PC at TSS. TSS are hence sending information to a dedicated server at the users which then distributes the information to the correct addresses.
- Messages have been traced in order to find reasons for missed or delayed messages. In one case, a delivery time of 17 min was experienced within the Internet mail system, while the additional delay in the internal network within the user's organization was 70 min, giving a total delivery time of 87 min from mail message left TSS until it was received by the user. The set up of the internal mail system is therefore important to follow up and to optimize parameters bringing delivery time down.
- Since the delivery time also is dependent on the size of the images, image compression has been tested during the study. By comparing compressed and uncompressed images, it is evident that a compression factor of 10 can be applied without loss of service specific information. By reducing the size of the e-mails to 1/10th compared to the originals, the transmission time is also reduced. Experiments have also demonstrated that for some R&D and/or value-adding applications the loss of radiometric information due to data compression can introduce limitations on the data applicability.
- Problems with phone/fax network to Eastern Europe is outside the responsibility of the project team, and have hence been difficult to solve.
- MIME support will be available at most gateways in the near future.

Benefits

User benefits. Several countries in Northern Europe have through multilateral agreements like the Bonn Agreement, HELCOM and the Copenhagen Agreement committed themselves to operate national surveillance services for monitoring of oil spills in national or adjacent waters. These services are normally being served by aircraft or ships or a combination of these. By introducing satellite as an additional source of information, several advantages could be obtained, as follows.

- The effectiveness of the surveillance services may increase. Larger areas may be covered during a period of time and/or the inspection frequency within certain 'high risk' areas may be increased. This will be obtained by giving NPCA the possibility of improved planning in the surveillance services taking into account satellite oil spill detection statistics from otherwise sparsely surveyed areas such as remote or 'low risk' areas.
- By introduction of EO data, a *combination of satellites, ships and aircraft* for surveillance should *increase the chances of early detection of oil spills*. These information sources have complementary functions. In contrast to, for example, aircraft, satellites can 'fly' during night-time and during bad weather conditions. It is important to state that satellite SAR data applied in the oil spill detection service is a tool for *detection* of oil spills, *not for investigation* of them. If such an indication becomes available, an aircraft or a ship is sent to investigate the slick for type and volume and, if possible, to identify a possible pollutant in the area.
- The near real-time aspect of the oil spill detection service may in general:
  - increase the probability of identification of an illegal discharge;
  - secure (if necessary) fast clean-up operations; and
  - prevent environmental damage.
- By introducing EO data in the surveillance services, improved *management* of surveyed waters may be achieved. The monetary impacts this will bring to society are, however, difficult to estimate.
- Improved development of environmental *impact assessment plans* leading to improved water quality in territorial waters.
- By compiling statistics within certain interesting areas, satellite data may be very valuable within prospecting of oil (natural seepage).

- Satellite images will help in getting a better overview of the oil spreading, and it would be a possibly source for input to oil drift models. By integration of satellite data into GIS, knowledge of the area is faster accessible.
- By introducing reliable, low-cost, add-on technological telecommunication solutions for distribution and presentation of images and related information concerning oil spills at sea, existing equipment located at users premises may be used during the analysing process of adequate satellite scenes. Hence, users have the possibility to build up *their own knowledge* regarding image analysing and detection of oil spills from satellite based information sources.

Conclusions

During the study most of the potential concepts of the CEO Programme were applied. In conclusion, the following can be summarized.

- The study has demonstrated that extensive users approaches (i.e. *ad hoc* workshops, real service demonstration) are needed to obtain new users. Use of WWW and traditional information and marketing means have not directly resulted in any new user contact, nor in any new user connection to the service. On the other hand, the CEO study has given the project team the opportunity to visit users and also offer them access to the service free of charge for a limited time period. The overall efforts resulted in six potential/new users connecting to the service.
- Use of satellite SAR for detection of oil spills at sea is a new application and many of the users are neither convinced about its cost effectiveness, nor the information reliability and quality. An operational monitoring service only based on utilization of satellite data does not provide the end user with all the information they require. Identification of the pollution type and source is not possible, and the satellite based information alone cannot be used for legal prosecution. Satellites are considered to be one of several means of providing an operational service for early warning of oil spills. A fully operational monitoring service will have to be based upon a combination of satellite and aircraft (and other means).
- The experiences and the users' feedback obtained during the study have demonstrated that the service with minor technological developments, can be considered a platform suitable for further application development.
- The main challenge for the Oil Spill Detection Service is the realization of a market where users are willing to pay the full service cost. The users do not yet trust the quality of the satellite based services.

Based upon these considerations and results coming from similar proof-of-concept-studies, also covering other application areas, and from the actions conducted in the Pathfinder Phase, the final version of the CEO concept was finally designed, consolidated and approved in December 1995.

The CEO Concept forms the basis for the Design and Implementation phase, planned to be completed by end 1998. The concept comprises four interrelated components, summarized as follows.

- **User Support** comprises the actions and measures to help the user to benefit from EO to meet his or her professional goal.
- **Enabling Services** initiates actions and measures and will provide software and systems to increase the exchange and accessibility of meta-data and information about Earth observation.
- **Application Support** stimulates the production of information from Earth observation data, in response to customers needs, and draws more customers into the system.
- **Monitoring and Co-ordination Services** manages, monitors and develops the CEO.

More information on the CEO Programme can be found in the Document Library of the European Wide Service Exchange, at the following WWW address: http://ewse.ceo.org/.

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VIEWPOINT

ENVISYS Environmental Monitoring Warning and Emergency Management System

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Informative Summary

The Mediterranean Sea is a well frequented sea route allowing access to Southern Europe, North Africa, the Middle East and the Black Sea. The result of this extensive marine traffic is a high risk of oil pollution, both intentional and accidental. In addition to the obvious ecological risks associated with such pollution in a closed sea area, it is in the interest of all nations bordering the Mediterranean to protect their coastal zones on which they depend for tourism, fishing and other activities.

Changes in our environment are strongly tied to the capabilities of human resources to mitigate their effects, with the use of new technologies, equipment, and methods. The minimization, if not elimination of the considerable political, economical and environmental repercussions and the need to seriously address these repercussions have been widely recognized for many years now. The ENVISYS Project provides a telematic framework, where appropriate counteraction means can be undertaken, taking into account that different types of hazards have different evolution and control times.

The ENVISYS Project

Recently started ENVISYS is an international cooperation project, partly financed by EU DG XIII in the framework of the Telematics for the Environment Programme. Its primary objective consists of the creation of a complete system for early detection of oil spills, monitoring of their evolution and provision of support to responsible Public Authorities during clean-up operations.

ENVISYS consists of a set of separate modules that together constitute the integrated monitoring and management system. The project, therefore, provides a basis for several independent, commercial products that can also be used separately in other contexts. The primary source of data is satellite data. The availability of large amounts of satellite data should be emphasized as this enables the applied research results of the project to be transferred from the domain of R&D to the domain of commercial exploitation. Because of that, the project has identified a user reference group (URG) with more than 400 organizations interested in the ENVISYS approach.

The project is building demonstrators in three European countries (Spain, Norway and Greece) by integrating existing remote sensing techniques (based on synthetic aperture radar (SAR) imagery), communication tools, geographic information systems (GISs), databases and multimedia tools.

The demonstrators provide automatic detection of oil spills, based on intensive research work realized during the preparation phase of a relatively pre-operational service in Norway by the Norwegian Space Centre, the Tromso Satellite Station, the Norwegian Computing Centre and the Norwegian

Pollution Control Authority. The demonstrator is being tested and verified in two Mediterranean regions, the South Aegean Sea (Cycladic Region) and Gibraltar area, as well as in the Finisterre Region (Galicia, Spain).

In this way, the knowledge and experience acquired during the Norwegian experiment, can be transferred to and tested in South European areas selected due to the frequent incidence of oil pollution and characterized by different difficulties and operational requirements.

Project Objectives

The objectives of the ENVISYS project are the following.

- To integrate into a fully operational system existing remote sensing, communication and software intensive technologies, as well as existing public infrastructure
  - for sea monitoring;
  - for detection of oil spills due to human activities;
  - to issue warning to responsible public authorities; and
  - to provide decision support to the said authorities during clean up operations.
- To investigate the cost effectiveness of chosen techniques and solutions in the selected geographic regions, which present different weather conditions, sea current patterns and coastlines.
- To investigate the applicability of similar concepts and techniques in other physical disaster phenomena, most notably forest fires and floods.

Expected Results

The project aims to detect a very high percentage of all slicks created during the demonstration, constrained only by satellite coverage of the area in question (in terms of time). As 24 h satellite coverage is anticipated in the imminent future the achievement of this aim could demonstrate the system's potential to be used, on a daily basis, as a very powerful tool for public agencies in this field.

Apart from the direct monitoring functions, the existence of a sea monitoring system, has a clear preventive action, by marketing and exploiting the satellite surveillance factor. It is observed and generally accepted that a major part of sea pollution comes from oil dumping in open seas.

The users of ENVISYS technology are regional, national and international authorities responsible for enforcing national and international law for marine environment. Secondary users are organizations and industry taking part in verification, assessment, and clean-up activities. The ENVISYS project focuses on providing assistance directly to the Environmental Authorities, enterprises and institutions involved in environment protection.

Basic Technologies Used

ENVISYS creates a platform integrating the following techniques.

Remote sensing techniques

Remote sensing techniques are the principal components of the ENVISYS technology. In the case of oil spills, detection by SAR is based on the dampening effect oil has on capillary and short ocean surface waves. In order to discriminate from 'look alike' phenomena, (which currently prevent the development of automatic tools) higher-level analysis based on special characteristics for oil slicks has been tested to a limited degree, and has shown promising results. The necessary development of automatic oil slick detection in this project will draw heavily on these results. Main sources are the ERS-1 and ERS-2 data as well as other non European satellite data as soon as they become operational.

Geographical information systems

GISs are a principal tool for presentation purposes and decision support. In particular, ENVISYS is interested in modelling the developments of oil slicks (based on data for sea currents and prevailing winds in the region where the disaster occurred) in order to support agencies conducting clean up and monitoring these operations. Currently, commercial GISs provide very powerful modelling tools which make such tasks feasible and quite practical.

Databases

In order to support public authorities in their clean-up operations, various types of data (images, maps, statistical data etc.) mainly related to the demonstration areas are stored in data bases. Examples of useful data include:

- historical data from previous oil pollution events (images, photos, maps, damages etc);
- detailed sea maps (bathymetry, sea currents, coastlines, coast types etc.);
- thematic maps (sea, coast and land use, fishing and sea cultivation, areas of ecologic importance, underwater flora, tourist regions); and

- chemical products used in clean-up operations associated with oil type and oil spill characteristics (dimension, depth etc.).

Telecommunication services

The early detection of oil spills depends on the timely delivery of satellite imagery at near real time (i.e. within a few hours from the satellite passing). This requires fast data communication links from the satellite ground stations to the system operations site. The ENVISYS project uses high speed leased lines of up to 2 Mbits s^{-1} for this purpose. Today, such infrastructure is available in—and between—every EU member state. Therefore the availability of the telecommunications infrastructure seems to be assured, and only the question of operational costs in the case of a future permanent operation have to be examined, related to the possible use of new broad-band telecommunications links (e.g. ATM networks).

Likely developments

The types of emergency situations covered by ENVISYS are totally dependent on frequent remote sensing data from appropriate parts of the electro-magnetic spectrum. The remote sensing sector is steadily growing, and there is no doubt that access to remote sensing data will increase thanks to the presence in orbit of ERS-1, ERS-2 and Radarsat. The large European remote sensing platform Envisat will follow in the late 1990s, and there are plans for numerous other commercial remote sensing satellites within ten years. This ensures satisfactory data access and frequent coverage, which strongly supports the potential for ENVISYS to be an important tool for environmental emergency monitoring in the future.

System Characteristics

The system contains the following features.

- SAR remote sensing data collection and processing (a typical image product will cover an area of 100×100 km).
- Automatic oil slick detection in the radar imagery.
- Emergency assessment. The extent of the emergency will be assessed and the resulting information will function as a basis for planning of actions.
- Emergency information for local and central pollution authorities, fishery authorities and the public in nearby coastal areas.
- Emergency management support, including the forecast of spill direction and the continuous monitoring of the oil spill evolution.

Functionality

The ENVISYS system will contain two main parts: a core system and a set of additional modules. The core system will be of general applicability for all kinds of environmental emergency monitoring based on remote sensing. The additional modules will be application specific.

The core system

The core system will consist of five modules. Four of the modules will represent different operation types or modes of the system, while the fifth module is a toolbox. The four modes of the system will be as follows.

- Monitoring. The objective is to detect and indicate possible environmental emergency situations. Remote sensing data from the geographical area of interest is analyzed as the data enters the system. If a possible emergency is detected, the remotely sensed data is put into a geographical context and presented to the operator for manual evaluation.
- Assessment. If the operator can confirm a possible emergency situation, the system is switched to the assessment mode. The objective of this module is to verify the emergency situation and assess how serious it is. The system integrates geographical, meteorological and ancillary information, and applies GIS and multimedia tools to efficiently inform the operator of the situation assessment.
- Information. This module contains an information report generator for the system operator, and the authorities responsible for the verification of the oil spill and the clean-up operation, the professionals of the interested sectors (tourism, fishing) and the public.
- Management. This mode is for management of an operation to reduce or eliminate the emergency situation and its environmental consequences. It includes two-way communication with the field operation and tools for continuous planning of the

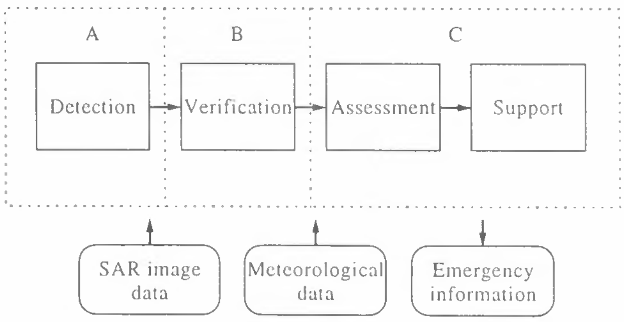

Fig. 1a System characteristics.

operation, Among the planning tools is a simulator for different scenarios of the emergency development. The simulator makes it easier to make strategic decisions for operations trying to limit the emergency.

- Basic tools. The toolbox contains functions that are used by more than one of the primary modules. This will include at least a GIS, multimedia functions and report generators.

The application-specific modules

A series of application-specific modules are connected to the core system.

- External remote sensing system. ENVISYS is linked to an external remote sensing system. The external system consists of one or more operational remote sensing satellites, a ground station, and possibly a remote sensing data preprocessor.
- Emergency detection. The emergency detection module receives remote sensing data from the preprocessor. Image analysis methods are used to screen the data for possible emergency situations.
- Data integrator. The data integrator combines other relative information, e.g. wind data from selected meteorological stations and the current location of emergency aircrafts with other data in the system.
- Information report generator. This module uses templates to generate recipient specific reports (e.g. to pollution authorities and the general public).
- Communication, planning and simulation. This is a set of sub-modules supporting the management module in the core system.

Methodology

The ENVISYS project draws heavily on currently existing techniques in processing of radar imagery and in emergency assessment and management systems. In addition, it is totally dependent on the timely availability of such imagery.

In general, all the basic technology necessary to develop ENVISYS exists. Parts of the system can be based on commercially available tools, and other parts can be based on experiments and methods previously developed in related activities. Hence, the main development activity necessary is integration of available methods and techniques.

The methodological approach taken consists of the following steps.

Collection of user requirements

Collection of user requirements, in particular current practices and problem areas, historical operational data and time related patterns of oil slicks, legal environments and future directions in conformance with national and European directives. This is considered as part of the user requirements based on the ENVISYS user/partners and also on the ENVISYS User Reference Group (URG) in order to produce the user requirement specifications (URS). Also, an assessment of the suitability of the existing work for incorporation in the final system is being conducted. In addition, a detailed report of currently available satellite imagery products shall be produced in relation to the demonstrator sites.

Detailed system architecture

Given the necessities for satellite imagery collection and processing, as well as the user requirements, a detailed system architecture is being designed together with the functional specification of each module. It should be noted that the communication requirements (satellite ground station to operator's site) differ from one demonstrator to the other. In addition, the functional design specifications (FDS) allows the incorporation of ready modules, in addition to off-the-shelf tools.

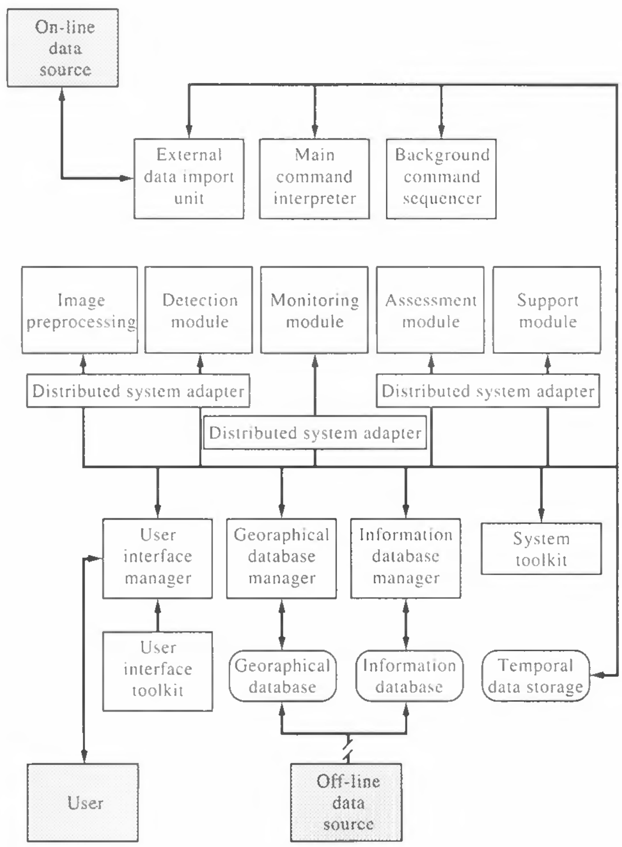

Fig. 1b Detailed system architecture.

Demonstrator implementation

In this context, the main tasks are the following.

- Oil slick detection. Basic image analysis techniques have been developed for automatic oil slick detection (Weisteen *et al.*, 1993). However, the current techniques have been tested on a very limited amount of remote sensing data. The results were quite good and demonstrated that oil slick screening is possible, but the results also indicate that the methods must be refined, tested on larger data volumes and made more robust to avoid unnecessary manual inspection.
- Integration with GIS. A commercially available GIS tool is integrated as part of the system. The GIS tool is available on different types of platform (i.e. PCs and UNIX workstations), and integrated with a window manager suitable for a multimedia environment (e.g. Microsoft Windows or Motif).
- Integration of image data and GIS system. The GIS system selected has this facility already built in.
- Integration of other data types. In addition to satellite imagery ENVISYS uses several other sources of data input. The project monitors standardization work in those areas where such work exists (e.g. in imaging, in remote sensing and in the GIS area) and use any available and appropriate standard data formats.
- Integration of a database. The system has built-in features for documentation of and experience assimilation from previous emergency situations. A commercially available database must be integrated with the system. Several suitable systems exist available on both PCs and UNIX platforms.

The demonstrators are implemented and tested in three different stages. The main goal of the first stage is to implement and perform a thorough testing of the basic capabilities of the different modules. All modules of the total system and all communication between modules are tested, but not necessarily together. This means that for instance the preprocessing and hazard detection modules and the communication between them could be tested in Norway while the modules for integration of imagery and other data types with GIS and multimedia systems could be tested in Greece.

Verification and demonstration phases

The precise test criteria to be used in the evaluation of the different stages are established as part of the user requirements analysis, but some of them include the following.

- Capability of detecting oil slicks. It is important both to detect all real oil slicks and to avoid as many false alarms as possible. Because many natural phenomena can have characteristics very similar to oil slicks, one must accept a certain number of false alarms. Most of these are discovered and discarded by visual inspection. The exact percentages that need to be covered must be established. Verification using continuous monitoring by e.g. aircrafts is far too costly. It is recommended to base detection verification on statistical sampling of data from other sources, e.g. reports from coastguard aircrafts and ships.
- Efficiency as a tool for assessment, information, and management. This is being tested for all emergency categories ranging from minor oil spills to major catastrophes. Within the verification period, no major catastrophes will, it is hoped, take place. Therefore, a couple of such situations must be simulated to obtain the necessary experience.
- Possibility of application to other emergency types. It is important that the general outline of the system can be applied to other emergency situations in the class described above. This is to be taken care of by the use of an expert panel with representatives from authorities with responsibilities within a representative selection of emergency types.
- User friendliness. This is an extremely important aspect of the system and is taken into account both in learning to use the system and in using it once it is there.

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- Mr. Wolfgang Boch of DG XIII for his support to the ENVISYS project and the Emergency Approaches through telematics;
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VIEWPOINT

The Activities of the Italian Coast Guard in the Field of Airborne Remote Sensing and the Eventual Use of Satellite Platforms in Marine Pollution Abatement Activities

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The Italian Coast Guard Corps operates twelve fixed-wing airplanes, type Piaggio P 166 DL3, for the performing of tasks related to the survey of marine environment. Three of them are fully equipped with a remote sensing system.

This system, including a bispectral scanner system Daedalus AA 2000 and a multispectral scanner system Daedalus DS 1268, can make a quick and effective survey both of the shoreline and large areas offshore and process and interpret real time data. Environmental (oil pollution erosion, coastal assessment) and policing purposes (identification and appraisal of illegal releases, prevention and repression of unauthorized building) are supported by such surveys.

Satellite platforms (ERS-1, ERS-2) can be utilized for surveillance duties, although, in the case of operational activities, a comparison with the data available from airborne remote sensing system must be made. The planning of such a programme cannot be carried out without a keen cost–benefit evaluation.

Background

The Italian Coast Guard Corps is a branch of the Italian Navy and gives support to the Ministry of Transport and Navigation. It is a highly professional and specialized organization carrying out, besides specific activities of a military nature, maritime policing activities in cooperation with various national Administrations. It operates in the following fields:

- search and rescue at sea;
- environmental protection and response to marine pollution;
- control of harbour traffic;
- harbour security;
- ship security;
- on and offshore maritime policing;
- regulation and surveillance of fishing activities;
- control of the merchant fleet
- control and policing of pleasure craft;
- maritime certificates;
- protection of pipelines and offshore oil platforms in the exclusive economic zone;
- coastal patrol;
- archaeological patrimony and underwater surveillance;
- support to anti-immigration patrols at sea; and
- participation in maritime operations in cases of natural calamity or national emergency.

The Italian Coast Guard deploys a variety of marine

REMOTE SENSING SCANNERS

(a)

- DAEDALUS AADS 1268

	CZCS	ATM
No. of Wavebands	11	11
Spectral Range (μm)	0.42 - 13.0	0 42 - 13 0
IFOV (mrad)	1.25, 2.5, 5.0	1.25, 2 5, 5.0
Focal length (cm)	15.2	15.2
Scan width (°)	86°	86°
Weight (kg)	140	140
Wavebands (μm)	Centre Width 1) 0.443 0 02 2) 0 490 0.02 3) 0.520 0.024 4) 0.560 0.034 5) 0.605 0.05 6) 0.670 0.064 7) 0.765 0.1 8) 0.885 0.11 9 - 11 As ATM	1) 0.42 - 0.45 2) 0.45 - 0.52 3) 0 52 - 0.60 4) 0.605 - 0 625 5) 0 63 - 0 69 6) 0.695 - 0.75 7) 0.76 - 0.90 8) 0.91 - 1.05 9) 1.55 - 1.75 10) 2.08 - 2.35 11) 8.5 - 13.0

(b)

- DAEDALUS AA 2000

	SEA VERSION	LAND VERSION
No of Wavebands	2	2
Spectral Range (μm)	0.32 - 14.0	3.0 - 14.0
IFOV (mrad)	2.5, 5.0	2.5, 5.0
Focal length (cm)	15.2	15.2
Scan width (°)	87°	87°
Weight (kg)	109	109
Wavebands (μm)	1) 0.32 - 0.38	1) 3.0 - 5.5
	2) 8.5 - 14.0	2) 8.5 - 14.0

Fig. 1 Remote sensing scanners.

craft, including 60 long-range vessels, 140 short-range boats with various features, 137 coastal short-range boats and 13 anti-pollution craft. Resources available include 12 fixed-wing patrol aircraft, type Piaggio 166 DL3, and four helicopters, type Augusta AB 412, the number of which is expected to increase to 21 in the future.

Remote Sensing Activities

The evolution of national legislation concerning the protection of the marine environment has made the specific responsibility of the Coast Guard Corps even greater in activities such as the control and abating of man-induced pollution and the management of protected marine environments. For this reason, development within both operational and professional areas of the Coast Guard is necessary and the importance of remote sensing has grown.

Remote sensing can be utilized by the Italian Coast Guard for surveillance of both the marine and coastal

Fig. 2 Daedalus scanner image of the Adriatic Coast, Northern Italy, between Marina Romea and the mouth of the River Po (Volano). In this false colour composite of channels 7–5–3 (red–yellow/green–blue), the visible band does not reveal any important feature on the sea surface, due to cloud cover.

Fig. 3 Thermal infrared image of the Adriatic Coast, Northern Italy, between Marina Romea and mouth of the River Po (Volano). It is a false colour processing of Daedalus scanner, channel 12, data showing marine areas with different temperature. Some of the intensity levels in the spectral response have been cut, to allow easier interpretation of the phenomena. Low temperatures (< 12°C) in blue; medium temperatures (12–14°C) in green; high temperatures (> 14°C) in red.

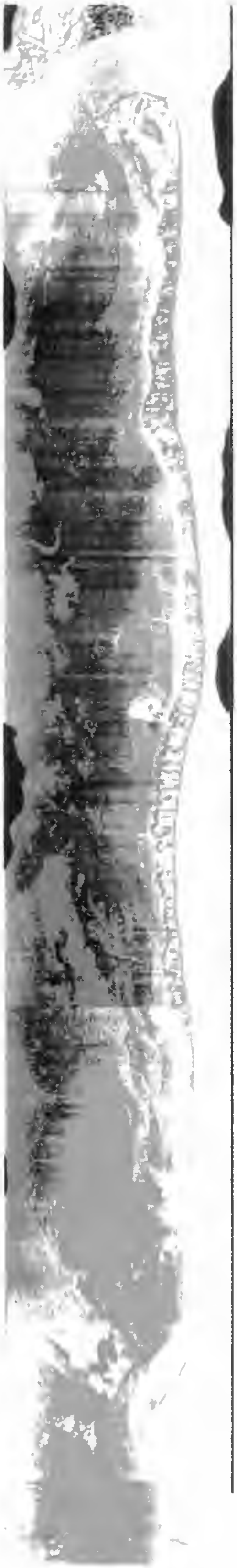

Fig. 4 False colour image of the Adriatic Coast, Northern Italy, between the southern part of the Venice Lagoon (Malamocco) and Chioggia. One can see the island off Pellestrina. Yellow colour filters have been applied to the processing of Daedalus scanner, channels 1 and 11, data in order to evidentiate the presence of hydrocarbons.

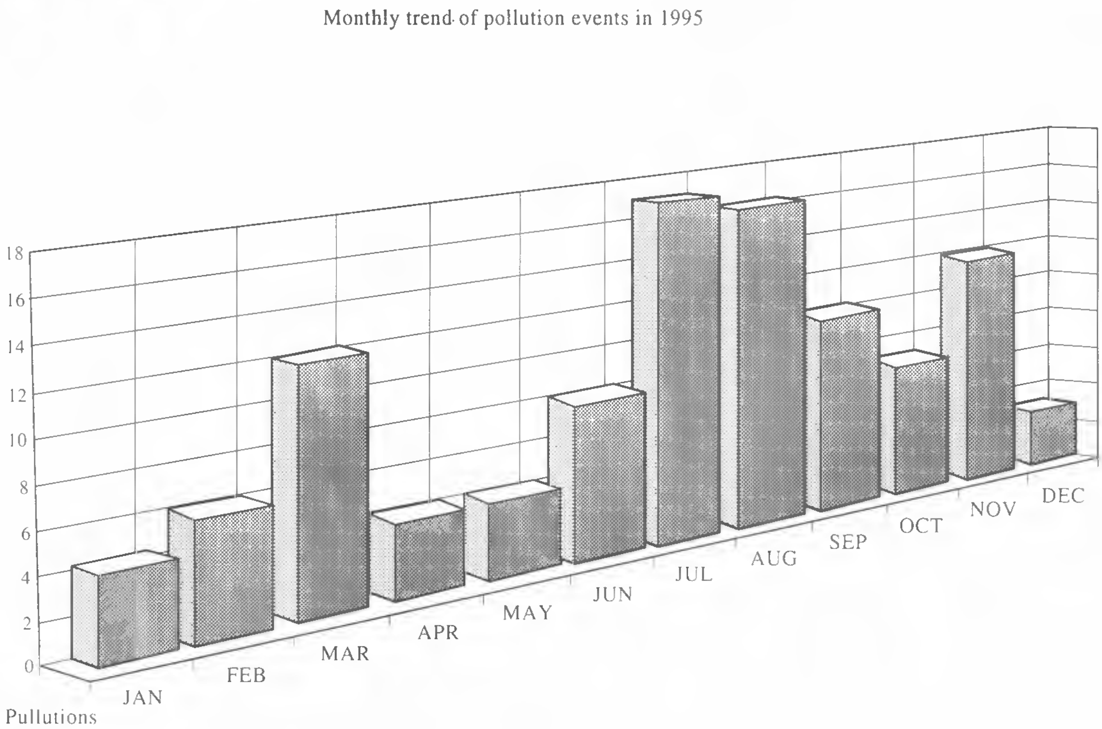

Fig. 5 Monthly trend of pollution events in 1995.

environment, in particular in the following areas of concern:

- ecology (oil pollution detection and sea health);
- geology (erosion, territory set up); and
- policing (control of unlawful waste, prevention and repression of unauthorized building).

Airborne remote sensing

Description of airborne remote sensing system. Fixed-wing aircraft have been equipped with a variety of sensors to perform, at low cost, the rapid monitoring of large marine areas and extended strips of land. The Piaggio 166 DL3 is equipped with:

- **Vinten 618**. An aerial camera system made up of two 70 mm cameras installed on the port side of the aircraft. Their axis are oriented 80° and 40° 30′ in relation with the surface, to allow side-taking and nearly vertical images. The film speed can be selected by the operator in order to cope with the specific task of the mission and with the aircraft speed and altitude.
- **Daedalus DS 1268**. A multispectral scanner system which detects and registers electromagnetic energy emitted by earth; it works on 12 recording channels which split up the electromagnetic spectrum into 12 intervals in the visible, near infrared and thermal infrared. Imagery is digitized on high density magnetic tapes, then converted into CCT tapes to

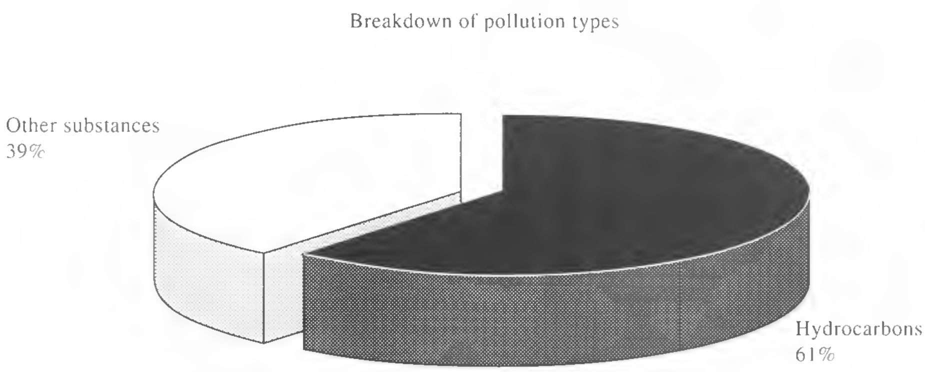

Fig. 6 Breakdown of pollution types.

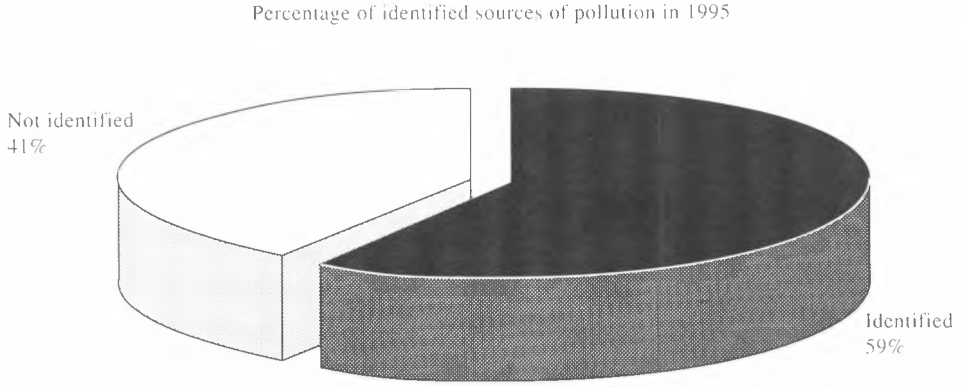

Fig. 7 Percentage of identified sources of pollution in 1995.

be processed by special software for the utilization of the required information. The processed imagery shows, in false colours, some physical parameters (temperature, radiance, reflectance) and gives the opportunity to analyse the features of the observed sea stretch.

- **Daedalus AA 2000**. A bispectral scanner system which works on two channels in the infrared and ultraviolet bands, with a 86° digitized field of view and a 5 mrad geometric resolution. It was especially designed for the surveillance of coastal zones affected by oil spill pollution. Oil slicks can be detected easily thanks to their high reflectance in the ultraviolet band. Also, a difference of emissivity between adjacent healthy and polluted surfaces can be seen in the infrared band. Daedalus AA 2000, in contrast to Daedalus 1268, was not intended to perform the digitization of imagery; it produces a hard copy image directly onboard (Fig. 1).

The remote sensing service—S.T.A.I. (Servizio di Telelevamento Ambientale e Istituzionale). For the rational use of remote sensing systems, the S.T.A.I. (remote sensing service) was established at the Italian Coast Guard Headquarters. This service arranges and schedules remote sensing missions carried out by Coast Guard aircraft and processes and reads the data which are the source of important information for the defence of the marine environment and the surveillance of all activities in- and offshore.

In addition to the above, S.T.A.I. is responsible for the standardization of remote sensing procedures, operational issues and the familiarization of airborne teams with procedures to maintain the efficiency of equipment and sensors.

A number of missions have been managed by S.T.A.I. in co-operation with the Civil Protection Department and the Ministry of Environment. In November 1994, when floods affected the Po Delta, the processing of imagery acquired by the Daedalus 1268 produced relevant information about both agricultural crops and built-up areas and about warp shifting due to tides in proximity to the shoreline (Figs 2 and 3).

In December 1995, in co-operation with the Ministry of Environnent, Coast Guard aircraft monitored the Lagoon of Venice, from Malamocco harbour to Chioggia harbour for an evaluation of the effects of oil pollution originating from a break in a pipeline. Data processing showed the spreading and the thickness of the oil slick and proved to be a valid tool for the allocation of anti-pollution resources coordinated by the Harbour Masters Authority of Venice (Fig. 4).

Coastal environmental monitoring programme using combined airborne/satellite platform data

The Italian Coast Guard, in co-operation with the Aerospace Engineering Department of La Sapienza University in Rome, are directing an experimental project incorporating airborne and satellite remote sensing for the monitoring of the sea surface close to the Italian coastline. The project is giving encouraging results, despite some bureaucratic obstacles.

The programme is based on data collected by the ERS satellites' SAR sensors (synthetic aperture radar) and imagery acquired by the airborne remote sensing system Daedalus AA 2000 and DS 1268 installed on board Italian Coast Guard aircraft.

The programme consists of:

- periodic surveys by Italian Coast Guard aircraft equipped with a remote sensing system, for the evaluation of coastal water quality and the detection of pollution in marine waters;
- the implementation of systematic detection of potential oil slicks by SAR sensors mounted on the

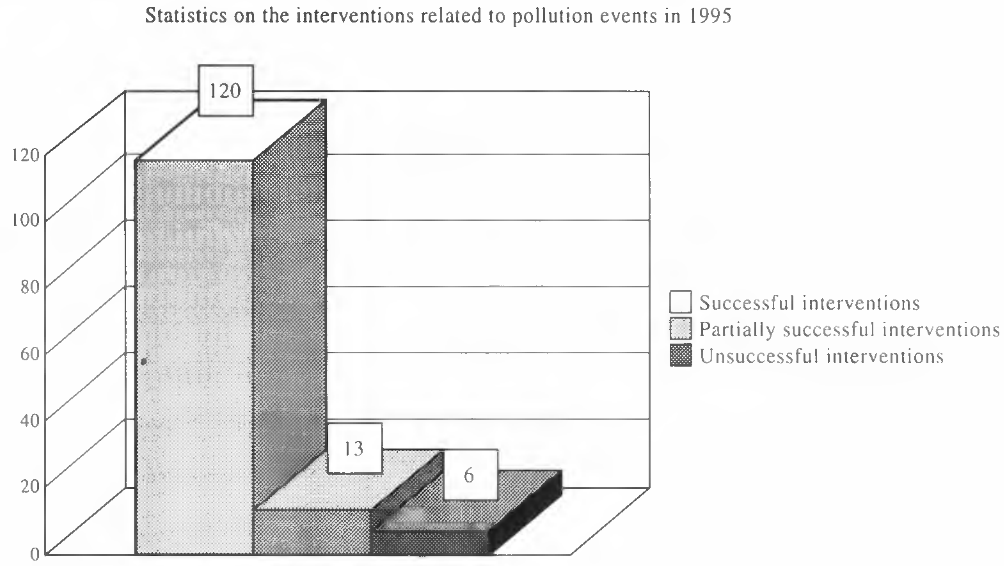

Fig. 8 Statistics on the interventions related to pollution events in 1995.

ERS satellites (through the study of quick look images available shortly after the satellite pass);

- *in situ* missions by Coast Guard aircraft and marine craft aimed at a detailed analysis of waters affected by possible oil slicks detected from ERS satellite quick look images (Figs 5, 6, 7 and 8).

Periodic aircraft surveys

Coast Guard aircraft equipped with sensors are particularly useful for periodic missions (for example, twice a year, to collect data before summer and in autumn) for the evaluation of coastal water quality. Calibrated algorithms, from a previous algorithms calibration mission, may be used in order to estimate the presence of chlorophyll. suspended sediments and suspended organic particles. These surveys can detect waste water discharges by means of the Daedalus AA DS 1268 CZCS sensors in the thermic infrared band.

In the first year of the programme, with development at an experimental stage, surveys are aimed only at the monitoring of chlorophyll α along the Italian coastline. In the future, surveys are to be carried out for the evaluation of organic particles (this second stage needs a calibration campaign of water quality parameters).

Systematic utilization of ERS satellite remote sensing information for oil slick detection and support of* in situ *missions

In the near future the operation of an ERS imagery acquisition system with a quick look delivery system is envisaged for the Italian Coast Guard. It would be similar to the operational marine pollution monitoring system established by the Norwegian Coast Guard.

Based on a delivery of ERS data with 3 h of acquisition, the system could process and make available in almost real time quick look imagery of the observed sea surface with a resolution below 100 metres for the stretch of sea observed. Immediately after the quick look is generated an analysis would be performed in order to verify the existence of oil slicks corresponding to dark areas in the image.

In the system configuration described above the operational stage starts whenever a potential oil slick is detected at sea. When this occurs an aircraft, type P 166 DL3, is assigned to verify the presence of pollution in the area suggested and perform a better evaluation of the slick *in situ*, for its abatement. Being able to rely on the Daedalus AA 2000 UW/IR is of great advantage. As soon as an oil slick is detected, the information is immediately released to the specialized staff on board the aircraft.

In the case of low ceilings the aircraft has to fly at lower altitude to check for the presence of pollution. The use of satellite SAR information is vital in this situation, as it is not dependent on weather conditions and can direct the aircraft to where potential pollution has been detected and needs to be verified.

In the event of an ascertained oil spill, updated information on its evolution is required continuously to enable a prompt response time and to modify strategies as the emergency develops. The spread of oil in the sea depends largely both on weather conditions and different external dynamic agents, and on the specific components of each single hydrocarbon. In addition, experience shows that even the most elaborate mathematical forecast models, need confirmation through a continuous and systematic monitoring of the scenario.

Further satellite imagery acquisition can track the shifting of slicks for many days and shows the full extent of the coastal waters affected. It can also enable the Coast Guard to control the dispersal of a slick on a scale, sufficiently large, to ensure that the entire oil slick has been abated. However, unless satellite platforms are available for the monitoring of the affected area within restricted time parameters (such as a revisit time of less than 12 h), the optimal surveillance is provided by aircraft equipped with radar and optic sensors. These considerations are confirmed by the Norwegian experience using a system based on frequent satellite observations.

Conclusions

The satellite and airborne coastal monitoring system described above is based, essentially, on tools and sensors operating presently. It is meant to make a more extensive use of information derived from satellite platforms, but at present is unable to offer a solution to some of the operational constraints that remain:

- infrequent satellite revisiting times;
- lack of satellite electro-optic sensors providing a ground resolution suitable for significant studies of water quality;
- strong disturbance caused to airborne electro-optic sensors by ceilings and fog.

The last difficulty can be overcome, because, thanks to sensors independent cloud cover such as ERS SAR it is possible to direct an aircraft to the area affected by pollution. Water quality evaluation, on the other hand, cannot take place using microwave sensors.

Poor temporal repetitiveness of satellite passes and low ground resolution of satellite electro-optic sensors is a major constraint. The objective to set up an operational, efficient coastal monitoring system in the Mediterranean Basin, capable of detecting oil slicks, to deploy immediately all available resources and eventually to succeed in abating the pollution is difficult to achieve. To be able to do so, an increased frequency in satellite passes would be required, together with an improved information content of the satellite imagery.

The system suggested has to be carefully evaluated in terms of cost–benefits. As a result of a cost–benefits analysis it might be discovered that, presently, satellite imagery is too expensive. A solution could be to benefit from international co-operation, whereby, Mediterranean Basin communities could subscribe to an agreement for mutual utilization of the system. By concentrating the efforts, financial and scientific, of all Mediterranean countries towards the protection of marine environment, the cost of satellite data could be considerably reduced.

latter is also described as $S_{dis} = S_b + S_v$ (Alpers and Huhnerfuss, 1989), with S_b being the breaking dissipation rate and S_v the viscous dissipation rate.

Mineral oils have a hydrophobic consistence. When spilled on the sea they tend to form 'thick' layers, exhibiting thickness of up to some millimetres or even some centimetres. Thus, the local viscosity is considerably increased (Alpers and Huhnerfuss, 1988) and the excess of viscous dissipation results in the damping of the surface wave field. However, open sea experiments (Singh *et al.*, 1986) using crude oil spills indicate that the spectral energy depression exhibits a maximum as a function of wavenumber (or frequency). Maxima in the spectral depression signature are typical when monomolecular slicks of surface active compounds are formed on the sea (Cini and Lombardini, 1981; Huhnerfuss *et al.*, 1987). They are the result of a resonance-type wave damping known in the western literature as the 'Marangoni effect'.

In order to explain this spectral depression form for the crude oil cases, Alpers and Huhnerfuss (1988) followed the assumption that the mineral oil spills in seawater may also contain surface active compounds as impurities, formed by photooxidation processes and bacterial decomposition. Hence, because of such impurities mineral oil films on the sea surface, may give rise to local surface tension gradients dependent on the evolution of their viscoelastic properties (i.e. their maturity). These are the result of the contractions and expansions of the thin films forced by the sea surface wave movement. As a result longitudinal waves ('Marangoni waves') are excited and the resonance between these waves and the sea surface waves causes the later to experience maximum damping.

To account for this resonance-type wave damping, a correcting factor, as a function of frequency, is incorporated in the source term S_v defined as, (Cini and Lombardini, 1978; Lucassen, 1982; Huhnerfuss, 1986; Cini *et al.*, 1987)

$$y = S_v^s / S_v^o. \quad (5)$$

The full solution of equation (4) is still a state of the art problem, since the sufficient and necessary description of the three source functions is quasi-unknown. Briefly, the rate of energy input (S_{in}) is to a satisfactory degree described empirically (Larson and Wright, 1975; Toba, 1973; Phillips, 1985; Mitsuyasu and Honda, 1986), but only one part of the energy dissipation rate, i.e. that due to viscosity (S_v), is theoretically and experimentally verified (Lamb, 1932; Mitsuyasu and Honda, 1982), while the other, i.e. that due to wave breaking and white cap formation (S_b) is phenomenologically approximated (Hasselmann, 1974; Komen *et al.*, 1984; Donelan and Pierson, 1987). Furthermore, although the mechanism of energy transfer among the waves, due to nonlinear resonant interactions (S_{nl}), has been theoretically treated and analytically described (Hasselmann, 1962; Valenzuela and Laing, 1972; Valenzuela and Wright, 1976), computational limitations permit only its partial solution, in some spectral regions. In greater detail the part of S_{nl} that concerns four-wave resonant interactions (i.e. the third-order, indicated as S'''_{nl} on Fig. 3), which dominate among pure gravity waves (Valenzuela and Wright, 1976), can be computed over a spectral range up to 2.5 times the wavenumber of the spectral peak k_p (Hasselmann and Hasselmann, 1985; Hasselmann *et al.*, 1985), which does not cover the gravity–capillary region, where the spill-induced phenomena dominate (Alpers and Huhnerfuss, 1989). In this region only the part of S_{nl} that describes the three-wave nonlinear resonant interactions (i.e. the second-order, indicated as S''_{nl} in Fig. 3), can be practically computed (van Gastel, 1987).

In order to extract the best possible results, even under the above constrains and limitations, a merging of the accumulated knowledge has been attempted and a numerical model of the gravity–capillary spectral evolution has been constructed (for an analytical description of the model, the reader is referred to the relevant EUR report of Pavlakis, 1995). The model is one dimensional and incorporates all the above terms except the four-wave (third-order) nonlinear resonant interaction mechanism (S'''_{nl}). This creates an inefficiency, but as this mechanism prevails in the pure gravity wave spectral region, having only a weak effect in the gravity–capillary one, the model converges to equilibrium solutions, for clean and spilled sea surfaces correspondingly. This is a feature of practical importance, since it can predict absolute RBC values in the gravity–capillary spectral region and delineate singularities of its spectral signatures that permit constructive conclusions.

Discussion

The model has been tested with encouraging results against open sea RBC data acquired over experimental spills of crude oil, published by Singh *et al.* (1986), and simulated monomolecular slicks, published by Huhnerfuss *et al.* (1994). An example concerning a crude oil spill is presented in Fig. 4. The experimental RBC signature (indicated as triangles in Fig. 4) was derived using C- and Ku-band radar at variable incidence angles (Singh *et al.*, 1986; Alpers and Huhnerfuss, 1988). The wind speed conditions, during the experiment varied between 3 and 6 m s^{-1}.

With the aid of the constructed model and using appropriate viscoelastic parameters for crude oil films RBC curves were computed for the above wind speed

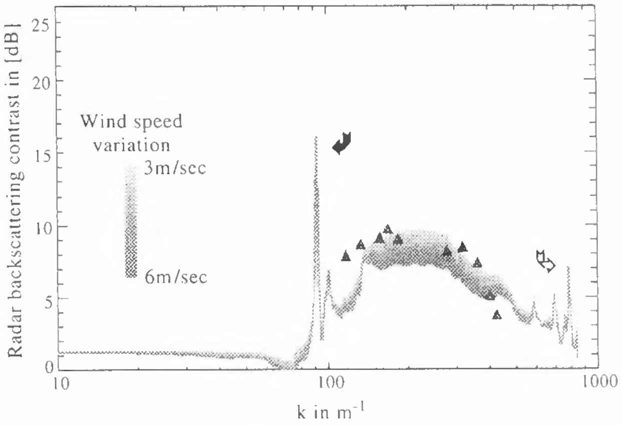

Fig. 4 Predicted radar backscattering contrast (RBC) signatures of a crude oil spill, within the 3–6 m s^{-1} wind speed range, and comparison with open sea experimental data of Singh *et al.* (1986) (triangles). Arrows indicate singularities due to non-linear hydrodynamic effects.

conditions. The curves, presented in Fig. 4, approximate well the field data. An interesting feature yielded by the computations is the spiky appearance of the curves at lower and higher wavenumbers (indicated by arrows in Fig. 4). This phenomenon indicates that certain discrete bands of the sea surface gravity–capillary waves lose relatively higher amounts of energy. Thus they become weaker and are damped more rapidly when a spill is present. Computationally this is a result of the action of the second order nonlinear energy transfer function S''_{nl}, that takes place dominantly in the gravity–capillary region.

Phenomenologically the spikes indicated by the black arrow in Fig. 4, appear to be related to the generation of a characteristic overshoot effect (i.e. local spectral peaks with minor energy depressions at both sides) at a specific spectral position in the gravity–capillary region. Such overshoots located at rather stable position, regardless of fetch or duration of the wave field, are termed 'third kind overshoots' and are confirmed by experimental data (Long and Huang, 1976; Plant and Wright, 1977; Bliven and Zheng, 1984). Furthermore, the spikes, indicated by the white arrow in Fig. 4, are related to the generation of parasitic capillary ripples at the tail of the spectrum yielding a peaks-and-troughs form that has been also confirmed by experimental measurements (Shemdin, 1986) and discussed theoretically by van Gastel (1987).

Among the above singularities, the most important for the purpose of our study, are the stronger spiky RBC bands (black arrow in Fig. 4) which are found in wavenumbers near 100 m^{-1}. This is because the Bragg wavenumbers sensed by most of the spaceborne SAR antennas in orbit fall within or near this spectral region. With the aid of the model, we expanded the predictions of the RBC for the same test spill as in Fig. 4, to wind speeds up to 16 m s^{-1}. The results indicate that the strong RBC within these narrow bands persists for wind speeds up to 13–14 m s^{-1} (narrow dark bands indicated by arrows in Fig. 5).

Based on these results, some first order assessments of radar performances in oil spill detection can be made via estimates of Bragg wavenumber spans, given by equation (1), for several microwave bands and angles of incidence. In this paper the L, S, C, X and Ku radar bands are considered for incidence angles ranging between 23° to 65°. These are represented in Fig. 5, as thick horizontal lines below the wavenumber axis, with large incidence angles to the right and small to the left.

Thus under low wind speed conditions, such as 3–7 m s^{-1}, oil spills can yield detectable RBC signals well above typical SAR noise levels (e.g. 3 dB) on C- and X-band SAR imagery. At higher wind speeds the hydrodynamic nonlinearities seem to be the vantage point of the S- and C-band radars. Hence, as it appears in Fig. 5, strong RBC of oil spills is possible, for intermediate to high, and low to intermediate angles of incidence, of S- and C-band SAR correspondingly. The C-band SAR antennas of the ERS-1 and ESR-2 satellites, for example whose near- and far-swath incidence angles fall within 20.10° to 25.9°, are close to an optimum oil spill detection capacity (the Bragg wave span of the ERS SAR is also marked in Fig. 5).

However, as was mentioned previously, the third order four-wave nonlinear resonant interactions (S'''_{nl}) are not incorporated in the computations of the model. Thus, since their effect dominates in the pure gravity wave spectral region, the model is not able to make realistic predictions for lower wavenumbers, such as those sensed by the L-band radars. Nevertheless, open sea experimental measurements (Hühnerfuss *et al.*, 1983) have shown that large slicks can induce weak damping in large gravity waves too (i.e. at low wavenumbers). In order to explain this effect, Alpers and Hühnerfuss (1989) suggested, from phenomenological considerations, that the wave system reacts dynamically when a spill disturbs its energy balance. More specifically, in an attempt to restore the wave spectrum equilibrium, energy is forced to flow backwards through four-wave nonlinear resonant interactions (i.e. from lower wavenumbers) to refill the loss induced by the spill energy sink at the gravity–capillary region.

Thus, based on this phenomenological conclusion, and since the energy transport via four-wave nonlinear resonant interactions is largest for neighbouring wavenumbers (Hasselmann *et al.*, 1985; Alpers and Hühnerfuss, 1989), a broadening of the predicted strong RBC narrow bands (arrows in Fig. 5) towards lower wavenumbers is expected (i.e. towards the L-band Bragg wave span). Moreover, such an energy

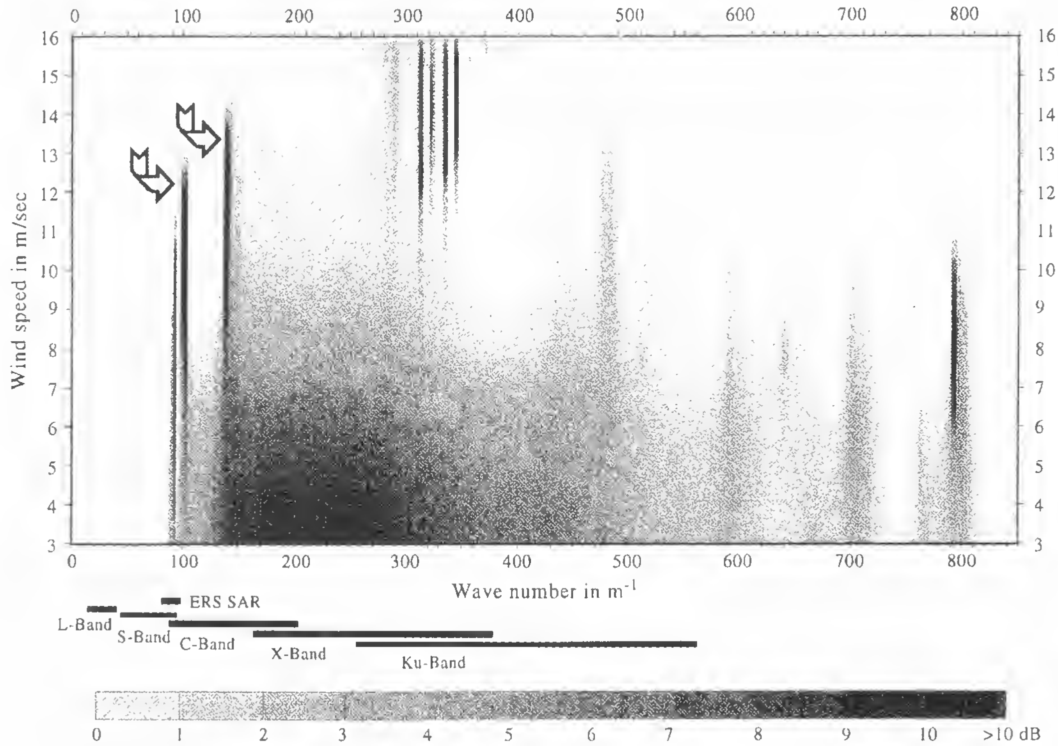

Fig. 5 Expansion of RBC predictions of Fig. 4, for a range up to 16 m s^{-1} wind speeds and Bragg wave spans (thick horizontal lines below wavenumber axis) sensed by L, S, C, X and Ku radar bands for incidence angles between 23° and 65°. Arrows indicate predicted strong RBC at higher wind speeds due to non-linear hydrodynamic phenomena.

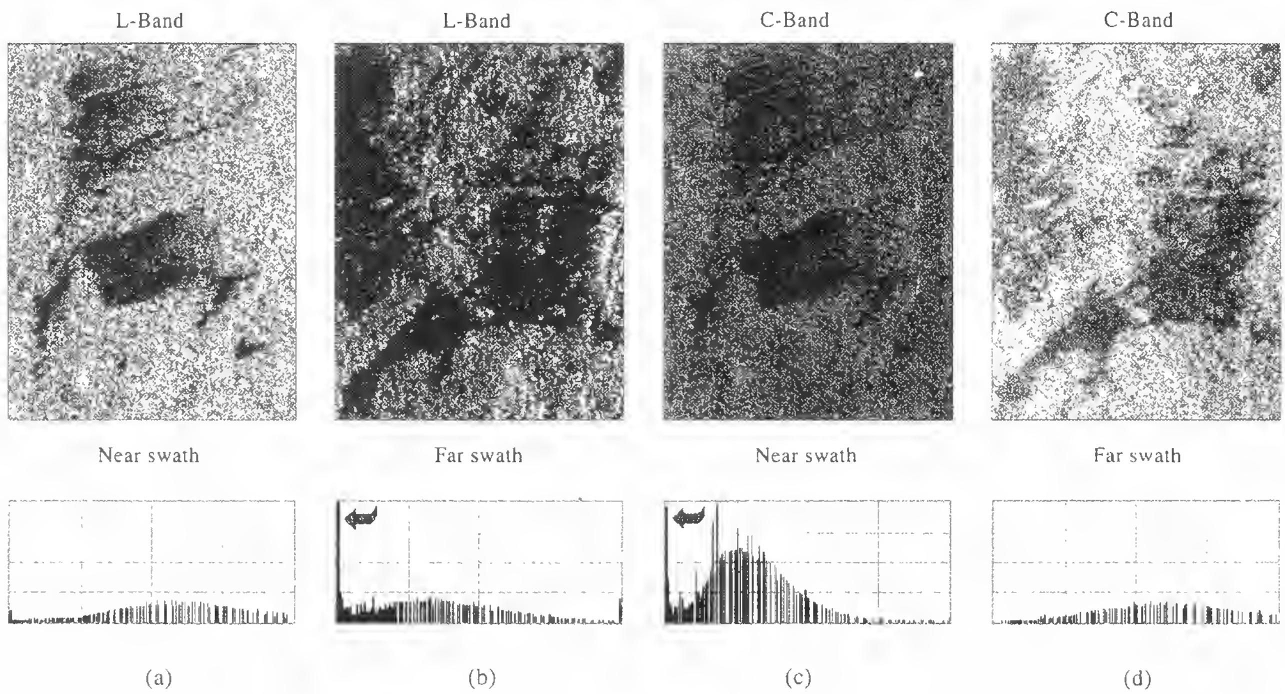

Fig. 6 Subimages of two oil spill signatures, found at near and far swath of coincident L and C-band SIR-C/X-SAR imagery (Arabian Sea, 9 October 1994), and their corresponding pixel intensity histograms. Arrows indicate the high accumulations of the central bi-modal histograms (b, c) at low pixel values.

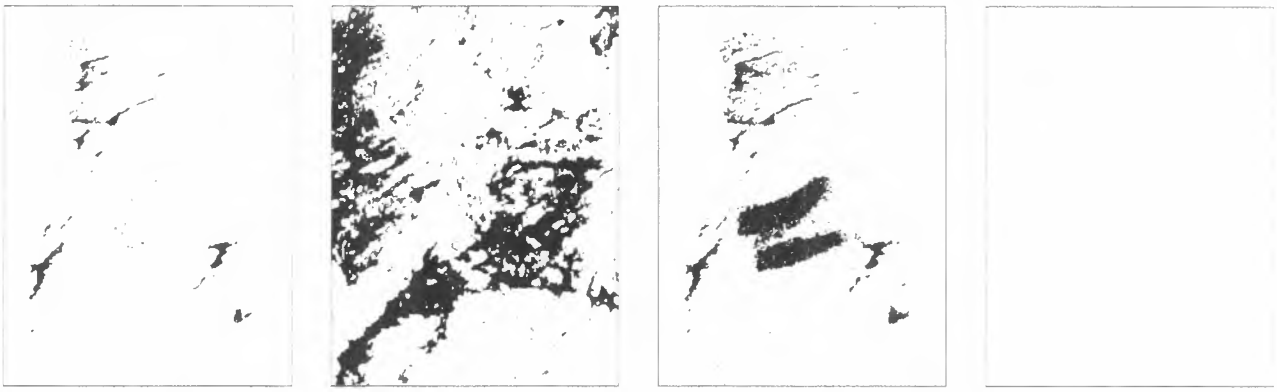

Fig. 7 Spill signature separation from the subimages of Fig. 6, via simple histogram stretching, of low-pixel-value ranges. Note the optimum separation from subimages b, c due to their clear bi-modal histograms.

refilling process should restrain the contrast strength from that overestimated by the model (i.e. greater than 10 dB as represented in Fig. 5) to lower values. However, the remains of a strong contrast local peak within the spectral region between L and C-Band is quite possible. Thus, a local optimization of oil spill detection capacity in this region, covered mainly by the S-band, can be expected.

Such a conclusion is supported by the inversion of the near–far swath oil spill contrast alterations that are usually observed on coincident L and C-band SAR imagery. An example of this effect, concerning oil spills detected on 9 October 1994 at the Arabian Sea during the SIR-C/X-SAR mission, is presented in Fig. 6. Here the four subimages show two mature oil spills found at the near and far swath of the same frame and imaged by L and C-band SAR coincidentally. In this case the contrast of the spills on the L-band imagery is stronger at the far swath than in the near swath. The opposite occurs on the C-band imagery, i.e. the same spills yield stronger contrast on its near swath than on its far swath.

This observation is also represented on the corresponding pixel intensity histograms below the subimages in Fig. 6. More specifically, the two central subimages (Fig. 6b, c), in comparison with those at the sides (Fig. 6a, d), yield clearly bi-modal histogram types indicating two distinctive areas. The pixels of the spilled sea are in spiky accumulations at low intensity values (indicated by arrows of Fig. 6b, c) while the clean sea corresponds to the broad distributions at higher intensity values. In both histograms the accumulation at low pixel values are considerably higher than the corresponding ones of the subimages at the sides (Fig. 6a, d). It is also essential to note that the spilled-sea pixel accumulation of the central subimages (Fig. 6b, c) exceed considerably the background, and thus can be separated easily. This does not occur in the subimages at the sides (Fig. 6a, d).

To this end it is worth noting that such an optimization enhances the potential of computer-based automatic oil spill detection systems for locating and delineating an oil spill, via image processing approaches. For example, a simple histogram stretching of a low-pixel-value range, defined by the first modal peak (arrows in histograms of Fig. 6b, c), isolates directly the spills of the central subimages (Fig. 7b, c), while failing for the others (Fig. 7a, d), since their corresponding first modal peaks are either weak (Fig. 6a) or non-existent (Fig. 6d).

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TECHNICAL NOTE

Towards an Operational Oil Spill Detection Service in the Mediterranean? The Norwegian Experience: a Pre-operational Early Warning Detection Service using ERS SAR Data

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A project for utilization of ERS-1 SAR data for detection of oil spill at sea was started in 1991 as part of the Norwegian Space Centre's (NSC) national ERS-1 programme. A pre-operational service utilising infrastructure for near real-time processing, analysing and distribution has been developed. Tromsø Satellite Station (TSS) took over the responsibility for operation of the pilot service in 1994.

The service covers two different operational aspects, i.e. near real-time detection and early warning of possible oil spills at sea in close co-operation with national pollution control authorities, and offshore oil exploration activities for oil companies. A phased service development model has been applied, from R&D until the current pre-operational use of ERS-1 and ERS-2 SAR images. The developments include both service infrastructure and an operational concept. A number of important results regarding the detection capabilities of the ERS SAR have been derived.

A cost–benefit analysis based upon Norwegian user requirements has documented the satellite based service cost-effectiveness compared to aircraft surveillance. Finally, activities towards utilization of data from the future radar satellites have also been initiated. © 1997 Elsevier Science Ltd

Since the mid 1980s development of the use of satellite radar data for marine applications has been a high priority strategy within the national Norwegian space policy. Norway has become a member of ESA, and participates the ERS programme. Tromsø Satellite Station (TSS) has been developed as a national facility for ERS data acquisition, processing and distribution. The national strategy has been to focus on near real-time data handling, meaning that the required information or data shall be at the users' site within 1 h of the satellite overpass.

The Norwegian oil spill detection project was originally proposed in response to ESA's Announcement of Opportunity for ERS-1 in 1986. This project later achieved the status of an ESA Pilot project. The project has been funded by international sources, it was performed under the responsibility of a steering committee chaired by NSC. It is important to recognize that the end user represented by the Norwegian Pollution Control Authority (SFT) participated in the project from the beginning. The phased development model and the results from the project were widely published, and found a large audience outside the project (Anderssen *et al.*, 1994; Bern *et al.*, 1993; Skøelv & Wahl, 1993; Wahl *et al.*, 1994a,b,c).

The project development consisted the following phases:

Phase 0: 1990–1991

Responsible institution: OCEANOR a.s.
Activities: Literature survey, ERS-1 prelaunch preparations, planning of field experiment.

Phase 1: 1991

Responsible institution: OCEANOR a.s.
Participating institutions: SFT, NDRE, Esso, Statoil.
Activities: A dedicated oil spill experiment at Haltenbanken in August 1991, where 3×20 tons of oil was released within the ERS-1 coverage, and studied under various meteorological conditions and sea states.

Result: The detection capabilities of the ERS-1 SAR, and its dependence upon the wind conditions were demonstrated.

Phase 1B: 1992–1993

Responsible institution: NDRE
Participating institutions: SFT, OCEANOR a.s, Spacetec a.s, Norwegian Computing Centre
Activities: Transmission of ERS-1 SAR low-resolution images via datalink from TSS to NDRE for further analysis immediately after data reception in order to demonstrate the near real-time capabilities. Images containing suspicious oil spill like features were verified by SFT by use of the surveillance aircraft. Experiments on automatic image analysis and feature extraction were performed. The operationalization aspects were also studied.

Result: More than 150 ERS-1 SAR images were analysed, and the feasibility of near real-time operations were demonstrated. The dependence of the detection capability upon the wind conditions and the sea state (calm days) was demonstrated. SFT formally requested offshore oil rig operators for explanation of satellite observations.

Pilot Demonstration Phase: 1993

Responsible institution: NDRE
Participating institutions: SFT, OCEANOR a.s., NERSC, TSS
Activities: A larger scale activity of the preceding phase was performed in close co-operation with SFT. The problems of distinguishing real oil spills from natural slicks were addressed in detail. Training of the operators at TSS in SAR image interpretation was initiated. A fruitful co-operation with the Dutch Rijkswaterstaat was initiated.

Result: 260 ERS-1 SAR images were analysed in near real-time, and clearly demonstrated the capabilities of detecting various types of pollutants. Practical criteria for discriminating between real oil spills and natural slicks were established by NERSC.

(Pre-)Operational Phase: 1994–

Responsible institution: TSS
Participating institutions: SFT, NDRE, NERSC
Activities: From Summer 1994 TSS took over the responsibility for the operations of the pre-operational service. ERS-1 and ERS-2 SAR images are analysed on a routine basis at TSS, and the national pollution control authorities are notified about observed possible oil spills. Additional service activities include analysis of SAR images in terms of identification of natural oil seepage from the seafloor. Cooperation with users outside Norway has been established. A cost–benefit analysis based upon the Norwegian user requirements was performed.

Detection Capabilities

The extensive use of ERS-1 and ERS-2 SAR low (i.e. 100 m) resolution images during the project has demonstrated the ERS satellites capability to detect even very thin pollutants in low wind speed of 3–4 m s^{-1} and thick emulsions at higher speeds of 10 m s^{-1} (Bern *et al.*, 1993; Wahl *et al.*, 1996).

Other pollutant examples detected during the project include: crude oil forming emulsions, run-off water from acid-pitch depository on land, drilling fluid from offshore oil rigs, waste from fish production plants, and fish fat remaining at the sea surface after fishing trawler catches.

Two main problems concerning the detection capabilities have been demonstrated (Wahl *et al.*, 1996).

- At low wind speeds, ocean slicks of natural origin are frequently observed and may cause false alarms unless experienced operators or very advanced pattern recognition methods are used.
- At high wind speeds the pollutant may be mixed with the seawater and no surface effect is detected by the SAR (e.g. the "Braer" disaster January 1993).

Pre-operational Service

The main service infrastructure elements are the ERS SAR data handling facilities at TSS. These consist of the fast SAR processor (CESAR) capable of generating a 100×100 km SAR image within 6–8 min, and the service information distribution links. The capacity of the service infrastructure allows near real-time information and image data transfer from TSS to the end users. TSS is capable of analysing and transferring image data to the end users within 1 h of data acquisition.

Automatic detection of potential oil spills was, at an early phase, considered to be mandatory for the service. An algorithm for this purpose was developed and verified during the project (Wahl *et al.*, 1994c; Weisteen *et al.*, 1993). Experience, however, has shown otherwise. Whereas the automatic slick detection is done within a few minutes, a trained operator can analyse a SAR scene within a much shorter time. The pre-operational service is therefore mainly based upon human, computer supported analysis and interpretation.

When entering the pre-operational phase in Summer 1994, the knowledge developed at NDRE was physically transferred to TSS. The operators at TSS have been through an extensive training period, and they are now responsible for the service operations. On average the service now analyse more than 300 ERS SAR scenes per month, which significantly exceeds the number from the previous phases.

Important service improvements in 1995 included implementation of a new service information distribution and presentation tool, SARA. SARA is based on PC and e-mail technology, and was developed by Telenor R&D in Norway. The SARA tool has now been installed at more than 10 users sites in Europe. In addition, a dedicated service workstation utilising satellite, meteorological and cartographic information is under development.

The main goal of the pre-operational service is to serve the end users with reliable information on possible oil spills within two hours after satellite overpasses. The primary analysis areas cover Norwegian waters, and have been defined by the Norwegian Pollution Control Authority (SFT). However, as a result of co-operation with other countries, the total area monitored has been largely extended. The current service therefore includes a near real-time analysis of ERS SAR data both from the Norwegian coastal waters, and from more central European coastal waters (Fig. 1). Information about possible oil spills are routed either directly, or via SFT, to the responsible national authorities. This service represents a first step towards establishing a fully operational service covering Norwegian and adjacent waters. The objective is, within 3 years, to establish a fully operational oil spill detection service utilising satellite and additional information.

Fig. 1 Pre-operational service area.

Assessment of ERS data has already been implemented in the national system for oil and chemical pollution reporting in Norway (Fig. 2). The SFT surveillance aircraft operations are coordinated according to the ERS overpasses, and the data analysis at TSS is coordinated according to the flight plan (Fig. 3). In addition, SFT has an agreement with DNMI regarding use of their oil drift model and other meteorological assistance whenever an oil spill is identified. This part of the service is operated outside TSS. Figures 4 and 5 show two examples of ERS-1 SAR images containing confirmed oil spills off the coast of Norway.

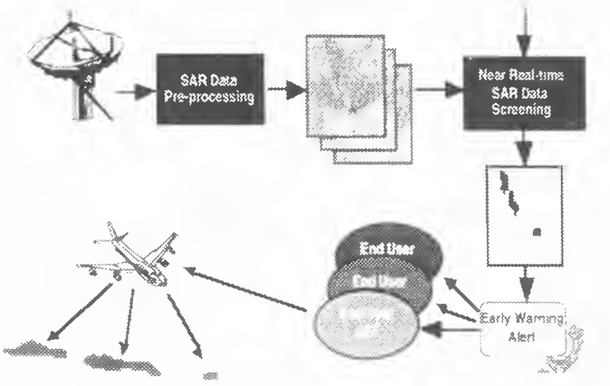

Fig. 2 National Oil Spill Detection Service Infrastructure Concept.

Fig. 3 Coordination of aircraft operations according to satellite coverage.

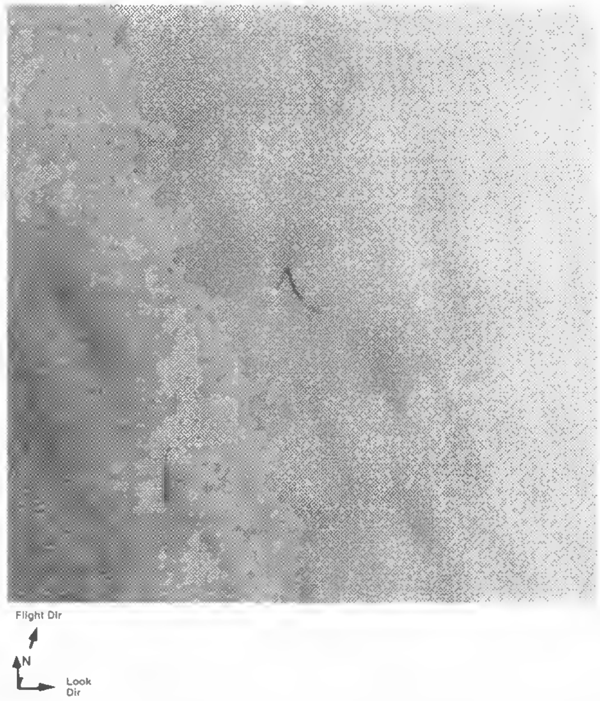

Fig. 5 ERS-1 SAR image dated 25-11-94 of a confirmed oil spill from an off-shore oil rig in the North Sea. Image size approx. 70×50 km.

Near real-time ERS SAR data read out at TSS is the current primary source of satellite input information for identification of possible oil spills/slicks. Since the availability of ERS-2 SAR data last summer, data from both satellites have been applied extensively. The one day off-set between ERS-1 and ERS-2 coverages has clearly demonstrated a strongly improved temporal coverage of the service areas. The service has hence clearly demonstrated the benefits from the Tandem Mission Period for operational, near real-time applications.

Fig. 4 ERS-1 SAR image of a confirmed oil spill off the cost of Finnmark, Norway. Image size approx. 70×50 km.

Extended Service Operations

In mid-1995 the service was selected by the EU/Centre for Earth Observation (CEO) for an Application Proof-of-Concept study, where the objectives were to assess and document user requirements. A number of users in North Europe have been interacting with the service since Summer 1995. TSS analysed all available ERS SAR data, and the users were informed about possible oil spills in their national waters. In return TSS received the user requirements and the feedback on the current service performance.

This work demonstrated that the current service concept and infrastructure are capable of meeting the main user requirements. The existing service is hence not the bottleneck for further market development. Nearly 10 new users were identified and approached during the study. This service represented a new application for many of the users, and they were not convinced about the cost-effectiveness, the reliability and the quality of the satellite based information, compared with the traditional surveillance methods.

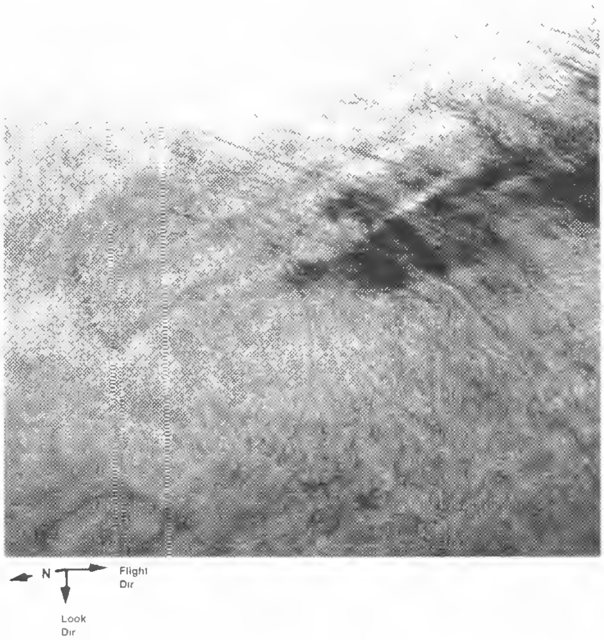

Fig. 6 ERS-1 SAR image showing a dark droplet formed seepage candidate (centre left position). Image size is approx. 60×60 km.

The users were also concerned about the service costs compared to traditional monitoring system costs.

A service cost–benefit analysis based upon the requirements of SFT was performed recently. This study assessed the costs and the benefits of utilising ERS SAR data into an operational oil spill service. This analysis has documented that under the given requirements, a combined satellite and aircraft based monitoring service is more cost-effective for operational monitoring than an aircraft only based system.

Natural Seepage Studies

Another service application has focused on application of ERS SAR data for detection of natural oil seepage from the seafloor off the coast of Norway. From the analysis of a total of 150 ERS-1 SAR images, ten seepage candidates have been identified. None of these candidates have, however, been confirmed by any in situ observations. eight of the candidates were detected at very favourable wind conditions (i.e. wind speed less than approx. 5 m s^{-1}). Comparison of the observed candidates with wind speed and direction estimates shows a reasonable good match between observed slick direction and wind speed direction.

A new signature pattern appearing as small (approx. 0.3×0.3 km) patches stretching out in the wind/current direction was also discovered. This signature is associated with seepage droplets which reach the sea surface at different times. The 'droplet signature' has been detected four times during the study (Anderssen *et al.*, 1994). Figure 6 shows an example of the droplet signature pattern observed during this work.

Main Users

The service now available is the result of a co-operation between Norwegian Space Centre (NSC), the Norwegian Pollution Control Authority (SFT), Norwegian Defence Research Establishment (NDRE), ESA, Marine Spill Response Corporation (MSRC), the oil companies Statoil and ESSO, and Tromsø Satellite Station. The primary objective of the first phase was to establish a pre-operational service for national users. However, in parallel with the nationally focused activities the early phase also include international marketing activities. The coverage area in combination with the near real-time capabilities of Tromsø Satellite Station represent advantages that are important for international marketing.

The referred CEO study has been an important service marketing activity. Co-operation with pollution control authorities in European countries such as Sweden, Finland, The Netherlands, Germany, UK, Poland and Estonia was developed during this recent period (Pellemans *et al.*, 1994). Some of these authorities, for which the satellite service was unknown at the beginning of the CEO project, have now made contracts with TSS on service operations. The total service turnover for 1995, including management, operations, R&D and marketing, was a few million Norwegian crowners. The user financial contribution was approx. 20–30%. The user contribution for 1996 is expected to exceed 30%.

Future Development

The results obtained from the project have demonstrated that there is still a need for continuous service improvements. Both shorter term activities dealing with improvements of existing algorithms, products and systems, and longer term activities dealing with new developments and improvements have been undertaken.

During the first half of 1996 RADARSAT data have become available, and is planned to be used by the service. This satellite has the capability to cover a larger area than the ERS satellite, and the SAR can also operate in additional modes compared with ERS. The capability of RADARSAT to detect oil is not yet fully understood, especially the limitations towards the outer parts of the swaths will have to be considered. Assessment of the capabilities of RADARSAT for detection of oil at sea has, therefore, been given high priority for the coming years.

Later on, ENVISAT will be launched by ESA. The ASAR onboard ENVISAT will also operate in additional modes compared with ERS. The ENVISAT detection capabilities will therefore also be addressed during the coming years.

From a technical point of view, a largely improved temporal and spatial coverage is expected towards the new century. Improvements in terms of temporal coverage were demonstrated during the ERS-1 and ERS-2 Tandem Mission period. It is, however, most likely that service cost aspects will be the most critical factors in terms of operational service establishments.

A limited cost–benefit analysis has been performed and documented the success of this service. In order to convince the users about the cost-effectiveness, extended cost–benefit analysis need to be carried out.

Conclusions

The new radar satellites such as ERS, RADARSAT and, once launched, ENVISAT represent a new tool for establishing operational oil spill detection services. Large, repetitive coverage of remote areas under practically all weather conditions are the main advantages from these satellites. The costs per unit covered is also comparable, and even cheaper than the costs obtained from traditional operational systems (Wahl *et al.*, 1996).

It is, however, important to note that satellite data cannot fully replace other monitoring platforms such as aircraft. Aircraft operations can, however, be more efficient and cost effective by using the satellite and the aircraft data jointly for operational monitoring.

Norway has, since the early 1980s, been heavily engaged in the development of the use of satellite SAR data for marine applications. A pre-operational satellite based oil spill detection service developed in close co-operation with the national end user, SFT, and now offered by the service provider TSS is a result of this engagement.

The focus has been to develop the near real-time capability to provide information about possible oil spills at sea to end users both in Norway and in other European countries. Today TSS is capable of informing an end user in Northern Europe about possible oil spills within their territorial waters within less than 2 h of ERS SAR data acquisition.

The activities within the oil spill detection development project have clearly demonstrated the ERS SAR capabilities of detecting oil spills at sea even under rougher sea states than initially expected. It is, therefore, expected that SAR data from the new radar satellites will become increasingly important sources of information for operational pollution monitoring at sea. TSS covers large parts of the Northern European waters, and already has a data handling infrastructure specially developed for near real-time provision of data and information to the users. TSS could, therefore, play a central role as the satellite data handling facility within an operational European oil spill detection service.

The improved temporal coverage obtained during the ERS Tandem Mission Period has been important for the users dealt with by the service. The Tandem Mission has hence been of benefit to operational users in addition to the off-line interferometric community. These benefits could hence represent a positive contribution towards increasing the users capabilities and willingness to increase their financial contributions to a further development of a commercial EO business.

Acknowledgements—The Norwegian oil spill development project has been coordinated by the Norwegian Space Centre on behalf of a steering committee with representatives from ESA, Marine Spill Response Corporation (MSRC), the oil companies Statoil and ESSO. These have all made substantial contributions to the project. The valuable information and feedback obtained from Rijkswaterstaat in the Netherlands and from all the other users especially dealt with during the CEO study is also gratefully acknowledged.

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TECHNICAL NOTE

Oil Pollution Monitoring on the North Sea

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The Netherlands Part of the Continental Shelf (NCP) is not only an ecologically valuable area, but is also important for economic reasons such as shipping, oil, gas and sand exploration, fishing and recreation. In general, the marine environment is polluted by emissions of harmful substances, originating from:

- shipping;
- offshore industry;
- transport via rivers; and
- atmospheric deposit.

Although, in general, the concentration of substances in river outflow (and atmospheric deposit) is low, the continuous character of the process contributes significantly to the total load into the marine environment.

The North Sea directorate (NSD), one of the regional directorates within the Ministry of Transport and Public Works, is responsible for the quality of water and soil, maintenance of the infrastructure at sea and the provision of information on North Sea data. The main tasks of the Operational Division:

- (oil) pollution combat (both on sea and on the shoreline);
- aerial surveillance; and
- law enforcement.

Aerial Surveillance

A total of 450 000 ships pass the Dutch coastline. The risk of pollution caused by operational discharges (controlled and regulated discharges under strict conditions (MARPOL) or illegal) is high. Also the number of accidents and collisions, where a large amount of harmful substance is discharged, is relatively high. For this reason the NSD inspects the NCP on a daily basis.

Since 1983, the general surveillance has been performed by remote sensing applications. The side looking airborne radar (SLAR) and infrared sensor (IR) provide the opportunity to detect pollution at long range, both at night and under unfavourable conditions. Some results over the period 1992–1995 are given here (see Tables 1–3).

Spaceborne Surveillance

Aircraft detection is influenced by various factors and has operational limitations (mainly weather conditions). With the launch of ERS-1, equipped with a synthetic aperture radar, a new instrument became available for surveillance applications. In the past three years, The Netherlands have participated in several projects to determine the operational capabilities and validity of ERS SAR imagery for (oil) slick detection. The following is a brief overview:

1993:	**Oil spill detection on the North Sea using ERS-1 SAR data**: Close cooperation with the Survey Department, the National Aerospace Laboratory (NLR), the European Space Agency (ESA) and Tromso Satellite Station (TSS).
1995:	**Validation of Surface Pollution detected by ERS SAR on the North Sea**: A joint Bonn Agreement test programme in cooperation with TSS.
1995: 1996:	**Application "proof-of-concept" study on Oil Spill Detection Service**: A Centre for Earth Observation (CEO) project together with TSS.

Table 1 Total number of flighthours and detected cases of pollution

Year	Number of flight hours	Number of pollutions	Pollutions per flight hour	Ships/platforms caught red-handed
1992	953	401	0.4	45
1993	1154	688	0.6	63
1994	1214	605	0.5	47
1995	1071	481	0.5	50
Total	4392	2175	0.5	205

Note: the total number of flight hours is a combination of various types of flights, also over inland waters etc.; the number of cases of pollution is only counted for patrol flights over sea.

First ERS SAR Project

This project was set up to validate ERS-1 SAR data for oil slick detection. The Survey Department, the North Sea Directorate, both Rijkswaterstaat institutes, and the Netherlands Aerospace Laboratory (NLR) joined this project. The experiment was conducted with the financial support of the Netherlands Remote Sensing Board (BCRS) and the European Space Agency (ESA). The objectives of the project are summarized as follows:

- to demonstrate the operational capabilities of ERS-1 SAR imagery for oil spill detection.
- to determine the value of the ERS-1 SAR imagery for oil slick detection.
- to propose an operational system for oil slick detection by means of ERS-1 SAR.

Measuring campaign

In the period 01-Jun-1993 to 31-Dec-1993 all ERS-1 SAR images of the NCP were requested. These images were received at (near) real time and processed into low resolution (LR) images. From the LR images the assumed oil slicks were detected by means of visual interpretation. It is emphasized that SAR, like airborne SLAR, only provides information on disturbances in the general surface wave pattern. Identification can only be obtained by visual reconnaissance. For validation purposes two out of the 12 orbits that cover the NCP have been selected for simultaneous surveillance with the remote sensing aircraft. In these surveillance flights slicks were detected by the SLAR system on board the aircraft. Because of the time required for covering the ERS-1 frames by the aircraft only limited possibilities were left for target investigation and observation.

Results

Table 4 shows the size distribution of all detected slicks by SAR and SLAR. The average size detected by SAR was 2.0 km^2, and by SLAR 1.6 km^2. The area covered by a slick on an ERS SAR image is only calculated by multiplying length and width of the slick. The actual coverage within the slick is not taken into

Table 2 Pollution qualification of all detected slicks

Year	Pollution qualification					
	Mineral	Vegetable	Chemical	Other	Unknown	Total
1992	191	26	3	3	178	401
1993	299	20	–	6	363	688
1994	203	13	–	3	386	605
1995	169	12	1	3	296	481
Total	862	71	4	15	1223	2175

Table 3 Quantity distribution of detected oilslicks (only visual observed oilslicks are presented)

Year	Number of detected oilslicks						
	< 1 m^3	1–5 m^3	5–10 m^3	10–50 m^3	50–100 m^3	> 100 m^3	Total
1992	135	31	11	11	2	1	191
1993	203	60	21	11	2	2	299
1994	134	43	17	5	2	1	202
1994	96	19	9	9	–	–	133
Total	568	153	58	36	6	4	825

Table 4 Size distribution of the slicks detected by SLAR

	Number of slicks		Total area (km^2)	
Area class	SAR	SLAR	SAR	SLAR
< 1 km^2	140	171	40	37
1–2 km^2	44	23	65	30
2–5 km^2	22	35	71	101
5–10 km^2	16	6	102	46
> 10 km^2	6	9	104	181
Total	192	244	382	395

account. Consequently, the actual coverage of a detected slick by SLAR is not included. In practice an oil slick will not be a homogeneous slick resulting in an actual covered area that is less than the presented figures.

Comparison of ERS SAR and SLAR results

Table 5 gives the size distribution of the detected slicks for the days on which both satellite and aircraft data were available. From this table it can be learned that the total number of slicks found is almost equal and the aircraft detected more small slicks while the satellite detected more relatively large slicks. For slicks that were not detected by the ERS-1 SAR data two explanations can be given:

- size of the slick; four out of the five missed slicks are relatively small (< 0.2 km^2); and
- time difference; in this case 1 h 28 min passed between the observation on SLAR and the satellite overpass. The slick could be partly dispersed and evaporated in between.

Conclusions

This study showed that ERS-1 SAR data have a large potential for detecting oil slicks on the North Sea on a regular basis. It was concluded that when slicks on SAR images are received at (near) real time, a good service could be provided that established an early warning system and optimized the flight plan of the aircraft (this was already implemented by the Norwegian Pollution Control Authorities). Based on the limited dataset of verified slicks (slicks that had been detected by satellite as well as detected and observed by the aircraft), it was not possible to determine the errors and omissions. It was therefore recommended to perform an additional test in which sufficient (verified) reference data was acquired. The report of this test (Oil Spill detection on the North Sea using ERS-1 SAR data) was presented in the Bonn Agreement contracting Parties meeting in Malmo, September 1994.

Table 5 Size distribution of slicks detected on days with simultaneous coverage

	Number of detected pollutions		
Area class	Satellite	Aircraft	Correspondingly
< 1 km^2	16	31	6
1–2 km^2	9	1	1
2–5 km^2	4	–	–
5–10 km^2	3	3	3
> 10 km^2	2	1	1
Total	34	36	11

Second ERS SAR Project

In January 1995 it was agreed to follow up on the recommendation and to perform a joint Bonn Agreement additional test, in which the United Kingdom, Germany and the Netherlands participated, in close cooperation with TSS in Norway. During the former Netherlands ERS-1 project, confirmed by the experiences of the Norwegian Pollution Control Authorities, the Tromso satellite station proved to be a ground station capable of providing near real-time ERS SAR images (within 1–2 h after the satellite pass). The aim of this programme was to validate SAR data by comparing it with airborne SLAR and visual observations. A preliminary report has been prepared.

Test project

The track of the ERS SAR covers an area, subdivided in frames of 100 km^2. The general idea was to survey an area of two adjacent frames (100×200 km) by an aircraft at the time of the satellite pass. Based on the coverage of the SLAR, three tracks of 200 km with a track spacing of 33 km were flown. All slicks detected by SLAR had to be visually observed in order to identify the type of pollution. It was therefore decided to use only the daypass at 10:40 UTC (descending orbit).

The satellite images were received at (near) real time and processed into low resolution (LR) images. The LR images were interpreted by the operator at TSS. The operator distinguished:

- assumed zero wind areas;
- natural slicks;
- sand banks; and
- oil slicks.

A distinction was made between oil slicks with a high, medium and low probability. The results of all processed and interpreted SAR images were faxed to

The Netherlands, by a notification message indicating possible slicks of interest.

ERS SAR results

In the given period, a total number of 60 images were analyzed by TSS and passed to The Netherlands. The number of assumed cases of pollution (probability medium or high) was 33. The SAR images were re-analyzed by an experienced Remote Sensing operator in the North Sea Directorate. The total number of detected slicks increased from 33 to 55 (23 possible cases of pollution were added and one was rejected). The rather high added number is mainly caused by difference of interpretation of one image on the 6th of May; because of low wind speed and appearance of natural slicks, a number of slicks were not recognized as possible cases of pollution by the operator at TSS (initially only five cases of pollution were marked against 28 by the North Sea Directorate). Other reasons may be:

- little experience in image interpretation on possible (oil) slicks by the TSS operators; and
- small slicks that were often not marked by TSS.

The size distribution of the slicks indicates that many detected slicks are small. (This is confirmed by the size distribution of (oil) slicks which are observed during marine surveillance flights.) The total area covered by these small slicks however, is relatively small compared with the total covered area (see Table 6). The average detected slick was about 1.5 km^2.

As former (statistical) studies on the relation between wind speed and the detection of slicks on SLAR or SAR already had indicated, most slicks were detected at lower wind speeds (1–3 Beaufort). This may be explained by the fact that oil slicks evaporate and disperse more rapidly at higher wind speeds.

Table 6 Size distribution of slicks detected by ERS SAR data

Area class	Number of slicks	Total area (km^2)
< 1 km^2	34	16.9
1–2 km^2	8	9.3
2–5 km^2	10	36.2
5–10 km^2	3	22.0
> 10 km^2	0	0
Total	55	84.4

Remarks:
1. Not all satellite passes were simultaneously flown by an aircraft (for meteorological, technical or other reasons).
2. The total number of detected slicks by means of SAR is highly influenced by the results for one day (the 6th of May).

Results of the aerial surveillance

During the test period a total of 34 ERS SAR validation missions were carried out by the German, English and Dutch Remote Sensing aircraft. SLAR images were processed and interpreted by the air crew and reported using the Bonn standard reporting format. An initial total of 35 cases of pollution were detected by SLAR interpretation. The tapes with SLAR recordings were reviewed in order to compare assumed missed slicks which were detected by ERS-1 SAR and apparently not by airborne SLAR. A total of 12 cases of pollution were added and 8 slicks were rejected (out of ERS-1 range). The final number of slicks detected by the SLAR was 39. A series of 26 out of the remaining initial 27 (35−8) were visually inspected; the 12 added slicks were only detected by SLAR. It appeared that 20 of the 26 visually inspected cases of pollution consisted of oil or an oily mixture.

Table 7 shows the size distribution of all slicks detected by SLAR. The average size detected by SLAR was 2.0 km^2. The area covered by a slick on an ERS SAR image is only calculated by multiplying length and width of the slick. The actual coverage within the slick is not taken into account. Consequently, the actual coverage of a detected slick by SLAR is not included.

The qualification of the slicks detected by SAR and verified by the air crew shows that about 80% of the pollutions consisted of oil or an oily mixture. One slick consisted of vegetable oil, two slicks were identified as algae; the other slicks consisted of 100% silversheen. Therefore, the type of these cases of pollution remained unknown.

Table 8 provides an overview of the size distribution of all slicks detected by ERS SAR and airborne SLAR. Since all cases of pollution (detected by SLAR) out of range of the SAR are rejected, the remaining possible explanations for the difference in the numbers, especially for the bigger slicks, are:

- the slick was discharged after the satellite pass;
- at low wind speeds the SLAR coverage was not equal to the SAR. The tracks for the aircraft were defined for mean conditions; SLAR coverage of approximately 10 nM to both sides at average wind

Table 7 Size distribution of the slicks detected by SLAR

Area class	Number of slicks	Total area (km^2)
< 1 km^2	23	7.2
1–2 km^2	5	8.6
2–5 km^2	5	10.1
5–10 km^2	5	38.5
> 10 km^2	1	14
Total	39	78.4

Table 8 Size distribution of slicks detected on days with simultaneous coverage

	Number of detected cases of pollution		
Area class	Satellite	Aircraft	Correspondingly
< 1 km^2	34	23	10
1–2 km^2	8	5	5
2–5 km^2	10	5	5
5–10 km^2	3	5	2
> 10 km^2	–	1	–
Total	55	39	22

speeds. At low wind speeds the actual coverage was less resulting in non covered areas in between two tracks;

- On days of low wind speed, circumstances change from time to time; at one moment the wind conditions are just sufficient for the necessary backscatter on SAR/SLAR in order to be able to detect pollution, a few minutes later the situation can be changed resulting in large dark areas where slicks can not be recognized; and
- Smaller slicks (< 1 km^2) that are detected on SLAR well before the satellite overpass (> 1 h) could in the meantime have been reduced to a size out of SAR resolution.

Conclusions

The operational capability of ERS SAR for slick detection had already been shown in former studies. The objective of this experiment was to validate SAR data by comparing it to airborne SLAR and visual observations. The results of this study are as follows.

- The classification of the detected slicks was mainly oil or oily mixtures (about 80%).
- In general, all slicks larger than 0.05 km^2 were simultaneously detected on SLAR and SAR.
- Most detected slicks were small in size, but contribute relatively little to the total covered area.
- Some slick-like phenomena on both SLAR- and SAR-images (especially small ones) were not interpreted as pollution by harmful substances.
- Within the test period, the satellite detected roughly 1.5 times more slicks in comparison to SLAR. However, the ratio is heavily affected by the results of one day (the 6th of May). If the number of detected pollutions for that specific day is discounted (28), the ratio is the other way around.

ESO Project

The third test focused on the communication, accessibility/availability of data and services of a provider (TSS) towards a user (NSD). Apart from the NSD and the Survey Department, the project team consisted of TSS, Telenor Research, Swedish Space corporation, SFT, NDRE and NRSC. This test has not been finalized at this moment. First results in The Netherlands indicate the following.

- The communication lines via internet used are not always reliable.
- The software package, called SARA, to handle the images, is user friendly.
- The time delay is a factor of concern; the requested data-availability of within 1–1.5 h of the satellite overpass is not always achieved.
- The number and frequency of useful SAR data (frames of the area of interest) is low.

A final report is being drafted.

Discussion of the Results

Integration within the existing organization

Spaceborne SAR has proved to be an useful application to detect, under certain conditions and within its limitations, pollution. To take this sensor into operation within a organization like Rijkswaterstaat, North Sea Directorate, one has to ascertain whether or not it will contribute something to the existing methods, and most of all, whether the new instrument is capable of giving additional desirable information which cannot be gathered by other means.

All countries bounded by the North Sea are faced with a increasing level of pollution of the sea. A considerable amount of this pollution is caused by operational discharges from ships and offshore installations. As a result of the Third North Sea Ministers Conference, the North Sea Directorate was given the task to intensify the airborne surveillance. The same Directorate is also evaluating its Remote Sensing results of the past decade in order determine routes and time schedules for a balanced coverage of the surveillance flights.

One way to intensify the surveillance is to increase the number of flying hours. In the year 1995 the aircraft is scheduled for about 1200 h. With an endurance of about 4 h, the aircraft can make 300 flights, in other words, one or two flights per day. The division of missions around the clock is 50% day and 50% night flights.

Apart from the additional exploitation costs, it will require a lot of manpower to intensify the surveillance from one flight a day to two missions (one day and one night sortie): from 1200 to almost 2900 h. Not only must the number of pilots be more, but also the number of operators and the evaluation capacity must increase.

Increasing the flight hours will almost certainly effect the total detected cases of pollution a year and the chance to catch a polluter red-handed is increased. The results of this project and experiences of the Operational department of the North Sea Directorate show that pollution detected by one sensor is not always visible by the other sensor 1 h later. Processes such as evaporation, dispersion etc. influence the detectability of pollution on sensors like SLAR and SAR.

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TECHNICAL NOTE

Operational Forecasting of Oil Spill Drift at Météo-France

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Météo-France has national and international responsibilities concerning marine oil pollution fighting:

- **In case of a threat of marine pollution by oil along the French coastline, the Préfet Maritime may request the services of Météo-France.**
- **Météo-France is engaged within the World Meteorological Organization (WMO) Marine Pollution Emergency Response Support System (MPERSS).**

Because of these engagements, Météo-France developed an oil spill response system. This system is designed to simulate the transport of oil in three dimensions. It consists of a hydrodynamic ocean model linked to an oil spill model including current shear, vertical movements and fate of the oil. The atmospheric forcing is provided by the wind and sea level pressure forecasts from a global atmospheric model. In the English Channel and the Bay of Biscay, a tide forcing is also included.

This oil spill response system is applicable anywhere in the world (with a coarser resolution far from the French coastline) and is available round the clock.

New developments, exercises and training are conducted jointly with the collaboration of CeDRE (Centre de Documentation de Recherche et d'Expérimentation sur les pollutions accidentelles des eaux).

Keywords: **Oil spill model, Torrey Canyon, Sea Empress.**

Observing the sea surface of the ocean and forecasting its evolutions is one of the missions of Météo-France. In case of marine pollution by oil, Météo-France provides assistance to the marine pollution emergency response operations authorities. Météo-France can intervene at a national level within the spill response plan POLMAR-MER in case of a threat for the French coastline, and at an international level within the Marine Pollution Emergency Response Support System (MPERSS) for the high seas. The MPERSS is a World Meteorological Organization (WMO) system implemented on an experimental basis since 1 January 1994. The purpose of this system is to provide a meteorological support to marine pollution emergency response operations on the high seas. The oceans and seas are divided into areas of responsibility where a national meteorological service is designated as area coordinator. Météo-France is the coordinator in area II and a supporting service in areas I, III and VII(B) (Fig. 1). The support to emergency operations may include a variety of elements such as: basic meteorological forecasts and warning for the area concerned, observation, analysis and forecasting of the values of specific meteorological and oceanographic variables required as input to marine pollution models, operation of such models and access to national and international telecommunication facilities.

Because of these engagements, Météo-France developed an oil spill response system, designed to simulate the fate and transport of oil in three dimensions. It consists of a two dimensional ocean model linked to an oil spill model including shear current, vertical movements and fate of the oil.

This oil spill response system is applicable for any location in the world and is available round the clock.

This paper summarizes the key features of the model and presents three examples of model applications:

- an application in hindcast mode for the *Torrey Canyon*;

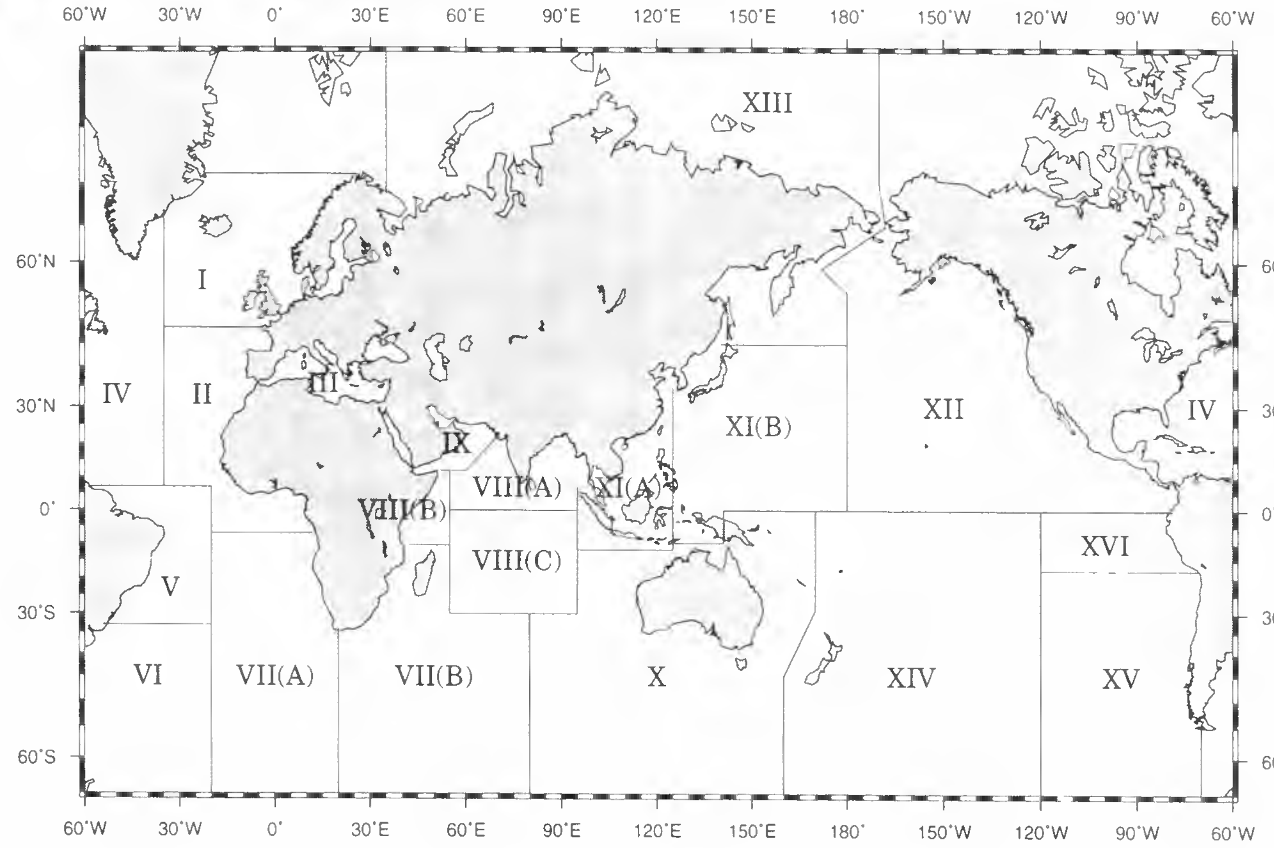

Fig. 1 MPERSS areas.

- an application in real-time mode for the Sea Empress accident;
- and an example of an exercise (Antipol 95).

Ocean Model

This part is designed to simulate the wind currents and tide currents.

The model is depth-integrated and solves the non-linear shallow water equations on a 5′ grid mesh:

$$\frac{\partial q}{\partial t} + q\nabla q + fk\Lambda = -g\nabla\eta - \frac{1}{\rho}\nabla P_a + \frac{1}{\rho H}(\tau_s - \tau_b) + A\nabla^2$$

$$\frac{\partial n}{\partial t} + \nabla(Hq) = 0$$

where t denotes time, q the depth-integrated current, the sea surface elevation, H the total water depth, f the Coriolis parameter, k a unit vector in the vertical, the atmospheric surface pressure, τ_s the surface wind stress, τ_b the bottom frictional stress, ρ the density of water, g the gravitational acceleration, A the horizontal diffusion coefficient (2000 $m^2\ s^{-1}$) These equations, written in spherical polar co-ordinates, are integrated forward in time on an Arakawa C-grid using a split-explicit finite difference scheme. The surface wind and bottom stresses are computed using a quadratic relationship. A gravity wave radiation condition is used at open boundaries.

The atmospheric forcing is provided by the winds and sea level pressure forecasts from a global atmospheric model. This model can be the model of the European Centre for Medium-Range Weather Forecasts (ECMWF) or the Météo-France model (ARPEGE).

In the English Channel and the Bay of Biscay, a tide forcing by 16 waves is included.

The bathymetry is extracted from marine charts for areas near the French coastline and from a global data base (Etopo5) for elsewhere.

Oil Spill Model

The oil slick is modelled as a distribution of independent droplets which move in response to shear current, turbulence and buoyancy. This approach to follow the movement of individual oil droplets has already been used in a number of oil spill models (Elliot, 1986; Venkatesh, 1990; Proctor *et al.*,

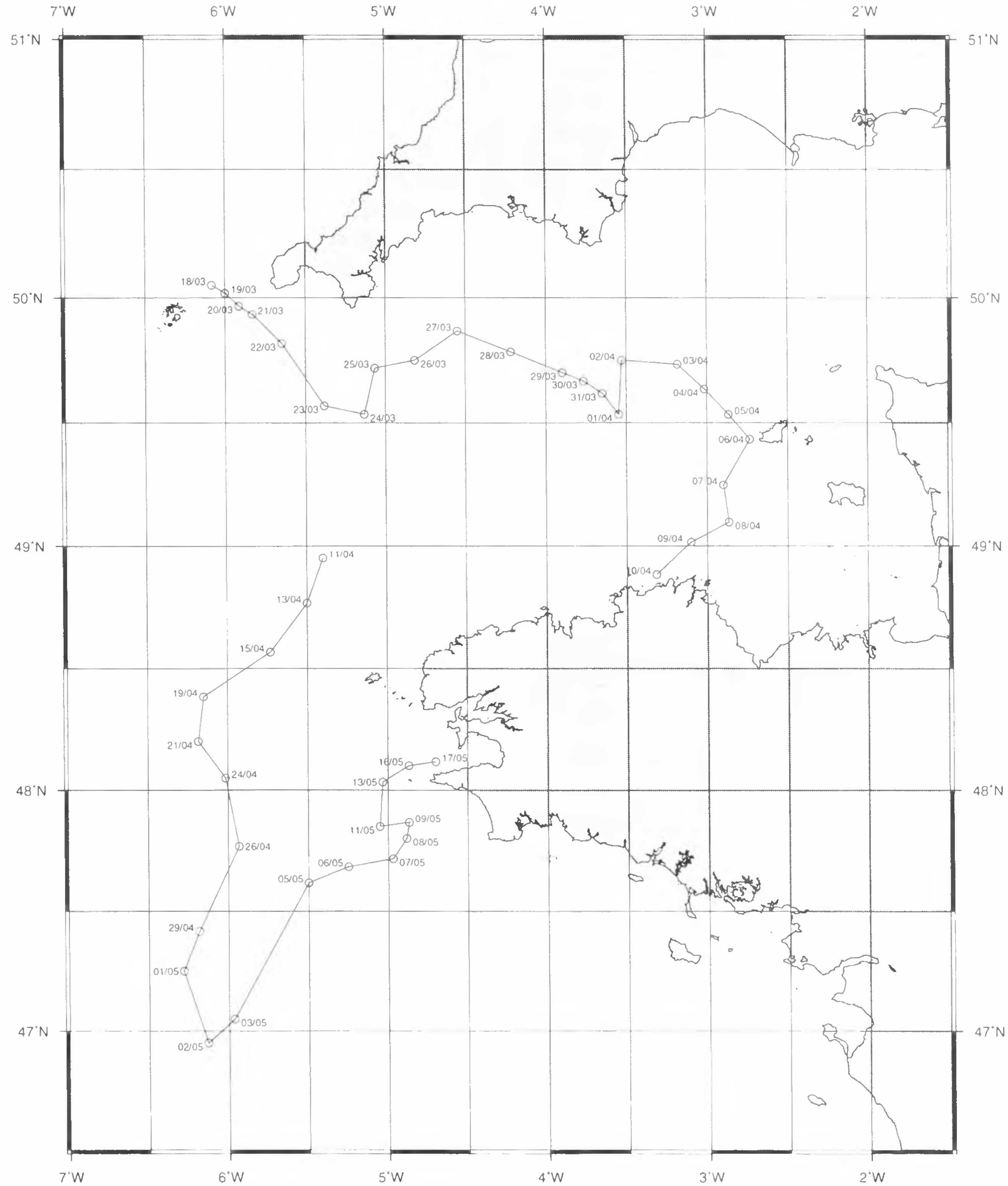

Fig. 2 Actual trajectory of the leading edge of the slicks, *Torrey Canyon* 1967.

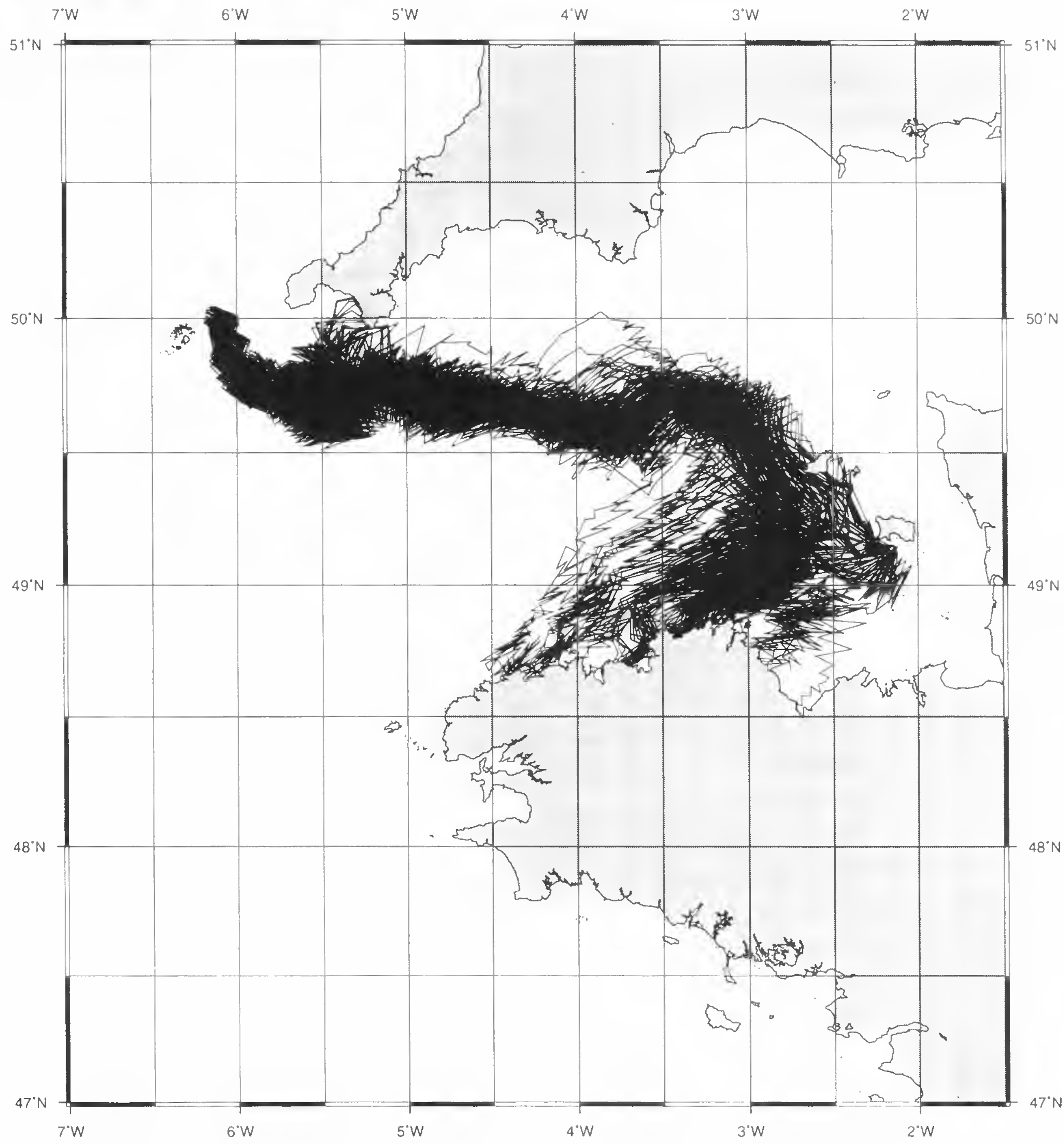

Fig. 3 Trajectories of the droplets of the first slick, *Torrey Canyon*.

1994) but with a crude formulation of the shear current.

Here, the shear current is calculated analytically for each droplet with a bilinear eddy viscosity model that assumes the vertical eddy viscosity to increase linearly with the distance from both the water surface and the bottom boundary (Poon and Madsen, 1991). The governing equation is:

$$\frac{\partial w}{\partial t} + \mathrm{i}fw = -\frac{1}{\rho}\frac{\partial P}{\partial n} + \frac{\partial}{\partial z}\left(\nu_t \frac{\partial w}{\partial z}\right)$$

in which $w = u + \mathrm{i}v$ is the horizontal velocity (u and v are the components of current), is an eddy viscosity and:

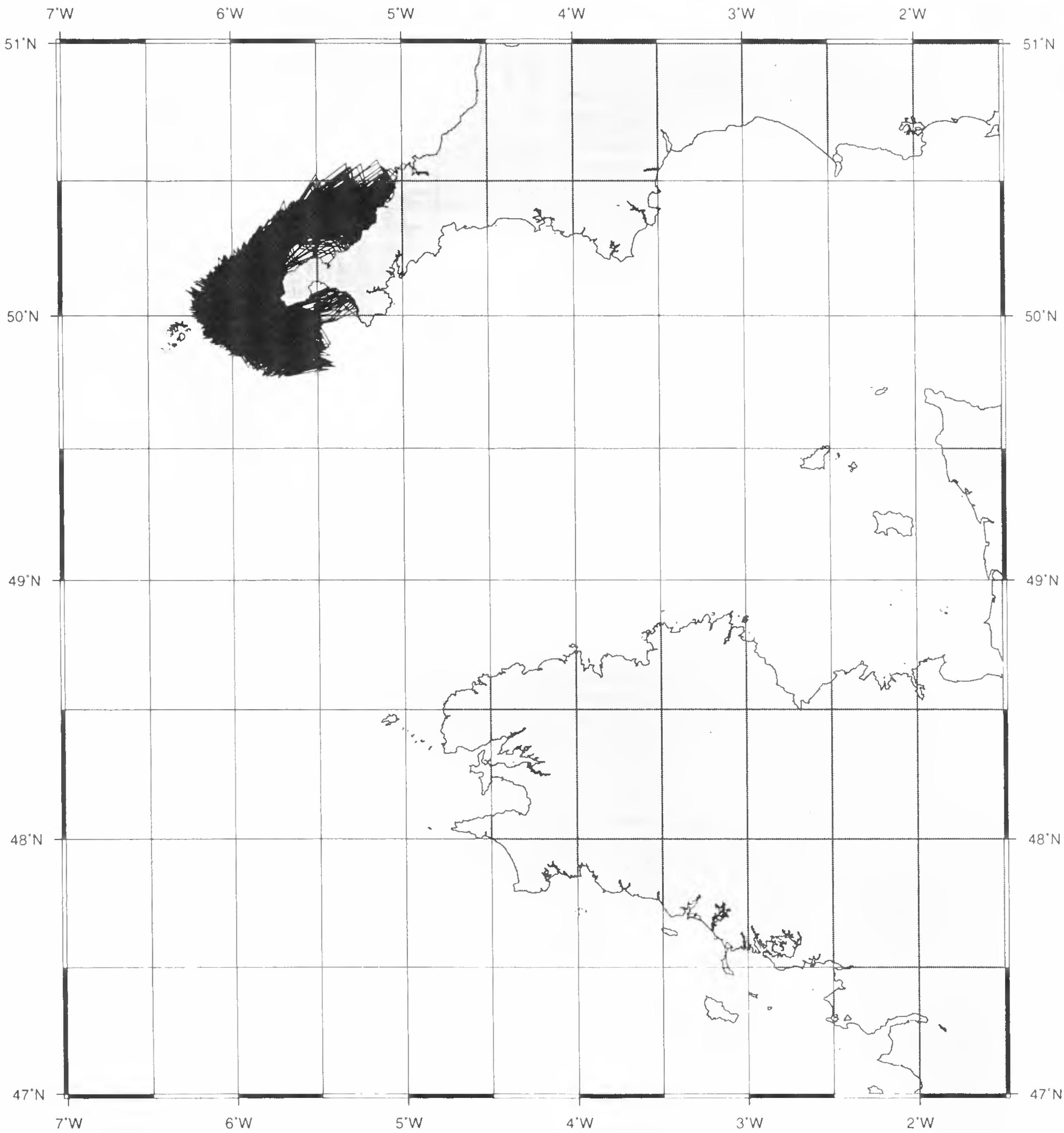

Fig. 4 Trajectories of the droplets of the second slick, *Torrey Canyon*.

$$\frac{\partial}{\partial n} = \frac{\partial}{\partial x} + i\frac{\partial}{\partial y}$$

The model is coupled to the ocean model by:

$$q = \frac{1}{H}\int_0^H w\mathrm{d}z$$

The turbulence (diffusion) is represented by a three-dimensional random walk technique.

In the horizontal, for a time step Δt, the motion is given by:

$$D_{\mathrm{h}} = R\sqrt{2K_{\mathrm{h}}\Delta t}$$

in the direction $\theta = 2\pi R$, where K_{v} is the horizontal diffusion coefficient and R a random number between

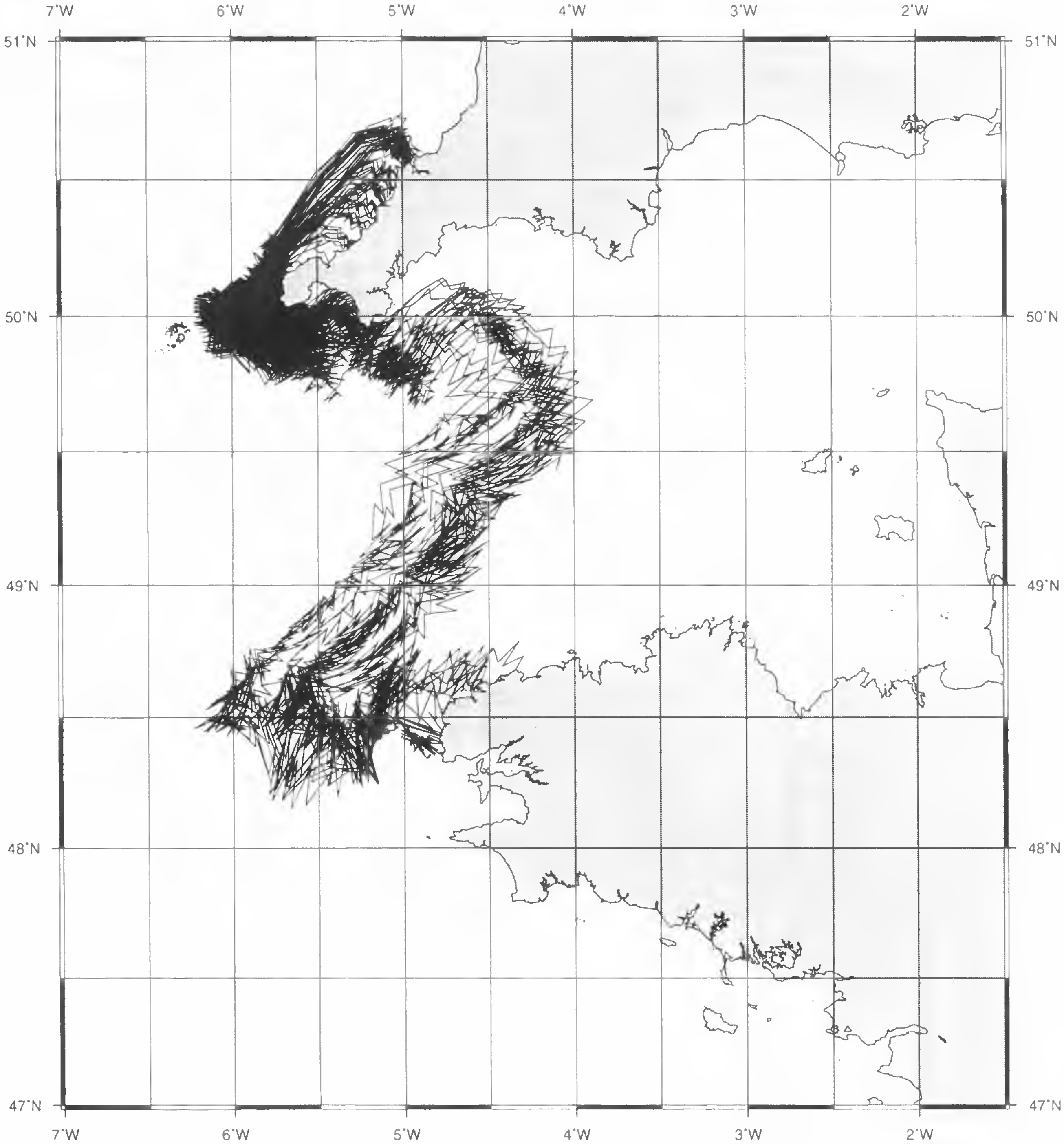

Fig. 5 Trajectories of the droplets of the third slick, *Torrey Canyon*.

0 and 1. In the vertical, the motion is:

$$D_v = (2R - 1)\sqrt{2K_v\,\Delta t}$$

where K_v is the vertical diffusion coefficient. The buoyancy force depends on the density and size of the oil droplets so that larger, more buoyant, ones tend to remain in the surface layer whereas the smaller droplets are mixed downwards.

The vertical speed U_f is (Elliott, 1986):

$$U_f = \frac{gd^2(1 - \rho_0/\rho)}{18\nu}$$

for the small droplets $d \leqslant d_c$

$$U_f = \sqrt{\frac{8}{3}gd(1 - \frac{\rho_0}{\rho})}$$

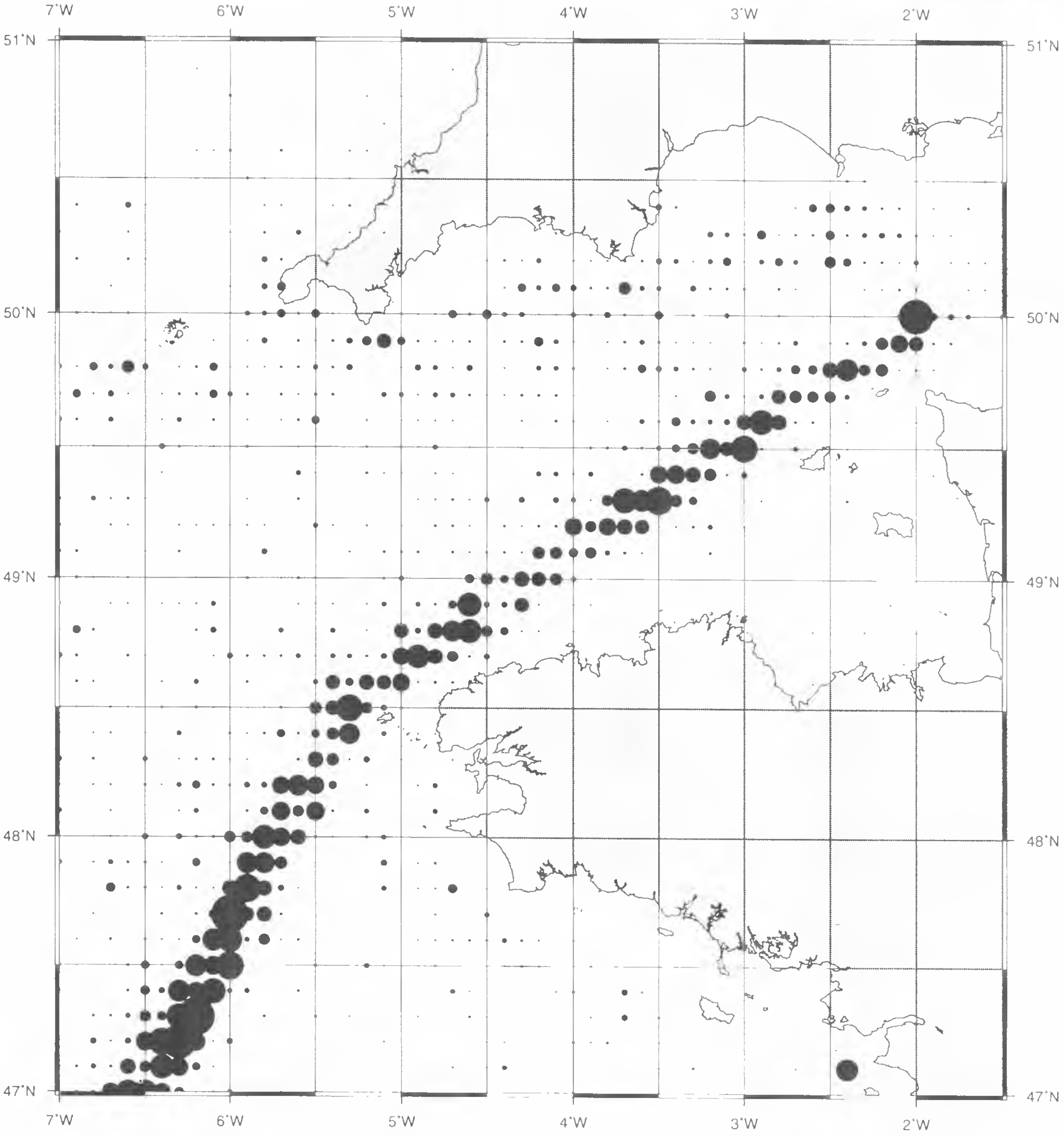

Fig. 6 Density of wind observations during the *Torrey Canyon* accident. (The size of the points is related to the number of observations).

for the large droplets $d > d_c$. The critical diameter d_c is:

$$d_c = \frac{9.52\nu^{2/3}}{\sqrt[3]{g(1-\rho_0/\rho)}}$$

with ρ the seawater density and ν the viscosity. About 65–70% of the droplets remain on the sea surface. If a droplet is moved on to land, then that droplet is considered beached and takes no further part in the simulation.

Numerical Simulation: The *Torrey Canyon* Example

The model was calibrated on a few well documented pollution incidents such as *Torrey Canyon*, English

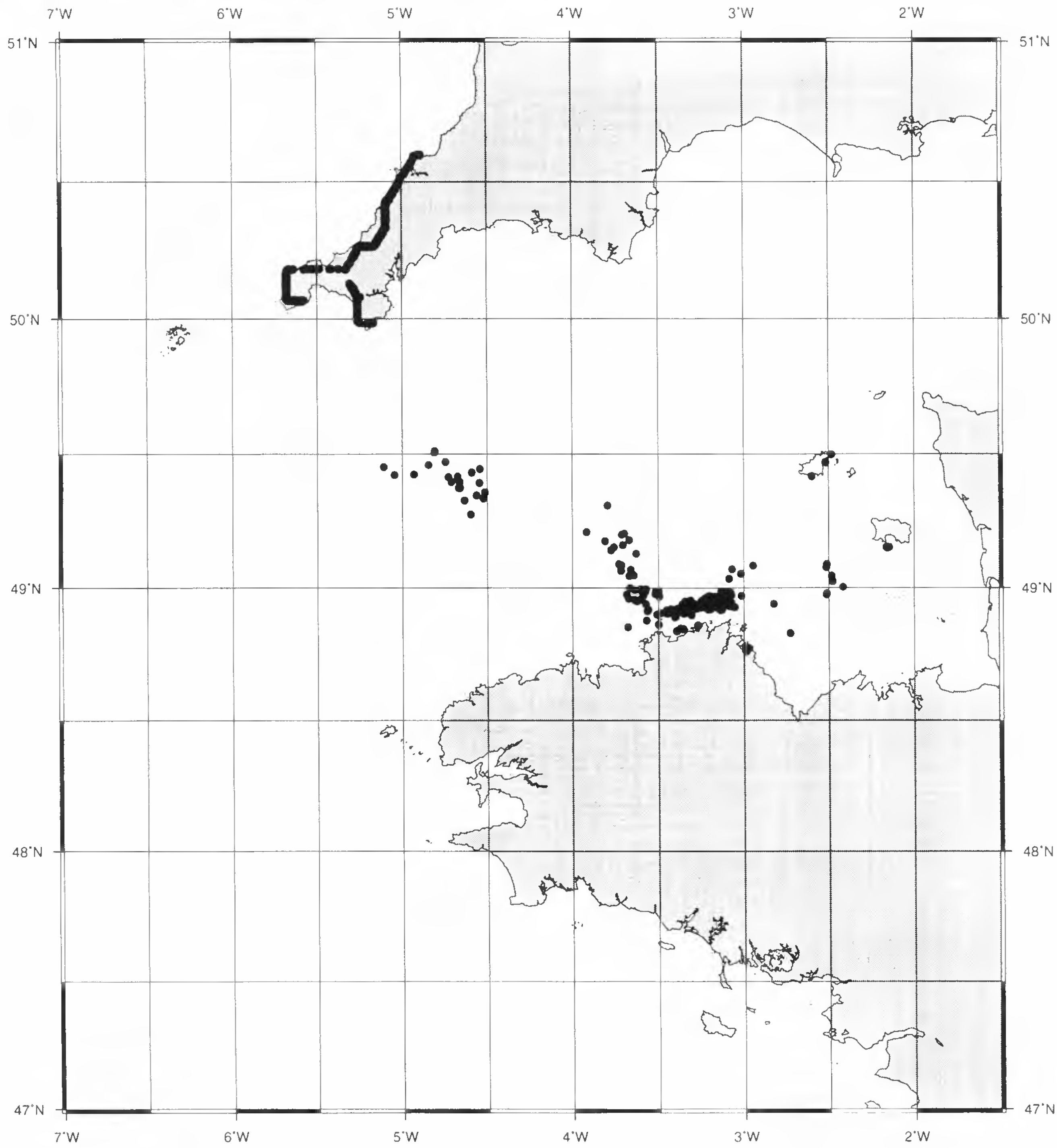

Fig. 7 Hindcast of the *Torrey Canyon* oil slick at 10 utc, 10 April 1967.

Channel, 1967 (Drici, 1994; Chaussard and Perrin, 1996), *Amoco Cadiz*, English Channel, 1978 (Drici, rd and Perrin, 1996; Chaussard and Perrin, 1996), *Tanio*, English Channel, 1980 (Chaussard and Perrin, 1996), Gulf War, Persian Gulf, 1991 (Dervillée and Jouvenot, 1993), *Aegean Sea*, La Coruna, Spain, 1992 (Daniel, 1995).

On 18 March 1967, the tanker *Torrey Canyon* ran aground on Seven Rocks reefs near the Scilly islands. 121 000 tons of crude oil were released into the sea. 30 000 tons were released immediately after the wreck. This slick moved across the Channel for 24 days and beached on the north coast of Brittany between Trébeurden and Bréhat island. Then it spread along the coast up to Morlaix river and Plouescat (Fig. 2). A second release (20 000 tons) spread along the Cornwall coastline. A third slick (50 000 tons) was released on 26 March when the

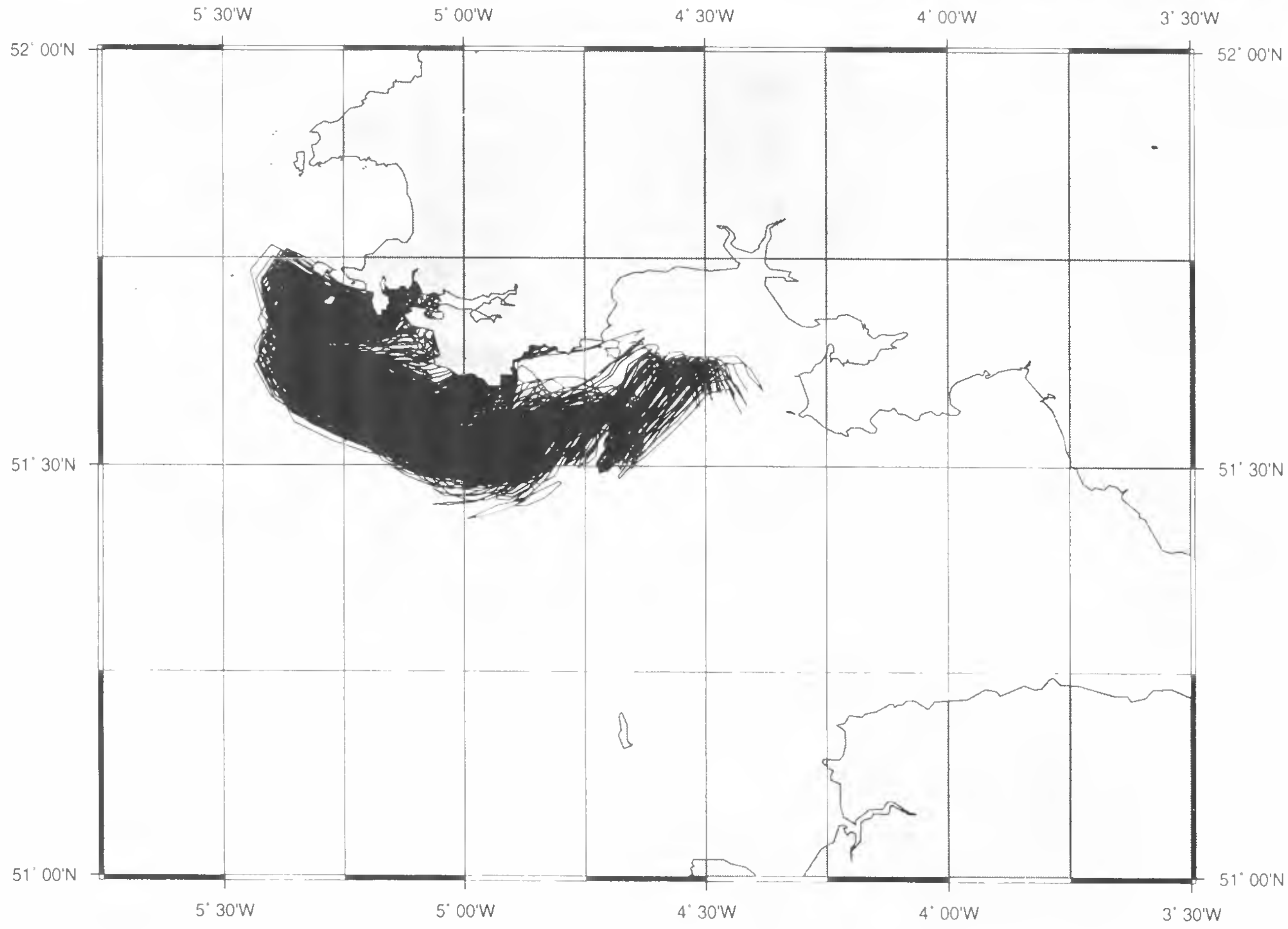

Fig. 8 Five day forecast trajectories of the droplets during the *Sea Empress* accident (starting from 5° 05′ W, 51° 32′ N).

wreck was broken into two parts. The slick moved across the Atlantic ocean offshore the Finistère coastline. It moved south until 2 May, and then moved to north east. Some limited pollution was reported on Douarnenez and Audierne on 19 May (Fig. 2). The last slick was burnt during the bombing of the wreck (28–30 March).

A two months simulation was carried out. A continuous release is assumed during 10 days, beginning on 18 March at 10 utc. During ten days, five droplets are released every 10 min. The atmospheric forcing, observed wind and pressure data, is issued from ships and buoys. An interpolation is made so that these data are available every 6 h on a 5′ grid mesh.

Figure 3 shows the trajectories of the droplets released from 18 March at 10 utc to 19 March at 14 utc. The temporal interval between each point is 6 h. The tide forcing appears clearly with a shift in the current every 6 h. The trajectories of the droplets fit exactly the observed trajectory. In particular, the simulated slick reached the coast on 10 April 1996 as it was observed.

Figure 4 shows the trajectories of the droplets released from 19 March at 14 utc to 25 March at 18 utc. All the droplets moved onto Cornish land.

Figure 5 shows the trajectories of the droplets released from 25 March at 18 utc to 27 March at 22 utc. During this period, winds were very light and the tide currents were predominant near the wreck. So the currents were alternatively north and south and the droplets moved alternatively to the south and to the north. Four packets of droplets moved to the north coast of Cornwall and three packets of droplets moved to the south. The trajectories of these droplets fit the observation during the first month of simulation and diverge after. The droplets move more slowly than observed across the Channel. The reason could be the lack of observations in this area (Fig. 6), so that the interpolation used observations closer to the coastline, and the winds were lower than actual winds.

Figure 7 shows the position of the droplets on 10 April 1967 at 10 utc. The first slick is reaching the coastline of Brittany. The second slick is entirely beached on the coastline of Cornwall. The third slick is in the middle of the Channel.

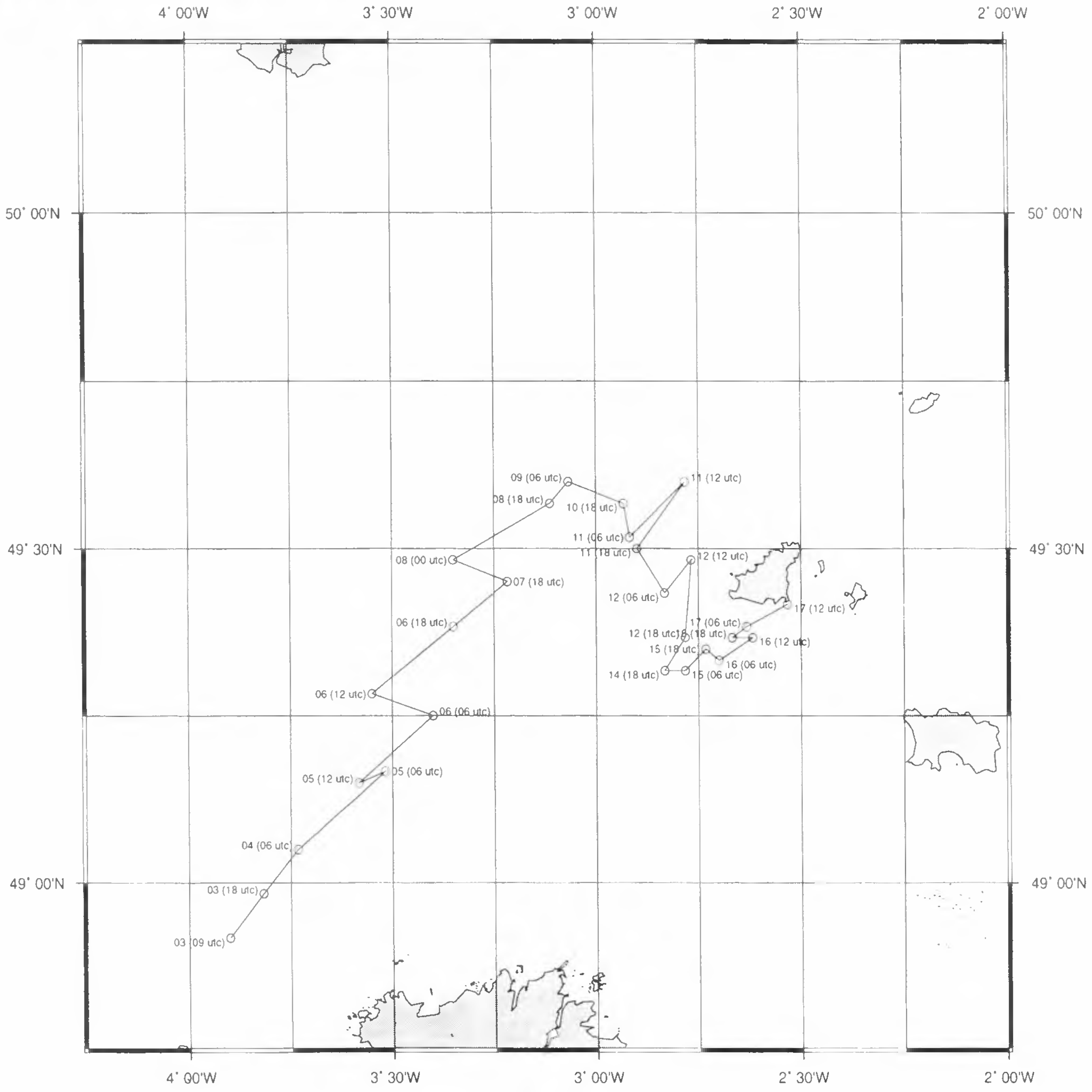

Fig. 9 Observed positions of the buoy during Antipol 95 (from 3 October 1995 to 17 October 1995).

The *Torrey Canyon* example showed that the model can accurately predict the movement of a slick provided that winds are accurate enough.

Real-Time Simulation: The *Sea Empress* Example

A meteorologist on duty at the marine service in Toulouse is able to run the model on request. He provides oil spill position, time and duration of the release and oil type (light crude oil, heavy crude oil, kerosene, gas oil, fuel oil, petrol). The model is then run for the required forecast period (typically 120 h). The output is oil spill position charts. A 120 h forecast can be carried out on a Cray C98 in a few minutes. This system enables an investigation of a forecast scenario to be made in real time.

During the *Sea Empress* accident (February 1996), CeDRE requested Météo-France to provide oil spill drift forecasts. Figure 8 shows the trajectories of the droplets for a five day simulation starting on the 22 February 1996 at 12 utc. The location of the slick was 5° 05′ W and 51° 32′ N. Wind and atmospheric pressure are provided by ECMWF model forecasts.

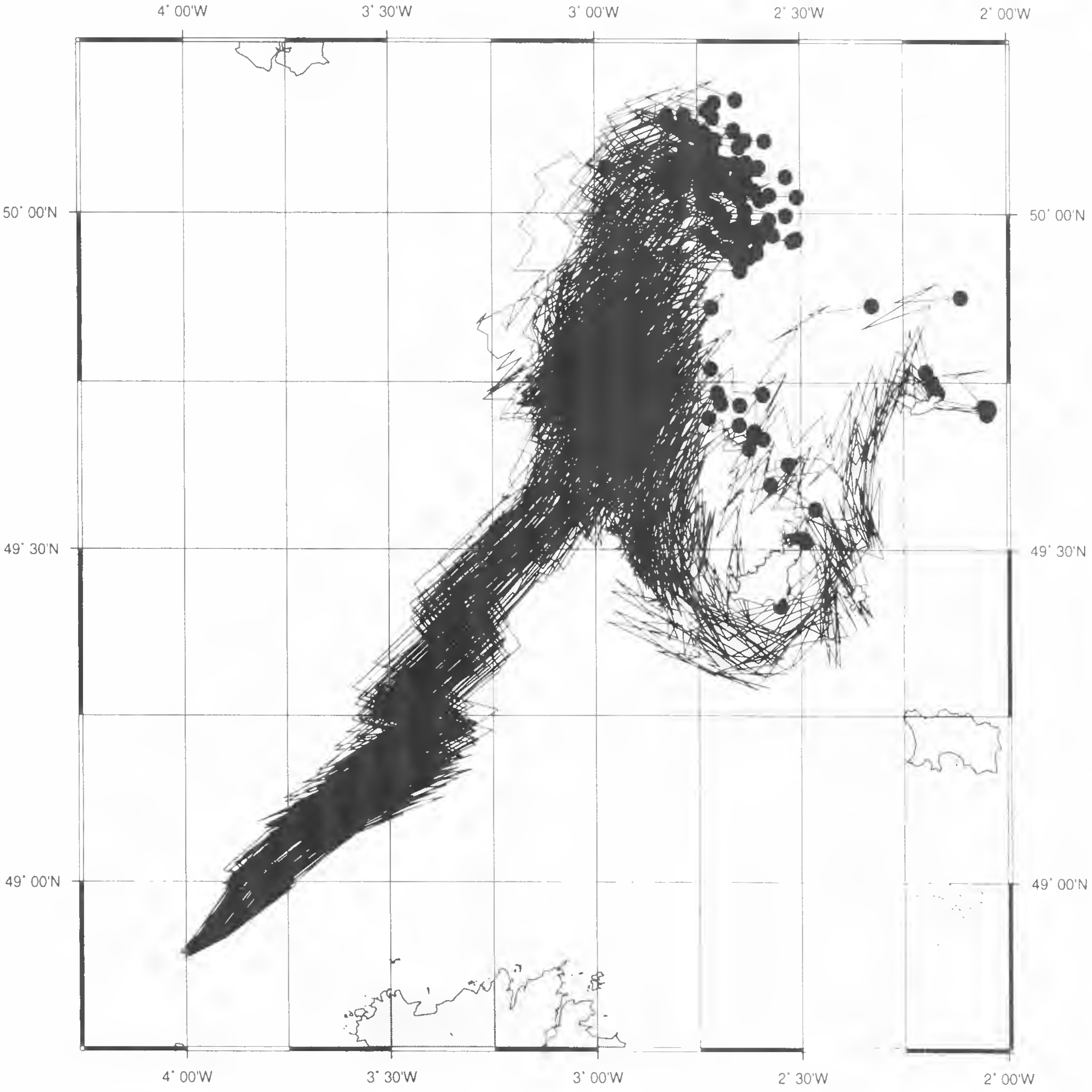

Fig. 10 Trajectories of the droplets (Antipol 95: from 3 October 1995 to 17 October 1995). The black disks indicate the position of the droplets on 17 October (12 utc).

First, the predicted slick moved to the west and then to the east which corresponded well with the observations.

An Exercise: Antipol 95

In association with CeDRE, the French Navy and Saudi Petroleum Overseas Ltd., Météo-France took part in the Antipol 95 exercise (3–4 October 1995).

Antipol 95 is a simulation of an accident with a tanker carrying 300 000 tons of light crude oil. The accident occurred north of Batz island (Brittany, English Channel) at 5 h 10 utc on 3 October 1995. The exercise included tug operations. A drifting buoy (NORDA type) simulated the oil slick drift. Figure 9 shows the trajectory of the buoy. For 2 days, Météo-France ran the model and sent oil slick drift forecasts to CeDRE. Figure 10 summarizes a 2 week model simulation. It shows the trajectories of the droplets starting from the position of the accident. There is one position every six hours. Wind and atmospheric pressure were issued from the ARPEGE model. At the beginning, the winds were Southwest and the droplets moved exactly as the buoy. From the 9

October, the winds were very light and the tide currents dispersed the slick. During this period of light wind, the spreading process was more important than the drift. The slick was broken into several parts: most of the droplets moved slowly to the north, whereas some of them moved to the south-east, passed south of the island of Guernsey and then went to the north. The trajectory of the buoy corresponds only to the trajectory of a part of the slick. It appears clearly that the drift of a buoy cannot represent the whole behaviour of the slick.

Conclusion

The Météo-France oil spill model is able to predict accurately the transport of oil in three dimensions. The atmospheric forcing is provided in real time by a global atmospheric model.

In some areas, improvements are necessary to increase the performance of the model.

Some processes such as evaporation or emulsification, play a significant role during the drift of a slick. In collaboration with CeDRE, the inclusion of a weathering oil model is under study.

The ocean model is adapted for well mixed waters. For stratified seas such as Mediterranean Sea the model is less accurate. The use of a three-dimensional hydrodynamic model which takes into account the effects of the deep circulation is under study.

Acknowledgements—This work was supported by Météo-France. J. Poitevin, head of the Marine Forecast service at Météo-France, initiated the project. A large number of individuals have been involved in this project. L. Dervillee and P. Jouvenot (Météo-France) worked on the spreading and the three dimensional movements of the droplets, K. Drici (Météo-France) included the tide currents in the model, L. Chaussard and L. Perrin (Météo-France) contributed to the generation of material upon which this paper is based. The help of P. Vincent (GRGS) on tide modeling was greatly appreciated. All the plots were made with the Generic Mapping Tools GMT version 3.

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TECHNICAL NOTE

An Oil Spill Monitoring System Based on SAR Images

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Oil pollution produced by natural or human causes is of great importance to both the environment and the economy, and it is a subject of increasing public concern. This paper presents a project for the development of a low cost demonstrator system for the detection of marine oil spills. The system is based in the analysis of satellite SAR images. SAR images are presently the only reliable remote sensing data suitable for the purpose. The main functionalities of the system include SAR raw data preprocessing, quick-look image generation and analysis, full resolution image generation and analysis and report compilation.

Keywords: **Oil spill, marine pollution, remote sensing, SAR.**

Informative Summary

Oil pollution at sea is an issue of great interest owing to its environmental and economic impact. The negative effects of pollution are greater for a closed basin such as the Mediterranean Sea. In this paper a project for the development and implementation of a low cost demonstrator system for the detection of marine oil spills is presented. The system is based on the analysis of satellite SAR images, as they are the only reliable remote sensing data suitable for the purpose that is presently available. The basic architecture of the system includes raw data preprocessing, quick-look image generation and analysis, full resolution image generation and analysis and report compilation.

Oil pollution in the sea is not only a subject of scientific or political interest, but it is also an issue of great public concern. As a consequence, since the early seventies the International Maritime Organization, IMO, has been working to prevent this kind of pollution in the frame of MARPOL (International Convention for the Prevention of Pollution from Ships), and some regulations have been issued. Among these measures is the prohibition of operational releases of hydrocarbons from ships in the Mediterranean Sea (1983).

In addition to the international agreements, there is a need to verify the fulfilment of such regulations. So, it is essential to have operative techniques for the monitoring and detection of oil spills.

The main sources of marine oil pollution are intentional and accidental releases from ships, natural slicks and pollution from land. It is estimated that operational releases from ships (tank cleaning and ballast release), account for 60–80% of the pollution (Videotel Marine International, 1986). Accordingly, oil pollution monitoring should be focused on these events.

The use of ships or aeroplanes for sea monitoring is not fully adequate, as they present two basic problems: limited coverage and high operational costs. Recently, with the advent of civil satellite SAR systems, increasing interest is devoted to their use for oil spill monitoring and detection, specially in the North Sea (Bern *et al.*, 1993; Pellemans *et al.*, 1994). Although there is not an ideal remote sensing instrument for the operational detection and monitoring of oil spills (Goodman, 1994), satellite synthetic aperture radar (SAR) presents a number of advantages over other systems, as follows.

- Imaging of broad areas, worldwide, on a regular basis.
- Day–night imaging capability.

- Independence of cloud cover.
- Ability to detect both oil spills and ships.
- Availability of satellite SAR systems: there are several operational systems (ERS-1/2, JERS-1, RADARSAT), and there will be follow-on missions in the mid term.

This paper presents a project for the study, development and implementation of a marine oil spill detection demonstrator system for the Spanish coast based on satellite SAR imagery. The second section presents the background situation of oil spill monitoring in Spain, and it is useful for the definition of the project's aims. Then the project's objectives are listed in the third section. A detailed description of the demonstrator system is given in the fourth section. The requirements of an operational system are reviewed in the fifth section. Finally, the conclusions are presented and the referenced bibliography is listed.

Project Background

The background to oil spill monitoring in Spain is presented in this section. The first point to be addressed is the importance of the coast to the country. The length of the Spanish coast is about 3900 km. The coastal areas are, in general, more densely populated than the inner regions in the country; more than 60% of the population live in coastal areas (within 50 km of the sea).

There are two important economic activities that can be affected by oil pollution and which would benefit from any measure taken in the direction of oil spill monitoring and detection: tourism and fishing. We only give a qualitative benefit analysis, as the quantification of it is rather difficult.

Tourism

Tourism is one of the most important economic sectors in Spain, and the majority of tourist activities are based on coastal resources. The negative effect that oil spills have on tourism is obvious. In this case, the main concern is focused on the arrival of the pollution at the seaside.

Fishing

Fishing is a traditional economic activity in Spain, with more than a million tons caught each year. Although most of the catches are made far away from the Spanish coast (North and South Atlantic Ocean mainly), coastal fishing should not be forgotten. Furthermore, the importance of fish farming is steadily increasing. Coastal fishing and fish farming are seriously affected by the presence of oil pollution.

The measures that the Spanish authorities have taken to implement MARPOL convention are mainly directed at prevention rather than monitoring of oil spills. The main Spanish harbours are equipped with installations in which waste water from the ships are treated and purified; this is an important way to prevent operational releases of oil pollution.

On the other hand, there is no systematic monitoring of the coast to detect oil spills. Some alarms on the presence of oil spills are issued by ships to the maritime authorities. In these situations, the authorities can send a ship or a helicopter (from the Customs Police) to verify the alarm and to try to identify the infractor ship. This situation is only suited for emergency cases, involving accidental releases of oil. A specialised organisation, SASEMAR, is in charge of oil pollution cleaning operations.

Project Objectives

The project objectives were selected with reference to the context presented in the previous section. The main objective of the project is the study, development, implementation and evaluation of a low cost, marine oil spill detection demonstrator system for the Spanish coast based on satellite SAR imagery. The evaluation of the demonstrator should justify a follow on and the implementation of a more advanced system, with a pre-operational status. The project is currently under evaluation by the Spanish authorities (Merchant Navy Authority and Science and Technology Ministerial Board).

The main objective of the project is divided into three sub-objectives:

- development and implementation of a demonstrator of an oil spill detection system based on SAR images;
- testing and evaluation of the demonstrator;
- feasibility study of a pre-operational system.

The description of the demonstrator is presented in the fourth section. Concerning the test and evaluation activities, two areas have been selected according to the probability of oil spills and their environmental impact: The Straits of Gibraltar and Tenerife (Canary Islands). Both areas have heavy marine traffic, oil refinery industry and important tourist activities. A number of SAR images from 1995 will be analysed and a study covering the frequency of spill events will be done.

Demonstrator Operation

The implementation of the demonstrator system resembles, as much as possible, the operational

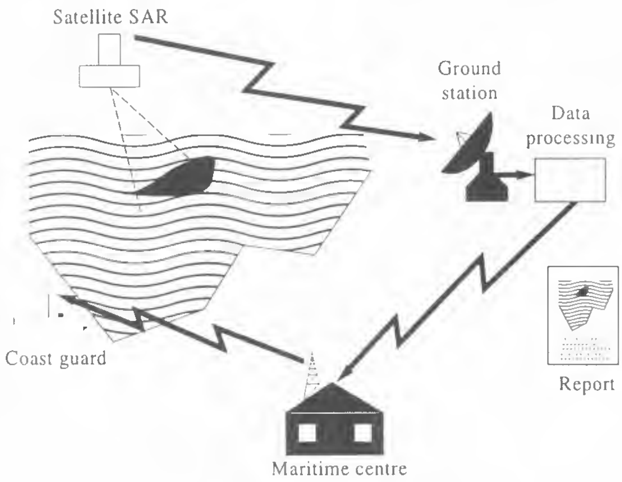

Fig. 1 Integrated system for oil spill monitoring.

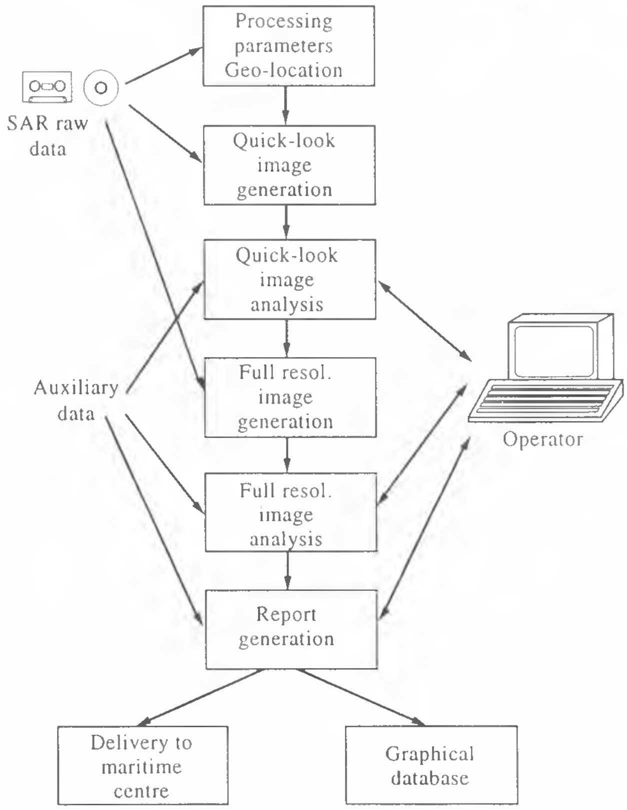

Fig. 2 SAR data processing system.

situation. The structure of an integrated system for oil spill monitoring is depicted below and in Fig. 1.

- Data reception system (Maspalomas Station). This subsystem is responsible for the acquisition of satellite SAR data and its transformation to computer compatible format.
- Data processing system. This is the specific aim of the project. The processing subsystem is responsible for all data processes to detect the potential oil spills (in the form of text and graphic reports) from SAR data.
- Report/alarm handling and dissemination from the receiving and processing station to the maritime authorities. A central unit and several regional sub-units are foreseen for the Spanish case.

The main characteristics of the data processing system are described in the following subsections. A schematic view of the demonstrator is presented in Fig. 2. Two examples of ERS-1 SAR images are given in Figs 3–6.

Hardware environment

The demonstrator system is developed and implemented on a commercial UNIX workstation. The main characteristics of the platform are: single processor, 128 MB RAM, 4 GB disk and CD-ROM and Exabyte tape units. This configuration can be readily upgraded if the performance is to be increased.

Data ingestion

The source of SAR data for the project are ERS.RAW products, on exabyte tape or CD-ROM media. For an operational system, the ingestion of SAR data in HDDT (high density digital tapes) would be considered. Once the data is loaded the next step is to read the header information and to determine the area covered by the data set. Then, the interesting data is selected and the areas of no interest (i.e. land) are disregarded.

The calculation of relevant processing parameters of the ERS.RAW data (PRF, timing information, Doppler centroid, FM rate and their slopes, etc.) is also included in the data ingestion step. This information is summarized in a processing parameters file, that serves as input to the SAR processors.

Quick-look image generation

Once the processing parameters are available, a ground-range projected quick-look image is generated from the raw data. The size of the quick-look image is at most 1 MB, and the pixels are coded in 1 byte (256 grey levels).

A number of processing algorithms and parameters need to be studied in order to optimize the system. These parameters are:

- decimation factors (in range and azimuth directions), that determine a reduction in the raw data volume to be processed and also in the quality of the generated image;
- number of looks (in range and azimuth), giving an indication of the radiometric quality of the imagery;

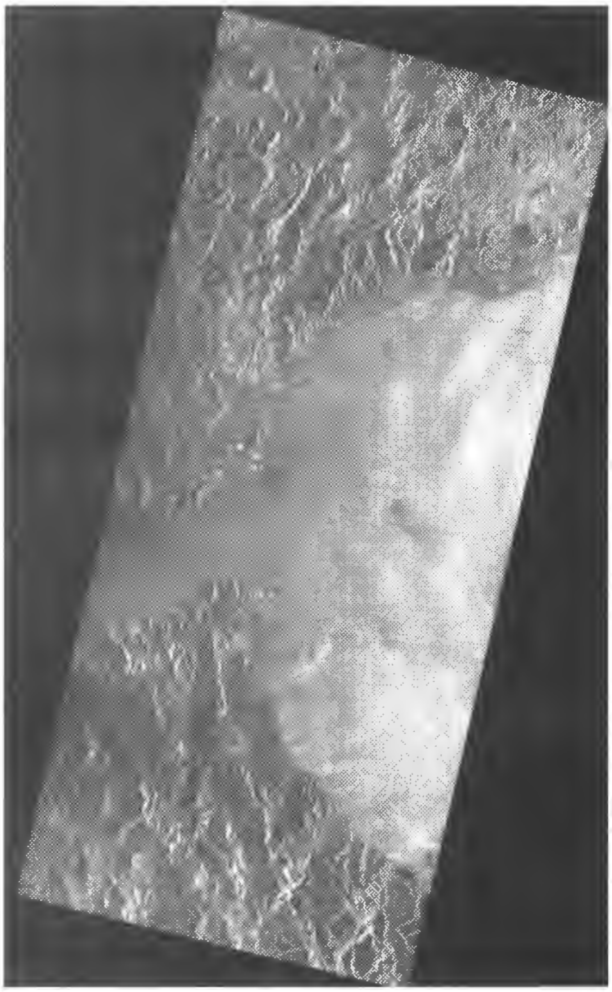

Fig. 3 ERS-1 SAR quick-look image of Straits of Gibraltar, acquired on 11th October 1992; © ESA 1992. The image covers an area of 100 km across track by 200 km along track; the pixel spacing is 200×200 m. An oil spill (the dark line feature) can be observed in the western part of the strait.

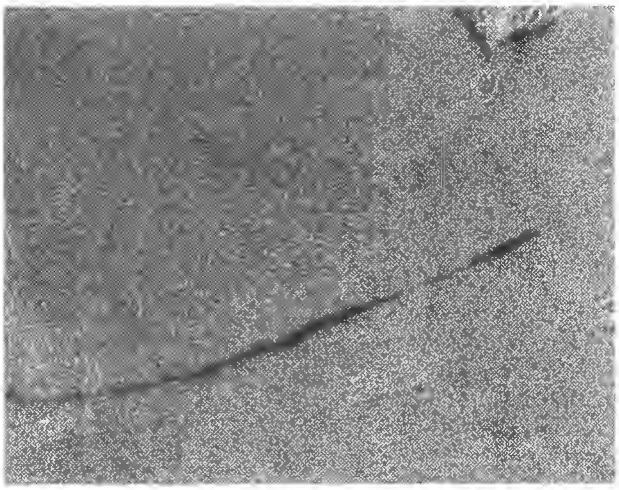

Fig. 4 Full resolution image of the oil spill shown in Fig. 3 (the pixel spacing is 20×20 m); © ESA 1992. Tarifa Island and the southernmost Spanish continental coast are located in the upper part of the image. The oil spill is clearly visible, along with several ships crossing the strait.

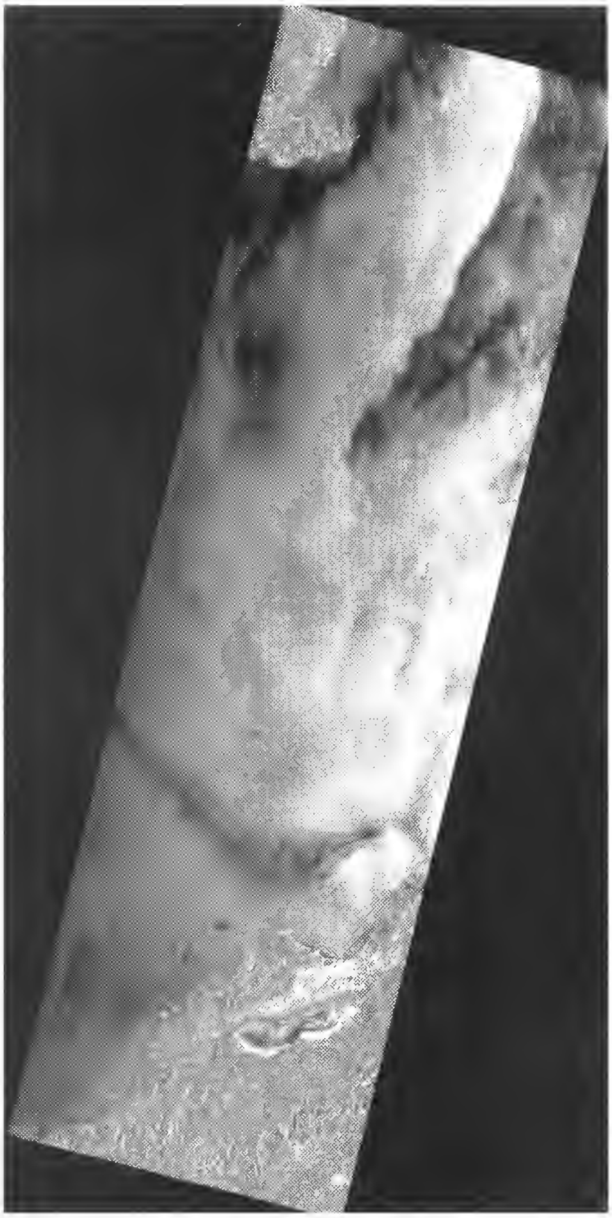

Fig. 5 ERS-1 SAR quick-look image of Alboran Sea (western Mediterranean) between Algeria and Spain, acquired on 2nd October 1992; © ESA 1992. The image covers an area of 100 km across track by 300 km along track; the pixel spacing is 300×300 m. The V-like dark feature close to the Algerian coast could be caused by natural films, as it presents filament structure. South and north of this feature there are smaller and darker features, that can be associated with oil slicks. The dark fringes close to the Spanish coast, Palos Cape and Mar Menor, are low wind areas.

- pixel spacing.

These factors influence both the image quality parameters (radiometric and geometric resolution) and the processor performance (processing time). A tradeoff between the factors is done. The preliminary values for the parameters are:

- range decimation factor: 1–2;
- azimuth decimation factor: 1–4;

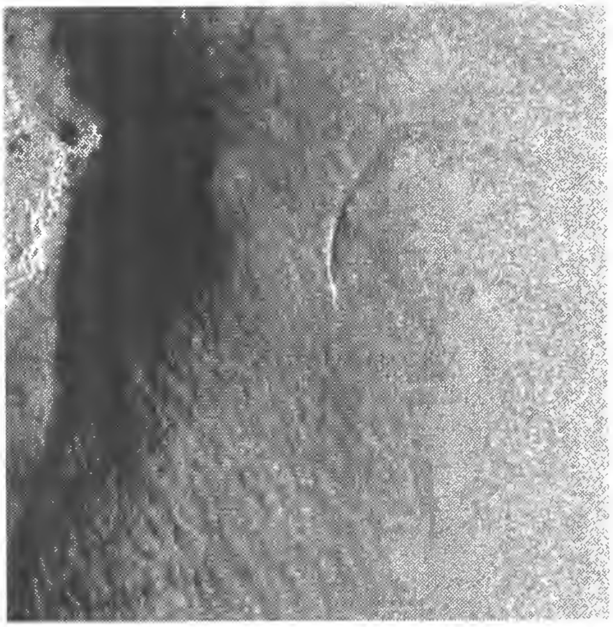

Fig. 6 Full resolution image of part of Fig. 5 (the pixel spacing is 20×20 m); © ESA 1992. Palos Cape is located at the left of the image. The dark fringe close to the coast is part of one of the low wind areas of Fig. 5. A ship can be seen in the middle of the image (small bright feature); behind the ship two longitudinal features can be observed, one bright and the other dark. This may correspond to the ship wake and an oil spill or just to the ship wake.

- number of range looks: 1–4;
- number of azimuth looks: 4–16;
- pixel spacing: 100–200 m;
- pixel quantization: 4–8 bits;
- processing time: 5–15 min for a 100×100 km scene.

Analysis of quick-look image

The generated quick-look image is automatically analysed for the detection of oil spills, as follows.

- A mask is overlaid on the image to fix the interest area (separating land and outer sea areas, if applicable). This task requires the knowledge of the image corner coordinates.
- The detection algorithm operates only in the area of interest. The basis of the algorithm is the search for small areas of low backscattering (dark areas in a light background). Depending on the quick-look image resolution, it is useful to detect ships in the areas surrounding potential targets.
- The potential targets identified by the detection algorithms are selected and marked on the screen. Appropriate tools developed to perform distance and surface measurements in the image, coordinate calculations and also to display auxiliary information may help the system operator (for instance, meteorological and oceanographic information).
- The system operator analyses the results and issues an alarm when a potential target has been identified.

Full resolution image generation

It is possible to process SAR raw data to generate high resolution sub-images from selected targets or from the full scene. This feature will help to clarify possible doubts. The characteristics of the full resolution SAR processor are:

- ground range projected images;
- number of azimuth looks: 3–8;
- pixel spacing: 12.5–30.0 m;
- pixel quantization: 8–16 bits;
- processing time: 5–10 min for a 20×20 km sub-scene.

Analysis of full resolution sub-image

It is possible to apply speckle filters to the full resolution SAR images in order to reduce the noise content of the image and thus improve the performance of the detection algorithms. The SAR image analysis algorithms for full resolution images are basically the same that those for quick-look images, the only difference being in the values of the detection thresholds and the application of detection algorithms for ships.

The results of the analysis of the full resolution sub-scene is presented on screen, overlapped to the image data. Land mask is also displayed if applicable. Appropriate tools perform distance and velocity measurements for any ship that may appear in the image.

The system operator analyses the results and has the opportunity to reject a potential target or issue an alarm.

Report generation

A text report is generated with the following information:

- listing of the targets and their geographic coordinates;
- calculated parameters for ships, if any, (location, velocity, direction and estimated size);
- meteorological and oceanographic information.

Compressed copies of the quick-look and full resolution images are appended to the report. The generation of a synthetic vector image, with the extracted information from the full resolution SAR sub-image will be considered, as it may reduce significantly the size of the report package. The size of the report package is about 100 kB, allowing a fast transmission through standard networks to the decision centre. The full images are sent later on, upon request, as the reaction time problem is solved. With the adopted methodology the amount of data has been reduced drastically from 300 MB of input raw data (for a 100×100 km scene) to about 100 kB.

The generated data (reports, quick-look images and full resolution sub-scenes) are archived in a graphical database, so that the data is available for further reference or study.

Towards an Operational System

Three basic requirements have been identified in order to develop an operational oil spill monitoring system based on satellite SAR images:

- availability of SAR data;
- fast reaction to alarms;
- high reliability of the alarms.

SAR data availability

A truly operative system should monitor the studied area at a frequency similar to that of the phenomena to be detected. Therefore, the time interval between SAR data of the same area should then be the time a ship takes to cross the imaged swath: i.e. an optimum repeat interval of a few hours. However, this is quite restrictive; more realistic is a revisit time in the order of one to three days. Although with this revisit time the area is still not imaged often enough, it can have a very important dissuasive effect if properly handled.

The revisit time is dependent on the configuration of the space segment: orbital characteristics (altitude and inclination), sensor characteristics (mainly the swath width), number of SAR satellites and location of the interest area (latitude).

It is obvious that this subject is beyond the scope of the project, as we are forced to work with the available space segment, which, for the time being, is limited to the ERS-1/2. This limits the revisit time to approximately two to three weeks. Nevertheless, it is worth mentioning the assured availability of SAR data for the forthcoming years, and the increase in the swath width (500 km RADARSAT already available, 400 km for ENVISAT).

Delay from data acquisition to alarm

The second requirement for an operative oil spill detection system is a rapid reaction time from input data reception to the triggering of the alarm. The reaction time should be kept from one to two hours, insuring there is enough time for the authorities to identify and take measures against any potential infractor.

The reaction time is determined by the ground infrastructure. With the existing ERS Ground Segment the delay in the delivery of SAR products is at least 2 weeks using the standard channels or 24 h using ESA BDDN (Broadband Data Dissemination Network), far from operational requirements. The key requirement is the availability of a data reception station that can provide the data within a few minutes of acquisition. The duration of the data processing steps are important only if the data acquisition problem is solved.

For the pre-operational and operational use of the system, a ground reception station for ERS, with SAR processing capability is needed. For the Spanish coast, the upgrade of the Maspalomas Station, in the Canary Islands, should suffice, as it coverage area includes the whole country (Fucino Station does not covers the Canary Islands). At the present time, Maspalomas Station receives SAR data from ERS satellites, but cannot perform any SAR data processing (the data are recorded and sent to the different PAFs for processing).

Alarm reliability

The reliability of the system is dependent on both external and internal factors. The external factors affecting the detectability of oil spills are as follows.

- Meteorological conditions, namely the wind speed in the area. It is well known that oil spills can not be detected by SAR when the wind is too low or too high. The lower and upper limits to the wind speed are 3–5 m s^{-1} and 13–15 m s^{-1} respectively.
- Presence of other features resembling the shape of oil spills, like plankton slicks and wind shadows in the sea.

The internal parameters which have to be investigated are the SAR processing parameters (radiometric and geometric resolution of SAR images) and the parameters and thresholds of the oil spill detection algorithms. Two parameters are to be studied:

- rate of undetected spills;
- rate of detected false oil spills.

Conclusions

Oil pollution in the sea is an issue of great interest owing to its environmental and economic impact. The negative effects of this type of pollution are greater for a closed basin as the Mediterranean Sea. The operational releases from ships are considered the main source of oil pollution in the sea.

A demonstrator system for the detection of marine oil spills has been presented in this paper. The input data for the system are satellite SAR images. The demonstrator, although modest, may represent a first step forward to the implementation of a pre-operational system for oil spill monitoring and detection for the Spanish coast.

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TECHNICAL NOTE

Small Synthetic Aperture Radar Satellite Constellations for Tracking Oil Spills

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After a short introduction to the Totally Integrated Maritime Traffic Surveillance System concept this paper examines the key issues related to three main problems concerning oil pollution at sea:

- **the early detection of accidental oil spills;**
- **the progress of oil spills to support containment and/or clean-up intervention; and**
- **the identification of culprits in the case of intentional discharges, for law enforcement purposes.**

The contribution made by advanced remote sensing satellite constellations, equipped with a complement of suitable instruments, is discussed for the specific test cases of the Mediterranean Basin and the North Sea. The key system features which enable an effective monitoring of both oil spills and the identification of the ships responsible for environmental damages are also discussed in some detail. © 1997 Elsevier Science Ltd

Keywords: **Oil spills, satellite systems, oil spill detection, environmental damage assessment.**

Background

Safety and environmental issues related to Maritime Navigation are a cause of great concern, especially in areas of dense traffic. Safety problems cannot be solved by relying on ships navigation and collision avoidance systems alone and requires the setting up of externally controlled surveillance systems for maritime traffic control similar to what is already done for air traffic. Such means can also be exploited for the relief of disasters, to support rescue operations and—in case of ships transporting dangerous cargoes—to aid the containment of environmental damage. The complex functions and tasks involved in planning, developing, procuring, maintaining and operating the various assets required for future Maritime Navigation including coping with safety aspects, environmental protection and the enforcement of international laws, can only be seen in an integrated context where all necessary and ancillary system components are coherently coordinated and managed to efficiently meet the objectives. The system block diagram of a Totally Integrated Maritime Traffic Surveillance System (TIMTSS) is shown in Fig. 1 and includes three basic functional subsystems:

Space Information and Communication System (SICS), which comprises:

- an Observation Satellite Constellation, providing imagery information services;
- a Telecommunication Satellite System, providing rugged telecommunication services between the surveillance and law enforcement field operations groups;
- the Maritime Traffic Surveillance Integrated Management System; and
- a Meteo Satellite System, providing weather information services.

Conventional Information and Surveillance System (CISS), which comprises:

- Airborne Surveillance Systems providing services complementary to satellites, and operational support to field groups;

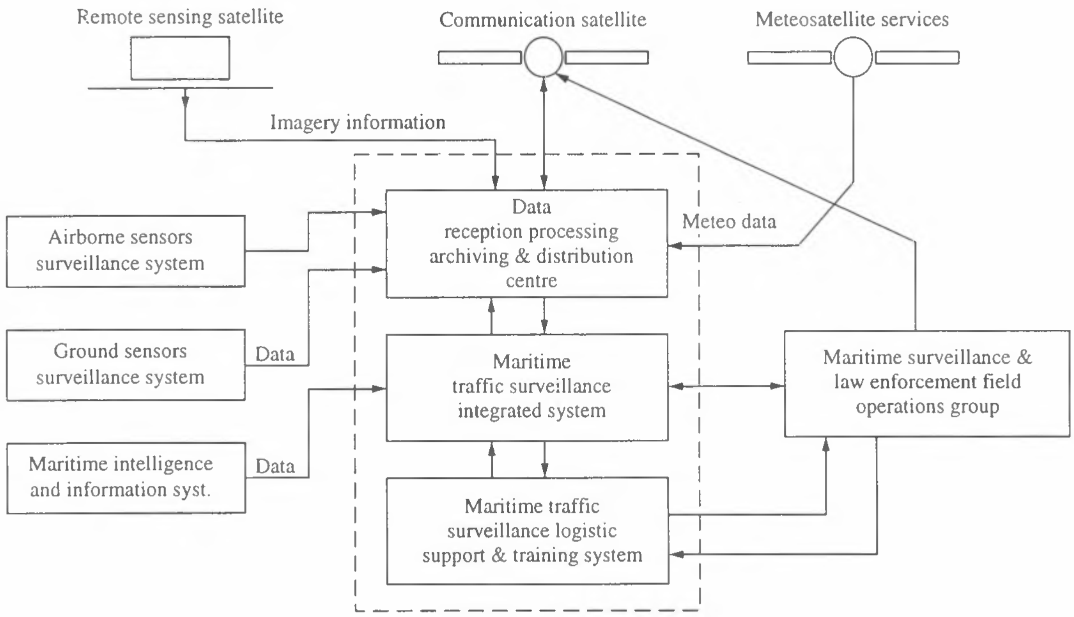

Fig. 1 Totally Integrated Maritime Traffic Surveillance System (TIMTSS): main functional block diagram.

- Ground Surveillance Systems, providing vessel traffic information to the operations; and
- a Maritime Intelligence and Information System providing vessel routes plans and identification information to operations.

Maritime Traffic Surveillance Integrated Management System (MTSIMS), which comprises:

- a Data Reception, Processing Archiving and Distribution System, providing totally integrated information for intervention planning, monitoring and control operations;
- a Maritime Traffic Surveillance Integrated System, providing planning, command and control services to field units in the area of their operational jurisdiction; and
- a Maritime Traffic Surveillance Logistics Support and Training System, providing total ground support for targeted Mission Readiness and Availability, as well as training services in order to develop operational efficiency and up-to-date expertise.

The TIMTSS concept may be implemented at Continental level (e.g. Europe) with regional management subfunctions converging in a common effort. This will permit, for example, the use of common Observation Constellations for Global instead of regional coverage, given that the other contributing systems are still part of the Total System configuration. Within the TIMTSS architecture it is important to outline the scope and application of the space segment, particularly concerning the Observation functions, related to environmental damage which is part of the SICS and of the associated ground segment which is included in the MTSIMS.

Environmental Hazards from Maritime Navigation

Among non bio-degradable pollutants discharged by vessels into the sea, oil is of the greatest concern. Oil spills, whether by accident or intentional action, seriously hamper the quality and quantity of marine resources and cause huge economic damage. This is especially true in the case of closed seas, such as the Mediterranean Basin, which has a water renewal cycle of about 90 yr. In general oil spilling in an open sea, such as oceanic regions, is of less concern since the water mass, with its vast circulation, dilutes the damaging effects. In fact, tank washing operations are currently permitted in open seas. Recent international legislation on the matter imposed the fitting of filtering devices aboard the new generation of tankers to render safer flushing of tanks in both open and closed seas. Therefore, in a not too distant future, oil pollution at sea is expected to become less of a problem except in the case of wreckage or major accidents. However, in the short–medium term, the situation will remain critical and requires to be addressed with the proper technical means. In the following we discuss two kinds of problems:

- accidents resulting in oil spills: the coordinates and the condition of the tanker in distress are usually known and therefore it will be relatively easy to operationally support the oil spill monitoring effort;

- the cleaning operation of tankers not complying with international rules: there is a great interest in developing means for the detection of these illegal discharges to prevent or contain their spread and also to provide a legal evidence for law enforcement purposes.

The Use of Satellite Systems in Case of Disasters

The wrecking of tankers may occur close to a coast or far from it. In the first case, weather conditions permitting, an assessment of the oil spill extent and potential damage, as well as post disaster oil spill tracking and monitoring, can be performed by airborne missions provided that the coasts belong to countries which possess adequate airborne surveillance infrastructures. In the second case, operational considerations may prevent the use of airborne systems and, therefore, satellites appear to be the only viable alternative for an early assessment of the disaster's extent and the subsequent monitoring of oil spills.

In the case of a disaster, it is assumed that the position of a distressed tanker is *a priori* known by a radioed S.O.S. message; its information can be used to command the satellite, so that its sensors will be directed to look at the disaster area with minimum delay. The detection of an oil spill, resulting from a tanker's wreckage, is required within the first 12–24 h from the time the accident has occurred. In addition, subsequent revisits of the disaster area are required at intervals of 24 h or less, to monitor oil slick migration due to local currents.

Owing to the necessary high revisit frequency to the disaster area, a single satellite system will not be adequate to satisfy all mission performance requirements, specially considering reliability and availability. Accordingly a satellite observation system should be based on a constellation of satellites, their number depending on the required revisit interval and field-of-view of the sensors.

Since the mission will also require all weather and day–night capabilities, to meet the high revisit frequency operational profile, each satellite should be equipped, if not exclusively, with a radar sensor. Synthetic aperture radars (SAR) are ideal for this task since they provide a cross-track ground resolution independent from the slant range. Resolution-wise, oil spill detection and tracking requires about 30–50 m ground resolution capability, although a better resolution around 10–15 m would be more suitable to evaluate oil slick boundaries. Any frequency band ranging from S to X could be adopted, although a preference for X-band seems to result from a number of pre-operational tests. Such radar sensors can be easily installed on small size relatively inexpensive satellites: see for example (Perrotta, 1991; Hall *et al.*, 1992; Pieplu *et al.*, 1994).

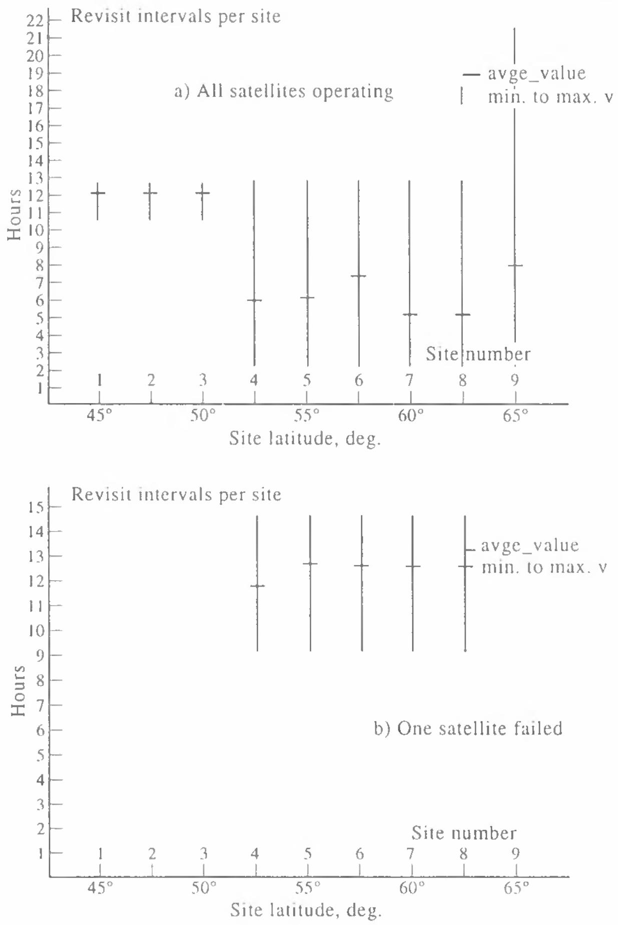

Fig. 2 Performance of a two-satellite system over the North Sea.

Figure 2, shows the revisit interval performance of two SAR satellites in a sunsynchronous resonant orbit of about 570 km altitude. The two satellites are spaced apart by 90° in mean anomaly, which provides optimum coverage performance for a North Sea scenario over a latitude band between 40° and 65°. It is here assumed that the SAR instrument can view laterally within an access arc extending from 20° to 55° off-nadir; and that this arc can be prepointed to cover different acquisition strips via satellite roll tilting (Perrotta, 1992). With both satellites operating, the average revisit interval is always less than 13 h, with peaks of 24 h at the highest latitude of 65°. Moreover, if one of the two satellites fails, then a peak revisit interval is less than 15 h over a reduced coverage between 52° and 62° latitude.

The particular case of the Mediterranean Basin is illustrated in Fig. 3 showing that the monthly passes of tankers are mainly concentrated along the Tyrrhenian, Adriatic and the Gibraltar–Cairo routes. The environmental risk index, resulting from both the traffic

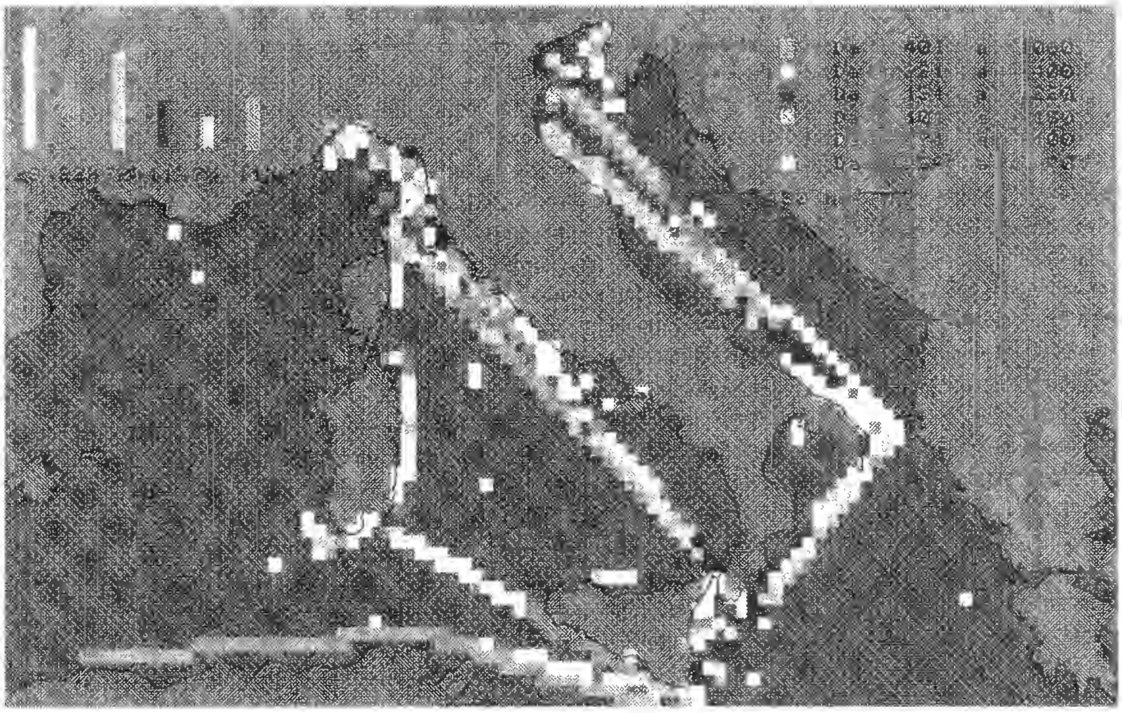

Fig. 3 Tanker traffic and monthly passes in the Mediterranean Sea.

concentration and the sensitivity of the coasts to the byproducts of ships' accidents—including oil spills—is shown in Fig. 4 with particular emphasis for the Italian case. The tanker traffic density is of the order of 10–20 per day along the Gibraltar to Cairo route and 2–3 passes per day along the Italian coasts facing the Tyrrhenian and Adriatic seas. The approximate width of these lanes varies from 50 to 100 km. The assessment of the two-satellite system defined above has been made computing the revisit interval over ten

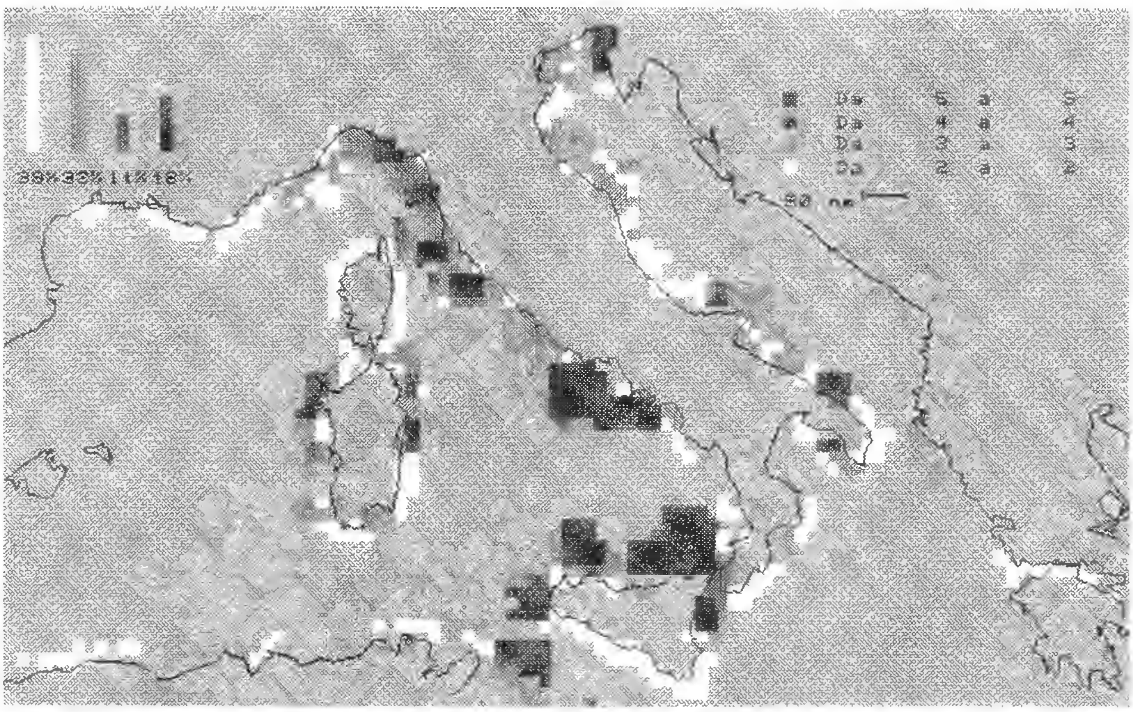

Fig. 4 Index of Environmental Risk for the Italian coast.

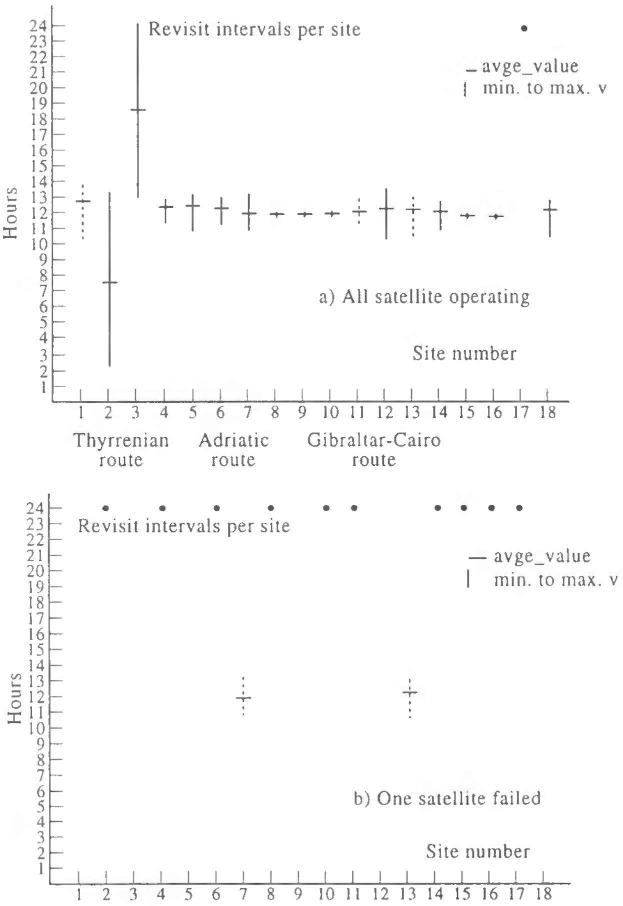

Fig. 5 Performance of a two-satellite system over the Mediterranean Basin.

evenly distributed points along the most dense path (Gibraltar–Cairo) and four points along the Tyrrhenian and Adriatic routes. Figure 5 shows the computed performance with both satellites operating and also with one satellite in failure. In the first case, the mean revisit interval is about 12 h with exceptional peaks of 24 h. In the second case, a maximum revisit interval of 24 h is guaranteed for only 85% of the test points. Therefore, in order to guarantee a continuous service, with at least one chance per day of observing all sites potentially susceptible to accidents, it is necessary to have more than two satellites.

Utilisation of Satellites for the Surveillance of Closed Sea Basins

Two main problems are of concern:

- the detection of illegal oil discharges at sea;
- the identification of the culprit: which is a task considerably more complicated than the former.

As a reference case the Mediterranean Basin scenario will be considered.

Detection of illegal oil discharges

For the detection of illegal oil discharges, one has to consider the distribution of the tanker routes in Fig. 3. The basic technique consists of getting regular updates of maps of the sea surface, possibly in both the infrared and radar bands, for comparing—on a daily basis—the newly acquired data with those obtained on the previous days in order to detect the presence of new oil spills and the drift of older ones. To give an example of the data volume necessary to accomplish this task, it is assumed that the observations are limited to the areas surrounding the Tyrrhenian, Adriatic and Gibraltar–Cairo routes. The total length of the traffic paths is about 6000 km and the width is around 120 km, this corresponding to roughly 200 daily images of 60×60 km. These images must be received, processed, compared with the archived ones and interpreted, thus giving rise to a considerable amount of work.

The satellite orbit choice should match the orientation of the major traffic paths. This necessitates the launch of satellites in inclined orbits which are suitable for covering both the Tyrrhenian and Adriatic routes, as well as the Gibraltar–Cairo one. An important difference from the monitoring of a disaster area, is that the location of illegal spills along these routes is not *a priori* known. Therefore 'blind surveillance' must be performed. Each satellite must be capable of wide swaths preferably implementing a dual SAR antenna to image sea strips on both sides with respect to the satellite nadir. The SAR instrument could have a resolution around 15 m and a swath width the order of 150 km. Under these assumptions, a number of satellite constellations were evaluated for the Mediterranean scenario, all characterized by an orbit plane inclination of 40°. The results are summarized in Table 1 for both the nominal case and a degraded configuration with one satellite failed: Table 1 shows that by increasing the satellites number the mean and peak revisit intervals decrease. This leads to a greater chance of a timely oil spill detection, better oil slick drift tracking, ships routes determination and, therefore, increases the probability of identifying the ships responsible for illegal waste according to the methodology discussed in next paragraph. On the other hand the number of images generated and processed daily will also increase in proportion, leading to the need for automatic photointerpretation tools: a technique which will have to be exploited for such data-intensive applications.

Of the constellations listed in Table 1, one was selected for an in-depth analysis of the feasible performance. Figure 6 shows the performance of a constellation of three SAR satellites equispaced in a

Table 1 Parametric evaluation of constellations for the Mediterranean Basin scenario

	Nominal case		One satellite failed	
Constellation type	Mean Rev Int. (h)	Peak Rev. Int. (h)	Mean Rev. Int (h)	Peak Rev. Int. (h)
4 sat. In S.S.O (~ 570 km alt.)	5.45	12.25	8.73	13.5
2 sats., 40° incl.; 180° spaced in RAAN	4.34	11.25	n.a.: performance falls below minimum acceptable	
3 sats.; 40° incl.; 120° spaced in RAAN	5.17	5.83	6.15	13.45
4 sats.; 40° incl.; 90° spaced in RAAN	2.63	5.51	3.53	9.9
5 sats.; 40° incl.; 72° spaced in RAAN	2.76	3.56	3.42	7.4

Notes:
(1) all 40° orbits have an altitude of about 490 km;
(2) all satellites have a 2-sided access arc;
(3) all satellites can position the f.o.v. within a 20°–55° off-nadir.

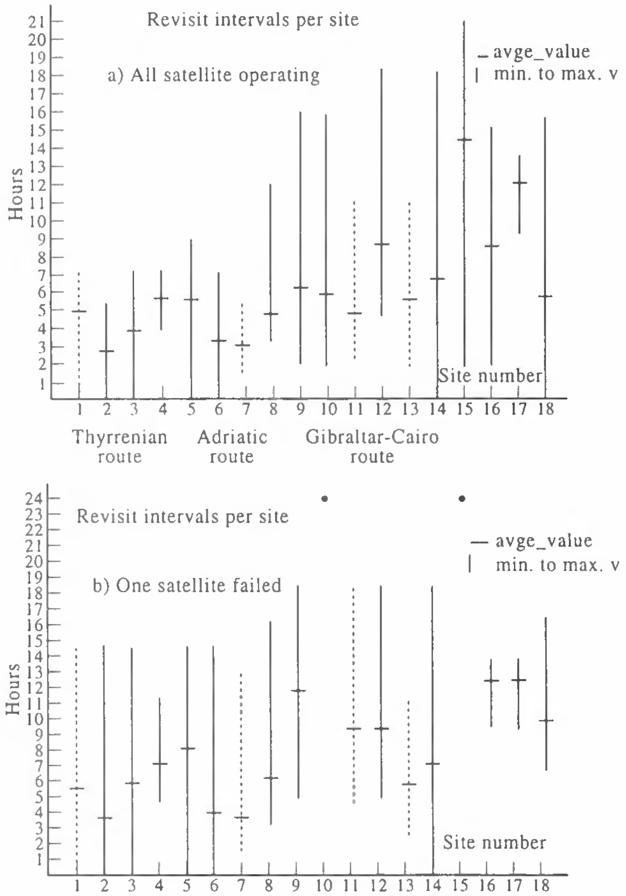

Fig. 6 Performance of a three satellite system over the Mediterranean Basin.

single orbital plane inclined by 40°. This constellation permits a mean revisit interval of less than 15 h with peaks of 21 h. With one satellite failed the peak revisit interval will increase to 24 h, which is still acceptable though a bit marginal.

While the above constellation is quite well matched to the traffic in the Mediterranean, no coverage at all is provided over the North Sea owing to the low orbit plane inclination. To widen the scope of such a satellite system, we considered the simultaneous optimization for the Mediterranean and the northern latitudes. This requires a double constellation with satellites injected in two differently inclined orbital planes. The computed performance of a satellite system including three satellites in a 40° inclined orbit and two satellites in a resonant sunsynchronous orbit show a mean revisit interval over the Mediterranean area which is a bit better than that achievable with a simpler constellation with only three satellites in a 40° inclined orbit. Over the North Sea the feasible performance is practically coincident with that shown in Fig. 2. Even better results over this area would be possible adding a sixth satellite.

Identification of the culprit

In addition to the identification and tracking of oil spills, it is also important to identify which ship was responsible for illegal waste. The latter task is very complex because it is necessary to detect and identify a whole variety of ships in transit and to correlate them to the tracked oil spills. There are, nevertheless, certain positive factors to be considered in this effort. For instance, a tanker is much larger than a fishing vessel and thus provides a stronger radar return. Other features can be exploited to discern tankers from other ships, among which the vessel velocity and mean velocity vector direction; and the ships electromagnetic (radar) signature or its infrared signature, provided that the data are compared with known data bases. Anyway we will assume that means can be devised to, at least, discern tankers among a population of vessels in a given sea portion.

Tanker tracking can be performed by sampling the area around preselected routes at regular intervals. At 15–20 knots cruising speed, a sampling time considerably less than 6 h seems necessary for ships' routes restitution. Data concerning departure time from harbour, harbour of destination and approximate trip-time forecast of tankers in transit, are normally

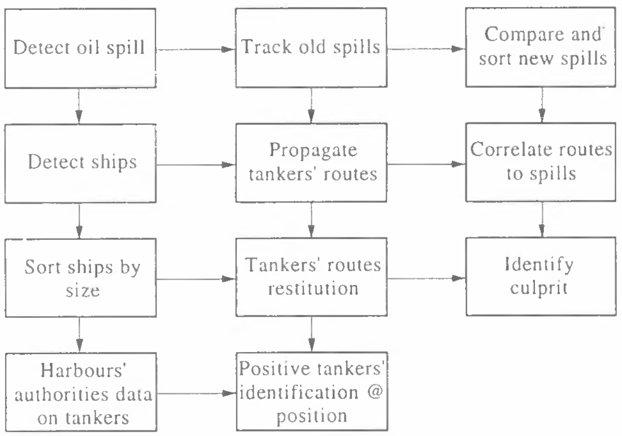

Fig. 7 Flow diagram of a satellite-aided identification of ships responsible for oil waste.

available from Harbour Authorities and contribute considerably to the identification of the vessels. In summary a methodology for detecting illegal oil discharges and identifying the culprit is outlined in Fig. 7 and include the following steps:

- perform routine surveillance of the busiest tanker routes using coarse resolution SAR sensors, possibly in combination with infrared sensors, having a medium swath width capability (order of 150 km) to detect presence and gross shape of oil spills, both new and old;
- correlate images taken on the whole area with previously acquired ones, to discern new from old oil spills;
- use coarse and fine resolution SAR, possibly in combination with infrared sensors, to detect ships above a minimum radar cross section value in order to avoid false alarms; the combined use of infrared sensors might support the sorting out of tankers using thresholding algorithms or other selection criteria; the combination of coarse and fine resolution SARs supports the determination of the vessels' position at the time of image taking;
- correlate the tankers' position datapoints, in time sequence, to derive the routes actually followed;
- if a new oil spill is detected, interpolate back from the routes actually followed to derive which tanker was closest to the oil spill at any time between two subsequent satellite passes;
- fuse the above data with ships/routes database, available from Harbour Authorities, to support the identification of the culprit.

Implementing this process requires important advances in satellite sensor technology, bulk data acquisition and processing in near real time, automation in data sorting and interpretation, and data fusion.

Using Satellites in the Relief Phase

Following the detection of an oil slick, the use of satellite remote sensing is a powerful tool to support Relief Operations directed to damage containment or clean-up activities. The 'observation variables' most significant during the Relief Phase are the following (Perrotta *et al.*, 1995a).

Oil spill size

Remote sensing can provide a synoptic view of large areas and can be used to estimate the dimensions of the spill and to monitor its temporal evolution. Visible, NIR and UV radiometers allow the detection of the oil spills and good delineation of the oil boundaries. For example, Landsat data are currently used to detect oil presence. However, systems such as Landsat are inadequate due to their low revisit frequency characteristics. SAR sensors, preferably operating at X-band, can be used in all-weather and day–night conditions, to delineate the spill boundaries, but do not provide information on oil thickness, volume and type. Not all current SAR systems may meet the required spatial resolution and certainly they do not meet the temporal resolution needs (revisit intervals of the order of few h), though data from various satellite systems might be combined to provide input for prediction models.

Thickness and volume evaluation

Passive microwave multispectral radiometers allow the detection of the oil thickness in the range of 0.1–10 mm with an accuracy of 0.1 mm.

Oil classification

Lidar fluorosensors are used to measure thicknesses less than 10 mm and to discriminate between oil types. Nevertheless such sensors have not yet reached maturity for space applications.

Wind fields

Wind field maps, if available, support oil slick motion predictions, thus facilitating its tracking. Microwave scatterometers are able to measure both the surface wind speed in the range of 0.5–30 m s^{-1} with an accuracy of about 2 m s^{-1} and a direction accuracy of about 20°. The resolution cell size is 50 km. Future instruments, such as ASCAT and NSCAT will have similar capabilities but they will offer improved coverage through increased swath width (double beam instruments). Even so, revisit times will be typically of the order of 1–2 days, rather than the required few h. Other data sources include passive microwave imagers and altimeters (wind speed only, not direction). At a local level the scale is too small for space based measurements with high spatial and temporal requirements, therefore their operational use is highly questionable.

Currents speed and direction

Precision altimetry packages and SAR are significant data sources. Nevertheless, at local level, as for the wind fields, the scale is probably too small for space based measurements characterised by high spatial and temporal requirements.

Sea surface temperature

Sea surface temperature data are used to derive marine current characteristics and profiles in order to predict the spill drift. Thermal infrared imagers are used for sea surface temperature measurements; most have spatial resolution and accuracies of the order of 1 km and 0.2–0.7 K respectively and are thus compatible with the stated application. Temporal resolutions depend upon the swath width and orbit type relying on clear sky conditions; revisits in the range of 3–24 h can be achieved. In principle, AVHRR can meet the requirements although, in practice, cloud cover might prevent sub-diurnal coverage of the European region.

However, not all of the above instruments will have the same priority and it is not necessary for all considered tasks to be performed by spaceborne sensors. For example, and especially in closed sea basins, some of the oil slick classification tasks would be better performed by airborne rather than spaceborne sensors. In addition, many existing satellites already provide information that can be used to support the modelling of marine currents and the assessment of meteorological and environmental conditions. Therefore, a dedicated satellite system should primarily address those tasks which are highly specific to the relief phase, with the greatest emphasis on the measurement of the oil spill extent, shape, and important parameters for oil slick motion tracking. In this context a SAR satellite constellation, that has the required revisit interval performance and resolution characteristics, is well suited to support relief phase operations. This satellite system may also carry thermal infrared (TIR) sensors for use in the characterisation of sea currents. Enhancement of the SAR instrument for multimode operation (e.g. adding a wavemode for surface wind characterisation) may be also considered within the scope of the primary mission.

The Ground Segment and Operational Considerations

The control and operation of the prospective dedicated satellite system will be performed by a Ground Segment designed for decentralising the operations, relevant to North Sea, Atlantic Coasts and the Mediterranean Basin, through a common satellite management centre. A proposed configuration includes:

- a satellite management centre, including at least one TTC station located in Central Europe;
- three Data Receiving and Processing Stations: one handling the satellite passes over the North Sea and two receiving data from satellite passes over the Mediterranean Sea. A sample coverage with data stations close to Stockholm, Marseille, and Cyprus respectively is shown in Fig. 8.

The TTC station and the Data Reception and Processing Centres would be interconnected and become a part of the Totally Integrated Maritime Surveillance Management System previously described.

The Processing Centres should be designed for maximum operational efficacy. Accordingly, they must be capable of processing, comparing, and interpreting large data volumes daily. The need for timely reaction and the complex processing and feature extraction algorithms to be implemented, may well justify the presence of massively parallel processors to speed up considerably all computing tasks and support the automatic photointerpretation activities, such as oil slick detection, vessel detection, sorting and identification, and data fusion. In addition the Processing Centres should implement a minimal archiving capability. As a matter of fact all data are very volatile and should be temporarily archived for a typical time period of one week, with exception of data of legal value which could be permanently archived.

Technological Considerations

In defining a cost-effective satellite system for oil spill detection and tracking and law enforcement, a number of advanced technologies should be considered, both on board and on the ground:

- the use of directive, mechanically steerable, antennas for satellite data transmission will enable transmitting SAR instrument data at up to 180 Mbit s^{-1} (as required by high resolution operating modes supporting vessel identification) to data stations equipped with small diameter antennas;
- advanced compression algorithms directly applied to the I/Q SAR sensor data streams generated on-

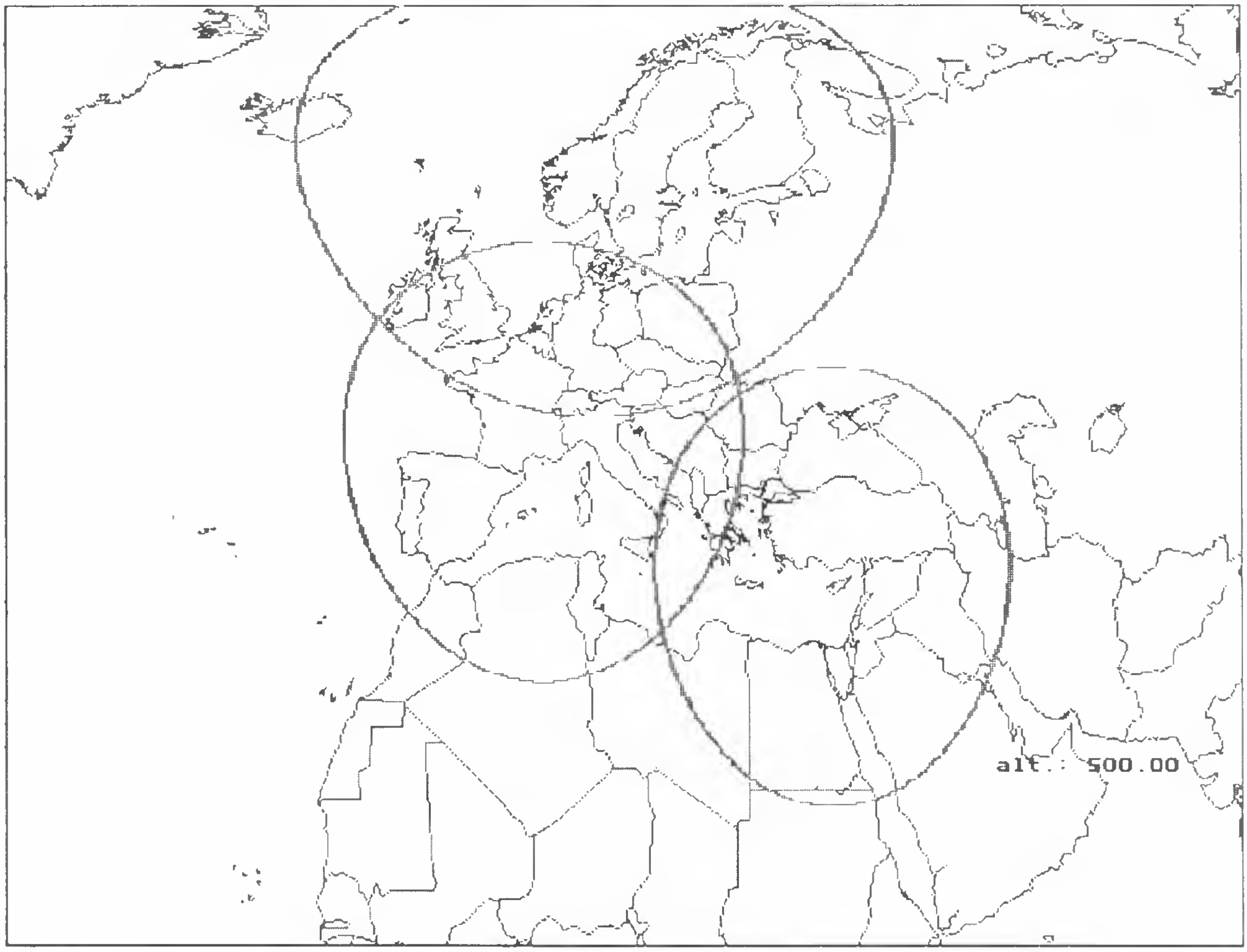

Fig. 8 Coverage of three Data Receive Stations (satellite altitude: 500 km; minimum elevation angle of 10°).

board will lead to important reductions in the data transmission rates, thus facilitating the data reception by small terminals;

- massively parallel computing, applied to the ground SAR data processing, will enormously speed up image restitution by a factor of 60–100, as already experimentally verified by Alenia Spazio in 1993. The large data volumes herein considered makes it important to rely on this technology;
- algorithms for automatic extraction of features seem particularly attractive to handle the large daily data volumes, taking into account the repetitiveness and specificity of the processing and interpretation tasks. Here too massively parallel computing helps considerably.

Concerning small satellites architecture and technology, there are several new developments by European and non-European companies, that can considerable reduce the cost of satellite production and integration. The satellite required to meet the mission needs discussed above may be very similar to that shown in Fig. 9 which is an artist's view of the 550 kg small satellite carrying an X-band SAR, which is proposed for the COSMO/Skymed mission (Perrotta *et al.*, 1995b). The estimated recurring costs for a small

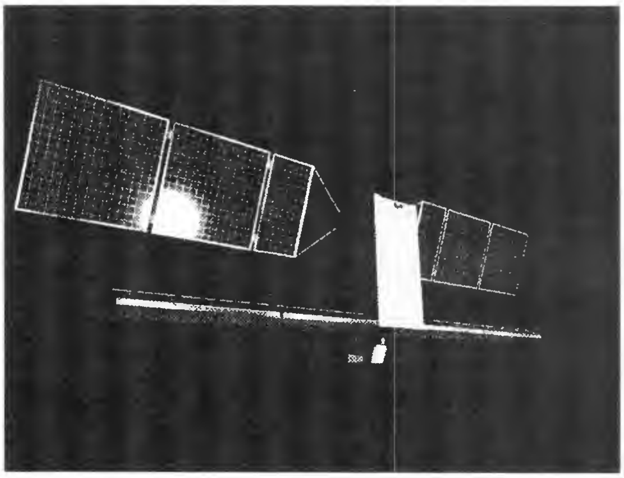

Fig. 9 Artist's view of the COSMO SAR satellite.

satellite in this mass class is of the order of U.S.$20–30m depending on the payload requirements and optional features dictated by any specific mission. Launch costs are estimated around U.S.$15m depending on the launcher type, market conditions and competition.

Conclusions

The main requirement of oil spill detection and monitoring, is the timely acquisition and processing of remotely sensed data, for use in containment and clean-up operations, with a limited delay from the occurrence of the event. Satellite systems capable of revisit intervals of 12–24 h are required to cope with the dynamics of accidental or intentional oil spills at sea. Continuous observing capabilities, independent of weather, suggest the use of a SAR as the main sensor. Constellations of 3–5 dedicated small SAR satellites are feasible and can provide excellent coverage of the high risk areas not only in Europe, but also elsewhere.

Moreover, enhanced constellations—provided with a greater number of satellites—can be designed to cope with the more challenging task of identifying tankers responsible for illegal oil spills in closed sea basins, with the aim of supporting law enforcement actions. In this latter case the complexity of the associated Ground Segment increases considerably and will be progressively more computer intensive. Advanced technologies, including massively parallel processing and automatic photointerpretation, will be essential for the realization of an effective system.

Eventually, in order that Remote Sensing may have a successful role in supporting risk and damage reduction of oil spills, as well as ensuring law enforcement efficacy, it should be considered within the concept of a Totally Integrated Marine Traffic Surveillance System.

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TESIS s.r.l. contributed to further developing the system concept, proposing its utilization both in the Disasters Relief Phase and to support Vessel Traffic Surveillance (VTS); and provided most of the background material concerning the Mediterranean Basin. The further expansion of the concept into the TIMTSS is due to Mr. P. Xefteris.

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REPORT

ERS Thematic Workshop. Oil Pollution Monitoring In The Mediterranean

Summary Report and Conclusions*

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Introduction

This report provides an overview of the presentations given, as well as a summary of the various plenary discussions developed as a result of "question and answer" sessions at the end of each presentation, and of the Round Table session at the end of the Workshop. General conclusions identified by the participants on the present situation, future prospects and the role that ERS SAR would play in the implementation of an operational service are also presented.

Starting from the experience in Norway of the Norwegian Pollution Control Authority, who, among others, have been making use of Radar data within a pre-operational service actively supported by the Tromso Satellite Station, the Workshop focused on the particular aspects and problems associated with information requirements and the potential for operational oil spill detection service within the Mediterranean.

The programme included poster and demonstration sessions as a complement to Sessions 1/2, 3 and 5 dealing with "Present Activities, Projects and Services", "User Perspectives", and "Planned Initiatives in the Mediterranean Basin", respectively.

Crucial points identified were:

- the requirements by end users and decision makers from any regular surveillance system implemented over the Mediterranean;
- the high cost of airborne surveys; the use of combined airborne/satellite information to reduce this;
- the political, legal and operational issues in combating oil spills;
- the suitability of SAR in general, ERS SAR in particular, to detect oil slicks;
- the adequacy/non adequacy of "raw SAR imagery" processing techniques when information on oil slicks has to be provided to the end users;
- the cost effectiveness of satellite monitoring as compared with airborne systems; and
- the difficulties of technology/operationalisation transfer.

Background

The Mediterranean has long been recognised as a unique and yet particularly fragile and vulnerable ecosystem. Evaporation exceeds rainfall and river-supplied fresh water, resulting in a net inflow from the Atlantic Ocean through the Straits of Gibraltar. Due to the structure of the Mediterranean Basin, individual water pockets would require a timescale of the order of 70–100 y in order to be flushed out of what is effectively an enclosed sea. This means that pollution flushing cannot be relied upon to the same extent as in

*This report was prepared with the contribution of G. Campbell, SERCO Servizi srl, under contract to ESA-ESRIN.

more open regions such as the North West Atlantic sea areas. In addition to the lack of natural cleansing processes, due to various geographical and historical peculiarities, shipping traffic levels within the region are among the highest in any area worldwide so there is a constant threat of spillage, both deliberate and accidental.

The United Nations recognised the particular problems associated with the region and sponsored the development of the Mediterranean Action Plan. As a first stage, under the Barcelona Convention and associated protocols, all states bordering the Mediterranean agreed that pollution was a common problem and that a monitoring methodology should be set up to ensure that the terms of the MARPOL treaty, banning discharges and dumping from ships in international waters, were enforced more effectively. Due to the disparity in wealth and available technology between the northern and southern states, however, the implementation and enforcement of MARPOL and the dumping related sections of the Barcelona convention has proved to be difficult if not impossible.

With the advent of satellite based SAR systems, a cheaper, albeit less flexible, source of surveillance and monitoring data became available and a number of service providers have responded to the challenge of supplying information, based at least in part on spaceborne SAR, to a variety of customers under operational or pre-operational conditions. The capabilities of the instrument are not yet fully appreciated by potential customers. In addition, services provided are often reliant on research institutions where the appreciation of customer expectations and requirements can be limited.

Main Issues from Sessions 1 and 2: "Present Activities, Projects and Services"

Contributions to the above Sessions were provided by the research, governmental and private sectors.

- The Norwegian experience of integrating ERS SAR with airborne data for oil spill surveillance and detection was summarised in a joint presentation by the **Tromso Satellite Station** (service supplier) and the **Norwegian State Pollution Control Authority—SFT** (end user). Lecturers reported on the pre-operational oil spill detection service presently performed over the North Sea area covered by the Bonn Agreement. Here, the ERS SAR imagery is combined with airborne surveillance and oil spill reports from civilian aircraft in order to provide notification to the appropriate national pollution control authorities.

  In practice, once the ERS SAR acquisition reveals the probable presence of oil slicks, the aircraft patrol route operated by SFT is planned in order to verify the phenomena. Using a fast, low resolution SAR processor installed at TSS, an SAR image with a 100×100 m resolution is produced in less than 8 min. After identification, interpretation and classification of an oil slick event by trained operators, SFT is provided with the information within 2 h of the satellite overpass.
- As it was described by the **Dutch Ministry of Transport and Water Management**, an oil detection service based on the provision by TSS of satellite based information is operational in The Netherlands and integrated into the Dutch airborne surveillance system. This is targeted towards a "rig patrol" activity aimed at ensuring that oil production platforms within the Dutch sector of the North Sea comply with the OSPARCOM agreements.
- **Meteofrance** illustrated a numerical model developed to predict areas affected by drifting spills, once the spills have been located and identified. Since 1994 the model has been used by the national Prefecture Maritime for spills in territorial waters, and by international coordination bodies for spills occurring elsewhere, out of French territory.
- The use of metocean data in slick drift forecasting was presented by **MeteoMer**, France, with details on the data performance requirements to be met, if reliable predictions on areas under threat from drifting slicks are to be ensured. MeteoMer also reported on the metocean services made available to customers.
- A preliminary information exchange infrastructure was described by **ACRI**, France. It is meant to represent a further step towards operational aid tools for organisations charged with combating oil pollution in the Mediterranean region. Inspired by the need to reduce the gap between decision makers, technicians involved in the problem everyday, and researchers modelling the various processes related to tackling oil pollution, the so-called "MOPISM" (Mediterranean Oil Pollution Integrated System Management) concept was illustrated in detail. The available data sources, communication methods and eventual user access points were outlined. The study's perspective seems to derive more from a risk analysis point of view rather than from a technology driven application of SAR.
- As reported by **INDRA Espacio**, Spain, an interest has been shown by the Spanish Government in their project related to a demonstrator system for oil spill detection using ERS SAR imagery. The system should rely on the data acquired at the Station of Maspalomas, Canary Islands, which ensures the geographic coverage of the Spanish portion of the

Mediterranean, as well as the "busy" waters off Algeria. One hindrance to the development and set up of an ERS SAR based oil spill detection service is the current lack of regular surveillance of Spanish waters.

- A detailed analysis of the interaction between microwave radiation and surface slicks was presented by the Institute of Oceanography of the **National Centre for Marine Research** in Greece. Their research work aims to provide a better understanding of such an interaction. A model has been developed that predicts the SAR backscatter of an oil slick based on the following parameters:
- wind data;
- ocean current;
- rheological data associated with the oil emulsion;

  as well as on the operating parameters of the satellite sensor.
- The results of a study conducted for REMPEC (Regional Marine Pollution Emergency Response Centre) on the contribution of space remote sensing to a sea atlas were presented by **IFREMER**, France. The atlas is meant to prepare a response to accidental marine pollution in the Mediterranean. It consists of maps providing detailed information on all aspects of interest on the Mediterranean coasts and along all main tanker routes, with the objective of assisting end users in the setting up of emergency plans and organising of accidental pollution response operations accordingly.

Main Issues from Session 3: "User Perspectives"

All contributions to this Session were centred on the analysis and review of the requirements that a regular surveillance system implemented over the Mediterranean should be able to meet. As it had already been highlighted in the previous Sessions, the combined use of airborne/satellite derived information seems to offer, from the cost/benefit point of view, the optimal solution to the problem of maximising the geographic area coverage at a reduced cost and with a high probability of detecting oil slicks.

In fact, although airborne data use is encouraged for the flexibility in routing and making available adequate instrumentation onboard, the cost is such that only a small fraction of national waters can be patrolled.

- The presentation given by the **Marine Pollution Control Unit** of the United Kingdom started with a report on the experience, some weeks earlier, with the *Sea Empress* disaster. In the context of a major incident like this, where sufficient resources were mobilised, the use of satellite monitoring may seem somewhat redundant. Considerable importance is attached, instead, to the use of SAR remote sensing for routine monitoring of illegal tanker discharges, due to the fact that daily air surveillance of the entire UK territorial water surface is practically impossible (typically only 10% of the total sea area is sampled over a year). The main requirements as it regards SAR data were identified as:
  - notification of the slick (location, size estimate, etc.) within 1 h; and
  - 90% confidence that the feature detected is an illegal slick.

  In the domain of legal prosecution, one interesting aspect is that SAR imagery of an oil slick would very likely be admissible as evidence of an illegal discharge in the United Kingdom. However, the shipping companies never contest oil spillage evidence and once the case comes to court, a "guilty" plea is made and the fine is paid. It is, in any case, very hard to succeed in bringing a ship master to court, especially in case of spills generated by ships leaving United Kingdom waters.
- The operational activities of the Italian **Harbour Master–Coast Guard Corps** were the subject of a presentation focused on the monitoring and patrol scenario within which their airborne based surveillance is routinely performed. The Corps, who have also combined the use of airborne and ERS SAR information with encouraging results, relies on 12 fixed wing aircraft equipped with a variety of optical and radar instruments, including Daedalus scanners, FLIR and SLAR. Their main patrolling tasks (approximately 1500 h per year are flown over the major shipping routes) not only encompass oil spill surveillance but also fisheries control, ship traffic monitoring and search and rescue standby. A selection of the areas to be patrolled is performed according to the level of risk. The Italian authorities, as do those in most other European countries, rely also on oil slick reporting by commercial airline pilots, who are not specially trained for this job.
- It was interesting to learn about the user development experience within the **Centre for Earth Observation** at the Joint Research Centre in Ispra, Italy, for both the Earth Observation market, in general, and the oil spill detection services incorporating SAR information, in particular. The results of a user requirements analysis were presented together with some considerations on the increased use of SAR data in operational oil pollution monitoring services. The suggested "three point user approach" on which any operationalisation of Earth Observation technology should be based includes:
  - a gradual user involvement;
  - an increase of end user awareness of EO capabilities; and

- an enlargement of the international cooperation.
- As a useful complement to the Session's content, the **Earth Watching** service run by **EURIMAGE** and **ESRIN** was illustrated, with particular reference to the oil pollution case. The service starts from basic information on a disaster, collected from the press and from the Eurimage Distributors' Network consisting of 39 official distributors operating in 27 countries in Europe, North Africa and the Middle East. An ERS SAR plan of data acquisition over the area concerned is worked out immediately in order to prepare a fast data reception channel. As a result of the quick data processing, an SAR image is generated (within 5–6 h from original acquisition) and placed in whole or in part on the Internet for access via the standard World Wide Web graphical interfaces (Mosaic or Netscape). Afterwards, laser copies are sent to newspapers.

Main Issues from Session 5: "Planned Initiatives in the Mediterranean Basin"

It was felt that the Workshop should also cover issues like the degradation of the environment in and around the Basin, as well as the status of political initiatives at local, national and international scale. All four presentations composing Session 5 focused on activities currently at the development or planning stage.

- The concept of a "Clean Seas" Project was illustrated by **Satellite Observing Systems**, United Kingdom. The project aims at demonstrating, through investigations made in three test sites, the capabilities of satellite data for monitoring the marine environment. The driving force is to quantify the effectiveness of satellite data in a global monitoring programme and to establish the requirements that any eventual operational service would have to meet. It emerged that all coastal states (end users of the service) are more willing to pay for adequate surveillance intended as a form of prevention of illegal discharges, rather than for clean up operations following the discharges.
- As it was reported by **CTM**, Italy (the UNEP Remote Sensing Centre for the Mediterranean), a number of baseline studies have been conducted by the Mediterranean Action Plan. Measuring the level of pollution is one of the tasks of the regional centres set up within the framework of the MAP. This kind of monitoring activity is, however, not globally performed and it still excludes many significant areas. In addition, it is based primarily on *in situ* measurements. How suitable it would be to utilise the framework provided by the UNEP–MAP Programmes to establish, as an international cooperation effort, an operational system for oil pollution detection and monitoring was outlined.
- The status of an international cooperation project called "ENVISYS", partly financed by DG XIII of the European Union in the framework of the Telematics for the Environment Programme was illustrated by **IMPETUS Systems and Telecommunications, Greece**. Remote sensing techniques are the principal components of the project, aimed at the creation of a complete system for early detection of oil spills, monitoring of oil spill evolution and provision of support to authorities during clean up operations. It is based on demonstrators to be set up in the South Aegean Sea (Cycladic Region), the Gibraltar area and the Finisterre Region, in Spain.
- An overview on the COSMO constellation of small satellites, planned for launch around 2001, was offered by **Alenia Spazio**, Italy. The presentation focused on the system's capabilities in the oil spill detection domain. Details of various proposed system parameters, as well as on the number of satellites carrying onboard SAR instrumentation, were provided. Typical user requirements such as, among others, the revisit time were analysed.

Poster and Demonstration Sessions

A further contribution to the Workshop was the posters and demonstrations. All featured various systems forming part of an oil spill detection system presently on trial, or projects meant to provide the underlying infrastructure to enable the accurate detection of oil spills.

- The Oil Spill Detection Workstation developed by **EOS**, United Kingdom, and installed at the West Freugh Ground Facility in the United Kingdom, operates on a demonstration basis. West Freugh ensures coverage of the Western Mediterranean region up to the coast of Sicily. Oil slicks are identified by backscatter damping, shape and similar parameters. An output of the system is a table of detections against confidence.
- Analysed through ERDAS Imagine in a small, joint **ESA/ESRIN** and **EURIMAGE** project, a data set of SAR acquisitions over the southern part of the Mediterranean (Strait of Tunis) revealed the probable presence of oil spills. A surprisingly large number of oil slicks, never detected previously, were identified.
- "IDEAS", developed by **Advanced Computer Systems**, Italy, is a software package designed to allow the storage of information in databases and to provide a management tool for interactive information handling. Satellite data are organised per segment of acquisition. A segment, as it is intended for satellites like SPOT and ERS, is a continuous

strip of satellite data. IDEAS manages, for each segment, descriptive information and quick look images, in order to enable data inspection and quality assessment.

- **Space Engineering**, Italy, described a methodology for fast screening of oil slicks in SAR images. The software package provides a complete analysis of an image in about 10 min. The technique was demonstrated for oil slicks occurring off the coast of Tunisia.
- **TER**, Italy, presented a decision support tool to minimise the cost of disasters in high risk areas. The system is based on satellite images as input data, but the use of aircraft data is also envisaged as a complement.
- The "ARCOBLEU" System, a French–Italian cooperation project, was presented by **ALENIA ELSAG Sistemi Navali**, Italy. The objective is the definition of a system for the surveillance and control of chronic and accidental marine pollution. A first module of the project involves the Corse–Liguria–Provence Basin as a pilot area.

Highlights of the Round Table Discussion

The Round Table discussion was animated by invited representatives from all main categories involved in the exploitation of remote sensing information, namely:

- industry;
- value adding service companies;
- data distributors;
- end users;
- scientific/research institutions;
- international programmes; and
- decision makers;

as well as by participants in the audience. A fruitful discussion was ensured as regards the two main themes:

- identification of a mechanism suitable to ensure a more significant end users' involvement in the complex process of transfer from research to operations;
- discussion on actions needed to make sure that this happens.

Clear areas for debate were:

Characteristics of the Mediterranean environment

It was emphasised how different the environmental conditions of Northern European waters are from the Mediterranean ones. Here, in general, oil slicks last longer. Due to the lack of any flushing and the enclosed nature of the sea, one cycle of water circulation is completed in a 80 y time-frame. In the North Sea and North Atlantic areas, wave forcing and atmospheric weathering can be left to break up the majority of illegal slicks, with much greater effort placed on the action of preventing illegal dumping.

Furthermore, due to the heavy dependence of the Mediterranean on financial support from tourism, it is more important to avoid the serious, detrimental effects of drifting slicks, than to prosecute offenders for illegal discharges. In order to prevent oil beaching, very fine scale ocean current models are required for the region. Some development in this area is ongoing. However, apart from the MeteoFrance system, these models are not integrated at present into existing slick forecasting systems.

Political, legal, operational issues in combating oil spills

Attention was focused on if and how the ERS SAR could be used to reduce the time needed to implement a clean-up action following an oil spill event. It was noticed that, whilst accidental slicks are usually reported in sufficient time to allow for implementation of counter-measures, deliberate pollution events have very short timescales. As an example, in The Netherlands, an airborne system has to report on slicks within 30 min to enable authorities to catch a deliberate discharge as it is in progress. (To be noted: a discharge operation requires approximately 45 min.) In Norway, prosecution, although recognised as an effective means of enforcement of pollution agreements, is not commonly undertaken. Instead, a continual dialogue is encouraged between the Pollution Control Authorities, the shipping companies and the oil operators.

Improved ship traffic control is also an issue within the Mediterranean region, as it allows an easier identification of ships undertaking illegal dumping activities, and reduces the threat of collision (one of the principal sources of oil spill). A major step in this direction seems to be represented by a recent EU directive on obligations by ships in navigation within territorial waters to report their positions and destinations.

The importance of regional activities within the Basin, to maintain all countries' interest in the common issue of environmental protection, and related actions, was recognised.

Legal aspects of dumping were discussed, with particular reference to:

- lack of reports on illegal tank cleaning activities and consequent high degree of stress on the environment;
- the opportunity to ensure that use of satellite information be part of a global implementation policy for conventions preventing dumping;

- need of awareness by ship masters of the possibility of being prosecuted;
- identification of an adequate surveillance system as a prerequisite;
- best efforts of individual countries in monitoring activities within their own territorial waters, in order to create the conditions for legislation to enter into force at regional scale.

The increasing role of port state control units currently involved in operational monitoring was emphasised in relation to prevention of illegal discharges that are likely to require considerable surveillance data information. In connection with such a requirement, the issue of a standardisation of both procedures and end products is fundamental.

Regarding major accidental spills, it was agreed that the satellite data information has a minor role during the event, when it is possible to mobilise considerable airborne and *in situ* monitoring resources, whereas it proves to be helpful with smaller, illegal spills. Here, spill statistics can be usefully generated in a routine manner. In addition, a major application potential was felt to be in sensitivity mapping of particular areas to oil spill events.

End user aspects

There was a general agreement that the service evolves in response to demands for its availability from the end user community. The latter appears not to be convinced yet of the cost effectiveness of satellite monitoring as compared with airborne monitoring.

It was recognised again that the transition from data provision to operational end user application has still to be achieved. Among other reasons, this might be due to the lack of integrated management systems to deal with the various sources of data available. To avoid major investments, the maximum use should be made, whenever possible, of already existing resources, in order to improve the performance of monitoring systems.

Further steps should be taken to overcome the reluctance to use satellite data rather than traditional information sources. In this connection, JRC emphasised the availability of EU financial support within the area of application development for EO data.

Suitability of ERS SAR for oil slick detection. Two main aspects were considered:

- level of confidence that an oil slick can be detected by SAR;
- level of confidence that a slick event observed in an SAR image corresponds to an actual slick on the sea surface (false alarm?).

As seen from the experience of Tromso Satellite Station, the high radiometric quality of the low resolution (100 m) image product is adequate to ensure slick detection in the windspeed range of 3–12 ms^{-1}. The probability of false alarms was recognised as being sufficiently low. TSS's experience has shown that the users' requirement, to be guaranteed at almost 100% that a slick feature in an SAR image is an actual illegal discharge, was met.

A calibration/validation campaign over the Mediterranean was suggested, as an equivalent to the one carried out extensively in Norway.

Regarding the use of SAR during the *Sea Empress* disaster, it emerged that slick features were hard to identify: large areas of wind sheltering gave rise to slick-like structures within the images and suppressed the signatures of actual slick events. SAR does not currently provide quantitative data apart from wavelength and propagation direction of surface waves. A substantial increase in the amount of available information on the sea surface is expected from the Envisat payload (especially from ASAR and MERIS instrumentations).

Operational services for coastal protection and pollution control authorities. Although the ERS mission had not be conceived to meet operational requirements, the Norwegian experience has proved that a pre-operational service can be implemented with satisfactory results.

In answer to the users' need for more frequent revisiting cycles, it was pointed out that the target could be reached more easily at present, with the contemporary presence of two radar missions (ERS and RADARSAT). Also, the opportunity offered by ERS Tandem should not be forgotten.

Regarding delivery times, the three days taken from data acquisition at Fucino Ground Station to delivery by ESRIN/EURIMAGE are inadequate. Near-real time (1 h) is required. Fast SAR processor systems would be needed at the Station.

Continuity of satellite missions was identified as a prerequisite. As to airborne surveillance systems, it must be remembered that, most of the time, these are in part dependent on information collected by the national air forces, i.e. a source likely to become unreliable in times of crisis.

As a message to service providers and users, the forthcoming Envisat mission opportunity was mentioned. The Advanced SAR platform will make available a medium resolution (75 m) image over a 400 km swath, representing approximately 50–60 MB of data. With very little additional investments, products and services could be tuned to follow user needs better, provided that the users/service providers take prompt action in this direction.

Conclusions

In terms of international cooperation, it is evident that the level of diversity between Mediterranean States is currently hampering any efforts to implement a cooperative monitoring system. There is a strong need for an integrated management plan to optimally utilise data from all available sources within a protection plan. A standardisation of the procedures applied by the pollution control authorities, as well as of the information output derived from their activities would be recommended.

Considering the fragile environment of the Mediterranean, it seems that protective actions are of top priority, if compared with actions undertaken to prosecute polluters.

The SAR technology, as a complement to airborne surveillance, is mature for an operational service provision. The role of the value adding industry is to produce information suitable to meet end user requirements, by combining data from different platforms collected at short revisiting time intervals.

Notification of a slick event is required by users according to terms of reference such as:

- delivery within 1–2 h;
- daily coverage of priority waters;
- better than 90% confidence in validity of information on detected slicks.

A notification of an event, containing useful information like: estimate of extent and thickness, exact position, likely source, oil type and, in addition, accurate metocean data in order to be able to forecast the evolution of a slick, is what users really want.

It appears that, in the absence of a service capable of meeting precise requirements such as those above in order to properly exploit a reasonably new data source like SAR, it is hard to talk of an operational monitoring service based on satellite information.

Detecting major disasters is one of the main applications, but routine monitoring of national waters to detect smaller illegal discharges is also important.

Optimisation of airborne patrol routes, prompt reporting, and fast processor SAR data release within 1–3 h from satellite overpass enabling identification of potential slicks should constitute the basis on which to build an operational service for the Mediterranean. Within such a system, it is felt that commercial airline pilot reports would still remain an important source of information.

Finally, considering that the migration towards operational exploitation of ERS data was one of the major driving forces to organise the Workshop, it has to be said that, in spite of the different ecosystem, there are no factors preventing the Mediterranean region from benefiting from an application of the techniques developed in Northern Europe to detect oil slicks.

Table 1 List of participants

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CONFERENCES & MEETINGS

CALENDAR

This section provides an overview of meeting activities in the area of spill science and technology. We have modified our procedure to list both past and upcoming conferences, symposia, workshops, and other meetings to allow our readers to be informed of the conference and to obtain a copy of the proceedings if they were unable to attend. The list includes meetings which promise to be important to the readership of *Spill Science & Technology Bulletin*, that is appearing to deal with the subject matter of the journal in some depth. Some of the meetings might focus entirely on oil and chemical spill science and technology, while others might have only a portion of their program dedicated to this topic. The readers are urged to use the contacts provided to obtain additional information.

New Date TBS
Sea to Sea: Regional Conference on Sustainable Use of the Marine Environment, Baharain.
Contact: Dr David Olsen, ROPME, P.O. Box 1358, Jeddah 21431, Sauda Arabia. Tel: 966 2 651 9868.

13–15 June 1995
17th Canadian Symposium on Remote Sensing—Radar Remote Sensing: A Tool for Real-Time Monitoring and GIS Integration, Sheraton Cavalier Hotel, Saskatoon, Canada.
Contact: Jeff Whiting, Tel: (306) 933 5423; Fax: (306) 933 7817.

25–28 June 1995
SETAC-EUROPE '1995: Environmental Science and Vulnerable Ecosystems, Copenhagan, Denmark.
Contact: Dis Congress Service Copenhagan A/S, Herlev Ringvej 2 C, DK-2730 Herlev, Denmark. Tel: +45 4492; Fax: +45 4492 5050.

22–25 August 1995
Environment Northern Seas, 3rd International Conference and Exhibition, Stavanger, Norway.
Contact: The ENS Foundation, Secretariat, P.O. Box 410, N-4001, Stavanger, Norway. Tel: +47 51 87 00 50; Fax: +47 51 55 05 25. Proceedings available on the WWW.

18–20 September 1995
Third Thematic Conference on Remote Sensing for Marine and Coastal Environments, Seattle, Washington, U.S.A.
Contact: ERIM/Marine Environment Conference, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org; WWW URL: http://www.erim.org/
For proceedings, contact: The Marine Technology Society, Washington DC, U.S.A.

17–22 September 1995
World Environmental Congress, London, Ontario, Canada.
Contact: Congress Group Science & Technology Integration Inc., U. W. O. Research Park, 100 Collip Circle, Suite 110, London, Ontario, N6G 4X8 Canada. Tel: +1 519 858 5055; Fax: +1 519 858 5056.

24–29 September 1995
MARIENV '95 International Conference on Technologies for Marine Environment Preservation, Tokyo, Japan.
For proceedings, contact: Secretariat, MARIENV '95, c/o Congress Corporation, 7th Akiyama Building, 6F, 5-3 Kojimachi, Chiyoda-ku, Tokyo 102, Japan. Tel: +81 3 3263 4039; Fax: +81 3 3263 4032.

27–30 October 1995
First International Conference on Marine Simulation—Towards Safer Seas and Cleaner Oceans.
For proceedings, contact: Captain M. Farghaly, Secretary General of the Conference, P.O. Box 1029, Alexandria, Egypt. Tel: 203 560 2748/560 4064; Fax: 203 560 2144.

27–29 February 1996
Applied Geologic Remote Sensing: Practical Solutions for Real World Problems, Las Vegas, Nevada, U.S.A.
For proceedings, contact: ERIM/Geologic Conference, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: 00 1 313 994 1200 ext 3234; Fax: 00 1 313 994 5123; E-mail: rrogers@erim.org and/or raeder@erim.org. Proceedings U.S.$125.00 each.

14–18 April 1996
Sixth Symposium on Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment, Orlando, FL, U.S.A.
For proceedings, contact: American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA, U.S.A., Tel: +1 215 299 5400.

26–31 May 1996
International Society of Offshore and Polar Engineers (ISOPE).
Contact: Tel: +1 303 273 3673.

16–20 June 1996
Offshore Mechanics and Arctic Engineering, Italy.
Contact: Tel: 00 39 212 705 7788. The 1997 meeting will be in Japan, April 13–17.

17–22 June 1996
PACON '96 Meeting, Honolulu, HI.
Contact: Tel: +1 808 956 6163; Fax: +1 808 956 2580.

24–27 June 1996
2nd International Airborne Remote Sensing Conference & Exhibition.
For proceedings, contact: ERIM, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org.; WWW URL: http://www.erim.org/CONF/conf.html.

14–17 July 1996
Coastal Society 15th International Conference, Seattle, WA, U.S.A.
Contact: Tel: +1 206 685 1108.

12–17 August 1996
Coastal Zone Canada, Quebec, Canada.
Contact: Tel: +1 418 724 1483.

2–6 September 1996
International Coastal Engineering Conference, Orlando, FL, U.S.A.
Contact: Tel: +1 409 485 4514. The 1997 Conference will be in Dallas, Texas, November 2–7.

6–9 September 1996
Contaminated Land and Groundwater—Future Directions, Portsmouth, U.K.
Contact: Nick Walton, The Engineering and Hydrogeology Groups of the Geological Society, Tel: 00 44 1705 842263.

9–12 September 1996
Emerging Technologies in Hazardous Waste Management VIII, Birmingham, AL, U.S.A.
Contact: The Industrial and Engineering Division of the American Chemical Society, Tel: +1 404 365 2447.

9–12 September 1996
Petroleum Tankership Operations: A Course for Shoreside Personnel, Houston, TX, U.S.A.
Contact: Tel: 1 212 435 4044.

9–12 September 1996
Spillcon '96 6th International Oil Spill Conference, Melbourne, Victoria Australia. For information on obtaining the proceedings contact the Australian Institute of Petroleum Information Service, 500 Collins Street, Melbourne, Victoria 3000, Australia, Tel: +61 3 9614 1466; Fax: +61 3 9614 1127.

10–13 September 1996
Third International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe (Warsaw '96), Warsaw, Poland.
Contact: Tel: +904 644 5524; Fax: +904 574 6704; E mail: warsaw96@mailer.fsu.edu.

23–26 September 1996
Oceans '96 MTS/IEEE, Ft. Lauderdale, FL, U.S.A.
Contact: Tel: +1 8000 810 4333. The 1997 Conference will be in Halifax, NS, October 6–9.

6–9 October 1996
Society of Petroleum Engineers Annual Meeting, Denver, CO, U.S.A.
Contact: Tel: +1 214 952 9393. The 1997 Meeting will be in San Antonio, TX, October 5–8.

7–10 October 1996
Canadian Waste Management Conference, Pittsburgh, PA, U.S.A.
Contact: Jennifer Adams, Environment Canada, Tel: +1 613 723 3525; Fax: +1 613 723 0060.

8–11 October 1996
Prevention is the Key: A Symposium on Oil Spill Prevention and Readiness, Valdez, Alaska, U.S.A.
For proceedings ($40.00 each), contact: Prince William Sound Community College Business Office, P.O. Box 97, Valdez, AK 99686, U.S.A., Tel: +1 907 835 2943; Fax: +1 907 835 2369; E-mail: vnpt@uaa.alaska.edu.

8–12 October
Pollution & Environment Technology Indonesia 96 and Water Tech Indonesia 96, Jakarta, Indonesia.
Contact: Eileen M. Lavine, The Regional Institute of Environment Technology/U.S.–Asia Environmental Partnership, Tel: +1 301 656 2942; Fax: +1 301 656 3179.

29–30 October 1996
Clean Gulf 96 Conference & Exhibition, Galveston, TX, U.S.A.
Contact: Clean Gulf 96, 3050 Post Oak Blvd., Suite 205, Houston, TX 77056-6524, U.S.A., Tel: +1 713 621 8833; Fax: +1 713 963 6291 or c/o Texas General Lands Office, P.O. Box 12845, Austin, TX 78711-2845, U.S.A.

4–7 November 1996
Eco-Informa '96: Global Networks for Environmental Information: Bridging the Gap Between Knowledge and Application, Lake Buena Vista, FL, U.S.A.
For proceedings, contact: ERIM, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org.; WWW URL: http://www.erim.org/CONF/conf.html.

10–15 November 1996
American Institute of Chemical Engineers Annual Meeting, Chicago, IL, U.S.A.
Contact: Tel: +1 212 705 7322.

16–17 January 1997
Symposium on Streamlining Analysis of Water and Waterborne Oils, New Orleans, LA, U.S.A.
Contact: American Society of Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA, U.S.A., Tel: +1 215 299 5400. Symposium Chair, M.S. Hendrick, U.S.C.G., Avery Point, Central Oil Identification Laboratory, Groton, CT 06340-6096, U.S.A., Tel: +1 203 441 2784; Fax: +1 203 441 2641; E-mail: m.hendrick/coil@cgsmtp.comdt.uscg.mil.

17–19 March 1997
Fourth International Conference—Remote Sensing for Marine and Coastal Environments, Orlando, FL, U.S.A.
Contact: ERIM, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org.; WWW URL: http://www.erim.org/CONF/conf.html.

7–10 April 1997
1997 International Oil Spill Conference, Fort Lauderdale, FL, U.S.A.
For conference information, contact: Oil Spill Conference, Suite 300, 655-15th Street, N.W., Washington DC 20005, U.S.A., Tel: +1 202 639 4202; Fax: +1 202 347 6109.
For program information, contact: CDR Mark Johnson, U.S.C.G. Tel: +1 202 267 6860; Fax: +1 202 267 4065. Proceedings (including 1991, 1993, 1995) are available from API Publications Office, American Petroleum Institute, 1220 L Street, N.W., Washington DC 20005, U.S.A., Tel: +1 202 682 8375; Fax: +1 202 962 4776.

28 April–1 May 1997
***In-situ* and on-site Bioremediation: The Fourth International Symposium,** New Orleans, Louisiana, U.S.A. Sponsor: Battelle.
Contact: The conference Group, 1989 West Fifth Avenue, Suite 5, Columbus OH 43212-1912, U.S.A. Tel: +1 614 424 5461; Fax: +1 614 488 5747; E-mail: 102632.3100@compuserve.com.

7–10 July 1997
Third International Airborne Remote Sensing Conference and Exhibition: Development, Integration, Applications & Operations—The Bridge Between Science and Applications, Copenhagen, Denmark.
Contact: ERIM/Airborne Conference, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org.; WWW URL: http://www.erim.org/CONF/conf.html. Proceedings available for first two conferences at U.S.$135.00 each.

3–8 August 1997
With Rivers to the Sea, Interaction of Land Activities, Fresh Water and Enclosed Coastal Seas. 7th Stockholm Water Symposium, 3rd EMECS-Conference, Stockholm, Sweden.
Contact: Stockholm Water Symposium/EMECS Conference 1997, S-106 36 Stockholm, Sweden, Tel: +46 8 736 20 21; Fax: +46 8 736 20 22; E-mail: sympos@sthwat.se.

17–19 November 1997
Twelfth International Conference and Workshops—Applied Geologic Remote Sensing, Denver, Colorado, U.S.A.
Contact: ERIM/Geologic Conference, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A., Tel: +1 313 994 1200; Fax: +1 313 994 5123; E-mail: wallman@erim.org.

Spill Science & Technology Bulletin

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A 200–300 word overview report of a specific technology that promises or realizes a breakthrough, or increases knowledge or understanding about spill effects or impacts of a countermeasure. Company logos will not be included, however, for further information, the name and address of the appropriate contact will be listed.

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Book: Bryan, G. W. (1976). Heavy metal contamination in the sea. In *Marine Pollution* ed. R. Johnston, pp. 185–302. Academic Press, London.

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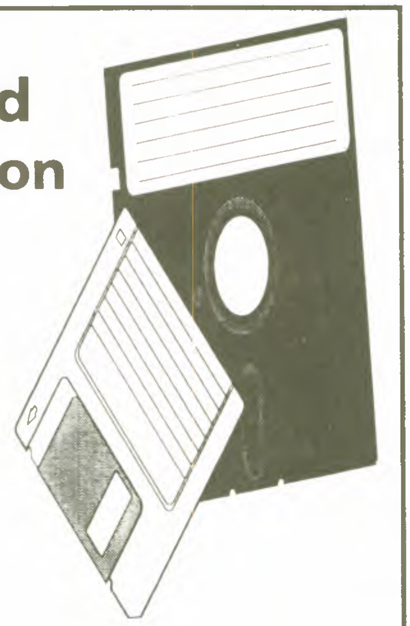

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