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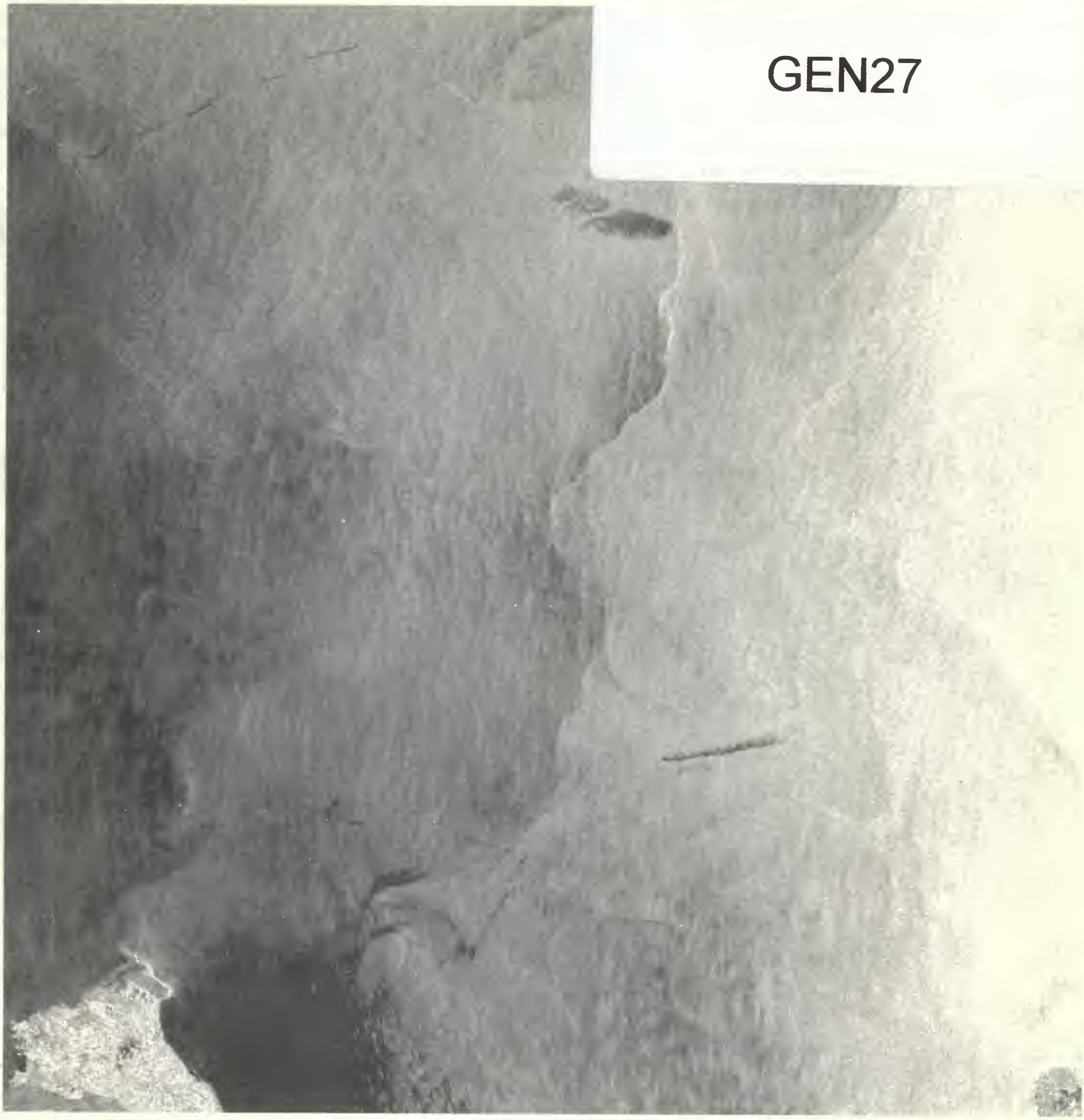

ERS THEMATIC WORKSHOP

Oil Pollution Monitoring in the Mediterranean

25-26 March, 1996
ESRIN, Frascati, Italy

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Printed at ESRIN
April 1996

ERS ***THEMATIC WORKSHOP***

Oil Pollution Monitoring in the Mediterranean

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Final Programme

Day 2

26th March 1996

NOTE: Ten minutes have been allocated for Questions after each presentation.

08.30 - 10.00 ***SESSION 3: User Perspectives*** *- Continuation of Day 1 -*
Chairman: L. Marelli,
Head of Department of Remote Sensing Exploitation, ESRIN

08.30 - 08.50 *Marine Applications of SAR : The UK perspective, with particular reference to user requirements - D. Bedborough, Marine Pollution Control Unit, UK*

09.00 - 09.20 *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 - R.Patruno & M.Mancini, Comando Generale Capitanerie di Porto, Centrale Operativa,Italy*

09.30 - 09.50 *Oil Spills Survey at Sea : What means are currently used and what can we expect from satellites? - L.Kerambrun, Centre de Documentation de Recherche et d'Experimentations des Eaux (CEDRE), France*

10.00 - 10.30 ***SESSION 4: POSTERS Introduction by Authors***
Fast SAR Image screening for oil slick detection - M.Melis & L. Piazzo, Space Engineering S.p.A., Rome, Italy.
Permanent Control of the Marine Environment in the Central Mediterranean Sea - A.L.Geraci, University of Catania, Italy.
ARCOBLEU : A system to monitor chronic and accidental pollution in the Mediterranean - F.Musso, ALENIA ELSAG Sistemi Navali, Genova, Italy.
A regional application of information from ERS SAR data: Occurrences of oil spills along the Mediterranean Coastal Zone - P.Pavlakis, National Centre for Marine Research, Athens, Greece
A support decision system to minimize disaster cost in high risk areas - R. Mura, TER, Rome, Italy

10.30 - 11.30 ***Poster Display and Coffee***

11.30 - 13.00 ***SESSION 5: Planned initatives in the Mediterranean Basin***
Chairman: L. Marelli

11.30 - 11.50 *The Mediterranean Action Plan initiative for the protection of the Mediterranean Sea from oil pollution - M. Raimondi, Centro di Telerilevamento Mediterraneo, Palermo, Italy*

12.00 - 12.20 *Towards an Operational Hazard Warning System in the Mediterranean - G.W. Jolly, Satellite Observing Systems, U.K.*

12.30 - 12.50 *ENVISYS: Environmental monitoring warning and emergency management System - N. Theophilopoulos, IMPETUS Systems & Telecommunications, Greece*

13.00 - 14.00 ***Lunch***

14.00 - 14.30 *Continuation of **SESSION 5.***

14.00 - 14.20 *Small SAR Satellite Constellations for Tracking Oil Spills - G.Perrotta & P.Xefteris, Alenia Spazio, Italy*

14.30 - 16.00 ***OPEN DISCUSSION:*** *Audience and invited participants*
Chairman: L. Marelli

16.00 ***Conclusions*** *and closure of the Meeting*

Day 1

25th March 1996

NOTE: Ten minutes have been allocated for Questions after each presentation.

09.00 - 09.30 **Registration**
At the Registration Desk near the Main Conference Room, Bldg. 1.

09.30 - 09.45 *Welcome address - A brief overview of ESA Earth Observation Programmes and their application - G. Duchossois, Head of Mission Management Office, ESA Headquarters, Paris*

09.45 - 10.00 *The involvement of ESRIN in Remote Sensing Data Applications - Background and objectives of the Workshop - G. Calabresi, Remote Sensing Data Utilization, ESRIN, Frascati*

Chairman of Sessions 1, 2 and 3: G. Duchossois

10.00 - 13.00 **SESSION 1: Present activities, projects & services**

10.00 - 10.20 *Towards an Operational Early Warning Detection Service in the Mediterranean: The Norwegian pre-operational experience of oil spill detection using ERS SAR data - J.Pedersen, Tromso Satellite Station, Norway, in collaboration with the Norwegian Space Centre, the Norwegian Defence Research Establishment and the Norwegian Pollution Control Authority*

10.30 - 10.50 *Pollution monitoring in the North Sea by air and spaceborne systems - H.Konings, Ministry of Transport, Public Works & Water Management, The Netherlands*

11.00 -11.30 **Coffee**

11.30 - 11.50 *Operational forecast of oil spill drift at Meteofrance - P.Daniel, Meteofrance, France*

12.00 - 12.20 *Metocean Input data for drift models application: The ''Loustic'' Case - P.Michon, Meteomer, France*

12.30 - 12.50 *Toward a decision aid tool for the problem of oil pollution in the Mediterranean - P.Bardey, ACRI, Sophia Antipolis, France*

13.00 - 14.00 **Lunch at ESRIN**

14.00 - 16.35 **SESSION 2: Continuation of Session 1**

14.00 - 14.20 *An Oil Spill Monitoring System for the Spanish Coast Based on SAR Images - A.Martinez, INDRA Espacio, Spain*

14.30 - 14.50 *ERS SAR for Oil Spill Monitoring : A regional application in the Mediterranean coastal zone - P.Pavlakis, Hellenic National Centre for Marine Research, Greece in collaboration with Commission of European Union, Institute of Remote Sensing Applications, Joint Research Centre, Ispra, Varese, Italy*

15.00 - 15.20 *The contribution of spaceborne remote sensing to an Atlas for preparedness and response to accidental marine pollution - F. Cauneau, Ecole des Mines de Paris, Sophia Antipolis, France*

15.30 - 15.45 **Coffee**

15.45 - 16.35 **SESSION 3: User Perspectives**

15.45 - 16.05 *Centre for Earth Observation (CEO) - Proof of Concept Study on Oil Spill Detection Services : User Requirements and Feedbacks - Carlo Lavalle, Joint Research Centre (JRC), Ispra, Varese, Italy*

16.15 - 16.35 *EARTHWATCHING from Eurimage: The Oil Pollution case - R. Biasutti, Eurimage*

16.35 - 18.15 **DEMONSTRATIONS**

16.35 - 17.15 *Introduction to Demonstrations by: J. Lichtenegger (Remote Sensing Data Utilization, ESRIN), R.Medri (Advanced Computer Systems, Italy), I. Jory (Earth Observation Sciences, U.K.), J.Pedersen (Tromso, Satellite Station, Norway)*

17.15 - 18.15 **Demonstrations**

18.30 **Cocktail at ESRIN**

19.15 **Courtesy bus to hotel**

REMARK

Please find below titles of papers/posters included in the Programme but not presented at the Workshop. Due to last minute commitments, lecturers could neither attend the Workshop nor provide written contributions.

DAY 2 - Session 3

"OIL SPILLS SURVEYS AT SEA : WHAT MEANS ARE CURRENTLY USED AND WHAT CAN WE EXPECT FROM SATELLITES ?

L. KERAMBRUN, CeDRE - France

DAY 2 - Session 4 - POSTERS

"PERMANENT CONTROL OF THE MARINE ENVIRONMENT IN THE CENTRAL MEDITERRANEAN SEA"

A.L. GERACI, University of Catania - Italy

INTRODUCTION

This is the second in the series of ERS Thematic Workshops organised by ESRIN, the ESA Establishment in Italy. The First Thematic Workshop "Flood Monitoring" was held in June 1995 at ESRIN. A full scale report on the main issues is included in the ESA Earth Observation Quarterly Bulletin No. 49.

BACKGROUND OF THE ERS THEMATIC WORKSHOP ON OIL POLLUTION MONITORING IN THE MEDITERRANEAN

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.

As well as 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 and other anthropogenic activities.

The reduction and elimination of such pollution is at the core of numerous international and regional agreements, the monitoring and implementation of which is the means to their success.

Today most oil pollution monitoring in the Mediterranean is carried out using aircraft and ship based sensors (cameras, radiometers etc), the coverage of which is normally limited by the availability and cost of operating such surveillance platforms in a monitoring role. In comparison the use of satellite data has long been recognised, as in many monitoring activities, as a source of regular extensive data coverage.

SATELLITE RADAR TECHNOLOGY FOR OIL POLLUTION MONITORING

In recent years there have been many new developments in the field of SAR (Synthetic Aperture Radar) image analysis, also taking advantage of the uninterrupted availability from 1991 onwards of the data collected from ERS-1 - the European Remote Sensing Satellite of ESA.

The data flow continuity is now ensured by the existence of ERS-2, the last born in the ERS family, launched on April 21st, 1995 and of RADARSAT, launched on November 4, 1995.

ERS radar data in particular have been recognised as a valuable source of information for oil slick and spill identification. In Norway the Pollution Control Authority (SFT) is one of the many organisations using this data within a pre-operational service. The main goal of the service is to provide the end users (Marine Spill Response Corporation, oil companies and Pollution Control Authorities) with reliable information on possible oil spills within 2 hours of a satellite overpass.

Similar services can be foreseen within the scope of the Mediterranean, and it is the purpose of this Workshop to discuss and review such opportunities.

AIMS OF THE WORKSHOP

The aim of the ERS Thematic Workshop is to bring together Parties interested in the monitoring of oil pollution using remote sensing techniques. It is hoped that not only those able to produce the information, but also those who utilise it will benefit from attending.

The audience is made up from those representing the "Providers" of remote sensing information, the "Users" and the Parties interested in improving or expanding their sources of information to meet the requirements of pollution monitoring. The organisers hope that the participants will contribute actively to the open discussions.

The Workshop focuses mostly on the use of remote sensing information, rather than on image processing techniques and technicalities in general.

WORKSHOP'S CONTENT

Sessions foresee specific topics for the lecturers to report on, such as:

- The problem of oil pollution
- Oil spill Detection using Remote Sensing
- Experience of Pre-Operational Services
- The environmental impact
- Operational Data Provision
- Review of Costs and Benefits

More in Detail, the Workshop sees the participation, as lecturers, of two main categories, i.e.:

1. **"PROVIDERS" of remote sensing information for oil pollution monitoring.**

   Presentations by those with direct experience, operational or research based, in the monitoring of oil pollution using satellite data. Topics include:

   - potential for an operational service in the Mediterranean,
   - past experience and results,
   - illustrations of project / study / practical case studies, with reference to monitoring using remote sensing data (primarily ERS).
   - reports of cost / benefit analysis carried out on the use of satellite data.

The aim is to address the delivery, use and benefits of the information provided by remote sensing, including the utilisation of complementary data sets when required.

2. **"USERS" of remote sensing information in oil pollution monitoring.**

   Presentations by representatives from value adding companies, government bodies (including coastguard and regional authorities), commercial companies and environmental organisations etc. Topics include:

   - experience in the use of satellite (primarily ERS) remote sensing information applied to oil pollution monitoring.

- user requirements for sensor performance, data access and delivery, legal issues etc.

- reports of cost / benefit analysis carried out on the use of satellite data.

Presentations come not only from the "users" already involved in the use of remote sensing data, but also from the "users" identified as people expert in pollution surveillance and control.

PROCEEDINGS

This collection includes all presentations received in time. Abstracts are included whenever presentations were not made available within the deadline. For cases where both full presentation text or abstract text are lacking we have produced a "pocket" at the end of this volume to host late contributions.

LANGUAGE

The Workshop is held in English. No simultaneous translation is foreseen.

CONTACT POINTS FOR FURTHER INFORMATION

For any information on Remote Sensing Data Applications you may contact:

The Remote Sensing Data Utilisation Section
ESA/ESRIN
Via Galileo Galilei
00044 Roma
Italy

Telephone: +39 6 941 80 626 or 625
Fax: +39 6 941 80 622

For additional copies of the proceedings related to both Flood Monitoring and Oil Pollution Monitoring Workshops please contact:

The ERS Help Desk
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Via Galileo Galilei
00044 Roma
Italy

Telephone: +39 6 941 80 666
Fax: +39 6 941 80 652

DAY 1

SESSIONS 1, 2, 3

- Contributions
  (in order of presentation)
- Demonstrations

Towards an operational oil spill detection service in the Mediterranean ?
The Norwegian experience: A pre-operational early warning detection service using ERS SAR data

J.P. Pedersen[1], L.G. Seljelv[1], T. Bauna[1], G. D. Strøm[2], O.A. Follum[3], J.H. Andersen[3], T. Wahl[4], Å. Skøelv[4]

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[2] Norwegian Space Centre, P.o. Box 85 Smestad, N-0309 Oslo, Norway, Tel: (47) 22 52 38 00, Fax: (47) 22 52 23 97
[3] Norwegian Pollution Control Authority, P.o. Box 125, N-3191 Horten, Norway, Tel: (47) 33 04 41 61, Fax: (47) 33 04 42 57
[4] Norwegian Defense Research Establishment, P.o.Box 25, N-2007 Kjeller, Norway, Tel: (47) 63 80 70 00, Fax: (47) 63 80 72 12

Towards an operational oil spill detection service in the Mediterranean ? The Norwegian experience: A pre-operational early warning detection service using ERS SAR data

J.P. Pedersen[1], L.G. Seljelv[1], T. Bauna[1], G. D. Strøm[2], O.A. Follum[3], J.H. Andersen[3], T. Wahl[4], Å. Skøelv[4]

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[2] *Norwegian Space Centre, P.o. Box 85 Smestad, N-0309 Oslo, Norway, Tel: (47) 22 52 38 00, Fax: (47) 22 52 23 97*
[3] *Norwegian Pollution Control Authority, P.o. Box 125, N-3191 Horten, Norway, Tel: (47) 33 04 41 61, Fax: (47) 33 04 42 57*
[4] *Norwegian Defense Research Establishment, P.o.Box 25, N-2007 Kjeller, Norway, Tel: (47) 63 80 70 00, Fax: (47) 63 80 72 12*

Abstracts

A project for utilisation 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 program. 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-benfit analysis based upon Norwegian user requirements has documented the satellite based service cost-effectiveness compared to aircraft surveillance. Finally, activities towards utilisation of data from the future radar satellites have also been initiated.

Introduction

Since the mid 80's 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 one hour after 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 has later achieved the status of an ESA Pilot project. The project has been funded by international sources, it has been performed under the responsibility of a steering committee chaired by NSC. It is important to recognise that the end user represented by the Norwegian Pollution Control Authority (SFT) has participated in the project even from the beginning. The phased development model and the results from the project have been widely published, and have found large interests outside the project [1, 2, 4, 5, 6, 7].

Service Development Phases

The project development from the start in 1990 has consisted the following phases:

<u>Phase 0: 1990-91.</u>
Responsible institution: OCEANOR a.s.
Activities: Literature survey, ERS-1 prelaunch preparations, planning of field experiment.

<u>Phase 1: 1991</u>
Responsible institution: OCEANOR a.s.
Participating institutions: SFT, NDRE, Esso, Statoil
Activities: A dedicated oil spill experiment at Haltenbanken in August 1991, where 3x20 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.

<u>Phase 1B: 1992-93</u>
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 sought verified by SFT by use of the surveillance aircraft. Experiment on automatic image analysis and feature extraction were performed. The operationalisation 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 detection capability dependence upon the wind conditions and the sea state (calm days) were demonstrated.
SFT formally requests 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 details. 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 observed possible oil spills are notified about to the national pollution control authorities.
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 has been performed.

Figure 1: Pre-operational service area.

Detection capabilities

The extensive use of ERS-1 and ERS-2 SAR low (i.e. 100 meter) 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 and thick emulsions at higher speeds of 10 m/s [2, 7].

Other pollutant examples detected during the project include: crude oil forming emulsions, run-off water from acid-pitch depository on land, drilling fluid from off-shore 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 [7]:
- 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 sea water 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 the fast SAR processor (CESAR) capable to generate a 100x100 km SAR image within 6-8 minutes, 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 to analyse and transfer image data to the end users within one hour after data acquisition.

Automatic detection of potential oil spills was at an early phase considered to be mandatory for the service. Algorithm for this purpose has been developed and verified during the project [7, 8]. Experiences have, however, 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 has been through an extensive training period, and they are now responsible for the service operations. On the 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 include implementation of a new service information distribution and presentation tool, SARA. SARA is based on PC and e-mail technology, and has been 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.

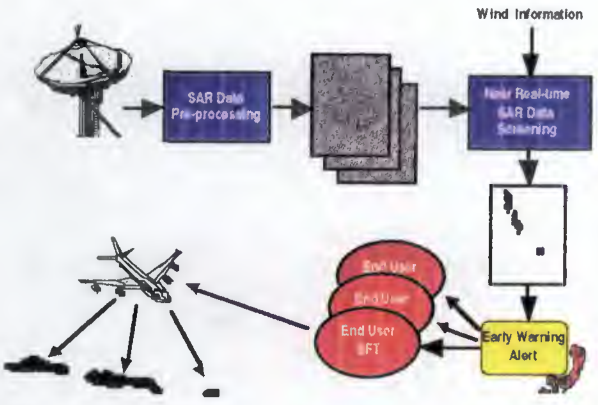

Figure 2: National Oil Spill Detection Service Infrastructure Concept.

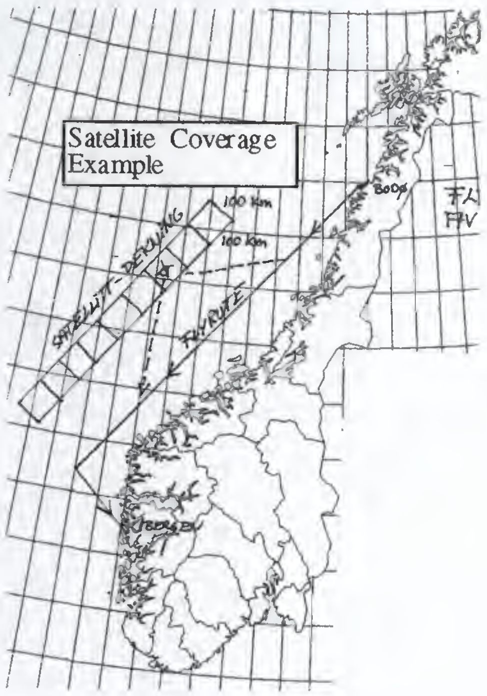

Figure 3: Illustration of the coordination of aircraft operations according to satellite coverage.

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 monitoring areas have 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 (Figure 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.

Assessment of ERS data has already been implemented in the national system for oil and chemical pollution reporting in Norway (Figure 2). The SFT surveillance aircraft operations are co-ordinated according to the ERS overpasses, and the data analysis at TSS is co-ordinated according to the flight plan (Figure 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. Figure 4 and 5 show two examples of ERS-1 SAR images containing confirmed oil spills off the coast of Norway.

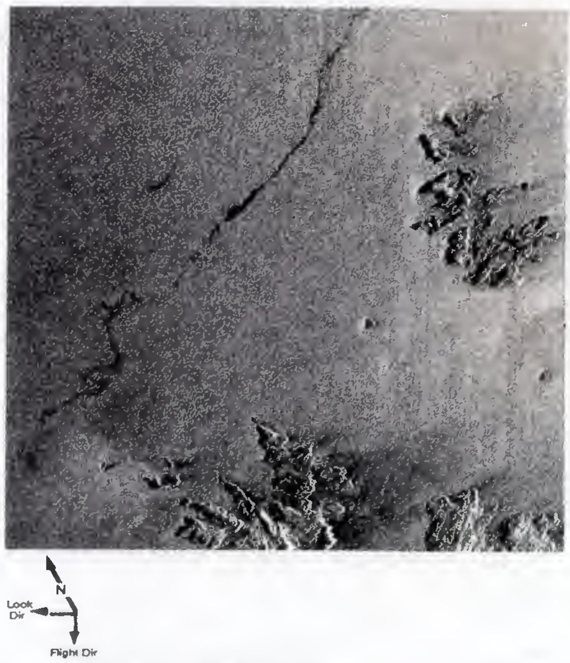

Figure 4: ERS-1 SAR image of a confirmed oil spill off the cost of Finnmark, Norway. Image size approx. 70 x 50 km.

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.

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 has analysed all availbale ERS SAR data, and the users have been informed about possible oil spills in their national waters. In return TSS has received the user requirements and the feedback on the current service performances.

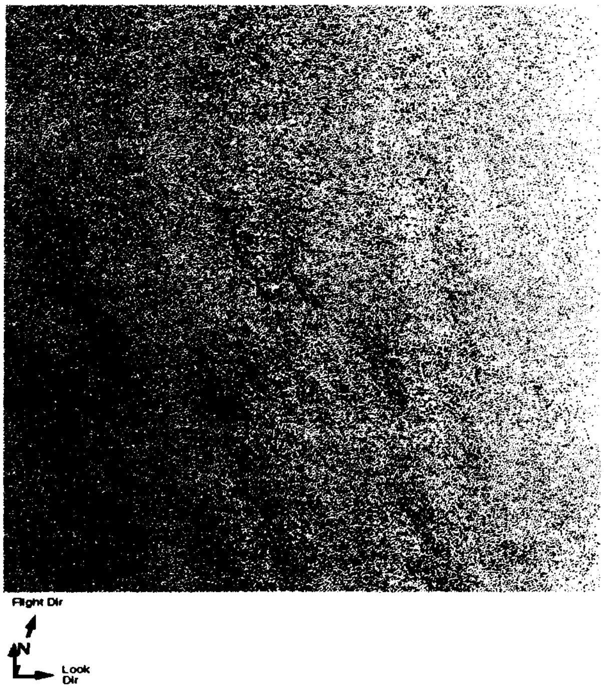

Figure 5: ERS-1 SAR image dated 94-11-25 of a confirmed oil spill from an off-shore oil rig in the North Sea. Image size approx. 70 x 50 km.

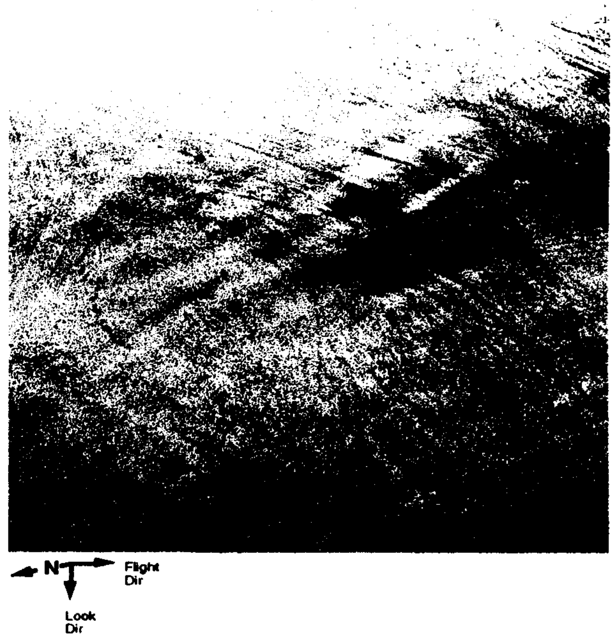

Figure 6: ERS-1 SAR image showing a dark droplet formed seepage candidate (centre left position). Image size is approx. 60 x 60 km.

This work has demonstrated that the current service concept and infrastructure are capable to meet the main user requirements. The existing servicce is hence not the bottlenecks for the 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 to the traditional surveillance methods. 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 has been 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, 10 seepage candidates have been identified. None of these candidates have, however, been confirmed by any in-situ observations. 8 of the candidates were detected at very favourable wind conditions (i.e. wind speed less than approx. 5 m/s). 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 x 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 4 times during the study [1]. 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 has been 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 the 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 has been developed during the recent period [3]. 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 app 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 are undertaken.

During the first half of 1996 RADARSAT data will become avialable, and will be used by the service. This satellite will have the capability to cover a larger area than the ERS satellite, and the SAR can also operate in additional modes compared to ERS. The capability of RADARSAT to detect oil is not yet fully understood, especially the limitations towards the outer parts of the swaths 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 to 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 has also been 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 ENVISAT represents 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, end even cheaper than the costs obtained from traditional operational systems [7].

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

Norway has since early 80's 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 to inform an end user in Northern Europe about possible oil spills within their territorial waters within less than two hours after 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 was expected. It is therefore expected that SAR data from the new radar satellites will become more and more 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 covergae 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 benefits for 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. It is therefore recommended that the satellite operator ESA make maximum efforts to provide ocean data from both satellites for operational applications during the remaining Tandem Mission Period, and that a discussion of a possible extension of this period for more operational purposes is raised soon.

Acknowledgements

The Norwegian oil spill development project has been co-ordinated 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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OIL POLLUTION MONITORING ON THE NORTH SEA BY THE NETHERLANDS

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1. Introduction

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

1. shipping;
2. offshore industry;
3. transport via rivers; and
4. 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 and 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 section Operational Devission main tasks are:

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

2. Aerial surveillance

A total of 450.000 ships pass the Dutch coastline. The risk of pollutions caused by operational discharges (controlled and regulated discharges under strict conditions (MARPOL) or illegal) is high. Also the number of accidents and collisions, were usually a big amount of harmful substance is discharged, is relatively high. For this reason the NSD inspects the NCP on a daily bases. 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 pollutions at long range, both during nighttime and under unfavourable conditions. Some results over the period 1992-1995:

year	number of flighthours	number of pollutions	pollutions per flighthour	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

Table 1. Total number of flighthours and detected pollutions (the total number of flighthours is a combination of various types of flights; the number of pollutions is only counted for patrol flights over sea.

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 2. Pollution qualification of all detected slicks.

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

3. Spaceborne surveillance

Aircraft detection is influenced by various aspects 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. 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 program 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.

4. First ERS SAR project

This project has been 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 has been conducted with the financial support of the Netherlands Remote Sensing Board (BCRS) and the European Space Agency (ESA).The objectives of the project are summarised 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.

4.1 Measuring campaign

In the period of 01-Jun-1993 until 31-Dec-1993 all ERS-1 SAR images of the NCP have been 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 2 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 onboard of the aircraft. Due to the time required for covering the ERS-1 frames by the aircraft only limited possibilities were left for target investigation and observation.

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

area class	number of slicks		total area [km^2]	
	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

Table 4. Size distribution of the slicks detected by SLAR.

4.3 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 date were available. From this table it can be learned that the total number of slicks found is almost equal and the aircraft has detected more small slicks while the satellite has detected more relatively large slicks. For slicks that were not detected by the ERS-1 SAR data two explinations can be given:

- size of the slick; 4 out of the 5 missed slicks are relatively small (<0.2 km^2)
- time difference; in this case 1:28 hour pased between the observation on SLAR and the satellite overpass. The slick could partly be dispersed and evaporated in between.

area class	number of detected pollutions		
	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

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

4.4. 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. One of the conclusions was that when slicks on SAR images are received at (near) real-time, it provides a good services for establishing an early warning system and optimizing the flight plan of the aircraft (this is 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 are 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.

5. Second ERS SAR project

In January 1995 it was agreed to fooluw-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 to provide near real time ERS SAR images (within 1-2 hours after the satellite pass). The aim of this program was to validate SAR data comparing it with airborne SLAR and visual observations. A preliminary report has been prepared.

5.1 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 area's, natural slicks, sand banks and oil slicks. A distinction was made between 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.

5.2 ERS SAR results

In the given period, a total number of 60 images were analyzed by TSS and passed trough to The Netherlands. The number of assumed pollutions (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 pollutions were added and 1 was rejected). The rather high added number is mainly caused by difference of interpretation of one image on the 6^{th} of May; due to low windspeed and appearance of natural slicks, a number of slicks were not recognized as possible pollutions by the operator at TSS (initially only 5 pollutions were marked against 28 by the North Sea Directorate). Other reasons can be:

1. Little experience in image interpretation on possible (oil) slicks by the TSS operator, and
2. small slicks that were often not marked by TSS.

The size distribution of the slicks indicates that many detected slicks are small. 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.

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

Table 6. Size distribution of slicks detected by ERS SAR data (not all satellite passes were simultaneously flown by an aircraft (due to meteorological-, technical or other reasons).

Former (statistical) studies on the relation between windspeed and the detection of slicks on SLAR or SAR indicated that most slicks were detected at lower wind speeds (1-3 Beaufort). This could be explained by the fact that oil slicks evaporate and disperse more rapidly at higher wind speeds.

5.3 Results of the aerial surveillance

In the testperiod a total of 34 ERS SAR validation missions have been carried out by the German, English and Dutch Remote Sensing aircraft. SLAR images were processed and interpreted by aircrew and reported using the Bonn standard reporting format. An initial total of 35 pollutions resulted from 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 pollutions were added and 8 slicks were rejected (out of ERS-1 range). The final number of detected slicks by the SLAR was 39. A serie 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 visual inspected pollutions consisted of oil or an oily mixture (the added 12 slicks had not been observed).

Table 7 shows the size distribution of all detected slicks by SLAR. The average size detected by SLAR was 2.0 km^2.

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 7. Size distribution of the slicks detected by SLAR.

The qualification of the slicks detected by SAR and verified by the aircrew shows that about 80% of the pollutions consisted of oil or an oily mixture. One slick consisted of vegetable oil, two slicks were observed to be algae; the other slicks consisted of 100% of silversheen, so the type of pollution remained unknown.

Table 8 provides an overview of the size distribution of all slicks detected by ERS SAR and airborne SLAR.

area class	number of detected pollutions		
	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

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

5.4. CONCLUSIONS

The operational capability of ERS SAR for slick detection has 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 shows that:

1. The classification of the detected slicks was mainly oil or oily mixtures (about 80 %).
2. Within the test period, the satellite detected roughly 1.5 times more slicks in comparison to SLAR.
3. Most detected slicks are small in size, but this is insignificant compared to the total covered area by the bigger slicks.
4. Not all detected slicks on both SLAR and SAR, especially small ones, are interpretated by the operator as a possible (oil) slick.

6. 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 that:

* The used communication lines via internet 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 request of data-availability within 1-1.5 hours after the satellite overpass has not always been achieved.
* The number and frequency of useful SAR data (frames of the area of interest) is low.

A final report is drafted.

7. Discussion results

7.1 Integration within the existing organisation

The technic of a spaceborne SAR proves to be an useful application to detect pollutions, under certain conditions and within limitations. To implement this sensor into an operational strategy within an organisation like the North Sea Directorate, one has to justify the investment by ascessing whether that the services contributes to the existing surveillance method, and most of all, that the SAR provides additional neccessary information that can not be obtained by other means.

All countries adjecent to the North Sea stress effort to decreasing the 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 Directorate is also evaluating its Remote Sensing results of the past decade in order revise the routes and time-schedules to achieve a balanced coverage of the surveillance flights.

One way to intensify the surveillance is to increase the number of flight hours. In the year 1995 the aircraft is scheduled for about 1200 hours. With an endurance of about 4 hours, the aircraft can perform 300 flights, in other words, one or two flights a day; equally devided over day and night.

Increasing the number of flight hours will effect the total number of detected pollutions annualy and increase the possibility to catch a polluter red-handed. The results of this project and experiences by the Operational department of the North Sea Directorate, show that a pollution detected by one sensor will not always be detected again by the other sensor after some time. Processes like evaporation, dispersion etc. influence the detectability of pollutions on sensors like SLAR and SAR.

8. Operational remote sensing in the Mediterranean

Recognizing the potential of spaceborne detection systems such as SAR and identifying the operational experience with airborne remote sensing, it could be considered to establish a surveillance organisation in countries adjacent to the Mediterranean by:

- Utilizing SAR imagery.
- Identifying/observing/verifying possible pollutions by visual observations from an aircraft.
- Incorperating satellite imagery in airborne remote sensing.
- Cooperating with North Sea countries to benifit from gathered experiences.

OPERATIONAL FORECAST OF OIL SPILL DRIFT AT METEO-FRANCE

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ABSTRACT

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

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

Due to 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 winds and sea level pressure forecasts from the global atmospheric model of the European Centre for Medium-Range Weather Forecasts (ECMWF). 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 coastlines) 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).

The Météo-France oil spill response system is 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.

OCEAN MODEL

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

$$\frac{\partial q}{\partial t} + q.\nabla q + f.k\Lambda q =$$

$$-g.\nabla\eta - \frac{1}{\rho}\nabla P_a + \frac{1}{\rho.H}\left(\tau_s - \tau_b\right) + A.\nabla^2 q$$

$$\frac{\partial\eta}{\partial t} + \nabla\left(H.q\right) = 0$$

where t denotes time, q the depth-integrated current, η the sea surface elevation, H the total water depth, f the Coriolis parameter, k a unit vector in the vertical, P_a 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)
These equations, written in spherical polar coordinates, 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 the global atmospheric model of the European Centre for Medium-Range Weather Forecasts (ECMWF).

In the English Channel and the Bay of Biscay, a tide forcing is also included.

OIL SPILL MODEL

The oil slick is modelled as a distribution of independent droplets which move in response to shear current, turbulence and buoyancy.

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. The governing equation is:

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

in which $w = u + i \cdot v$ is the horizontal velocity (u and v are the x and y components of current), ν_t is an eddy viscosity and : $\frac{\partial}{\partial n} = \frac{\partial}{\partial x} + i \cdot \frac{\partial}{\partial y}$.

The model is coupled to the ocean model by :

$$q = \frac{1}{H} \cdot \int_0^H w \cdot dz$$

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

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 mix downward.

If a droplet is moved on to land, then that droplet is considered beached and takes no further part in the simulation.

NUMERICAL SIMULATIONS

The model was calibrated on a few well documented pollution incidents:

Torrey Canyon, English Channel, 1967
Amoco Cadiz, English Channel, 1978
Tanio, English Channel, 1980
Gulf war, Persian Gulf, 1991
Aegean Sea, La Coruna, Spain, 1992

REAL-TIME SIMULATION

On the 21 December 1994, an accident occurred between Madeira and Cap de S. Vicente, Portugal.

The Météo-France oil spill model was tested in real-time mode over the period 21 December 1994 - 6 January 1995.

Since Météo-France has the responsibility on this area within the World Meteorological Organisation (WMO) Marine Pollution Emergency Response Support System (MPERSS), oil spill charts were sent to meteorological offices of Spain, Portugal and Morocco, and also to an oil company, owner of the ship.

Recently (February 1996) during the Sea Empress accident, Météo-France sent oil spill drift forecasts to Cedre.

EXERCISES

In association with Cedre, the French Navy and Saudi Petroleum Overseas Ltd., Météo-France took part in the exercise Antipol 95 (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 5h10 utc on 3 October 1995. A drifting buoy (NORDA type) simulated the oil slick drift. During two days, Météo-France run his model and sent oil slick drift forecasts to Cedre.

OPERATING PROCEDURE

The user 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 are oil spill position charts.

A 120 hours 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.

METEO-FRANCE CUSTOMERS

In case of a threat of marine pollution by oil for the French coastline, the Préfet Maritime may request Météo-France services.

Météo-France is engaged within the World Meteorological Organisation (WMO) Marine Pollution Emergency Response Support System (MPERSS)

On a commercial basis, oil spill drift forecasts can be sent to any customer who ask for (for example, oil and shipping companies).

FUTURE DEVELOPMENTS

In collaboration with Cedre, inclusion of a weathering oil model (evaporation, emulsification, dissolution, etc...)

Development of a container drift model.

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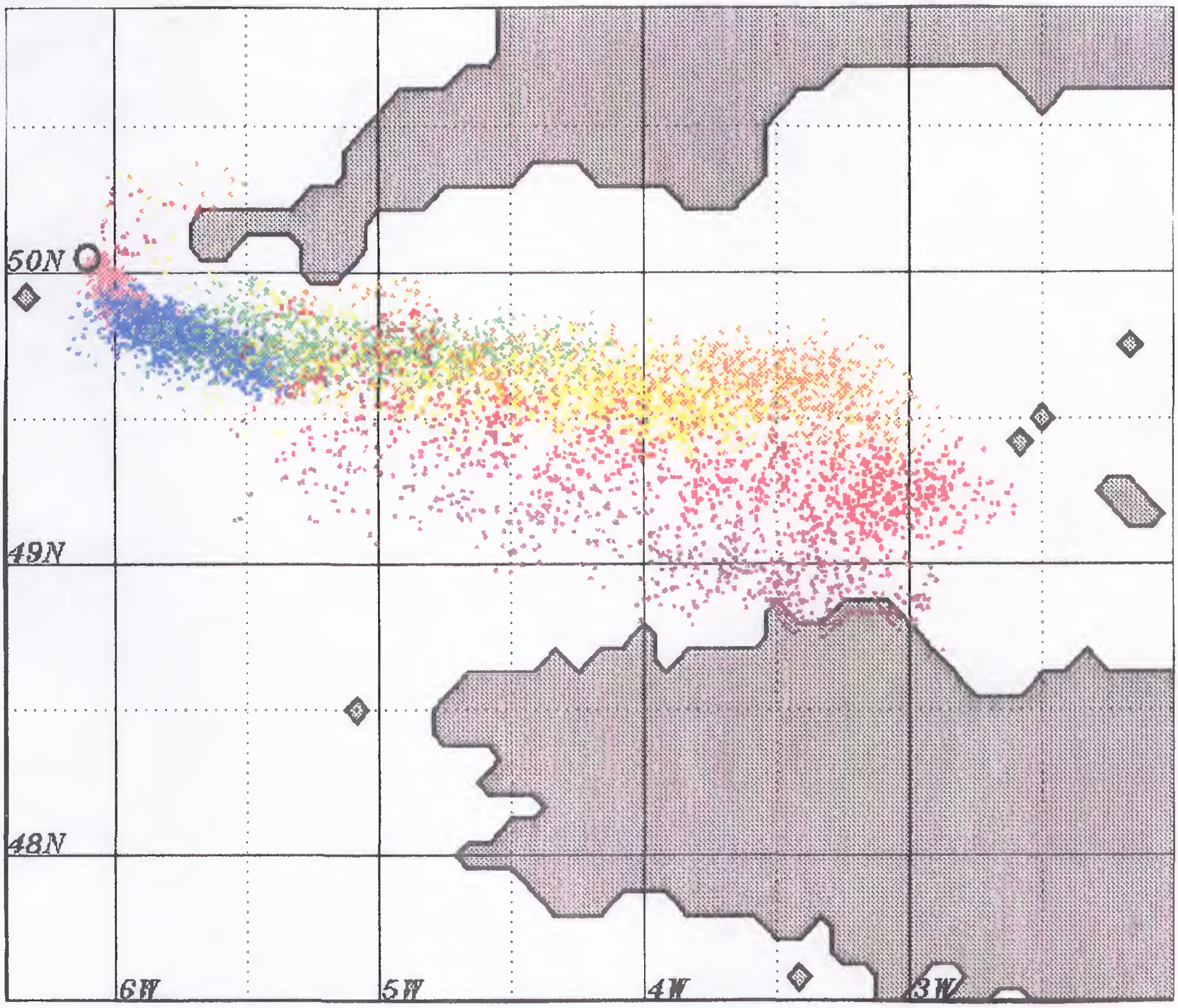
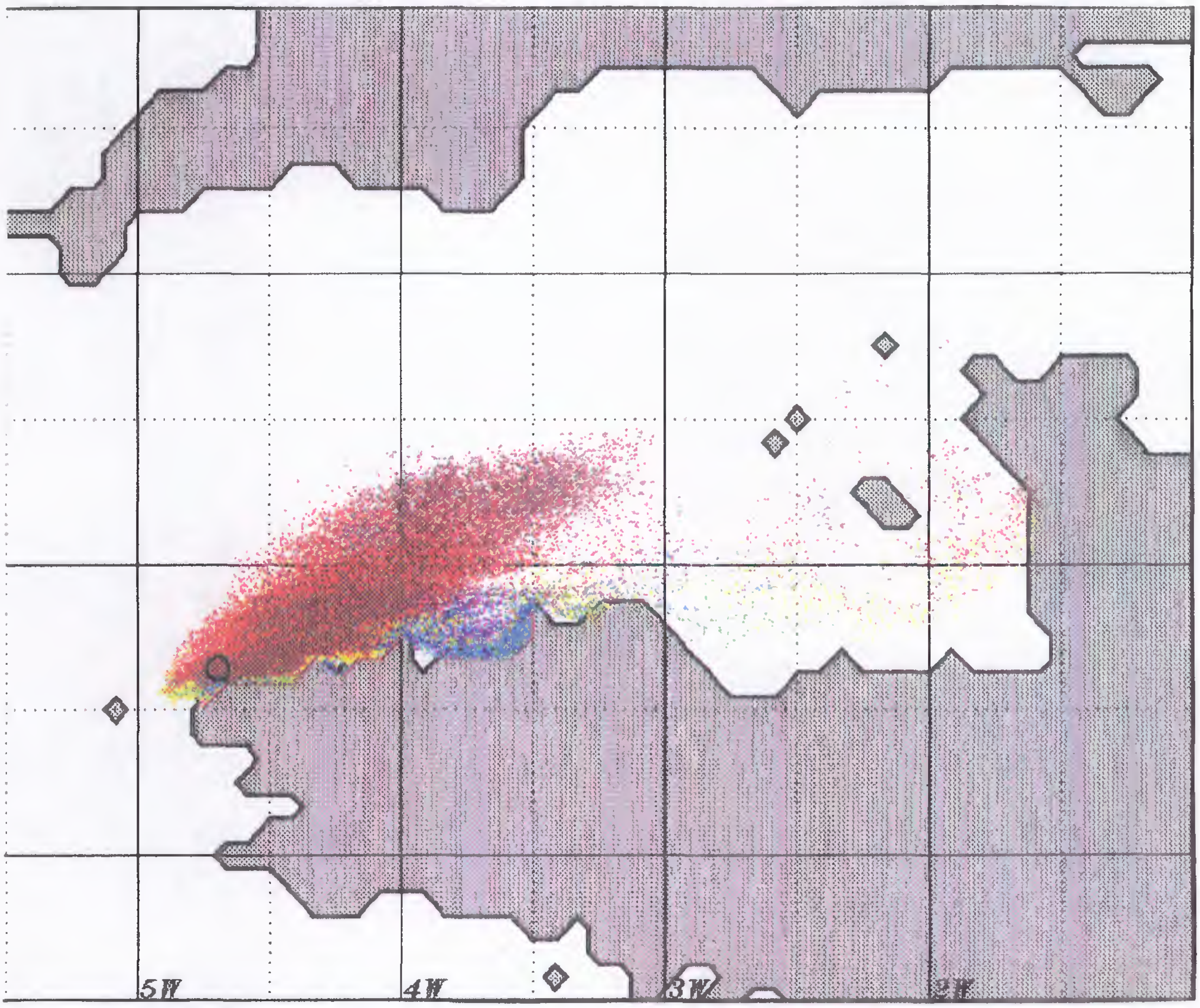


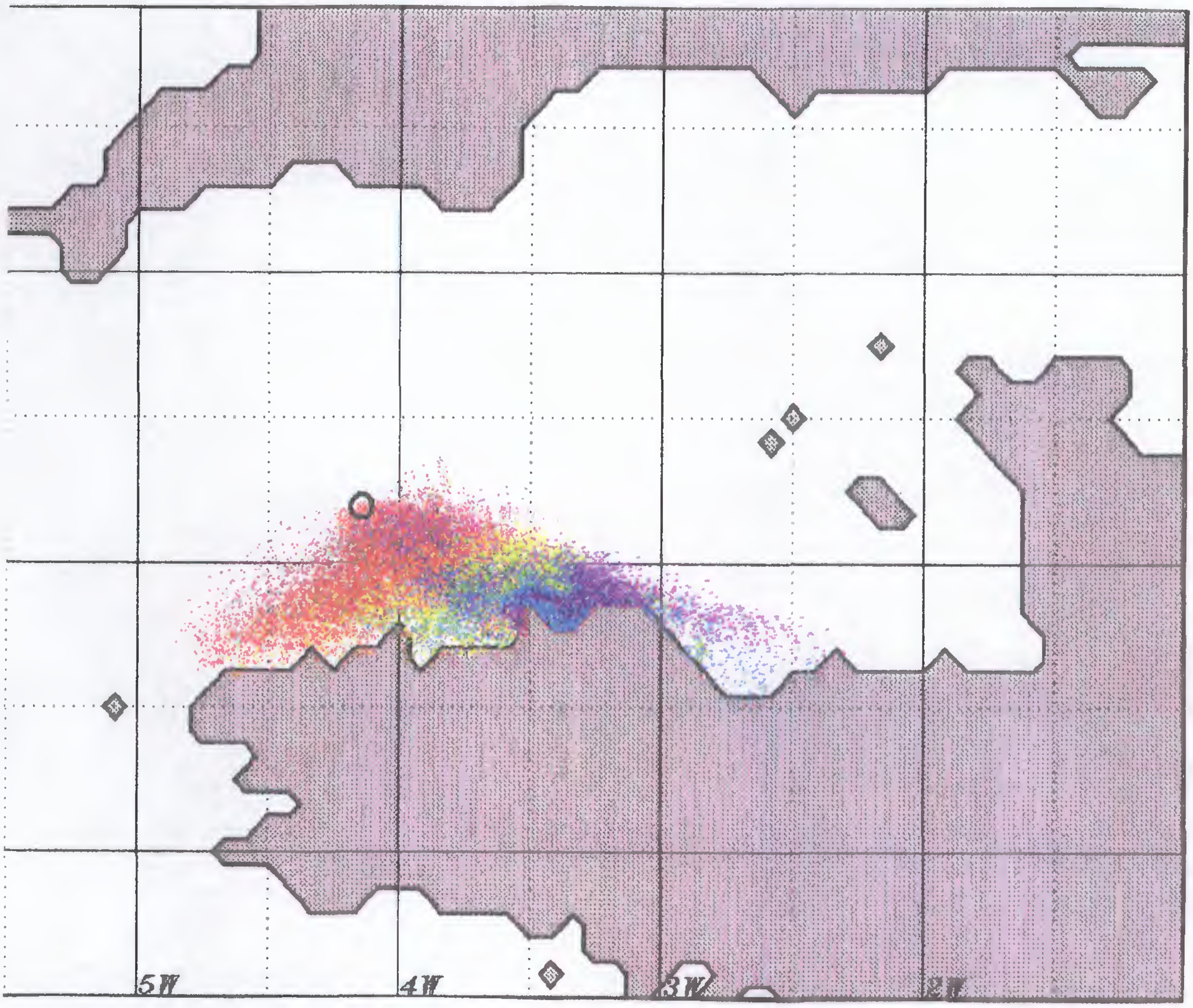
TORREY CANYON 1967

The circle indicates the accident position. The colours indicate different positions of the slick during the simulation from 17 March to 12 April



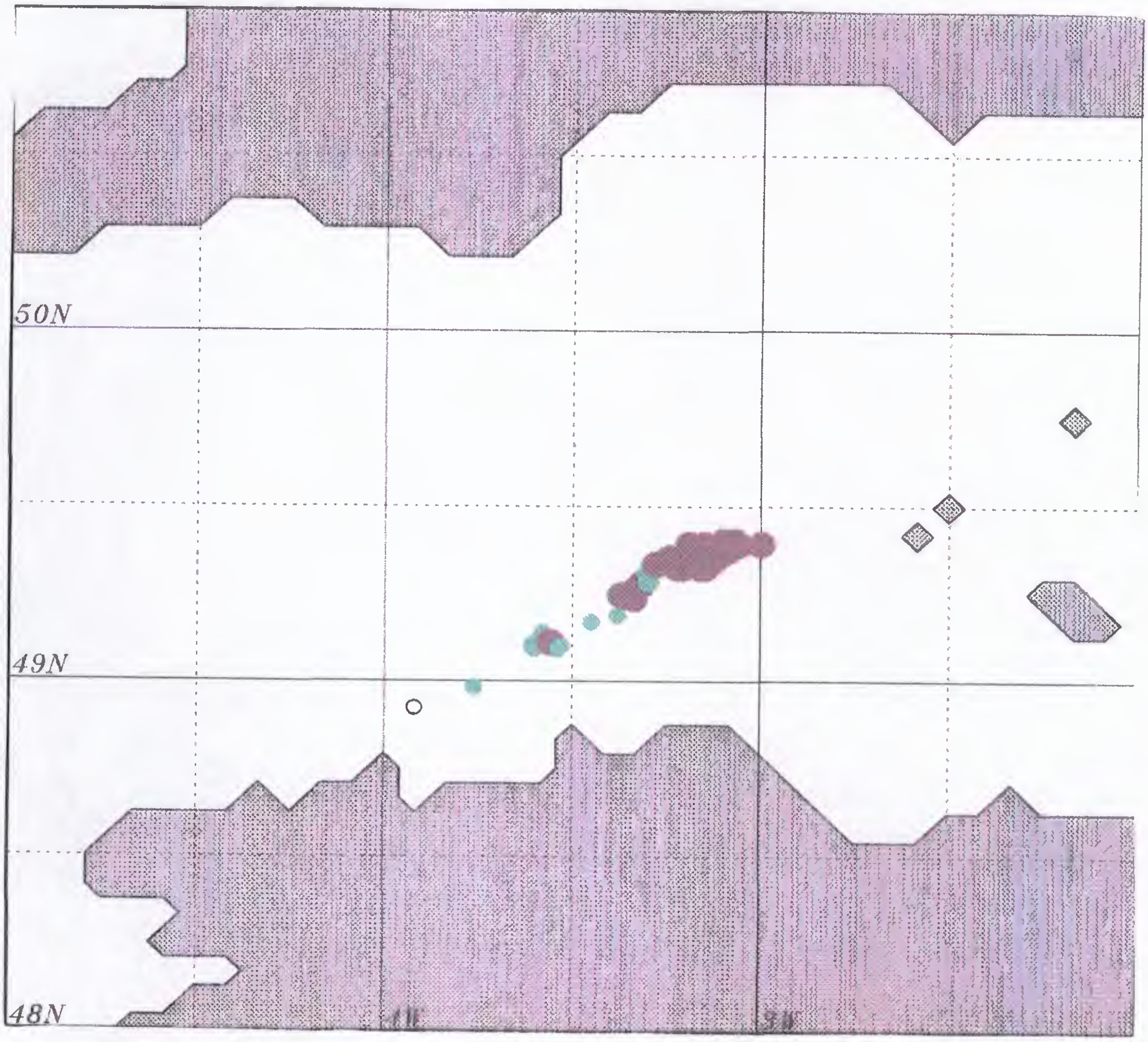
AMOCO CADIZ 1978

The circle indicates the accident position. The colours indicate different positions of the slick during the simulation from 17 March to 2 April.



TANIO 1980

The circle indicates the accident position. The colours indicate different positions of the slick during the simulation from 6 March to 25 march.



ANTIPOL95: Oil slick position on October 7, 1995.

The circle indicates the accident position, brown droplets are on the sea surface, green droplets are below the sea surface

METOCEAN INPUT DATA FOR DRIFT MODELS
APPLICATION : LOUSTIC CASE

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ABSTRACT

Real-time monitoring and crisis management of oil slicks or floating structures displacement requires a good knowledge of local winds, waves and currents used as input data for operational drift models.

The state of the art of commonly used metocean information does show a lack of both accuracy time and space resolution : direct use - without analysis and interpolation - of coarse grid wind field model, calculation of sea-state significant wave heights and mean periods through unadequate abacus, determination of wind drift current by the raw classical law of 'three percent of wind speed and forty degrees from wind direction'.
As a consequence, companies dedicated to monitoring or dealing with marine pollution or accidental lost floating structures, have a dramatic need for accurate metocean data with a particular emphasis on forecasting and operational features.

Fortunately, thanks to their world-wide and all-weather coverage, satellite measurements have recently enabled the introduction of new methods for the remote sensing of the marine environment.

Within a French joint industry project, a procedure has been developed using basically satellite measurements combined to metocean models in order to provide marine operators' drift models with reliable wind, wave and current analyses and short term forecasts.
Particularly, a model now allows the calculation of the drift current, under the joint action of wind and sea-state, thus radically improving the classical laws.
This global procedure either directly uses satellite wind and waves measurements (if available on the study area) or indirectly, as calibration of metocean models results which are brought to the oil slick or floating structure location.

The operational use of this procedure is reported here with an example of floating structure drift offshore from the Brittany coasts.

I. INTRODUCTION

The increase in maritime traffic, pollutant and dangerous materials, and therefore accident risks that can dramatically damage environment and communities, does nowadays constitute a real problem .

Within a french joint industry project, operational tools based on innovature remote sensing use of satellite data, were developed in order to provide reliable metocean analysis, such as wind, waves and currents, used for tracking floating objects and oil slicks.

In a first part, satellite metocean measurements are presented in this paper, considering the measurement principle and the associated operational parameters.
In the second part, a description is given of an operational procedure combining satellite data and models to determine reliable metocean parameters (wind, sea-state, current).

This procedure is illustrated in the third part with the case study of a buoy displacement.

II. SATELLITE METOCEAN MEASUREMENTS

Measurement principles

Satellite information about the marine environment is mainly provided by :

• geostationary satellites : visible, infrared and micro-wave images, which provide qualitative approaches of metocean structures,

•orbiting satellites, such as GEOSAT (Nov. 86 - Sept. 89), ERS1 (from July 91) and TOPEX (from August 92),

which measure:

* significant wave heights and wind speed every 7km - with the three satellite altimeters,
* wind fields (speed, direction) from ERS1 scatterometer - with a wind vector every 25 km, and on 500 km wide swath, on the right of the track,
* some raw directional water surface spectra - from ERS1 Synthetic Aperture Radar (SAR) in wave mode - every 200 km on the right of the track,
* sea surface temperature, from infrared radiometer (ATSR) of ERS1.

State of the art of satellite measurements

When considering practical applications of satellite measurements, several details should be pointed out:

- satellites offer a very dense coverage of the world's oceans [3].

- measurements can be performed in all-weather conditions. Significant wave height and wind speed altimeter measurements from both ERS1 and Topex are very reliable [4-5-6], even during storm conditions,

- wind scatterometer data generally show good agreement with analysis, specially since their latest improvement (cmod4), despite some problems of directional ambiguity and lack of high wind speed values in the data set (greater or equal than 50kt)

- SAR in wave mode requires an inversion algorithm before it can be used for operational applications [7]. This transformation provides a common practice directional wave height spectrum and thus, most of the sea state parameters (periods, directions, spectral peaks, ...) answering marine operator's needs,

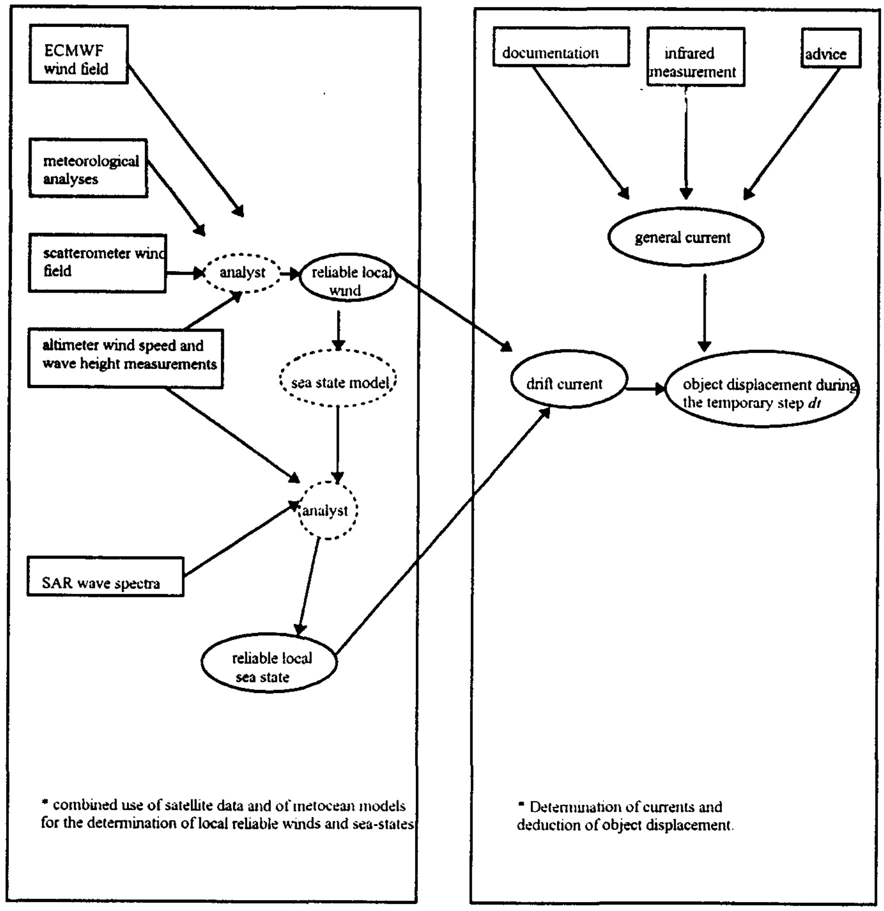
- all satellite data are interesting since they give access to metocean information that can be used either directly, when satellite track is on the location of interest, or indirectly for calibration and validation of metocean models, the results of which are then brought to the point of study [8],

- use of satellite data requires some complex analysis schemes [9-10].

The processing steps, i.e. sea state representation models, prediction tools, cross validation, require dedicated tools and skills, which are briefly examined in the following.

III. DRIFTING OIL SLICKS OR FLOATING STRUTURES DISPLACEMENTS: GLOBAL PROCEDURE USED FOR LOCAL METOCEAN PARAMETERS DETERMINATION

A global procedure has been developed, which is summarized in the following flow chart:



As described on the above figure, this operational method goes through two main steps:

1. Combined use of satellite data and metocean models for the determination of local reliable winds and sea-states

A good knowledge of local wind and sea state is a key factor for drifting oil slick or floating structure tracking. Some models are used to determine these metocean parameters, and give good results. However, locally, differences with reality can be observed.

A new alternative has appeared with the availability of satellite data. Methods applying satellite measurements of the marine environment can be used on an operational basis. These methods which rely on the combination of satellite data and metocean models for the computation of directional wave height spectra and wind, are described hereunder:

- use of wind field models

The input consists in wind fields originating from several meteorological models. These wind fields (analyses, ECMWF wind fields) are submitted to pre-processing for time and space interpolation, cross validation with available satellite measurements (scatterometer, altimeter) and checking by a meteorological expert (*figure 1*).

- use of sea-state models

Open sea directional wave height spectra are then computed from the previous wind fields. The computation model used here is a single point one, using spectro-directional methods. Generation, propagation and dissipation of spectra wave components are computed on orthodromic lines converging to the location of interest [11-12] (*figure 2*). Engineering parameters [13] are then calculated from the spectra (*figure 3*). Cross-validation of the results can be performed with altimeter and SAR wave mode measurements.

- use of satellite data

Meteorological analysis, ECMWF wind fields and hindcast sea-states are compared to satellite measurements. This comparison can be achieved locally on a specific area (*figure 4*), but can be extended to the analysis of a precise meteorological situation which generates swell [14-15].
This method allows detection of areas with uncorrectly described winds and meteorological phenomena: for example, wind is too weak, the structure of a perturbation is brought forward and sea-state is not computed accurately on the site.
In this case, satellite measurements enable validation and calibration of wind fields as well as improvment of sea-state computation.

2. Determination of currents creating the floating object or drifting oil slick displacement

The drift current profile in the water column is then computed from the previous wind and directional sea state data. In order to meet operational studies' needs (physical estimations in short term delays), this model relies on a simplified hypothesis, such as the sufficient stability of the wind. However, compared to the state of the art in operational drift prediction, this model allows a good estimation of the drift current because it considers wave influence on the drift current. It is indeed recognized that waves play an important part in near surface circulation [16-17], either directly, by creating a wave driven current called *Stokes drift* or indirectly, with the influence of surface waves on sea surface roughness, (modification of the wind profile and the stress transfered from the wind onto the sea), as well as on water turbulence and momentum transfer inside the water (which controls the vertical structure of the current).

Figure 5 illustrates a result of the model. For a determined depth, metocean parameters are shown at a specific point:

- direction and speed of *local wind* ('vent'),
- *local sea state* ('etats de mer') parameters like significant wave height, peak periods, ...
- direction, speed, and vertical profile of the *drift current* ('courant de derive'), generated by previous wind and sea state,
- direction, speed, and vertical profile of the *Stokes drift* ('derive de Stokes'), computed by sea state energy spectrum and Kenyon expression [18] (note the exponential decrease with depth).

- direction and speed of *other actions* ('autres actions'), including tide, permanent current, direct action of wind on the object, ...

These directions are determined within a geographic reference and speed is expressed in m/s.

IV. DRIFTING OIL SLICKS OR FLOATING STRUCTURES DISPLACEMENTS : A CASE STUDY

During a transatlantic race in October 1993, the ship « Loustic » was caught in a storm and lost her ARGOS positioning buoy. This buoy was not damaged and drifted during three months, giving its position until it reached the Britanny coast (*figure 6*).
The application of the aforedescribed tools enabled us to hindcast the metocean conditions (wind, directional wave spectra, current) that led to the buoy displacement. Consequently, the real and the model tracks of the buoy could be drawn for inter-comparison.

IV.1. Metocean conditions

* <u>Meteorological conditions</u>

General climate in Bay of Biscay and French coasts largely depends on the polar front perturbations, determined by the situation and the importance of the Acores anticyclone and Iceland depression area.
In automn, Acores anticyclone is at a low latitude and the Iceland depression directs south. The polar front is then at our latitudes. The air masses create perturbations circulating from west to east and commonly reaching the Bay of Biscay. This is called the <u>west pertubated regime</u>.(*figure 7*). Naturally, this scheme can vary and it may happen that the Eurasian anticyclone reaches our lands in such a way that perturbations can divert south or north. The cold <u>eastern winds</u> dominate during several weeks. (*figure 8*).
However, weather on the near Atlantic is often very different, depending on the polar front bringing important perturbations.

During the three months' simulations (October, November and December), two perturbations systems essentially appeared, broken by temporary systems.

<u>01/10/93 to 08/10/93</u>
This period showed high pressure on the Açores and depression circulation at the latitude of Iceland on the near Atlantic, south-west and north-west wind blew with an important intensification with the arrival of the front.
This situation is frequent in all seasons, bringing rather quick weather changes. It's the well-known west perturbed current at the middle latitude.

<u>09/10/93 to 18/10/93</u>
During this period, the Açores anticyclone moved to the south, and the west perturbed current circulating at the rather low latitude (40-45°N) reached the near Atlantic. Dominating winds were thus strong and directed North-East to East.

<u>19/10/93 to 28/10/93</u>
High pressure appeared on Iceland resulting with East to East-NorthEast current on the near Atlantic.

As assumed, November and December months were characterized by a classic west perturbed current with - south-west and north-west winds - intensifying as the front arrived, showing thus a normal winter situation.

* Current conditions

The total surface current is the combination of the drift current, generated by the instantaneous wind and sea state conditions, and of the other various more general currents (tidal, geostrophic, ...)

For this application, tidal currents were omitted since the area is far off the coast. It is assumed that the movement can be computed as the vectorial sum of the permanent current and wind and sea state -induced drift vectors.

- Permanent current : In the Gascogne Gulf and the near Atlantic, current is weak and particulary influenced by persistant wind conditions.
In Automn, a permanent current leads to the East, then to the North-East sector, along the spanish coasts. In the middle part of the Bay of Biscay current leads to the East, between 4° and 5° west meridiens, then North-East, North, North-West and at last West. All along the year, in calm weather situations, current speeds are weak, nearing 2 / 3 miles per day.

When high west winds dominate during a long time on the Northern spanish coast, a high current leaves the North part of the Bay of Biscay. This current called "Rennel current" does not extend very far but can reach 1 to 1.5 knots speed (first days of October situation). [27-28-29]

IV.2. Determination of local wind, sea-state and current parameters along the track

Local parameters along the track are determined with the aforedescribed global procedure.
Satellite data brought a tremendous contribution to daily hindcast wind adjustment and validation. Indeed, satellite allowed a precise determination of local wind variations brought by meteorogical models. Some differences between hindcast winds and scatterometer measurements were noted (for example, 10 knots speed and 20 degrees in direction in december) (*figure 9*). As a consequence, the simulated buoy track is far closer to the real one, when satellite information enhance initial raw wind fields (*figure 10*).

The results of this procedure for computation of local wind, sea state and current are illustrated on *figure 11*.

IV.3. Results: simulation of the buoy displacement and comparison with real track

For this application, computing step of the track (dt) is six hours for October and December, and three hours for November, due to a more perturbed meteorological situation. The Argos position measurements are irregular in time, so that they are interpolated every six hours for visual display.
Moreover, since the smallness of the buoy, direct wind action on the buoy was not taken into consideration.

Simulations of the drifted buoy displacement, calculated with adjustment on first Argos position measured each month, are presented hereunder:

figure 12: 01/10/93 at 12h to 01/10/93 at 00h
figure 13: 01/11/93 at 00h to 01/12/93 at 00h
figure 14: 01/12/93 at 00h to 21/12/93 at 06h

Since the buoy drifted three months, only one position adjustment per month was performed. Of course, for real time studies, adjustment is more frequent, because permanent information can be received by a company in charge of floating polluant or object survey.

At the end of November, we observed that the simulated buoy displacement was situated East compared to measurement. Meteorological analysis showed an atmospheric front, with different winds on both sides. It was then essential to describe this phenomenon accurately. This task, rather difficult within delayed-time studies, is far easier in real time assistance conditions, benefitting from the availability and accessibility of various convergent metocean information, among which geostationary satellite images.

IV.4. Importance of the drift current model

We can point out that the current drift model developed within this project gives satisfactory results at these middle latitudes. Thus, if we compute the buoy track with the raw and crude classical empirical drift current law (current is three per cent of wind speed and directs about 45 degrees on its right, in North hemisphere), and the same wind, wave, general current parameters, simulated tracks widely keep off the real one. *(figure 15).*

V. CONCLUSIONS

An operational procedure was developed within a French joint industry project, in order to provide marine operators' drift models with reliable wind, wave and current analysis and short term forecasts.
Its application to the case of study presented in this paper does point out two main key points of this methods: use of drift current model which takes into account the global wave influence and of satellite measurements which represent a tremendous contribution to real time calibration and validation of metocean models input (wind) and output (sea-state). Thus, this tool should allow improvement in the survey and prediction of floating object or drifting oil track.

Lastly, MétéoMer is now involved in applied projects for slick detection from SAR images. Once analysed, these measurements will enhance the aforedescribed procedure, bringing direct ground truth information about the state of a pollution.

ACKNOWLEDGEMENTS

The operational methods for the use of satellite mesurements to determine drift buoy or polluant displacement were developed within the CLAROM project "Utilization of satellite data for Applied Knowledge of Marine Environment". The contributions of the participants - Bureau Veritas, ELF, IFP, IFREMER, MeteoMer, STNMTE, and CEDRE - are gratefully acknowledged here.

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Figure 1 - ECMWF wind fields and satellite wind measurements

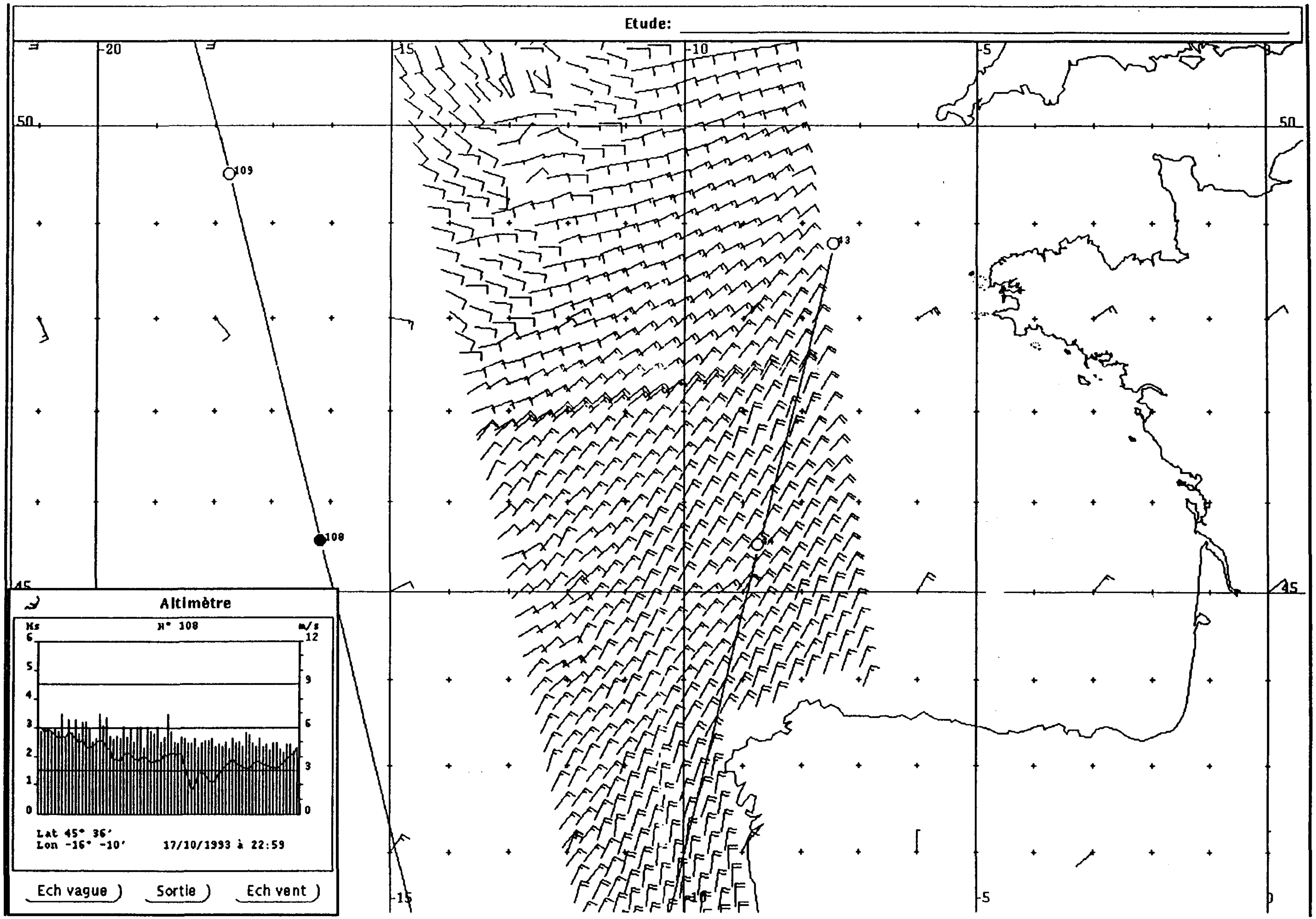


Figure 2 - orthodromic lines converging to the location of interest

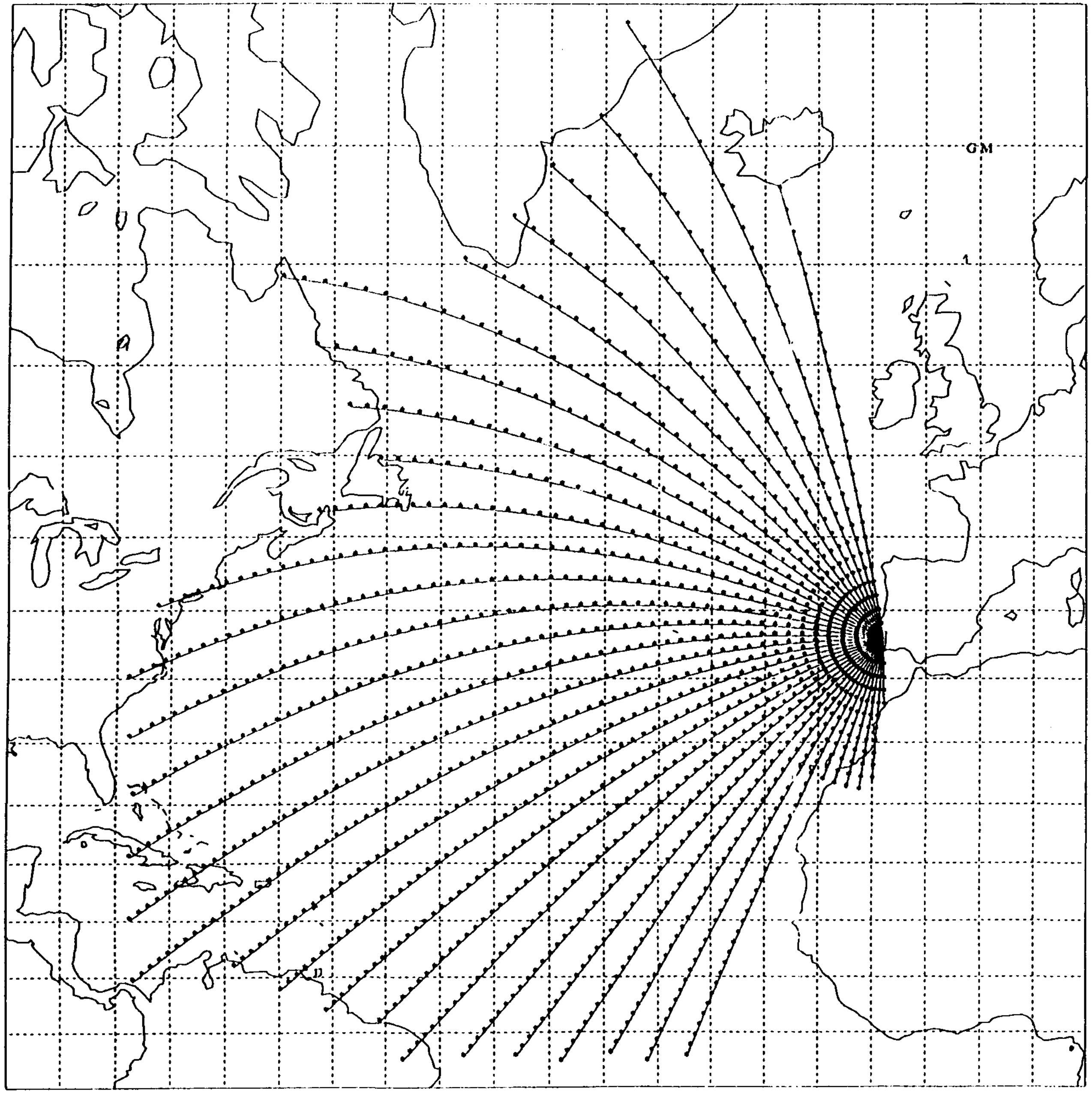


Figure 3 - sea state directional spectrum

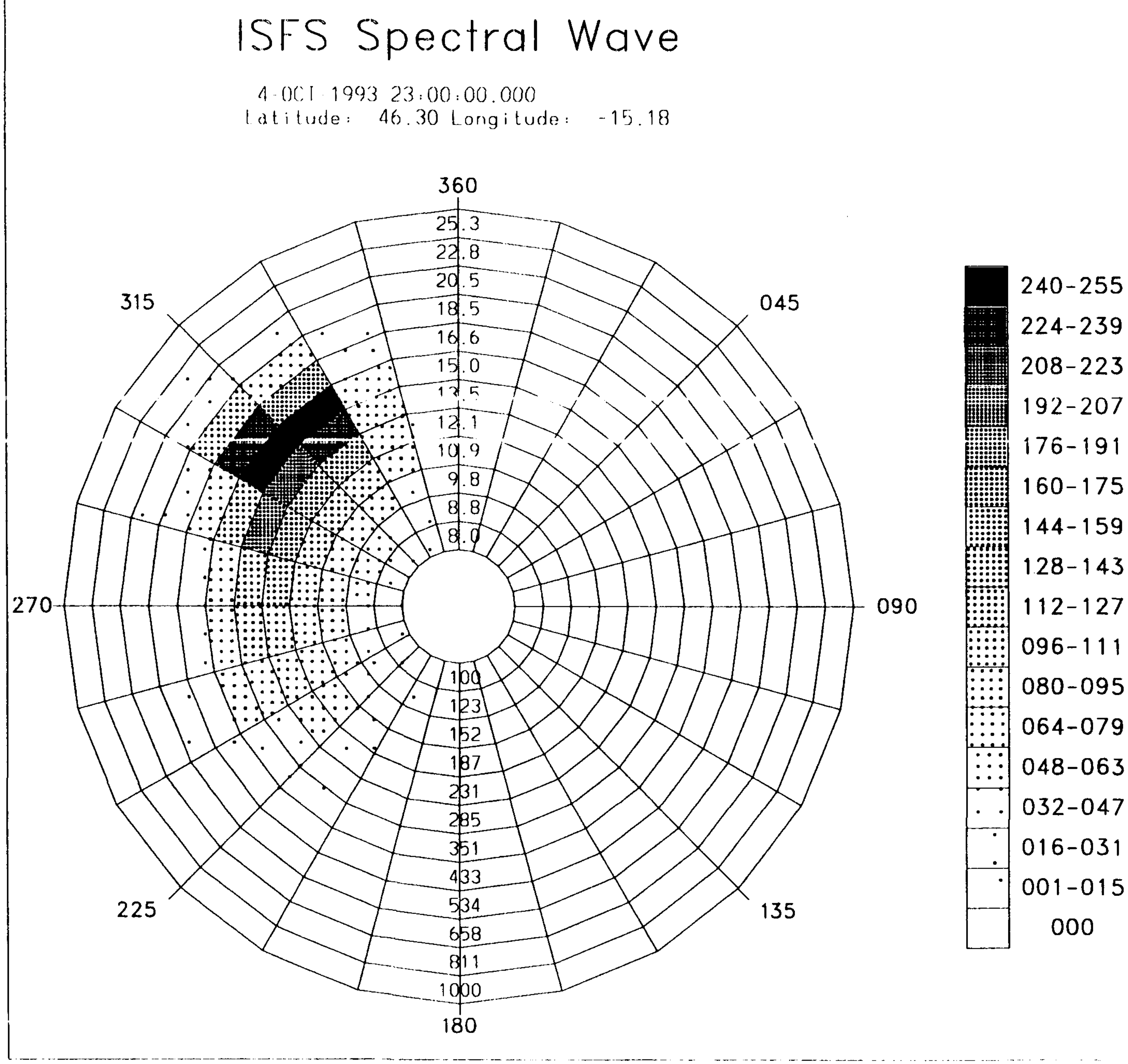


Figure 4 - satellite data around Sept. 13, 1993 - 00h and ECMWF wind field

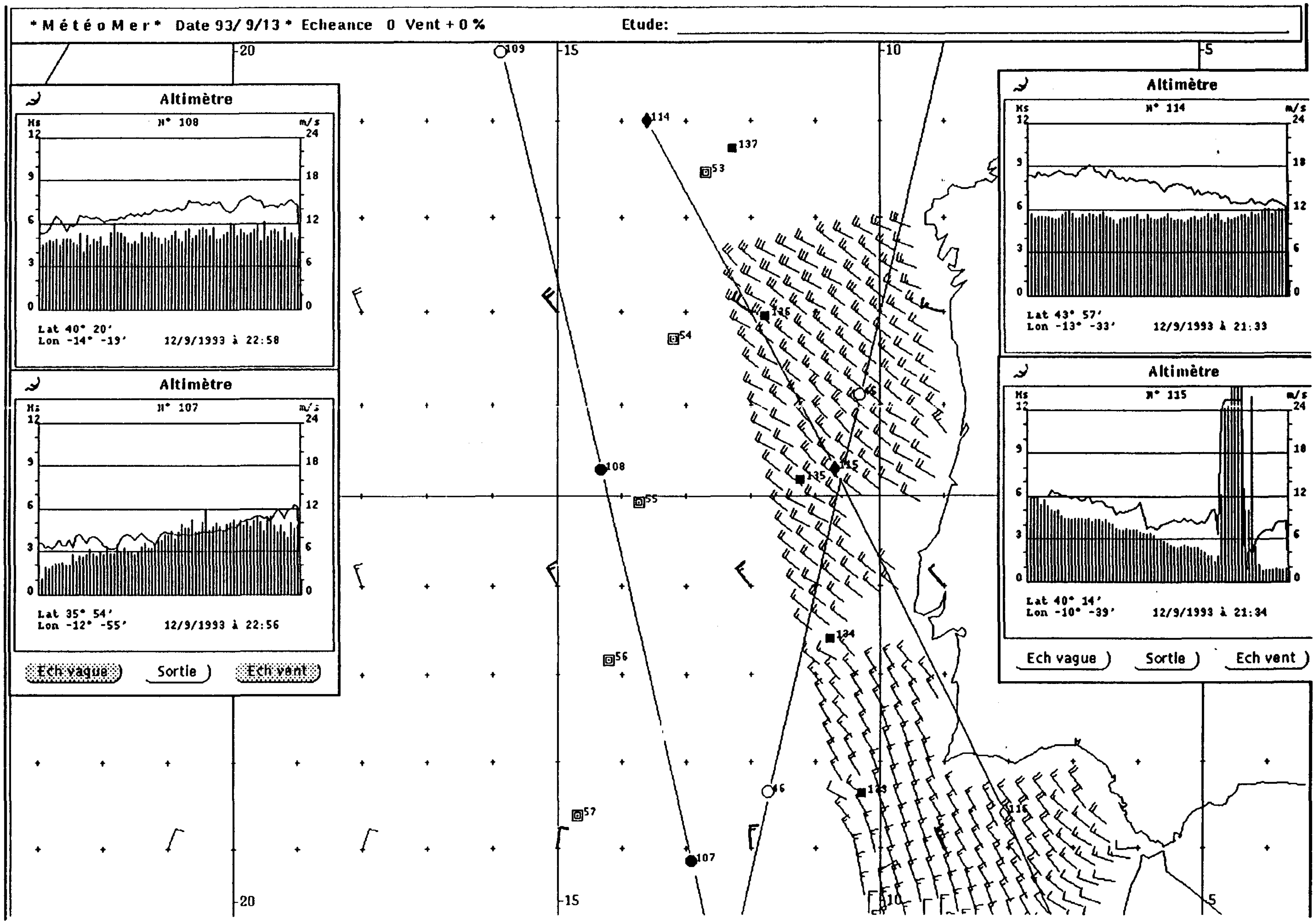


Figure 5 - Result of the drift model

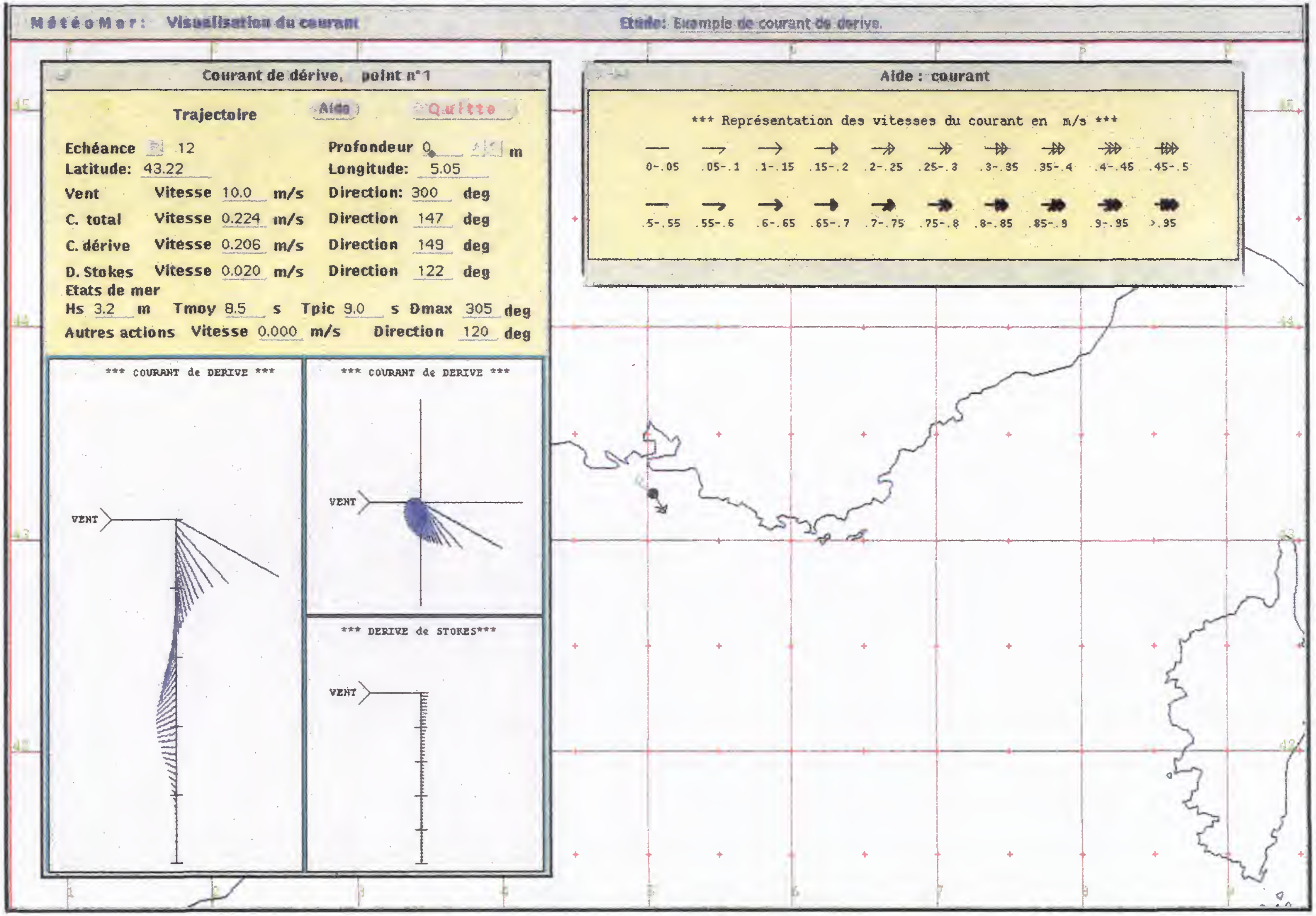


Figure 6 - Buoy displacement during October, November and December 1993

Météo Mer Date du dernier point 356 : 0 : 0 Nombre de points 327 Etude: FIGURE 6: buoy displacement during october, november, december 1993.

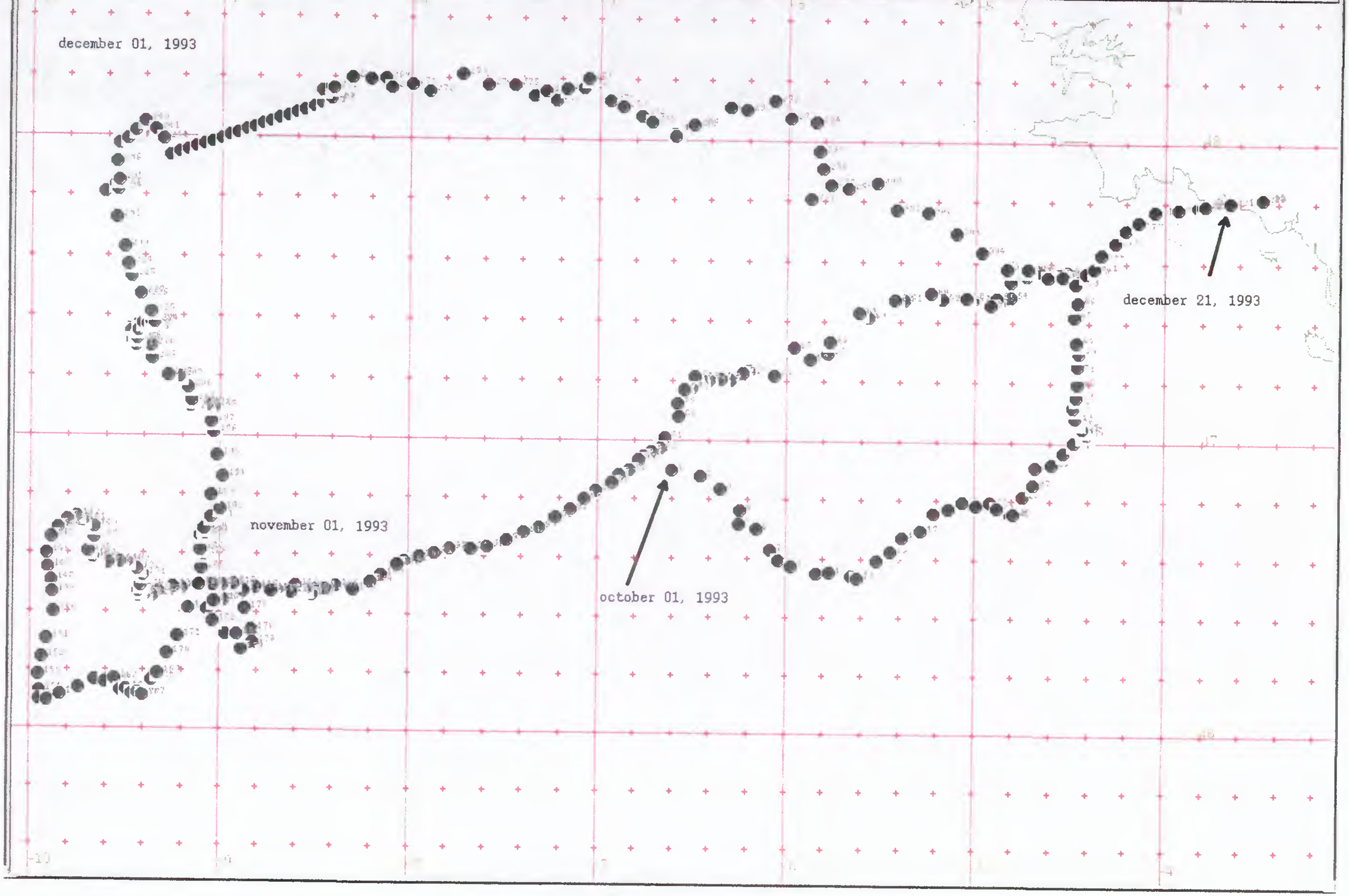


Figure 7 - Meteorology analysis - West pertubed regime

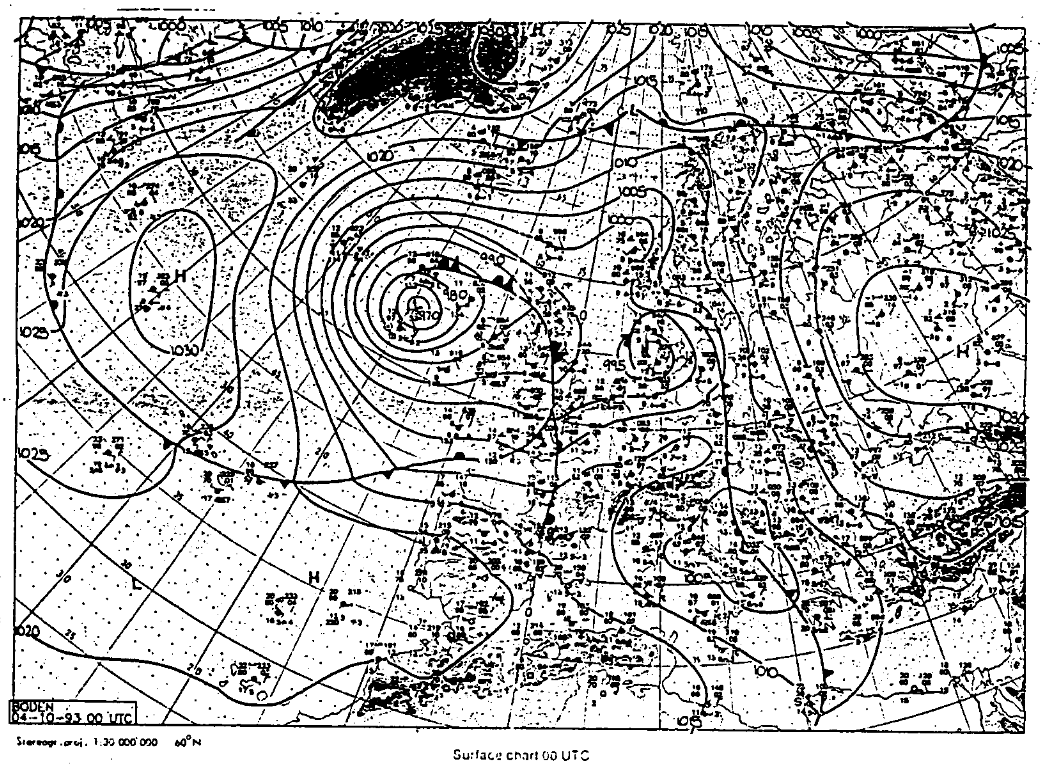


Figure 8 - Meteorology analysis - East pertubed regime

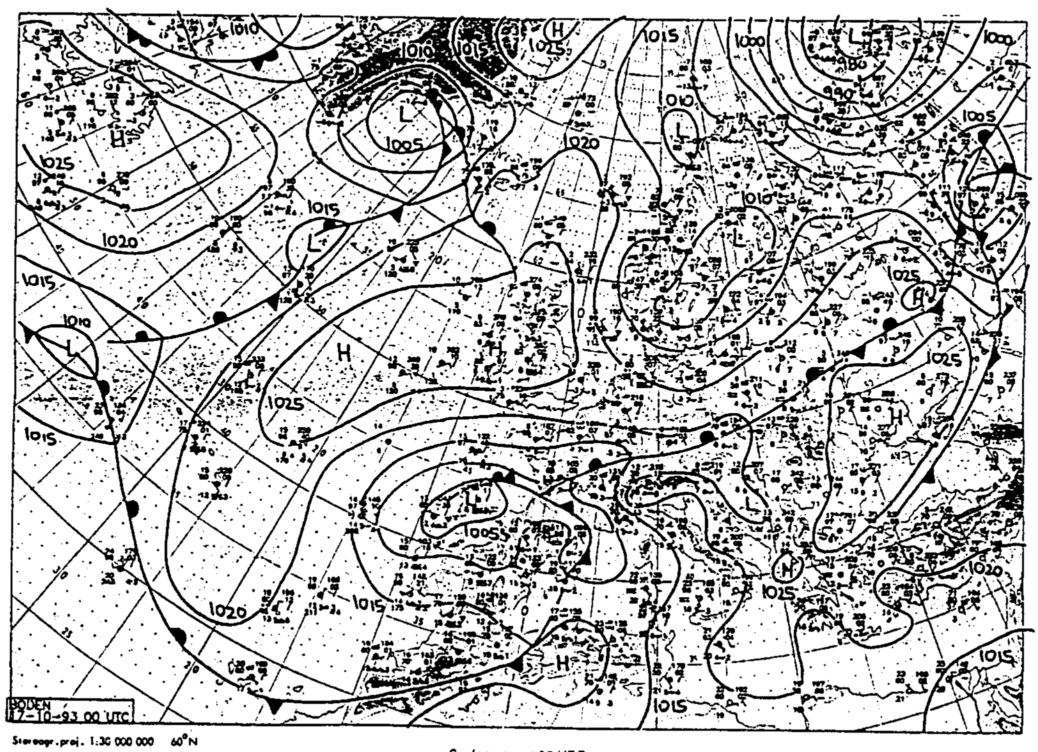


Figure 9 - Scatterometer and hindcast wind fields - 15 Dec. 1993 - 00h

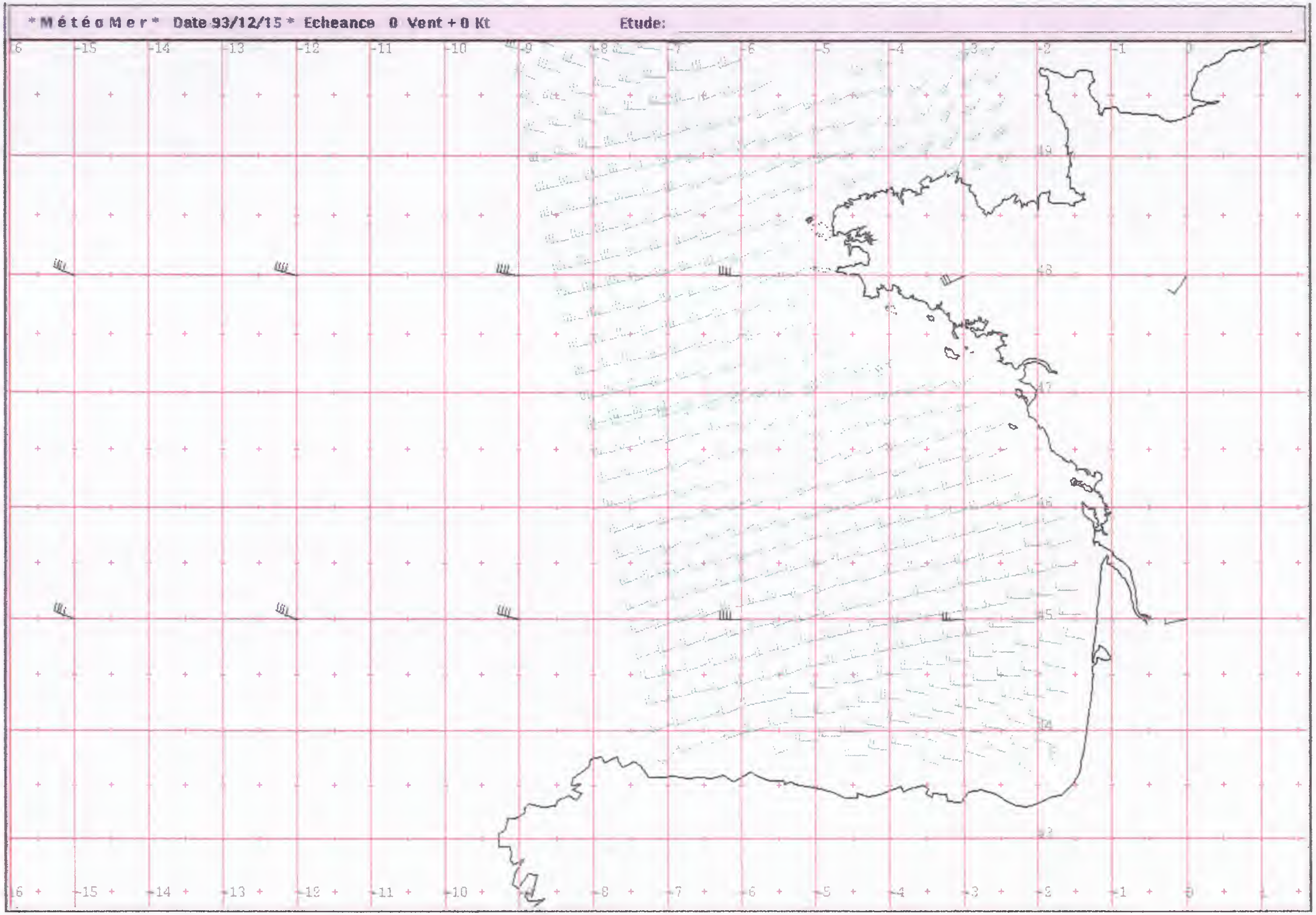


Figure 10 - Use of satellite data

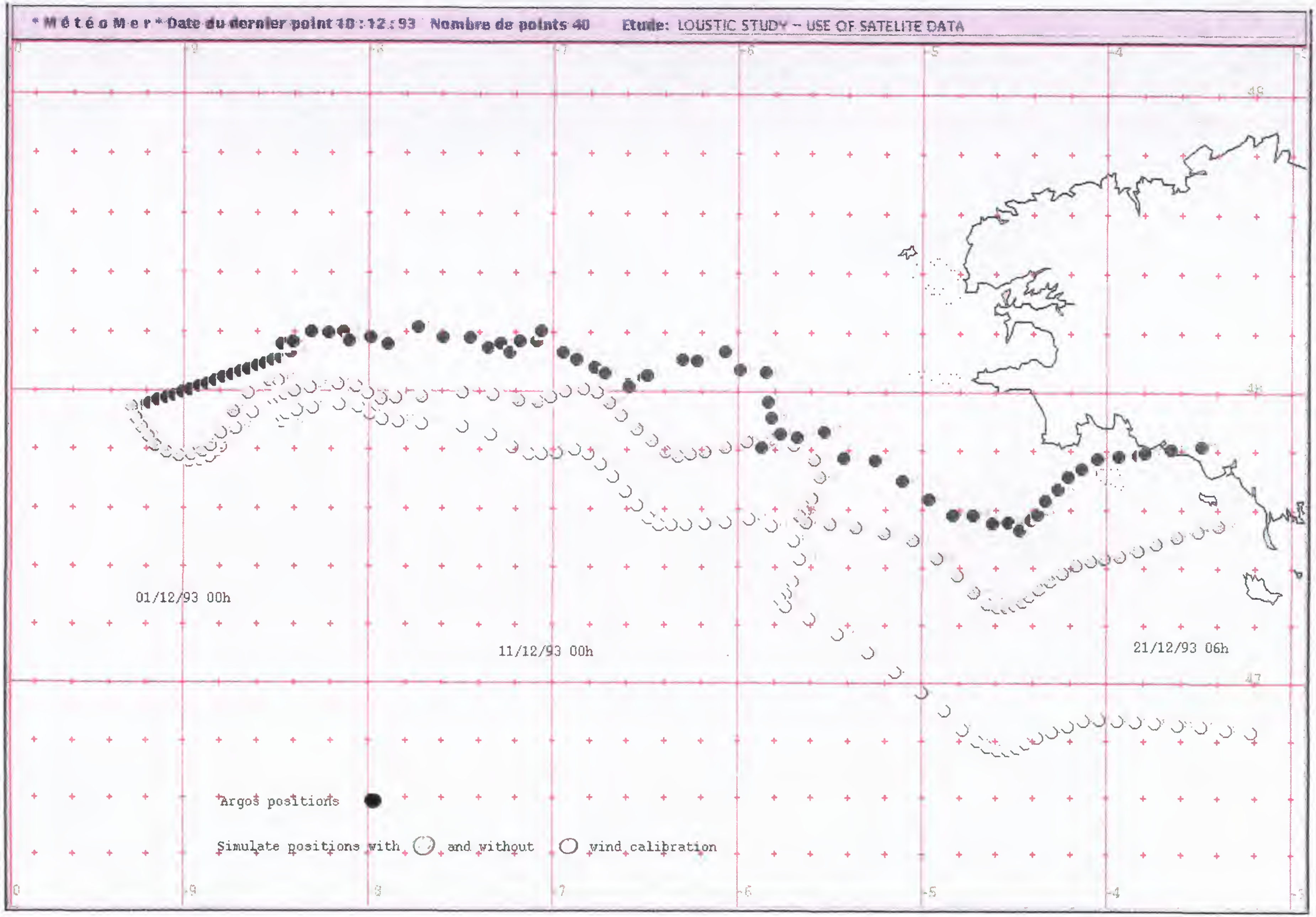


Figure 11 - Local metocean parameters on 5 October 1993 - 00h

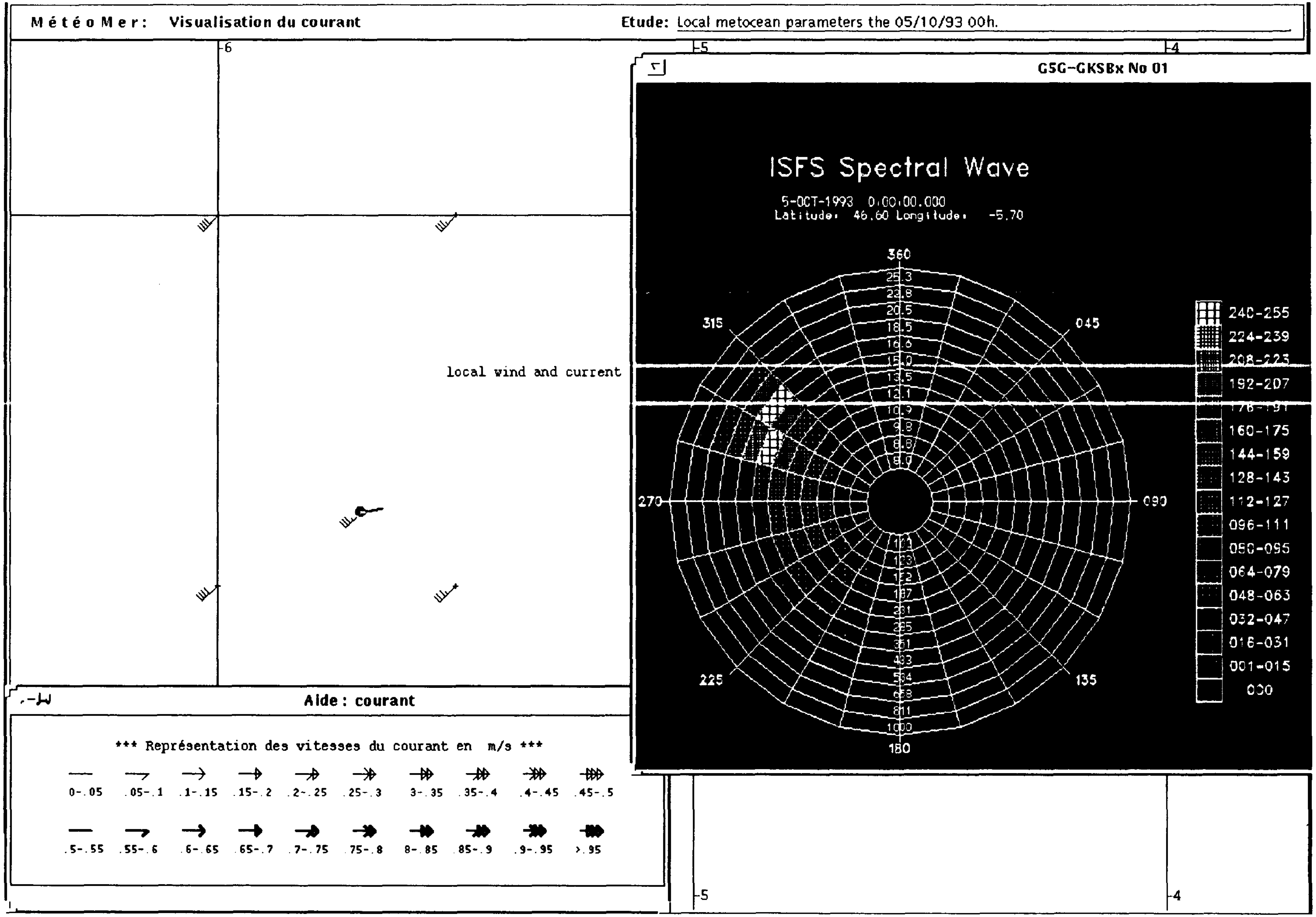


Figure 12 - Simulated and real buoy tracks during October 1993

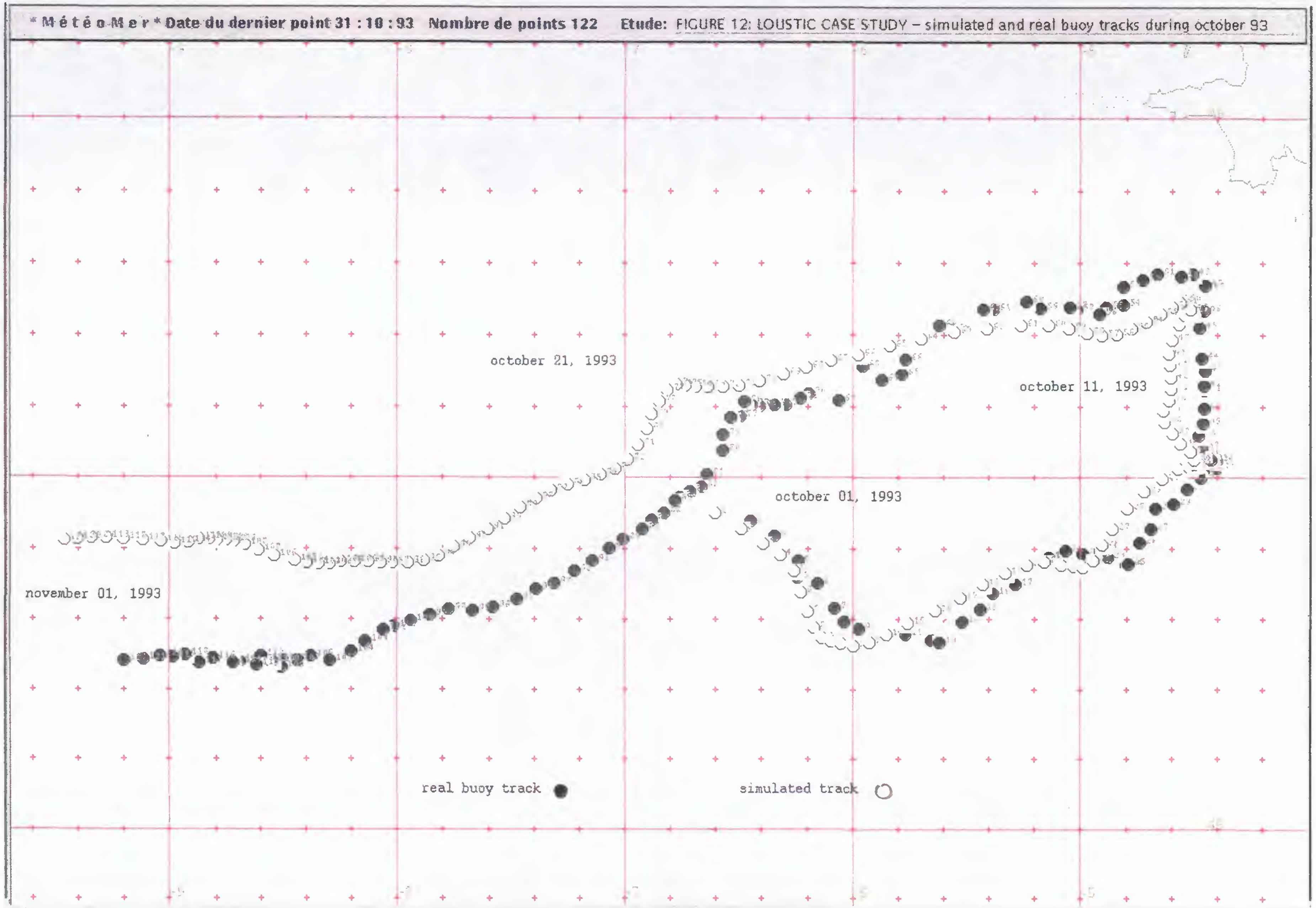


Figure 13 - Simulated and real buoy tracks during November 1993

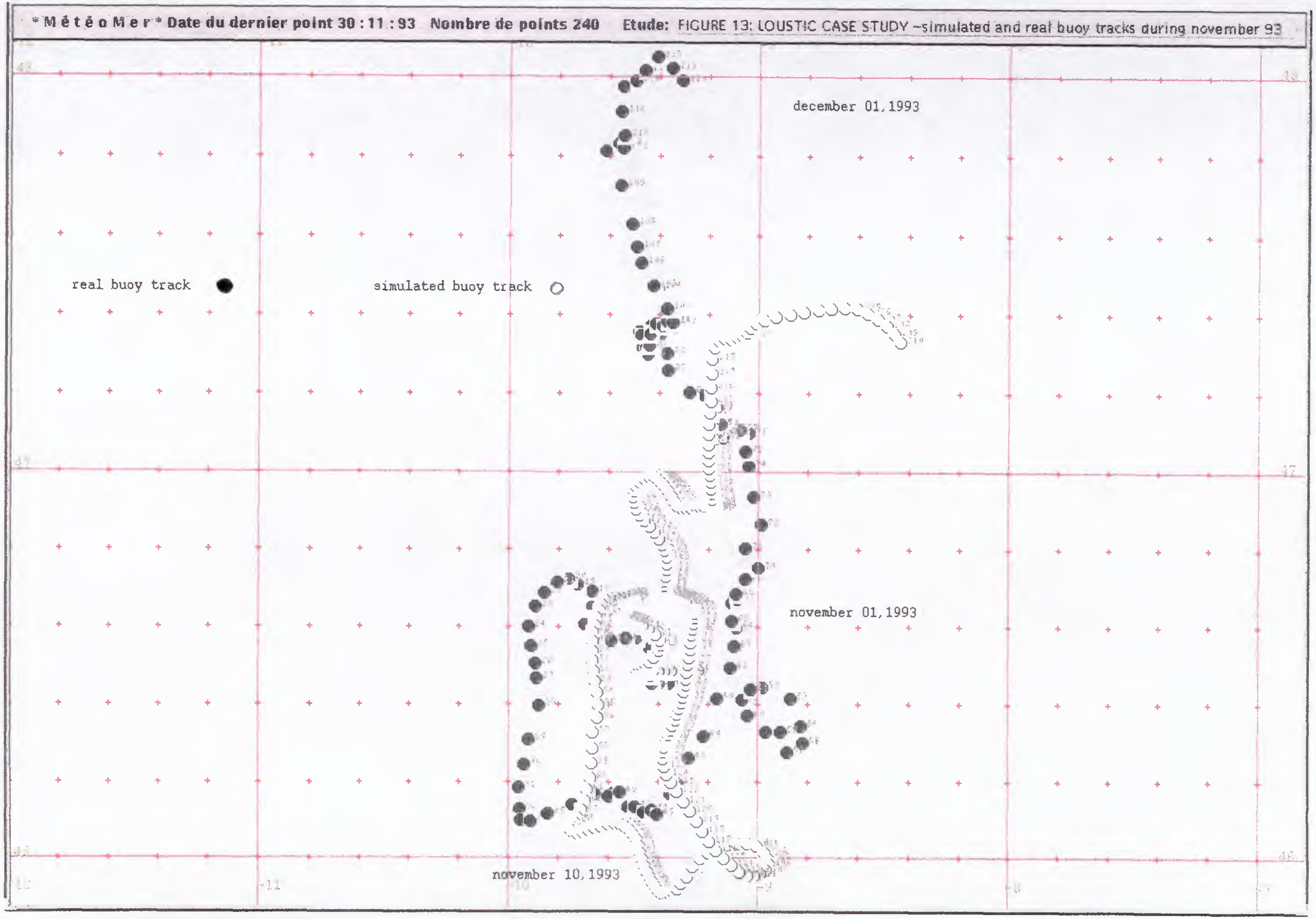


Figure 14 - Simulated and real buoy tracks during December 1993

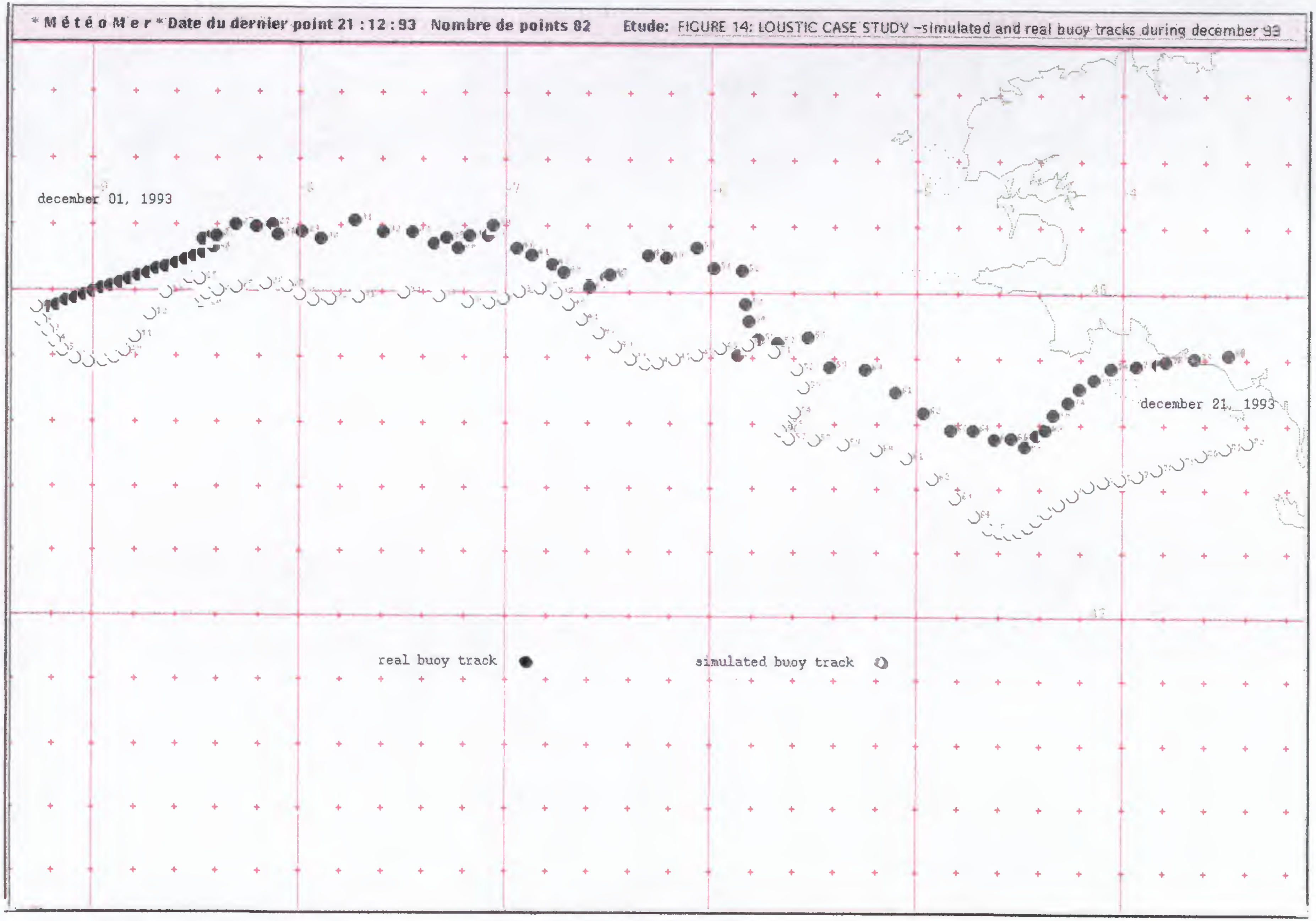
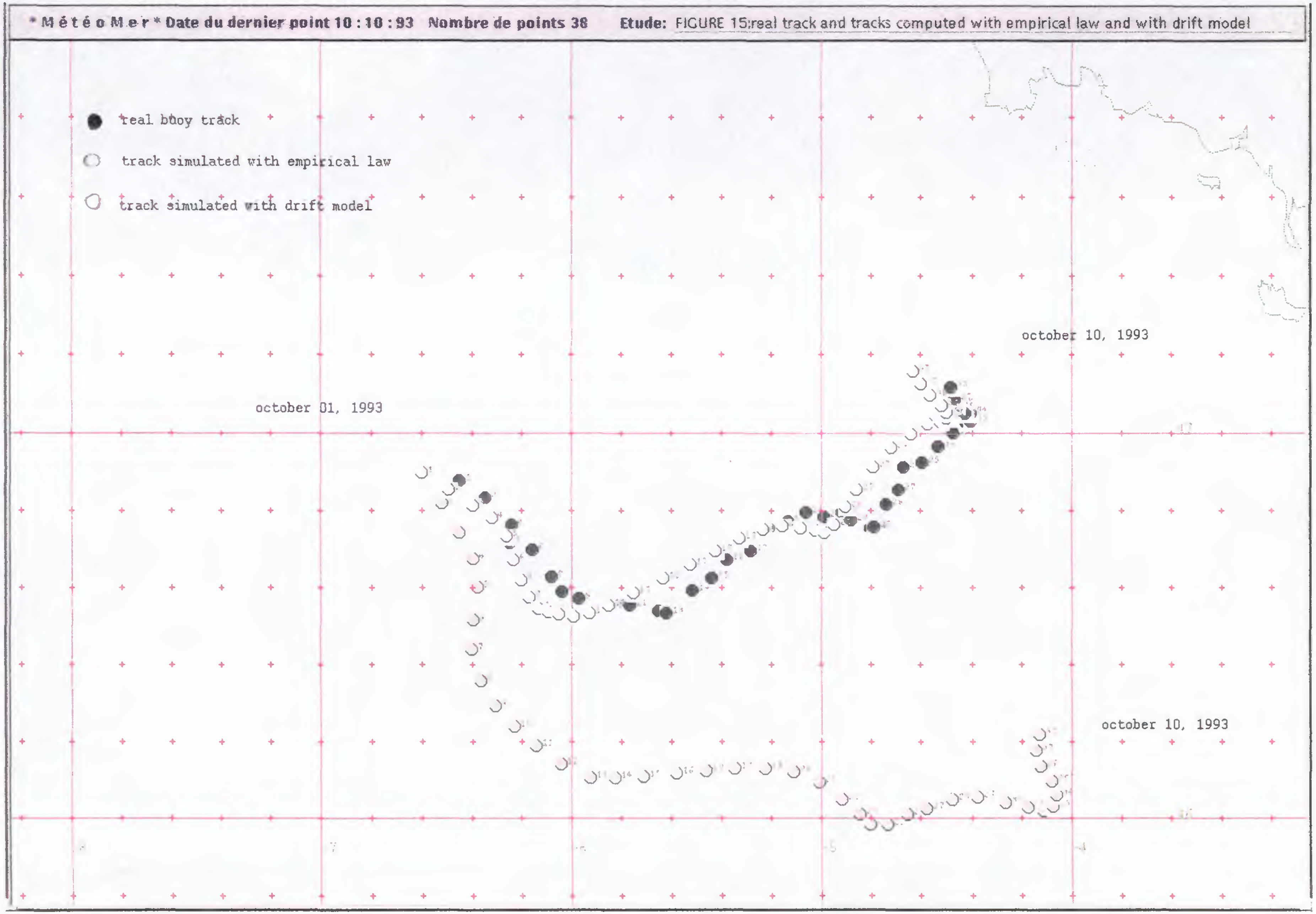


Figure 15 - Real tracks and tracks computed with empirical law and drift model



Toward a decision aid tool for the problem of oil pollution in the Mediterranean

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Abstract

This paper attempts to identify the commonality of different decision aid systems through the example of "hydrocarcarbon spill at sea" which addresses risk assessment and risk management, with reference to the newly recognised Sciences of Danger, called "cindynics".

The concept of MOPISM (Mediterranean Oil Pollution Integrated System Management) is introduced : an analogy is made with a living organism, having senses, nervous system, memory and brain; space-based Earth observation data and information playing the role of the vision. Socio-economic and environmental benefits are expected from a MOPISM able to provide useful decision aid to the user in right time. Evolution theory applies to the MOPISM.

MOPISM with the most developed brain that makes the best use of all its senses will have the favour of responsible users to receive the most funding and will provide the maximum return on investment.

Oil pollution monitoring in the Mediterranean cannot be looked at independently of a more global system that should consider all the aspects including : monitoring, analysis, understanding, modelling, predicting, managing to address the overall problem of hydrocarbon at sea for a risk assessment and more generally for risk management.

The Mediterranean is a good example, in the sense that it is a close system with fairly well defined borders with other parts of our biosphere.

Monitoring is one very important element of a more sophisticated system that the different users - in our case, the authorities in charge, insurance companies, owners (cargo, platforms, pipelines), observatories, ...- need, to address the problem of hydrocarbon natural, artificial or accidental release in or close to the sea.

A presentation of a different approach for all system that uses or could use space-based Earth observation data and information in a way that shows clearly its contribution to the overall problem is proposed in this paper.

The problem :	clearly identified oil spill risk management
The location :	the Mediterranean
The users :	- oil owner (cargo, ships, platforms, government, ...), - insurance companies, - organisations responsible geographically and legally - observatories in charge - any body interested

Very often action is needed because natural system can't absorb fast enough with time scale compatible with actual human activity. Something has to be done. For hydrocarbon pollution, it may be a need of external regulation by eventually removing oil.

Actions are required : it is important to take them as fast as possible and cost of action should be minimum for the maximum benefit.

The user in charge should be faced with the following economic system :

maximise the final result in terms of politically acceptable,
environmentally, technically, and economically sound ,
taking into account the cost of taking decision and actions taken.

It is important to quickly simulate different solutions for action and for that, the user must rely on an efficient decision aid tool.

For environmental problems, a generic form can be proposed on the idea that decision aid tools to be efficient should have some analogy with living organisms that survive natural selection.

This introduces the concept of MOPISM : Mediterranean Oil Pollution Integrated System Management of the family of SEISM (Standard Environmental Integrated System Management).

A MOPISM has the same functionalities as a sophisticated living organism i.e. its senses (*in situ* measurement, underwater sonar, remote sensing), its nervous system (communication links, high speed networks, ...), memory (archive, catalogue, database management) and most important its central nervous system (processor, scientific models, economic and social models, ...) to be able to monitor, understand, simulate, predict and communicate with the USER.

If all these functionalities exist and are well balanced, the usefulness of a MOPISM will be enhanced and will justify the investment for its development. The mission of a MOPISM is to provide decision aid to the USER.

In our case, the monitoring aspect (observation) requires a good "global and local vision" capability that comes from space and/or airborne dedicated instrument.

Socio-economic benefits will be of value only if there is an efficient integration of different sources of information with adapted processing and modelling.

This approach could help reducing the gap between managers and technicians, users and service providers, between remote sensing specialists, experimenters, field experts and modellers.

It is only through practical applications with operational integrated systems that an overall return on investment can be expected. The initial investment in a MOPISM and then the cost of the actions proposed by it will reduce cost of poor management by lack of information by a significant amount.

Evolution theory is a good analogue for the study of a MOPISM.

At the beginning, a MOPISM should be designed and raised to survive a harsh environment. Survival rates are very small after breading phase in "non-competitive" environment will have stopped. MOPISM should prove their efficiency to be financed and be prosperous and develop.

The initial choice of the different MOPISM to design and/or develop is very important and any MOPISM without all necessary component will have little chance to prove any usefulness in front of an other one taking advantage of all capability available.

The role of the different elements of a MOPISM should be as sharp as any organism sub-system. Functionality should be clearly distinct : the vision (airborne or space-based Earth observation) is not the touch (*in situ* observation) and even less the brain (specialised process, modelling, simulation, ...). Any hypertrophy of one element to the deficit of an other one would be a prejudice for the MOPISM and would reduce its chance of survival. Natural selection would develop the brain (system aspect) more than any component.

The dinosaurs-type MOPISM has no long term future.

Evolution of MOPISM will take place with time as a function of technical evolution and experience of past MOPISM generation.

In the early age of the SEISM concept (nowadays) we should be very careful that in our trial of developing MOPISM, we don't neglect any element to assure the survival of the species :

- very good vision :
  - farfield and global (space-based dedicated instrument)
  - near-field and local (airborne instrument)
- very good touch :
  - sampling;
  - *in situ* permanent or on demand *in situ* sampling capability
- very good smell :
  - specific sensor (volatile component, evaporation and sensor)
- very good hearing :
  - sonar (traffic monitoring, accident, ...)

and also :

- very good communication
- very good archiving and cataloguing
- very good brain

OIL POLLUTION MONITORING IN THE MEDITERRANEAN

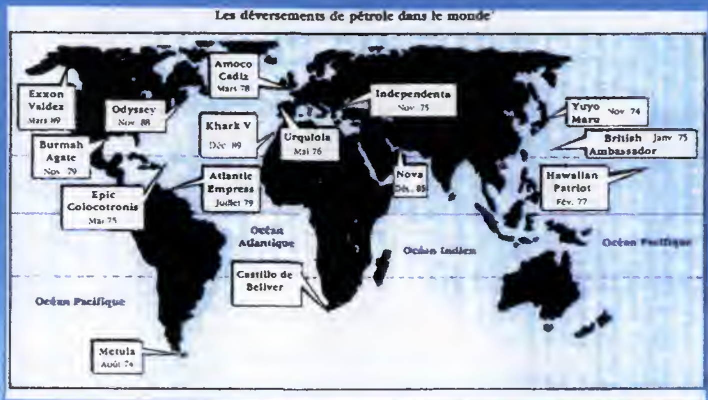
25-26 March 1996
ESRIN - FRASCATI

ACRI
Philippe BARDEY
Sophia Antipolis
FRANCE

ERS © ESA

DECISION AID TOOLS FOR THE PROBLEM OF OIL POLLUTION IN THE MEDITERRANEAN : THE "MOPISM" CONCEPT

Mediterranean Oil Pollution Integrated System Management



Depuis 16 ans, 160 pétroliers ont été impliqués dans des déversements.
La quantité de pétrole deversée permettrait de remplir plus de dix petroliers géants et la couche de pétrole correspondante pourrait couvrir plusieurs fois la mer Méditerranée toute entière.
Le plus gros déversement a eu lieu en juillet 1979, au large de Trinidad, où 2 044 000 barils de pétrole ont été déversés (Atlantic Empress).

Comment comprendre que l'activité petrolière internationale, prise comme un système d'ensemble, deverse en mer des quantités de petrole capables de recouvrir plusieurs fois la Méditerranée ?

Comment expliquer la vulnerabilité et la fragilité des tankers petroliers qui transportent d'énormes cargaisons ?

Comment expliquer que l'on tolère des equipages negligents à qui l'on confie de pareilles bombes ecologiques ?

Rien ne sert d'accuser separement le capitaine, la compagnie, les armateurs, le secteur de commerce petrolier, les autorités terrestres ou maritimes. Il s'agit d'un système global.

Ce système est porteur de DEFICITS SYSTEMIQUES CINDYNOGENES.

Dans le cas du petrolier, on a tort de considerer que le probleme est justiciable de position simpliste (DSC 2).

- On n'a pas su dans le transport maritime petrolier, corriger les déficits organisationnels. Il y a encore subordination des fonctions de sécurité aux imperatifs de production (DSC 5) et la dilution des responsabilités entre équipages, armateurs et compagnies est considerable (DSC 6).
- On n'a pas voulu tirer les conséquences des naufrages et déversements dans la conception des tankers (DSC 7).
- On ne forme pas les equipages à leurs responsabilites ecologiques (DSC 9).
- On manque, evidemment, de méthode dans l'ignorance des grilles d'analyse cindyniques (DSC 8 et DSC 10).

SOURCE :

L'ARCHIPEL DU DANGER
INTRODUCTION AUX CINDYNIQUES

Georges-Yves KERVERN   Patrick RUBISE

Augmentation de la population urbaine et zones écologiquement sensibles en Méditerranée

TABLEAU A   Les déficits culturels

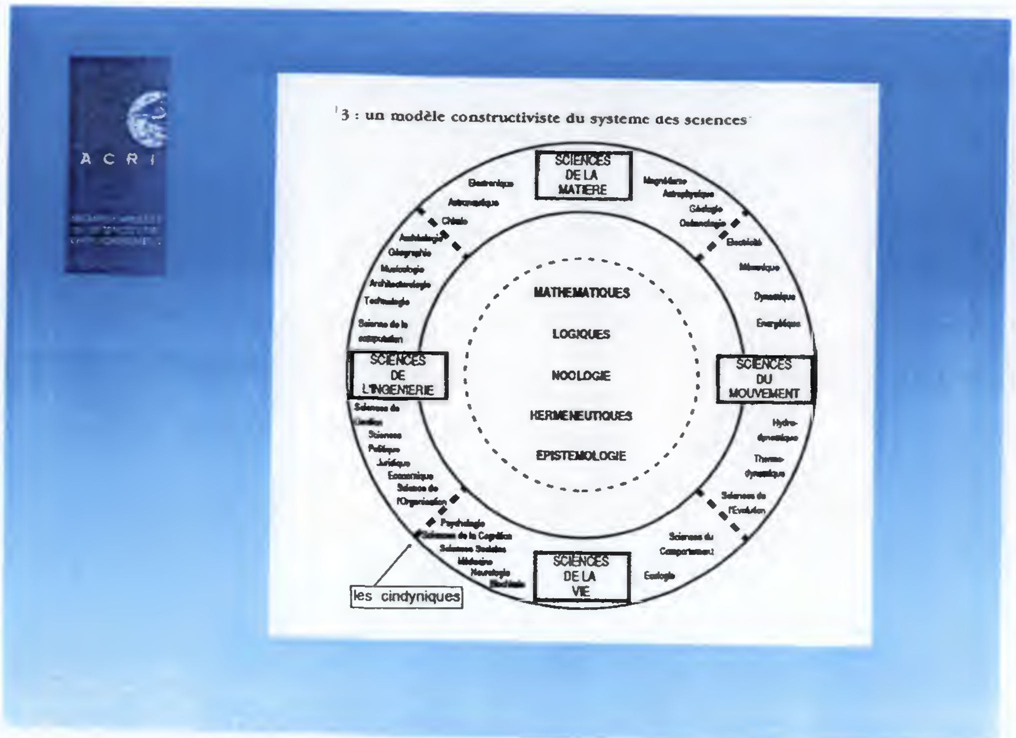
Domaine du déficit	Numéro du DSC	Désignation du DSC
CULTURE D'ORGANISME	DSC 1	Culture d'infaillibilité
	DSC 2	Culture de simplisme
	DSC 3	Culture de non-communication
	DSC 4	Culture de nombrilisme

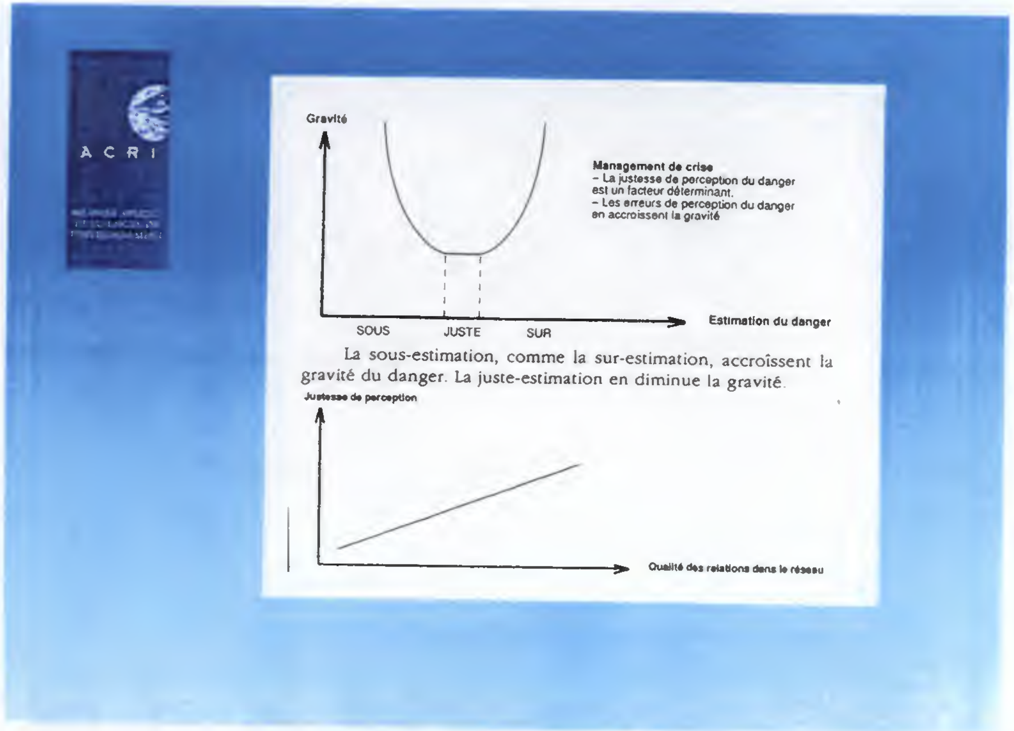
TABLEAU B   Les déficits organisationnels

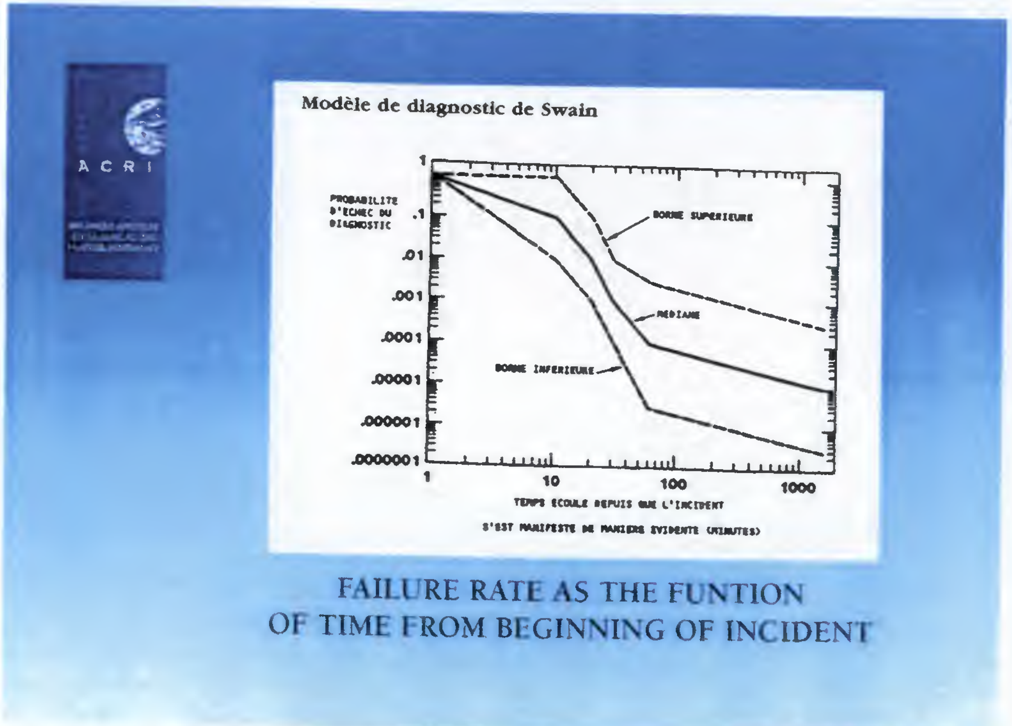
Domaine du déficit	Numéro du DSC	Désignation du DSC
ORGANISATION	DSC 5	Subordination des fonctions de gestion du risque aux fonctions de production ou à d'autres fonctions de gestion créatrices de risques
	DSC 6	Dilution des responsabilités. Non explicitation des tâches de gestion des risques. Non affectation des tâches à des responsables désignés

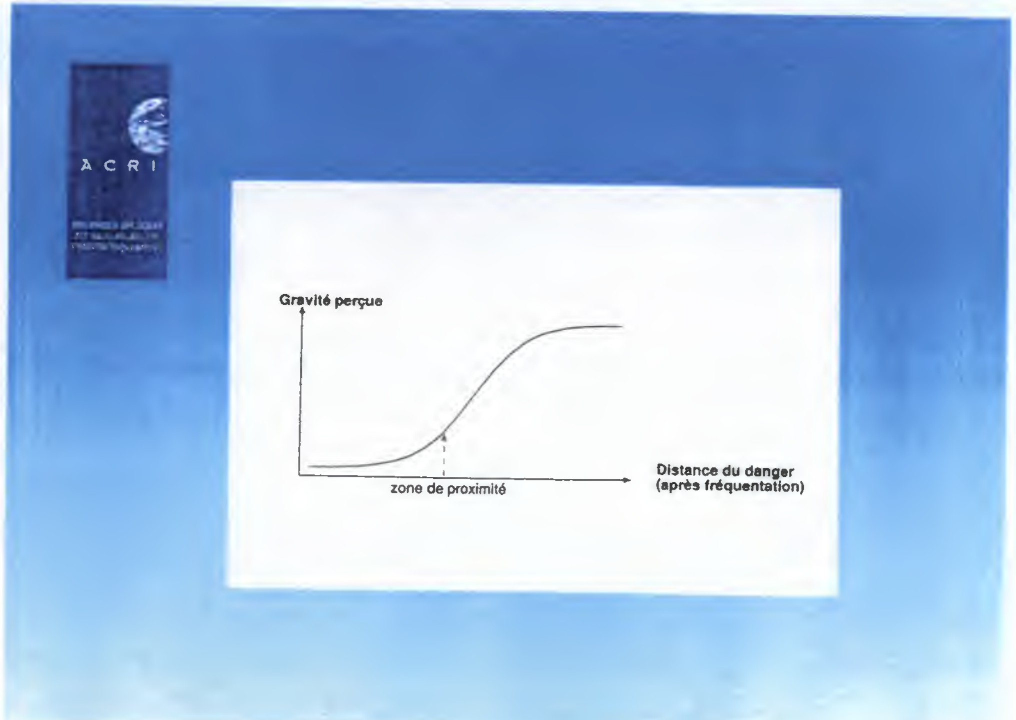
TABLEAU C   Les déficits managériaux

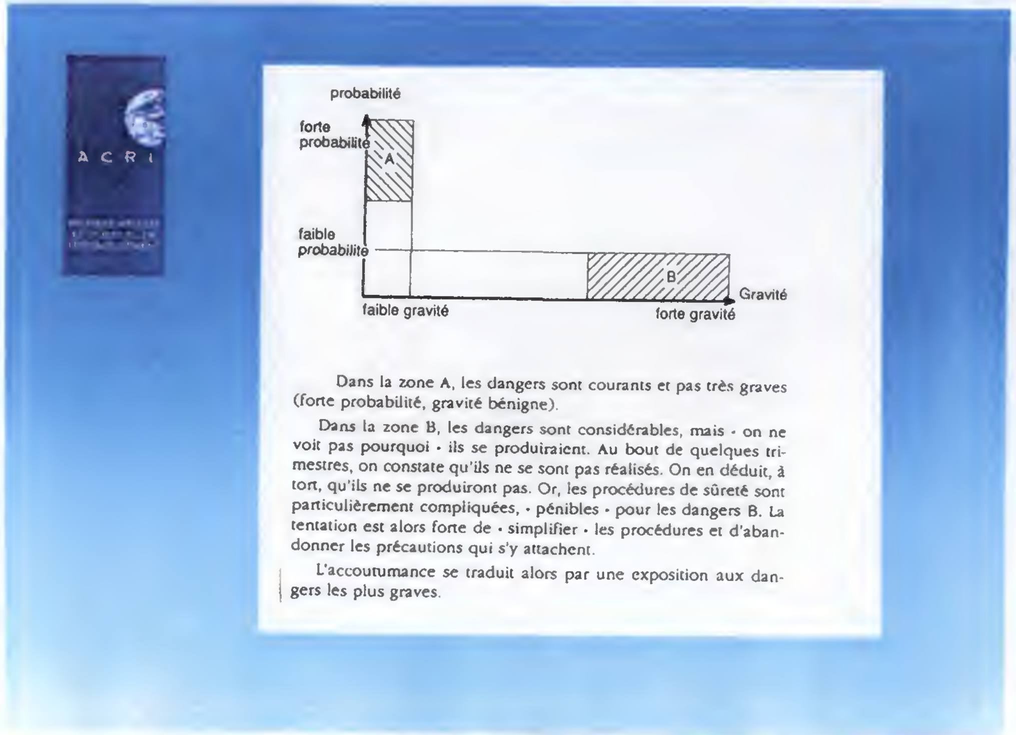
Domaine du déficit	Numéro du DSC	Désignation du DSC
MÉTHODE DE GESTION	DSC 7	Absence d'un système de retour d'expérience
	DSC 8	Absence d'une méthode cindynique dans l'organisation
	DSC 9	Absence d'un programme de formation aux cindyniques adapté à chaque catégorie de personnel
	DSC 10	Absence de planification des situations de crise

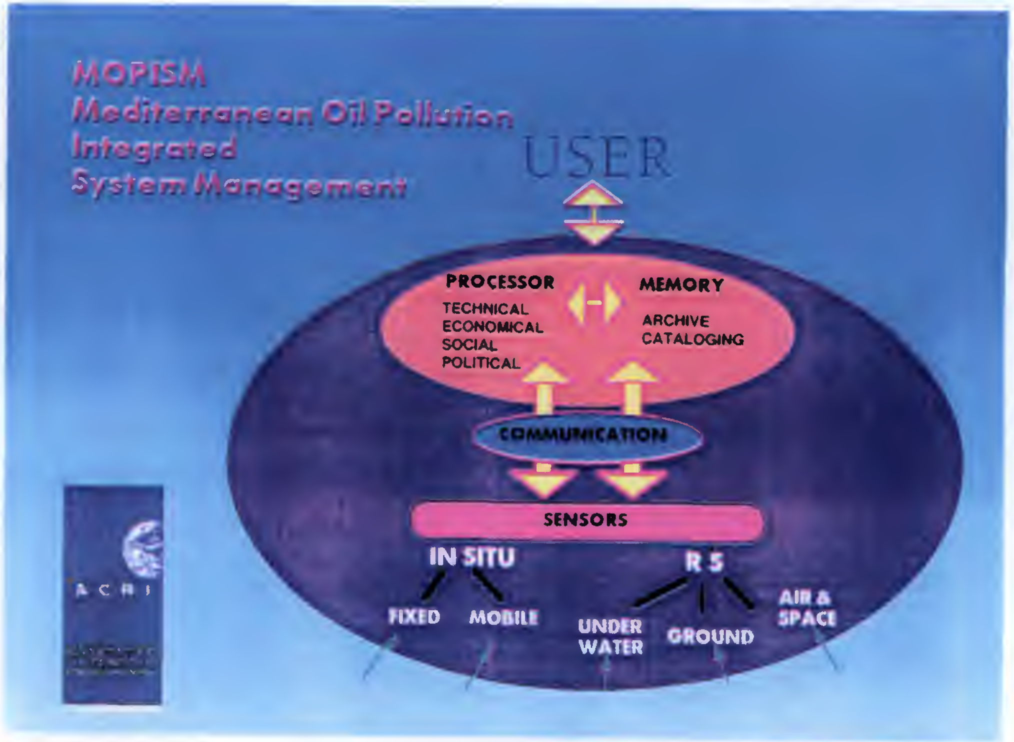

ACRI
3 : un modèle constructiviste du systeme des sciences
SCIENCES DE LA MATIERE
SCIENCES DU MOUVEMENT
SCIENCES DE LA VIE
SCIENCES DE L'INGENIERIE
MATHEMATIQUES
LOGIQUES
NOOLOGIE
HERMENEUTIQUES
EPISTEMOLOGIE
les cindyniques

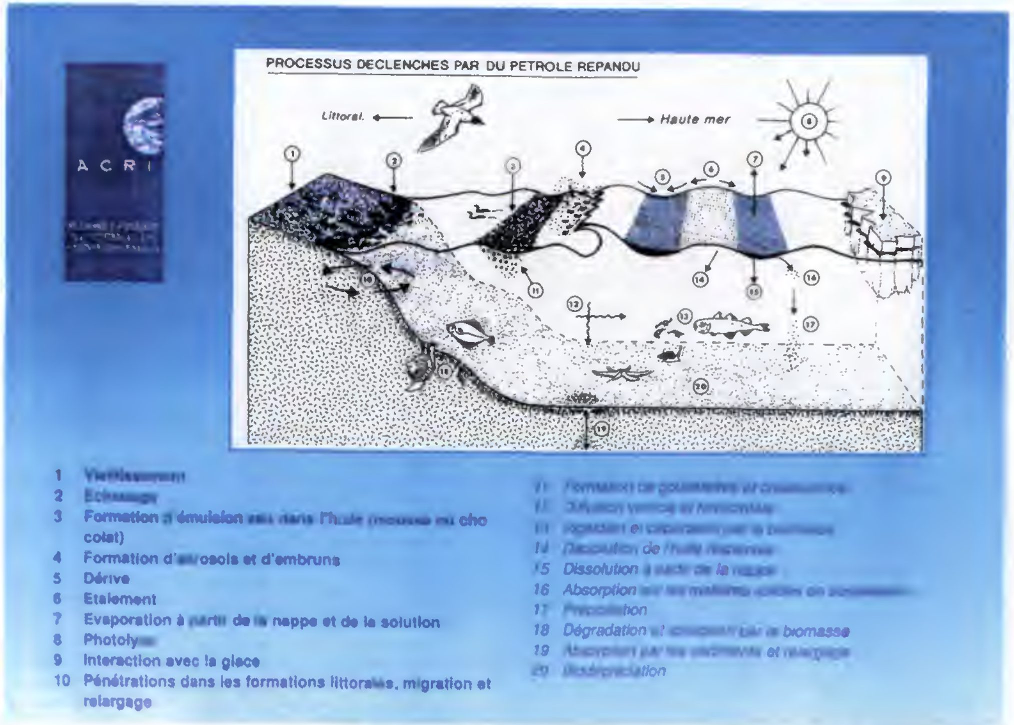

ACRI
Gravité
Management de crise
- La justesse de perception du danger est un facteur déterminant.
- Les erreurs de perception du danger en accroissent la gravité
SOUS
JUSTE
SUR
Estimation du danger
La sous-estimation, comme la sur-estimation, accroîssent la gravité du danger. La juste-estimation en diminue la gravité.
Justesse de perception
Qualité des relations dans le réseau


ACRI
Modèle de diagnostic de Swain
PROBABILITE D'ECHEC DU DIAGNOSTIC
1
.1
.01
.001
.0001
.00001
.000001
.0000001
BORNE SUPERIEURE
MEDIANE
BORNE INFERIEURE
1
10
100
1000
TEMPS ECOULE DEPUIS QUE L'INCIDENT S'EST MANIFESTE DE MANIERE EVIDENTE (MINUTES)
FAILURE RATE AS THE FUNTION
OF TIME FROM BEGINNING OF INCIDENT


ACRI
Gravité perçue
zone de proximité
Distance du danger
(après fréquentation)







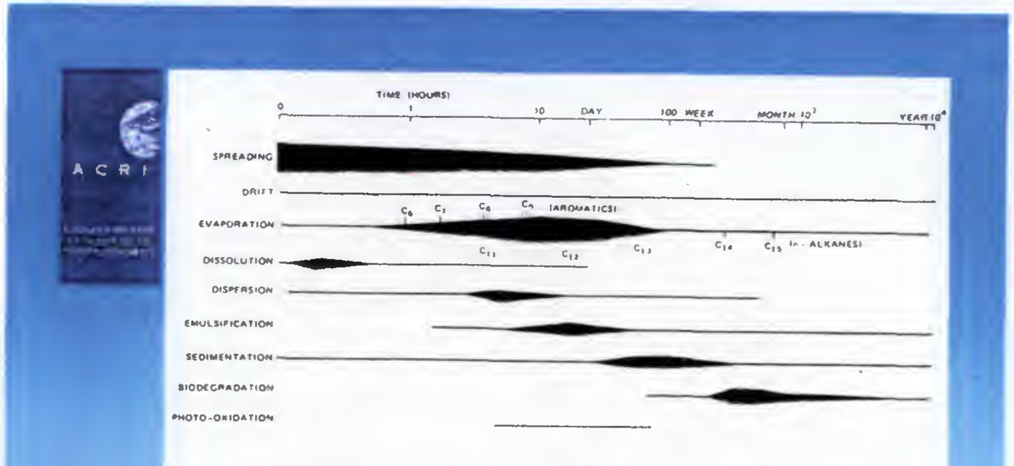


FIGURE 5 : Processes versus time elapsed since the spill. The line length indicates the probable timespan of any process. The line width indicates the relative magnitude of the process through time and in relation to other contemporary processes.

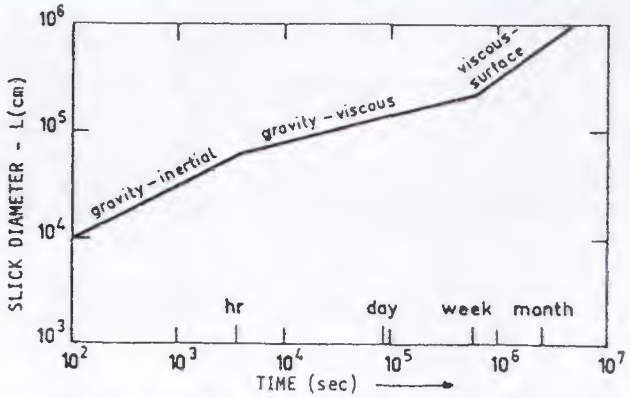


FIGURE 1 : SLICK SIZE AS A FUNCTION OF TIME FOR A 10,000 TON SPILL (FAY 1969)

NOTE: THE CURRENT SPEED, U est, IS ESTIMATED AT THE AVERAGE VALUE FOR THE INCIDENT (30 CM/S) FOR THE TURBULANCE THEORY, AND ESTIMATED AT 5 CM/S FOR THE SURFACE TENSION THEORY TO MAXIMIZE POSSIBLE AGREEMENTS BETWEEN FAY'S THEORY AND THE OBSERVATION (MURRAY, 1972).

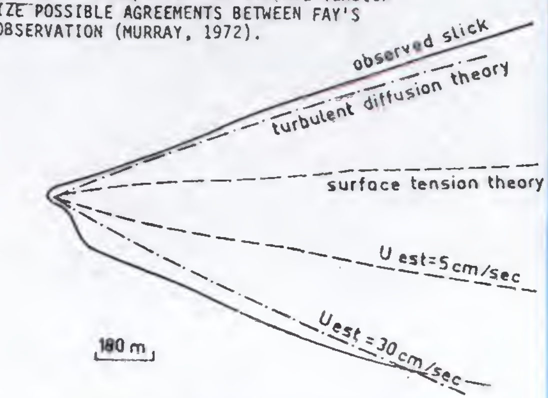
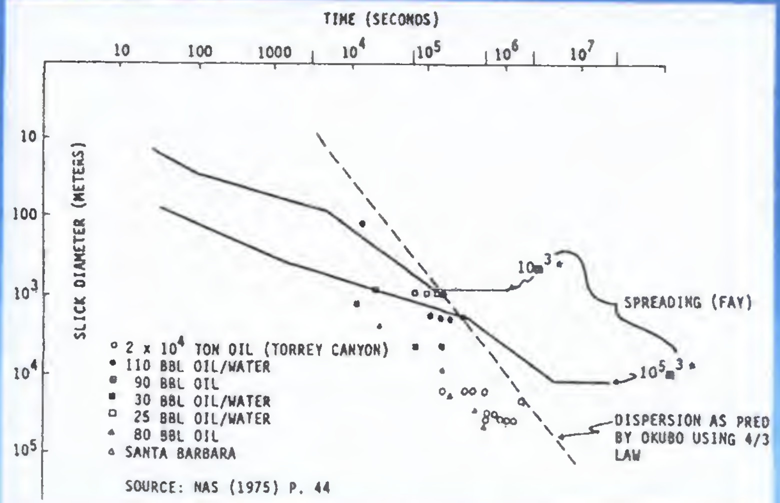
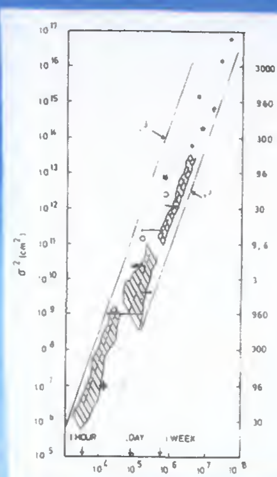


FIGURE 6 : COMPARAISON BETWEEN OBSERVED AND PREDICTED SLICK OUTLINE USING FICKIAN DIFFUSION THEORY AND SURFACE TENSION THEORY OF FAY



SLICK SIZE AS A FUNCTION OF TIME



Variance vs. diffusion time: fit of the t^3 law locally. (Okubo, 1974). The horizontal solid lines represent observed characteristic dimensions of oil spills. Data for these are taken from Fay (1969)

- x Characteristic dimension of blue shine area on the Tromsøflaket experimental oil spill (Audunson et al. 1978)
- o Characteristic dimension of blue shine area during the Bravo oil spill (Audunson, 1980)
- • Simulated extent of an oil spill in the Ekofisk area (Audunson et al. 1979)

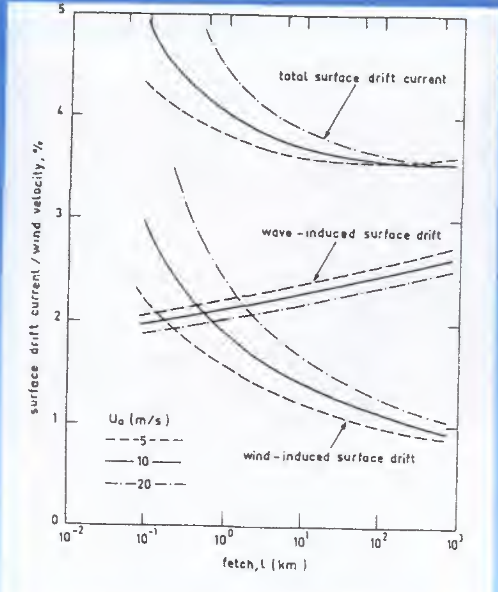
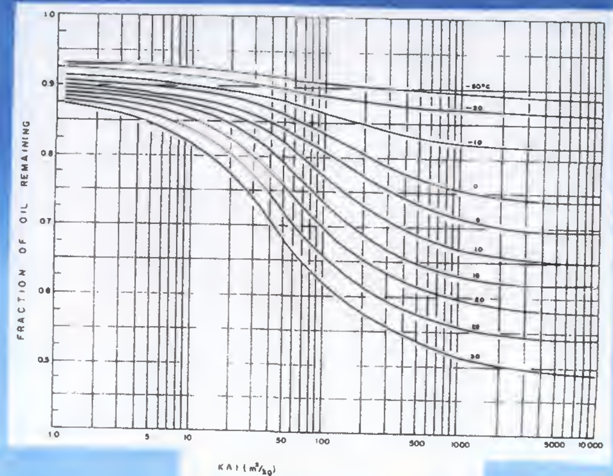


FIGURE 4 : WIND-INDUCED SURFACE DRIFT CURRENT VARIATION WITH FETCH (WU,1975)



- Evaporation curves for light and medium crude oils

	Oeil humain	Appareil photo	Caméra vidéo	Caméra vidéo bas niveau de lumière	Scanneur UV	Scanneur IR	Radar latéral	Radiomètre micro-ondes (1 fréquence)	Radiomètre micro-ondes (3 fréquences)	Fluorocapteur à laser
Type	Passif	Passif	Passif	Passif	Passif	Passif	Actif	Passif	Passif	Actif
Long. d'onde/fréquence	Visible	Visible	Visible	Visible (UV)	UV	IR	Micro-ondes	Micro-ondes	Micro-ondes	UV
Paramètre	Réflexion	Réflexion	Réflexion	Réflexion	Réflexion	Emission	Signal rétrodiffusé	Emission	Emission	Florescence induite
Temps clair										
Jour										
Nuit										
Tout temps										
Détermination du type d'huile										
Détermination de l'épaisseur du film								0,1-2 mm	0,005-3 mm	0,003-0,06 mm
Détection de l'huile sous la surface										
Cartographie										
Limites de détection	Variable				0,5-2 5 Km en fonction de l'altitude		40-180 Km	500 m	500 m	150 m
Transmission de l'images										
Identification des navires										
Documentation sur la position										

Aptitude dépendant des circonstances — Aptitude indépendante des circonstances

PERFORMANCE OF AIRBORNE INSTRUMENTS
FOR OIL SPILL DETECTION

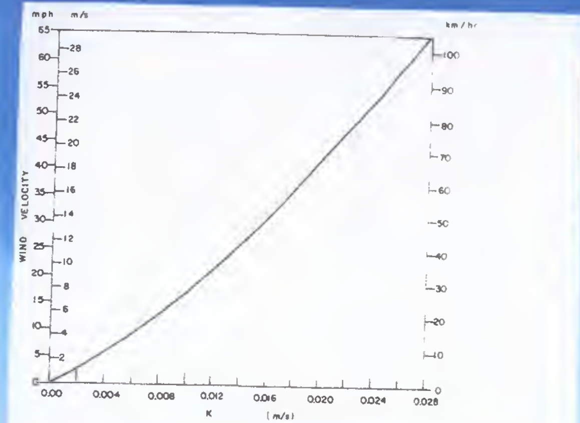


Fig.1 - Determination of the mass transfer coefficient K from the wind velocity

AN OIL SPILL MONITORING SYSTEM BASED ON SAR IMAGES

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1. INTRODUCTION

Oil pollution in the sea is not only a subject of scientific or politic 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 in the prevention of 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 we can mention the prohibition of operational releases of hydrocarbons from ships in the Mediterranean sea (1983).

It is important to note that the environmental effects of oil pollution are stressed for a closed basin as the Mediterranean Sea; furthermore, it is surrounded by countries in which tourism plays an important economical role, and can be seriously affected by the presence of pollution.

Unfortunately, in addition to the international regulations, there is a need to verify the fulfilment of such regulations. So, it is of main interest to have operative techniques for the monitoring and detection of oil spills. The degree of these techniques changes for each country.

The main sources of marine oil pollution are intentional and accidental releases from ships, natural slicks and pollution from land. It is estimated that the operational releases from ships (tank cleaning and ballast release), accounts for 60-80 % of the pollution (VMI-86). 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: the limited coverage supported and the elevated operational costs. Recently, with the advent of civil satellite SAR system, increasing interest is devoted to their use for oil spill monitoring and detection, specially in the North Sea (Bern-93), (Pellemans-94).

Although there is not any ideal remote sensing instrument for the operational detection and monitoring of oil spills (Goodman-94), satellite SAR presents a number of advantages over other systems:

- Imaging of broad areas, worldwide, in a regular basis
- Day-night imaging capability
- Independence of cloud coverage
- Possibility to detect both oil spills and ships
- Availability of satellite SAR systems: nowadays there are some operational systems (ERS-1/2, JERS, RADARSAT), and there will be follow on missions in the mid term

This communication 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. Chapter two presents the background situation of oil spill monitoring in Spain, and it is useful for the definition of the project aims. The project objectives are listed in the third chapter. The detailed description of the demonstrator system is given in chapter four. The requirements of an operational system are reviewed in chapter five. Finally, the conclusions are presented in chapter six and the referenced bibliography is listed in chapter seven.

2. PROJECT BACKGROUND

In this section we will try to describe the background situation of oil spill monitoring in Spain. The first point to be addressed is the importance of the coast in the country. The length of the Spanish coast is about 3900 km. The coastal areas are, in general, more densely populated that 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 economical 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 can be considered as the most important Spanish industry, and the majority of the tourist activities are based on coastal resources. The negative effects that oil spills can have on tourism are obvious. In this case, the main concern is focused in the arrival of the pollution to the vicinity of the seaside.

- Fishing. Fishing is a traditional economic activity in Spain, with more than a million tons captures a year. Although most of the captures are done far away the Spanish coast (North and South Atlantic Ocean mainly), coastal fishing is not to be forgotten. Furthermore, the importance of fish farming is steadily increasing. These two later activities can be seriously affected by the presence of oil pollution.

The measures that the Spanish authorities have taken to implement MARPOL convention are mainly in the direction of prevention rather than monitoring 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 an 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. An specialised organisation, SASEMAR, is in charge of oil pollution cleaning operations.

3. PROJECT OBJECTIVES

The project objectives have been selected considering the context presented in the previous chapter. 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 give reasons for the 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 can be 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 following chapter. Concerning the tests and evaluation activities, two areas have been selected according to the probability of oil spills and their environmental impact: Gibraltar Strait and Tenerife (Canary Island). These two locations have in common the presence of 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.

4. DEMONSTRATOR OPERATION

The implementation of the demonstrator system is to resemble as much as possible the operational situation. The structure of an integrated system for oil spill monitoring is depicted below and in figure 1.

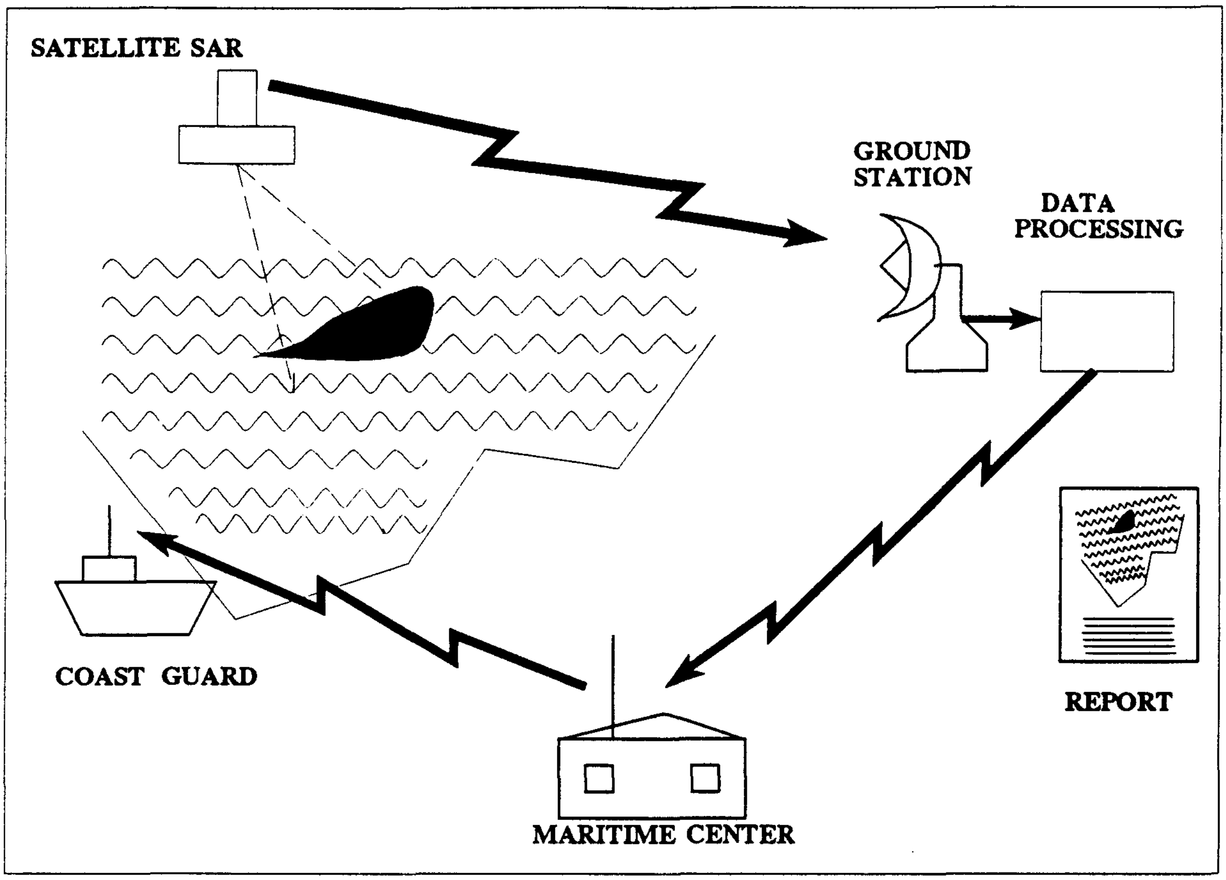

Figure 1. Integrated system for oil spill monitoring.

- Data reception system (Maspalomas Station). This subsystem is responsible for the acquisition of satellite SAR data and transformation to computer compatible format.

- Data processing system, that is the specific target of the project. The processing subsystem is responsible of all data processes to obtain the potential oil spills (in the form of text and graphic report) 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 expected for the Spanish case.

The main characteristics of the data processing system, that is the main subject of the project, are described in the following subsections. A schematic view of the demonstrator is presented in figure 2. Two practical examples of ERS-1 SAR images are given in figures 3, 4, 5 and 6.

4.1 Hardware environment

The demonstrator system will be developed and implemented on a commercial UNIX work station, whose characteristics are:

Sun Sparc 20/71, 1 processor running at 75 MHz
128 MB RAM, 4 GB disk memory
CD-ROM reader unit
Exabyte tape unit

4.2 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 is to be considered. Once the data is in the computer the next step is to read the header information, and to determine the area covered by the data set. Then, a selection of the interesting data is to be done, disregarding non interesting areas (ie. land).

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 will be summarized in a processing parameters file, that will serve as input to the SAR processors.

4.3 Quick-look image generation

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

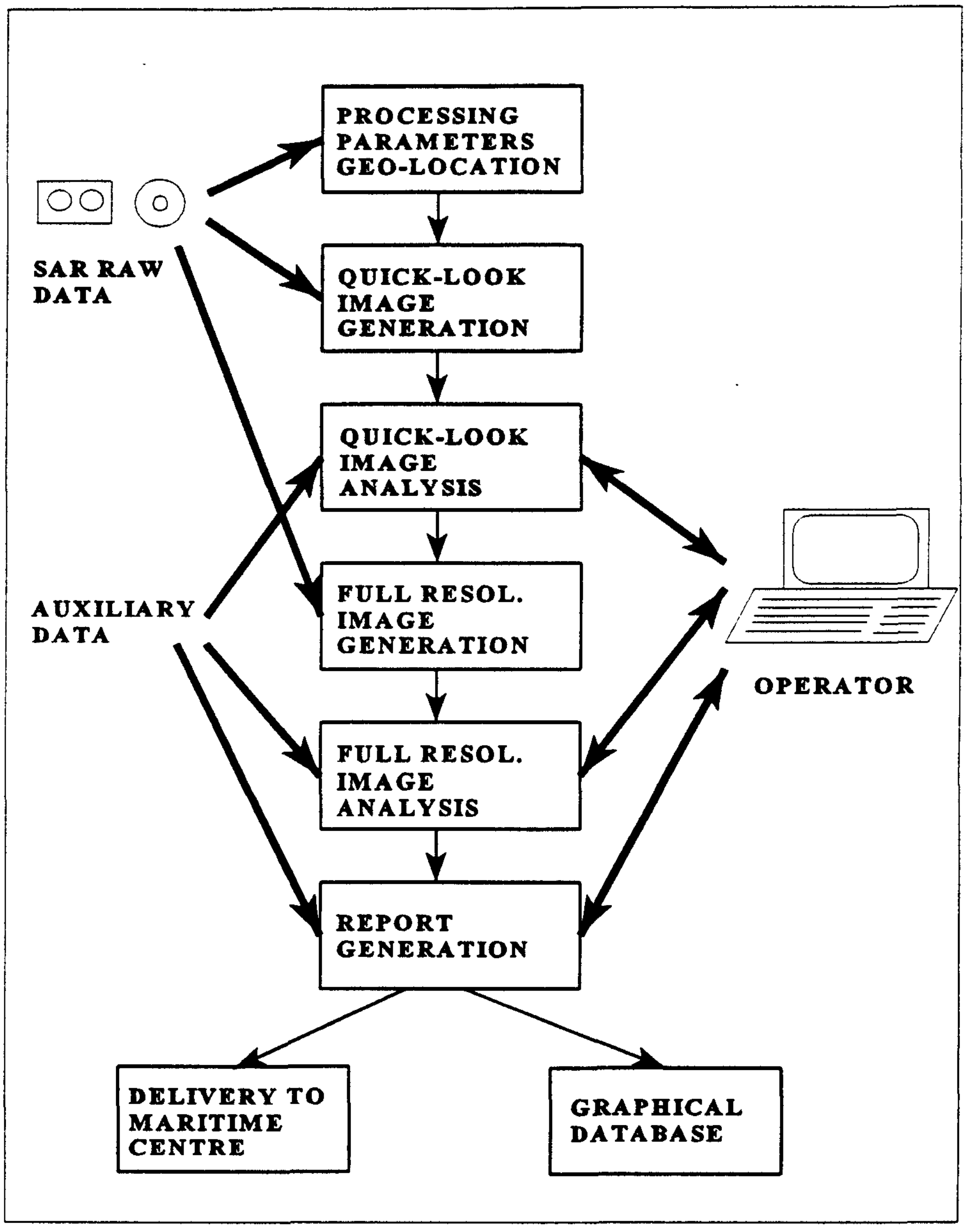

Figure 2. SAR data processing system.

A number of processing parameters need to be studied in order to optimize the system; these parameters are:

- decimation factors (in range and azimuth directions)
- number of looks (in range and azimuth)
- pixel spacing
- pixel quantization

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

- range decimation factor: from 1 to 4
- azimuth decimation factor: from 1 to 4
- number of range looks: 1 to 4
- number of azimuth looks: 4 to 8
- pixel spacing: 100 to 200 m
- pixel quantization: 4 to 8 bits
- processing time: 5 to 10 minutes for a 100 km x 100 km scene

4.4 Analysis of quick-look image

The generated quick-look image will be automatically analysed for the detection of oil spills. The following steps are envisaged:

- A mask will be overlaid on the image to fix the interest area (separating land an outer sea areas, if applicable). This task requires the knowledge of the image corner coordinates.

- The detection algorithm will operate only in the interest area. The basis of the algorithm is the search for small areas of low backscattering. Depending on the quick-look image resolution, it will be useful to detect also ships in the surrounding of potential targets. The processing time of the detection algorithms should be less than 5 minutes.

- The potential targets identified by the detection algorithms will be selected and marked on the screen. Appropriate tools will be developed to perform distance and surface measurements in the image, and also to display auxiliary information that may help the system operator (meteorological and oceanographic information).

- The system operator will analyse the results and will have the possibility of rejecting a potential target, issue directly an alarm and also to further process the data of interest.

4.5 Full resolution image generation

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

- ground range projected images
- number of azimuth looks: 3 to 8

- pixel spacing: 12.5 to 30.0 m
- pixel quantization: 8 to 16 bits
- processing time: 5 to 10 minutes for a 20 km x 20 km sub-scene

4.6 Analysis of full resolution sub-image

It will be possible to apply speckle filters to the full resolution SAR images in order to improve the performance of the detection algorithms.. The SAR image analysis algorithms for full resolution images will be basically the same that those for quick-look images, with the only difference 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 will presented on screen, overlapped to the image data. Land mask will also be displayed if applicable. Appropriate tools will be developed to perform distance and velocity measurements for the ships that may appear in the image.

The system operator will analyse the results and will have the possibility of rejecting a potential target or issue an alarm.

4.7 Report Generation

A text report will be 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 will be appended to the report. The generation of a synthetic vector image, with the extracted information from the full resolution SAR sub-image will be addressed, as it may reduce significantly the size of the report package. The size of the report package will be about 100 kB, allowing a fast transmission through standard networks to the decision centre. The full images can be 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 km x 100 km scene) to about 100 kB.

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

5. TOWARDS AN OPERATIONAL SYSTEM

We have identified three basic requirements that are needed to get an operational oil spill monitoring system based on satellite SAR images:

- Availability of SAR data
- Fast reaction to alarms
- High reliability of the alarms

5.1 SAR Data Availability.

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

The revisit time is dependent basically on the configuration of the space segment:

- orbital characteristics (altitude and inclination)
- sensor characteristics (mainly the swath width)
- number of SAR satellites
- location of the interest area (latitude)

It is obvious that this subject is beyond the scope of our project, as we are forced to work with the available space segment, that for the time being is limited to the ERS-1/2. This fact 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).

5.2 Delay from data acquisition to alarm triggering

The second requirement for an operative oil spill detection system is the reaction time from input data reception to the alarm triggering. The reaction time should be kept from one to two hours;

in this way, 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 two weeks using the standard channels or 24 hours using ESA BDDN (Broadband Data Dissemination Network), far away from operational use. The key point 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 Island, should suffice, as it coverage area includes the whole country (Fucino Station does not covers the Canary Island). At the present time, Maspalomas Station receives SAR data from ERS satellites, but can not perform any SAR data processing (the data is recorded and sent to the different PAF's for processing).

5.3 Alarm reliability

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

- 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 and 13-15 m/s respectively.

- presence of other features resembling the shape of oil spills, like plankton slicks and wind shadows in the seaside.

The internal parameters which has 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.

6. CONCLUSIONS

Oil pollution in the sea is an issue of great interest due to its environmental and economical impact. The negative effects of this type of pollution are stressed for a closed basin as the Mediterranean Sea. The operational releases from ships are considered the main source of oil pollution in the 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 in the analysis of satellite SAR images, as we consider that these are the only reliable remote sensing data suitable for the purpose. 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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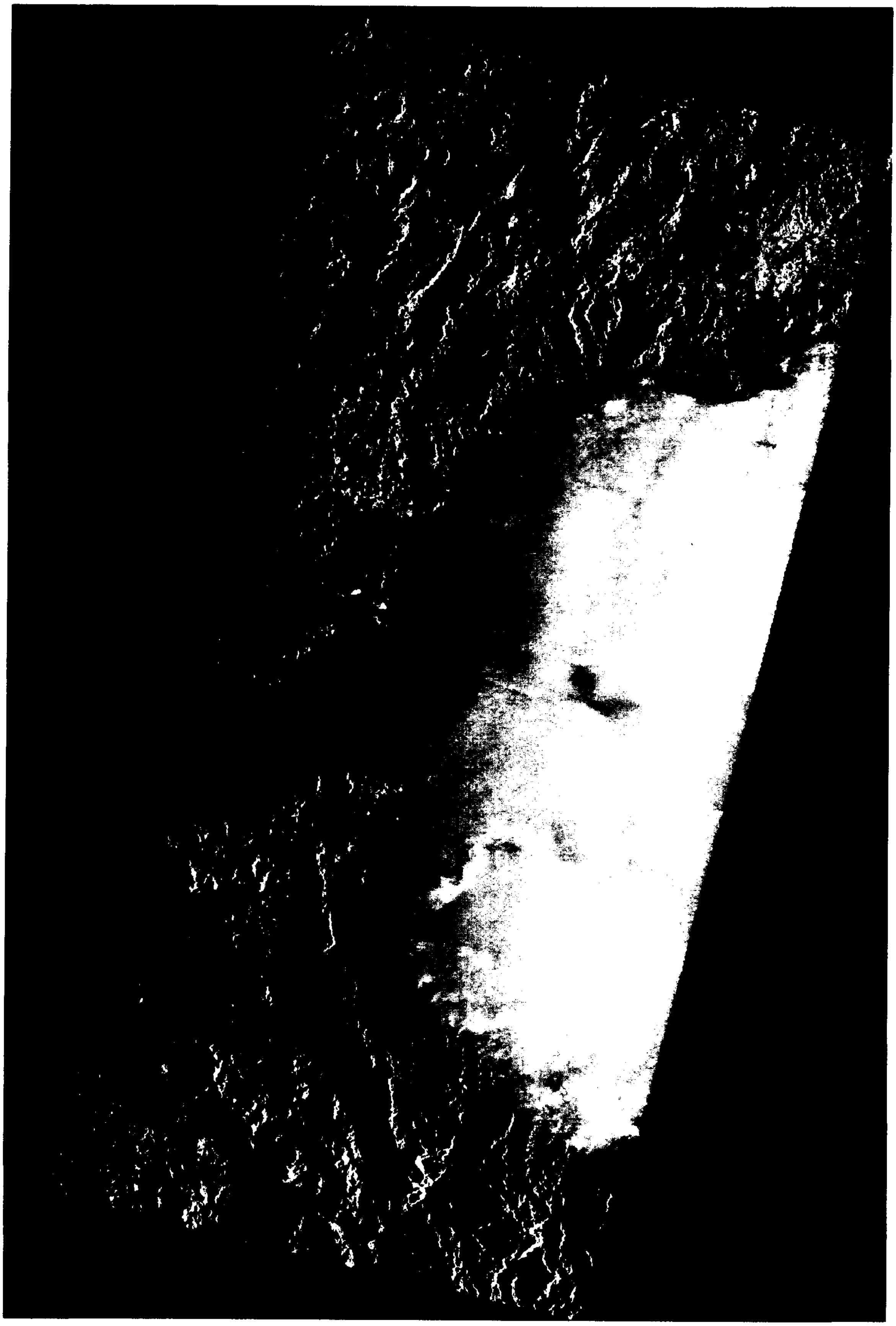

Figure 3

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

Figure 4

Full resolution image of the oil spill shown in figure 3 (the pixel spacing is 20 m x 20 m) (C) 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.

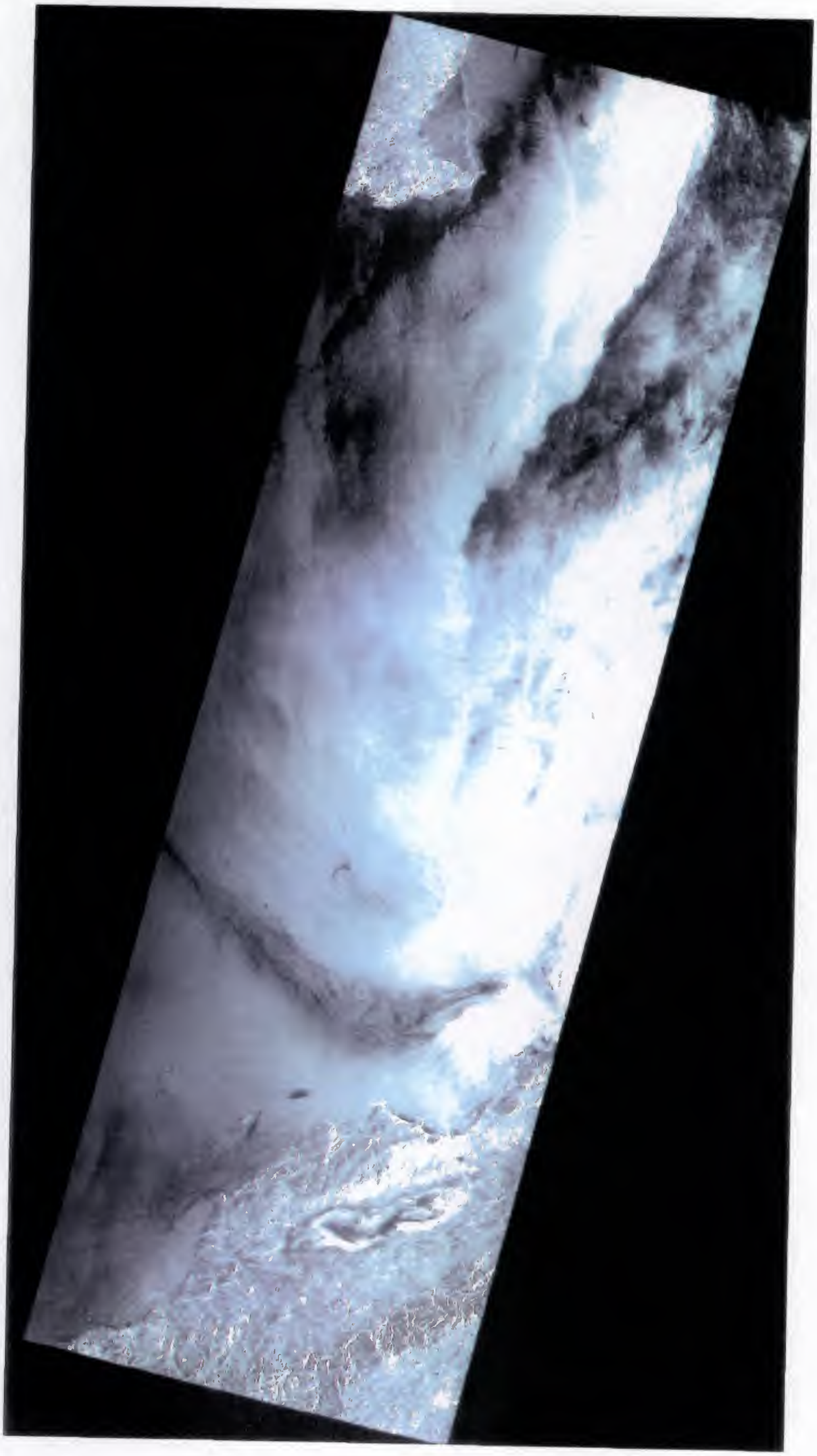

Figure 5

ERS-1 SAR quick-look image of Alboran Sea (western Mediterranean) between Algeria and Spain, acquired on 2nd October 1992 (C) ESA 1992. The image covers an area of 100 km across track by 300 km along track; the pixel spacing is 300 m x 300 m. The V-like dark feature close to the Algerian coast can 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.

Figure 6

Full resolution image of part of figure 5 (the pixel spacing is 20 m x 20 m) (C) 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 figure 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 corresponds to the ship wake and an oil spill or just to the ship wake.

The potential of ERS SAR in oil spill monitoring and a regional application in the Mediterranean coastal zone.

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Abstract

The results of an investigation, aiming to shed more light in the physical mechanisms, that enable the SAR to "see" the oil spills on the sea surface, are briefly presented. The detection capability is expressed in terms of wind speed, and singularities of oil spill signatures, on the ERS SAR imagery, are discussed. In addition, a short assessment of the oil spill occurrences, in the Mediterranean coastal zone, based on the interpretation of a sample set of ERS-1 SAR images, is given. The results indicate, that oil spills, attributed to leakage or tank washing discharges, which usually escape detection and response, comprise a considerable threat in the Mediterranean Sea. Moreover it appears, that certain regions are exposed to chronic pollution, calling for more focused monitoring and abatement measures.

Introduction

Mineral oil discharges in the sea, either by ship and offshore platform accidents, or leakage and flushing of oil tankers, constitute a potential source of pollution for the marine environment. The lethal effects of the mineral oil, to the fragile marine and coastal local ecosystems, have been by far well recognized. However as long as there is a global reliance on petroleum products, oil spills will continue to occur, thus making necessary the strengthening of their monitoring.

It is hopeful, that this continues threat has long ago triggered the sensitivity of the international community, leading to multinational oil pollution monitoring and abatement measure conventions. It is also a good step ahead, that many countries have started to employ airborne surveillance patrol operations, over marine areas of their concern. However due to the small coverage in relation to the high costs, of such operational facilities, their application is considerably limited, in a small number of coastal countries.

On the contrary, current and future missions of spaceborne SAR sensors, similar to ERS-1 and its successor ERS-2, which are expected to capitalize on the all weather day and night imaging capability, offer a good opportunity for surveillance, and hopefully at regular time intervals. Under this possibility many countries are considering their use, in order to survey sea areas for oil spill monitoring.

The potential of radars in the detection, of man made mineral oil spills on the sea surface, is well established. Moreover the large-area search, makes it a promising tool for oil pollution monitoring. However the effect of the sea state in the detection capability, as well as the extraction of signatures, that may enable the discrimination of man made mineral oil spills among natural "look-alikes", are still under skepticism. To a great extent, the problems in resolving such questions, originate by the fact, that the physical mechanisms, which influence the radar response over an oil spill, have been still unclear (Masuko et al 1995).

It is known since ancient times (Aristotle, Problematica Physica, 23, no. 38), that viscous mineral oil spills damp the high frequency sea surface waves (i.e. in the gravity-capillary spectral region). Due to this effect, the radar backscattering from the spilled area is also reduced, making them visible on the SAR imagery. However it is known by experience, that oil spill detection by radars is limited by the sea state. Too low sea states will not produce sufficient sea surface roughness in the surrounding sea, to contrast to the oil, and very high seas will result to increasing microwave backscattering from the spilled area, reducing its contrast to the surrounding sea.

Moreover under certain air/sea boundary layer conditions, other sea surface manifestations of natural origin may result to SAR expressions, similar to those due to man made mineral oil spills. Although an experienced eye may discriminate a mineral oil spill, among natural "look-alikes", a unique signature identified via an automatic system, sufficient to support the necessity for immediate response, is still a subject for research.

Obviously the great number of the SAR scenes, acquired so far over the oceans by the ERS SAR missions, comprise a good background for such research. However the orbit pattern and acquisition scenario, of these experimental missions, may not serve the requirements of a fully operational oil spill monitoring scheme, as far as the incident response is concerned. On the contrary, the amount of the archived data may offer the initial aid, in the isolation of areas facing higher pressure of oil spill pollution. Should that be done, then monitoring schemes may be initialized, over such specific areas of high priority, whose regular surveillance may be possible, even in the constrains posed by the current acquisition pattern limitations.

To enable the effectiveness of the available spaceborne ERS SAR systems, in helping as a functional aid in monitoring oil spill pollution, an investigation was undertaken, whose principal conclusions, of practical use, are briefly presented here.

The effect of the wind speed in the oil spill detection by the SAR

At oblique incidence angles, as in the case of the ERS SAR, the radar backscattering strength, from the sea surface, is dominated by the Bragg scattering mechanism. This is directly related to the height, of the wind-generated gravity-capillary sea surface waves. The wave height, of this explosive type wave modes (i.e. when the wind is blowing), can be satisfactory represented, as a function of the wind speed.

Donelan and Pierson (1987) showed, by theoretical consideration, that a minimum wind speed of the order of 2 to 2.5 m/sec (depending on the sea surface conditions i.e. temperature, salinity etc), is required to generate sufficient sea surface roughness, to be detected by C-band radar. Although detailed experimental work, in the open sea, has not been done systematically, some reported cases (O'Neil et al 1983, Hielm 1989, and others), as well as open sea experimental observations (Bern et al 1992), indicate that the lower wind speed limits, are in accordance to those theoretically estimated (i.e of the order of 3m/sec).

On the other hand, at very high wind speeds (typically above 15 m/sec), the oil is washed down by the waves (Alpers 1993), and the spill disappears from the surface, thus making it impossible to be detected by the SAR. However, the upper limit for detection seems to be lower that the above (some reported cases bring it to as high as 10-14 m/sec e.g. Singh et al 1986), since it appears to be variable, depending on the imaging radar parameters, as well as on oil type and spill age (Bern et al 1992).

Following a modeling approach (Pavlakis 1995a), based on the integration of the energy balance equation of the sea surface waves (Hasselmann 1960), the effect of an oil spill, on the evolution with the wind of the sea wave spectrum, was studied. The wave damping effect caused by the spill, was incorporated in the model, via the resonance-type damping theory (known also as Marangoni damping), (Cini and Lombardini 1978, Lucassen 1982, Huhnerfuss 1986, Cini et al 1987). Using first order Bragg backscattering theory (Alpers and Huhnerfuss 1988), and estimating rheological parameters for a crude oil spill, the effect of the wind on the radar backscattering contrast, was computed. The estimates of the rheological parameters of the spilled sea surface (i.e. viscosity, dilational modules of the oil film, and the surface tension), were obtained by curve fitting to open sea radar backscattering experimental data (Singh et al 1986), acquired over a crude oil spill, using multiband radar at variable angles of incidence. Parameters of different types of crude oil spills, or other petroleum products in the sea, can be estimated in the same way, if similar field experimental measurements are undertaken (Wismann 1993).

The results concerning the crude oil spill under examination, are presented on figure 1. Here the relative clean/spilled sea surface radar backscattering contrast, presented as gray level variations (between 0 to 10 dB and higher), is given as a function of wind speed and wave number. The Bragg backscattering region, which approximately correspond to the radar bands of interest, for incident angles between 23 to 65, are also indicated on the wave number axis of the plot. In this case it is turned out, that from the operational point of view, a well detectable contrast signal on C, X and Ku band radar imagery (i.e. higher enough than the speckle noise level, e.g. assuming higher than about 3dB), is possible for wind speeds up to about 9 to 10 m/sec. Furthermore L and S band radar sensors, would not be capable to detect that spill.

An important result of this study, is the abnormally higher contrast values, at certain narrow bands, some of which lie at the region sensed by the C-Band radar sensor (focused on figure 2). This phenomenon, which is related to nonlinearities of the sea surface wave spectrum development, may be of particular importance for the ERS C-band SAR sensors, because it increases its capability to "see" oil spills under even higher wind speed conditions (up to about 13m/sec). Therefore, given that wind speeds up to this limit, fall in the highest probability of wind speed occurrences in the world oceans (Long et al 1965), it can be concluded that the SAR sensors of the ERS missions should be considered, as a significant part in the operational oil spill monitoring.

On the oil spill SAR signature

The use of the spaceborne SAR imagery, for operational oil spill monitoring, is usually considered together with the development of computer based systems, which may automatically, in real or semi-real time, alarm the occurrence of a spill (Frette et al 1992, Stock and Jory 1994). The greatest problem of such facilities, is posed by the natural sea surface manifestations, which under certain air/sea boundary conditions, result to SAR expressions similar to those due to man made mineral oil spills. These may include, natural slicks, threshold winds, wind shadows behind islands, surface currents, internal waves, reflections of the bottom topography in shallow waters, fresh water bodies at river outfalls, plums of municipal sewage etc. The frequency and peculiarities, of such occurrences, depend on the nature and the prevailing environmental conditions, of the geographic site. Therefore, an automatic oil spill detection system, needs to be well fitted to the singularities of the site concerned.

Among the aforementioned "look alike" manifestations, the natural slicks (monomolecular films of active compounds, formed on the sea surface by photooxidation processes and bacterial decomposition), and the threshold wind field variations (i.e. sea areas perturbed by winds of speeds lower than or about the level, when sea surface ripple generation begins), appear to have the greatest effect in false alarms (Pavlakis 1995b). These two are related to each other, in the sense that at high wind speeds the natural slicks disappear, or the existence of natural slicks raise higher the wind threshold level, for ripple generation on the sea surface (Wei and Wu 1992). Therefore, at extended moderate to high sea surface wind fields, the "false alarm" effect, due to these occurrences, may be eliminated.

However at coastal areas, this is not usually the case. For example, natural monomolecular slicks are frequently encountered in the Mediterranean coastal areas, particularly during summer and autumn. Thus since the coastal areas lie at the primary interest, of the authorities for regular oil pollution monitoring and immediate response, these factors have to be considered, as the major obstacles of the automatic oil spill detection systems.

The current state of the art, among the automatic oil spill detection systems (Stock and Jory 1994), use for oil spill discrimination, criteria mostly based on the shape characteristics of the spill. It is an experience, gained by the present study (Pavlakis 1995b), that although the dynamic nature of the spill, may result to an extended variety of shapes, some identified trends (e.g. elongation, possible general alignment to the wind direction, feathering at its boundaries etc), usually result to considerable reduction of false alarms.

However it is constructing to mention here, that a better understanding of the physical mechanisms, which control the radar echo from an oil spill, may lead to the means for its discrimination. Mineral oils, when they are spilled on the sea, due to their "hydrophobic" consistence tend to form "thick" layers, exhibiting thicknesses of up to some millimeters or even some centimeters. Thus the local viscosity is considerably increased (Alpers and Huhnerfuss 1988), resulting to the modification of the surface wave field, due to the excess of the wave viscous dissipation. In addition it was found by open sea experiments (Singh et al 1986), that the radar backscattering return, from an oil spill, measured as a function of frequency, exhibits characteristics, similar to those coming from the natural slicks. More specifically they both are exhibiting maximum.

Maxima in the spectral depression signature, well predicted by the Marangoni resonance-type damping theory, result when thin monomolecular films of surface active compounds, are formed on the sea surface (Huhnerfuss et al 1987). So far no experimental evidence is available, which allows the conclusion, that resonance-type wave damping can be also induced, by "thick" mineral oil layers. Alpers and Huhnerfuss (1988), in order to explain this spectral depression form for the crude oil spills, made the assumption, that the mineral oil spills in sea water, may contain also surface active compounds as impurities. Hence local concentrations of such compounds, in the spilled area, may give rise to locally stronger radar backscattering reduction (Huhnerfuss et al 1989).

Strong lateral differences also, in the expected radar backscattering reduction, were computed (Pavlakis 1995a), when a spill was assumed as a pure hydrophobic "thick" layer (i.e. free of surface active compounds), of variable viscosity (e.g. due to variable thickness, or variable concentrations of the different crude oil fractions). This theoretically found result, was turned out to be dependent on the impact, the viscosity variations have, on the nonlinear energy transfer mechanism, which takes place, during the sea surface wave development. Therefore it can be concluded, that a mineral oil spill, may usually appear on the SAR imagery, with some structure (figure 3) in the area it covers. Obviously, some further theoretical and experimental investigation of these mechanisms, may tune the means for such a practical use, of the SAR imagery.

The role of the ERS SAR missions in the operational monitoring of oil pollution

Oil spills may occur, both in the open sea and in the vicinity of coastal waters. There have been so far spectacular accidental spills, involving the loss of very large quantities of crude oil, from disabled supertankers and offshore platforms. The greatest majority of them caused the immediate response, of the responsible authorities. However it is important to stress here, that in itself the size of the spill, does not necessarily tell much about its potential to cause damage.

Even a small spill can wreak havoc, in an ecologically sensitive environment. For example, near Norway in 1981 a small operational discharge of oily bilge washings, from the tanker Stylis, killed an estimated 30,000 seabirds, because it impacted a location where they were seasonally abundant (Kornberg 1981). Moreover local meteorological and oceanographic singularities may facilitate, the continues concentration of oil fractions, particularly in areas facing frequent oil spilling. Such a striking example is the dramatically reported, by the anthropologist Thor Heyerdahl (1971), "shocking" and "terrible" pollution, by "floating asphalt-like material" (large quantity of floating tar), in the mid-Atlantic gyre (known as the Sargasso Sea), which was observed during his east-west crossings of the Atlantic ocean in 1969 and 1970, in small papyrus raft boats.

In most cases, the primary source of floating tarballs, is thought to be the tank washings, rather than the weathered residue of accidental spills. Unfortunately, the discharge of the oily wash or ballast water content of the tanks into the sea, as the oil tankers travel to pick up their next load, is still an operational practice.

Although it is impossible to predict the location or magnitude of an accidental oil spill, it has to be expected, that spills from "deliberate" discharges of tankers, are most frequent in coastal areas, of the most heavily traveled sea lanes, as well as in the vicinity of oil terminals. In this case, which triggers the most concern of the authorities, the incidence response is of great importance. Thus the role of the spaceborne SAR sensors, in such operational monitoring, is strongly dependent on the platform orbit pattern, acquisition frequency, and data processing/delivery time. Assuming that the above spaceborne SAR imaging chain, reaches an acceptable time, then they have a potential role to play, particularly in monitoring of extended and remote coastal areas, where the high costs does not permit regular survey by airborne facilities.

However the information content about oil spill occurrences, on the amount of data so far acquired, appropriately linked with other geographic and environmental information (i.e. ship traffic routes, oil terminals, refineries, offshore oil production, oceanographic and environmental sensitivity information etc), can at present be very useful, in laying down of authoritative guide-lines, for reducing the current state of marine pollution. One obvious foreseen result, will be the identification of areas facing higher pressure. The later may also enable, the establishment of regular spaceborne surveillance scenarios, efficient even under the limitations of the current spaceborne SAR missions.

Monitoring oil spills in the Mediterranean with ERS SARs

As a first step towards the above ideas, an application in the coastal zone of the Mediterranean sea was attempted. The Mediterranean sea is a semi-enclosed sea, covering about 2.5 million square kilometers, whose surrounding coastal zone is habituated by an estimate 81 million people, expected to increase to as many as 170 million by 2025 (UN Statistical Office 1992-93). Due to the mild climate, and the historical background of the region, the number also of tourists, visiting the area at an annual basis, is estimated to reach to as many as 260 million by 2025. Obviously the above numbers indicate strong, and diversely related to the environment, financial and industrial activity. For example only in the north-west corner of the Mediterranean (Spain, France, Italy), there are well over 50,000 industrial enterprises (Alpers 1993), while investments on related to tourism, recreational facilities are continuously increasing, on an annual basis all around the Mediterranean coastal zone.

About 40 oil related sites (i.e. pipe terminals, oil refineries, offshore oil platforms etc) are distributed along the Mediterranean coastal zone, from and to which an estimate 0.55 and 0.15 billion metric tons, of crude oil and petroleum products correspondingly, are annually loaded, unloaded and transported by oil tankers. Moreover due to the singularities of the coastal physiology, the coastline length of the 20 non uniformly industrialized countries bordering the Mediterranean sea, is not analogous to their share in the oil chain activity. Although the Mediterranean has been declared, by the MARPOL convention, "as special area", where deliberate petroleum discharges from ships are prevented, there is ample evidence of repeated numerous offenses against it. In 1972 it was estimated, that the total amount of mineral oil released into this region, was 300,000 metric tones. At present, estimates vary greatly, going as high as 1,200,000 tons (Alpers 1993).

Over the coastal zone of this area, a set of 190 ERS-1 SAR frames, acquired between 14-Apr-92 and 19-Sep-93, and randomly selected among the thousands archived so far, by the European Space Agency, were interpreated to trace oil spill occurrences. Among them, 58 frames showing 139 oil spill expressions were found. The location of the SAR frames, and the position of the validated oil spills, are presented on the map of figure 4. The shape appearance, of the majority of these spills, was found to be either as elongated segments collocated with ship wakes, or short zigzag stripes (figure 5). Obviously such appearances indicate, either leakage on the course of the ship, or bilge water discharging during tank cleaning maneuvering.

For a first order comparison, the map showing the ship accidents in the Mediterranean, which have caused or likely to have cased pollution during 1992 (IMO/UNEP 1993), is presented on the figure 6. The comparison of the two indicate evidently, the considerably higher frequency of the "deliberate" oil spilling, which usually escape detection and response. Therefore despite the MARPOL convention, this source of oil pollution is still a potential threat for the Mediterranean marine and coastal environment.

Although the sample of the interpreted ERS-1 SAR frames can be regarded as small, some conclusions can be drawn. More specifically, the geographic distribution of the validated spills indicate a general abundance, along the Northern Mediterranean coastal zone, while in most cases, local concentration of spills were found in the vicinity of oil chain related sites (i.e. pipe terminals, refineries etc) (figure 7). Unfortunately this, expected to some degree result, indicate that measures for prevention are not strictly applied. A characteristic example is presented on figure 8, where the detected spill (dark feature indicated as A), appears to come directly from the refinery located at this area (Corinth-Greece).

Furthermore spill concentration appears also at the approach of congested waterways, such as Gibraltar Straits, Messina Straits, and Port Said, or zones of major maritime transit traffic of oil, such as SE-NW zone of Ionion to the Adriatic Sea, and the Aegean sea, as the passage between the Mediterranean and the Black sea (figure 7). Finally it is worth to stress, the considerable concentration of spills in the range of two neighboring ERS SAR frames (figure 4), south of Sicily and north of Port Said, indicating higher pressure and possible localized chronic pollution, at these confined regions.

Obviously the identification of such areas is an important preliminary step, for planning focused and intense monitoring schemes. It may also be possible, such plans to be realized, even in the limitations of the current ERS SAR acquisition scenario. Moreover such information may enable, the development of effective Environmental Sensitivity Index maps (i.e. Wildlife Management Area Boundaries, National and State Park Boundaries, fishing and spawning areas for fish and crustaceans, in situ burn and dispersant exclusion zones, water intakes, sea grass beds, bird rookeries, etc), linked also with information, such as name and phone number of an area contact, acreage, spawning months, migration periods, types of species, access points, etc. An integrated effort of this kind will greatly enable a better planning for response, by possible reorganizations of the available means, as well as in the risk evaluation assessment.

Towards this direction a potential background to start with, are the thousands of available archived ERS SAR data, acquired during the last 5 years over the Mediterranean region. The interpretation of these data, will obviously address the potential of the spaceborne surveillance for a cleaner environment, since at least it will reveal the problem of oil spill pollution, in its read dimension.

Acknowledgments. The present investigation was carried out, in the frame of the HCM program of the European Commission. The authors also wish to express their thanks to the European Space Agency, for all the kind support from its services.

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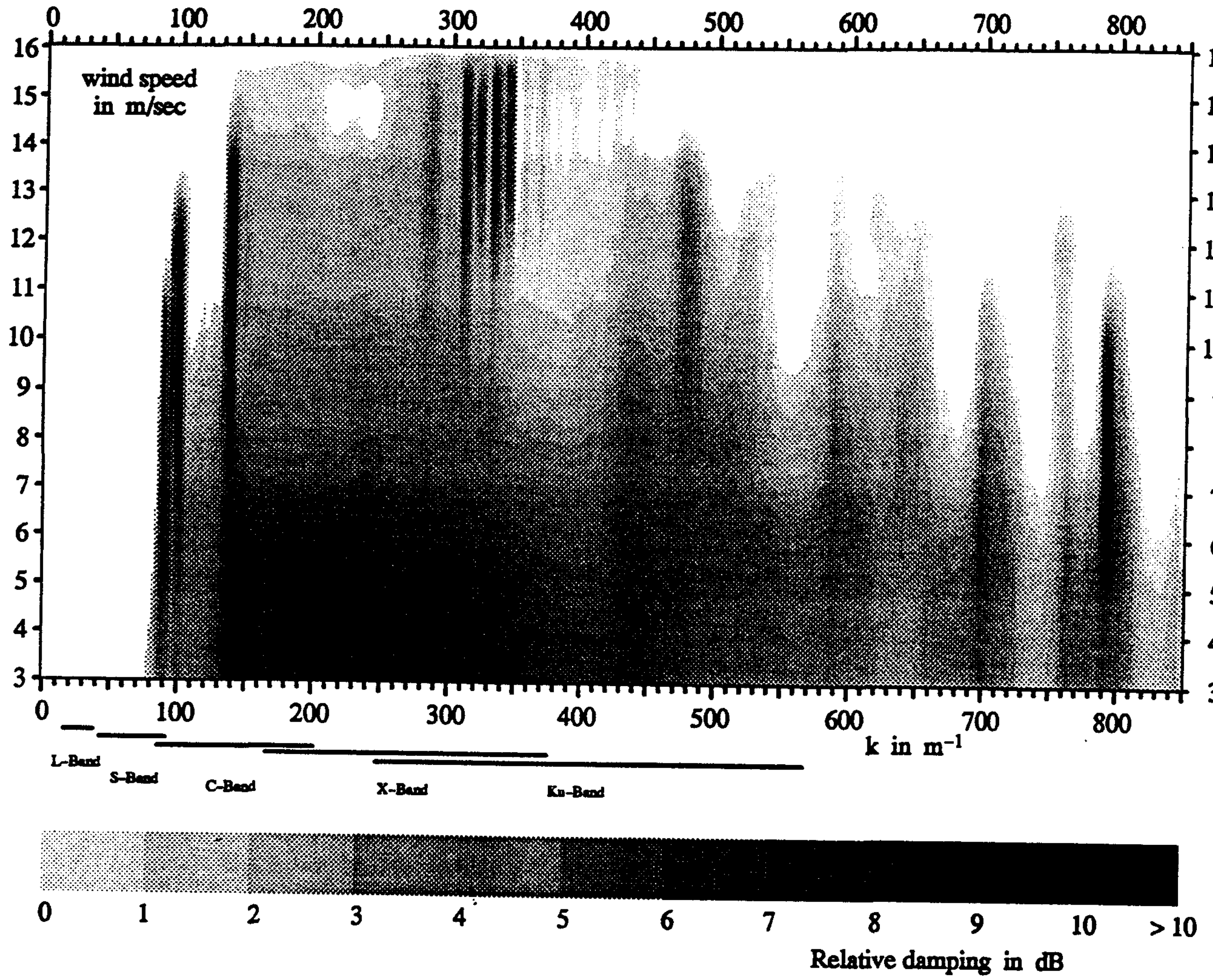

Fig 1. Expected radar backscattering contrast as a function of wind speed, for a crude oil spill capable to induce resonance-type wave damping. The computations were based on oil film rheological parameters, yielded by best curve fitting to the field data of Singh et al 1986. The horizontal lines below the wave number axis indicate the regions of the Bragg waves for the corresponding radar bands, for angle of incidence between 23° to 65°.

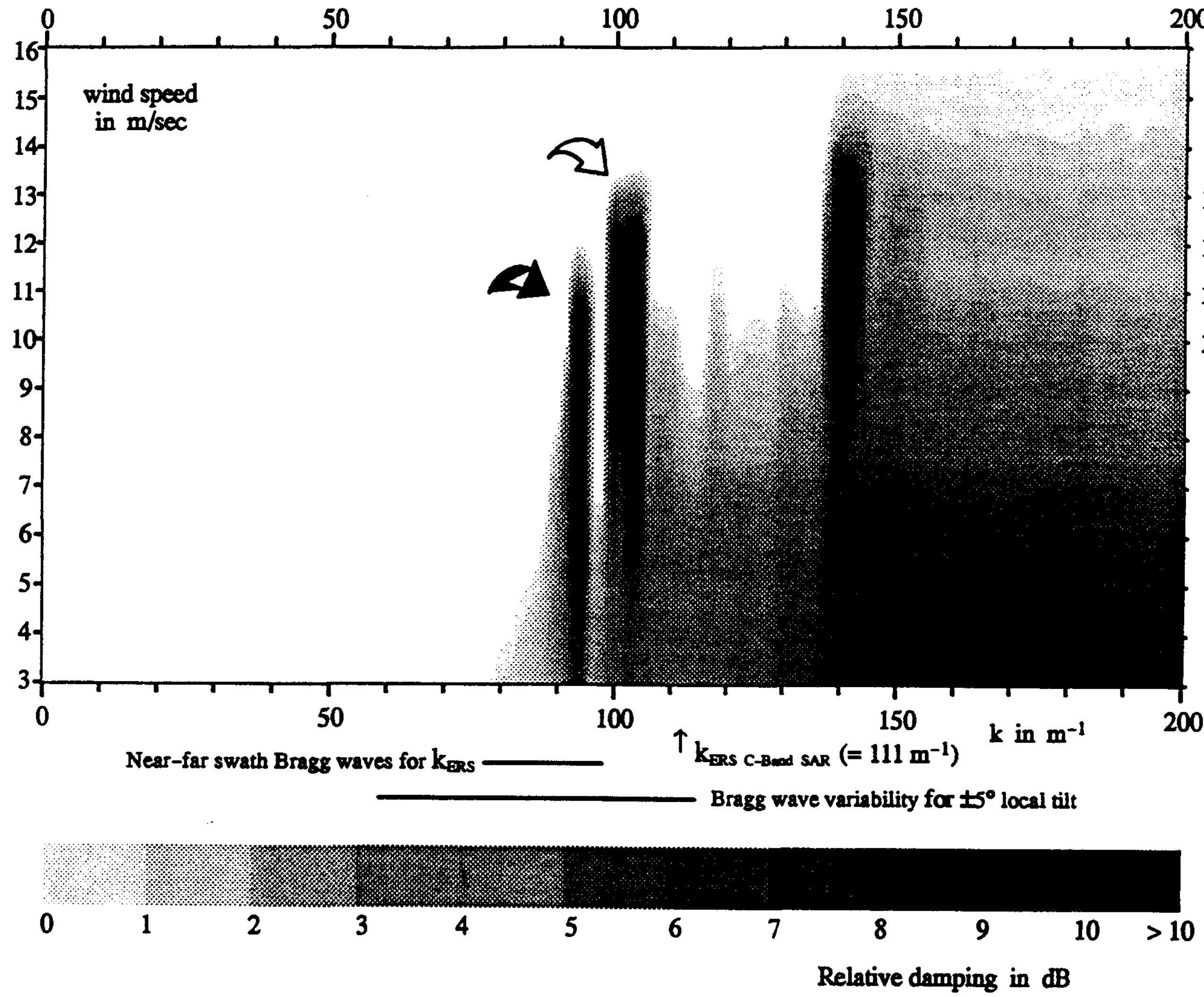

Fig 2. Detail plotting of figure 1, showing the abnormally higher radar backscattering contrast at certain narrow bands, falling in the spectral region sensed by the C-Band radar sensor. The upper horizontal line below the wave number axis, indicates the Bragg wave span of the near-far swath incidence angles of the ERS SARs. The lower one indicates its possible expansion, assuming $\pm 5^o$ local sea surface tilt due to long gravity waves.

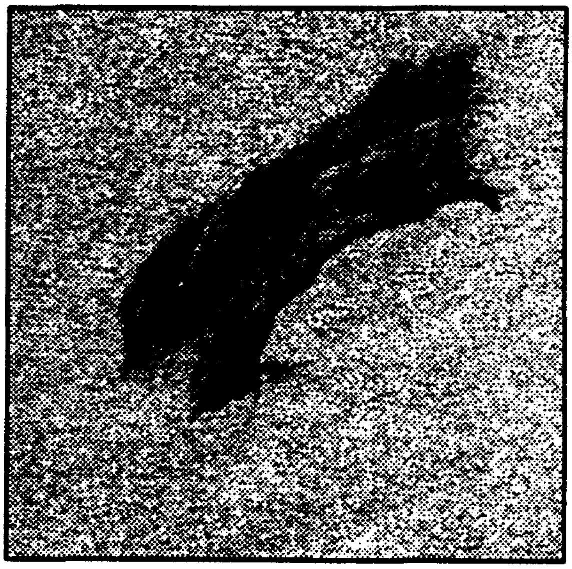

Fig 3. *Oil spill detected on ERS-1 SAR image, showing considerable gray level texture, due to variable radar backscattering from the spilled area.*

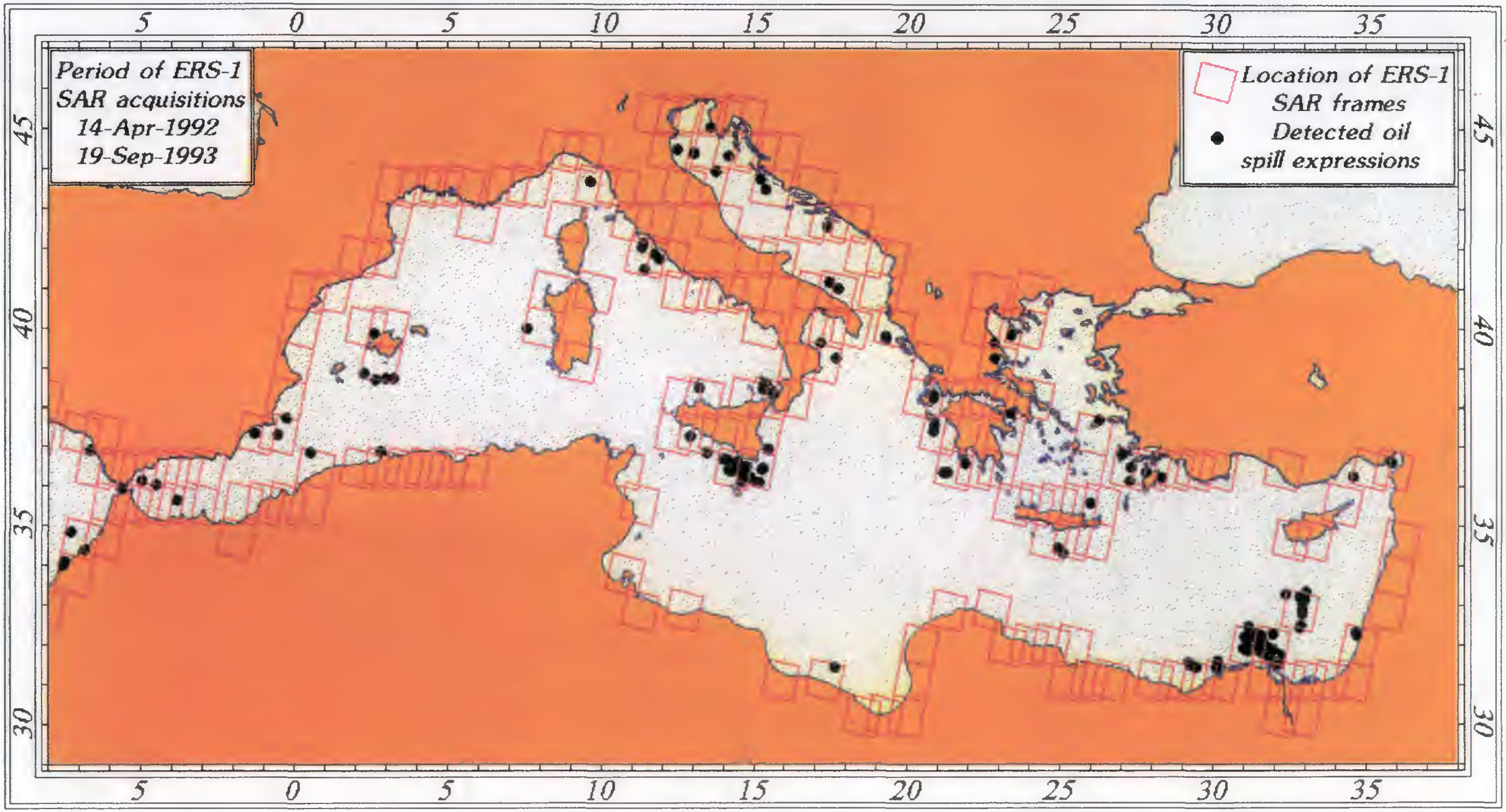

Fig 4. Location of the 190 studied ERS-1 SAR images along the Mediterranean coastal zone and the interpreted oil spill expressions (circles).

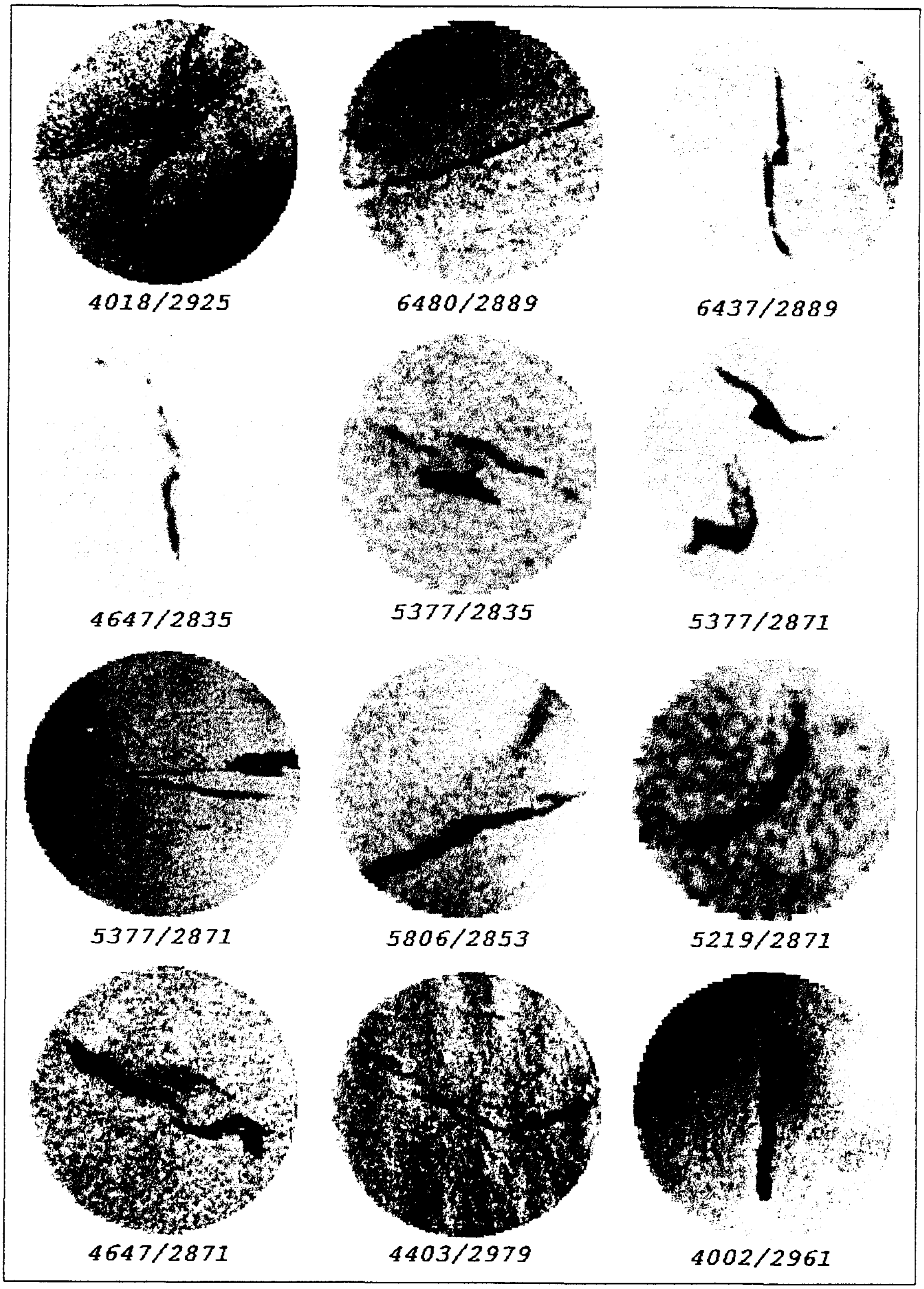

Fig 5. Characteristic shapes of oil spill expressions indicating leakage (collocated with ship wakes elongated spills) or bilge water discharges (tank cleaning maneuvering). Numbers correspond to the ERS-1 SAR orbits and frames.

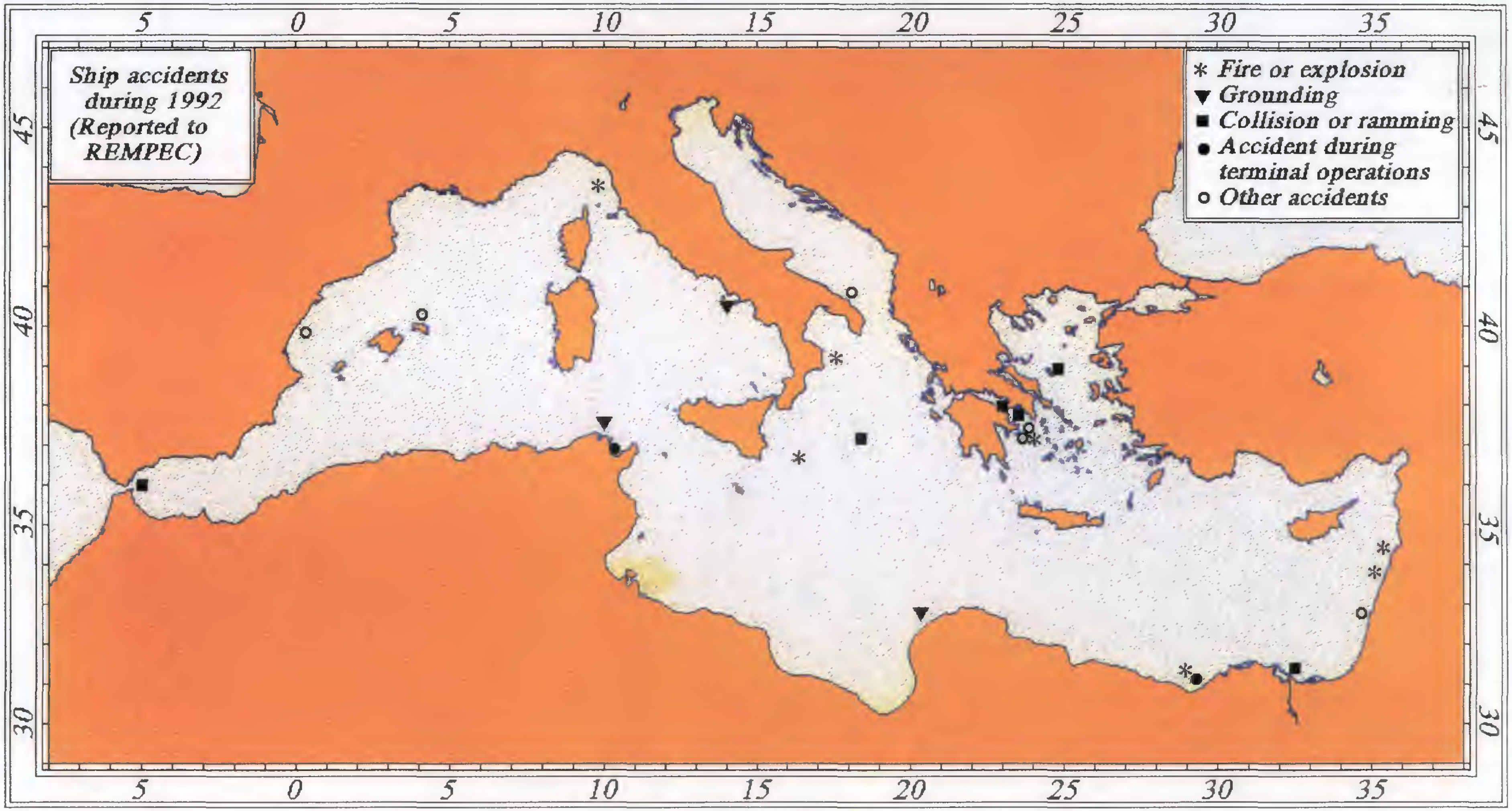

Fig 6. *Accidents causing or likely to cause pollution of the Mediterranean sea by oil and other harmful substances (reported to REMPEC in 1992).*

Fig 7. *Location of oil related sites in the Mediterranean and detected oil spills by the ERS-1 SAR.*

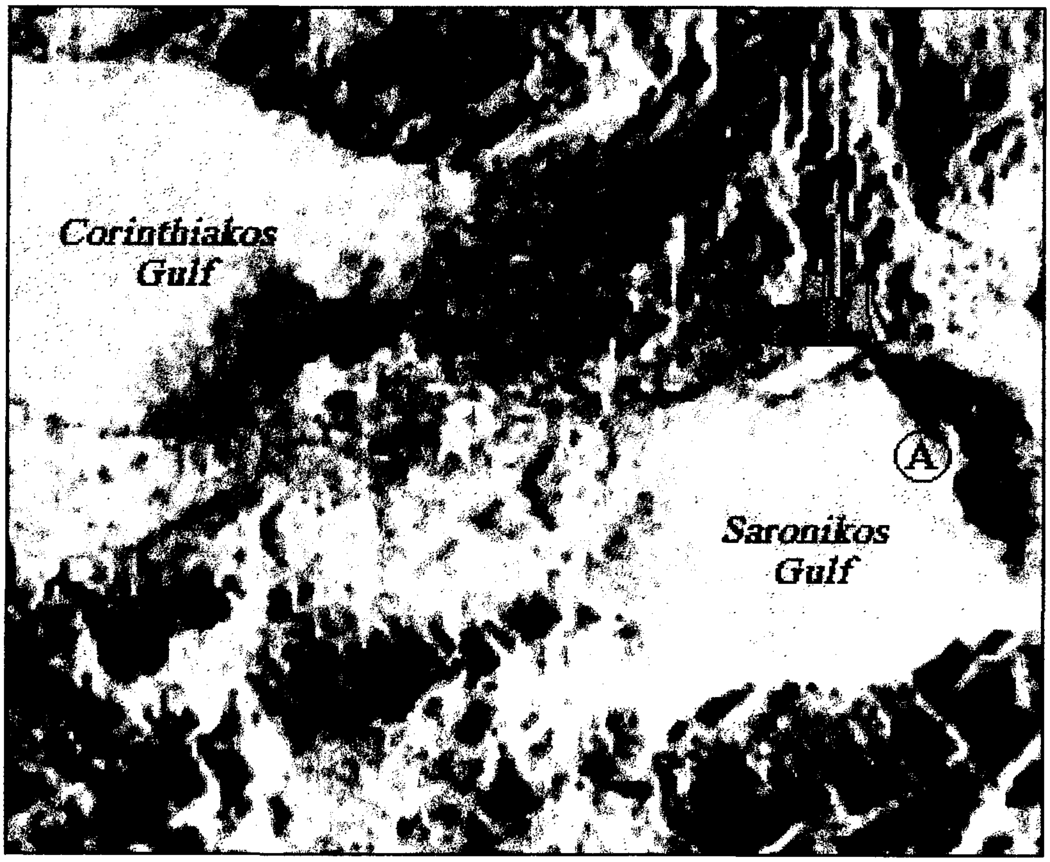

Fig 8. *ERS-1 SAR subimage (orbit:7166/frame:2835/28-Nov.-1992/09:12:33), showing a spill (marked as A), possibly due to terminal operation at a coastal refinery site (Corinthos-Greece).*

The Contribution of space-borne remote sensing to an atlas for preparedness and response to accidental marine pollution.

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ERS THEMATIC WORKSHOP ON OIL POLLUTION IN THE MEDITERRANEAN
25-26 MARCH 1996
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Abstract

The project of an atlas for preparedness and response to marine accidental pollution in the Mediterranean participates in the main mission of the Regional Marine Pollution Emergency Response Center (REMPEC, Center for the International Maritime Organization -IMO, and the United Nations Environmental Plan - UNEP), which is a regional center dedicated to the information and coordination for preventive and emergency operational actions. The aim of this atlas is to participate to, in the context of sub-regional developments, the mission of the Mediterranean Action Plan (PAM), which coordinates its specialized centers through integrated programs.

Dealing with a selection and an adequate organization of data, which reveals to be often sparse and uncomplete, the goal is to provide to the end users a set of informations in order to assist him, as well as in its preparedness, as in the so-called response. This atlas is built-up on the two fundamental notions, which are the risk and the sensitivity of a given site. These two notions can be evaluated on the basis of existing data, which may be not already used in this aim, the final information is synthetized in the more elaborate way as a vulnerability index.

In this project, satellite remote-sensing is foreseen to play an important role. Starting with the state of the art of the use of satellite data for preparedness and response to marine accidental pollutions, we show which are the contributions that may be expected in the domain. As some sparse experiments have shown the possibilities offered by space borne remote sensing for the help of emergency situations management in the case of accidental pollution events : *e.g.* for the covering of meteo-oceanological conditions of intervention. In such cases, limitations have also been clearly identified : access delay to the sites, liability of the information acquired in all-weather conditions. The preparedness implies the extensive collecting of the informations which will be used, when the day will come, with interest by the operator. Sea state climatology, currentology of sites are examples of characteristics of sites for which satellite remote sensing has a significant bring. The methodology for collecting and integration of such data is exposed.

1 - Introduction

Regarding the problems linked to the marine pollution, the mediterranean is a very specific case, due to physical and geographical reasons. From an oceanological point of view, this sea has a negative net balance of water (loss of 1 meter per year), mainly due to the effect of evaporation. This results in a very defavourable situation for the elimination of various pollutants, resulting of natural or anthropic processes. The Mediterranean shores are of the most densely populated of the world, with a forecasted population of 300 million inhabitants after the year 2000. Many action plans from international organizations are under development to adress these problems. *e.g.* European Community is funding research programs on renewable energies in the mediterranean basin for the next decades.

Nevertheless, the growths of human activities is already having a significant impact on the Mediderranean environment. Among these, accidental and chronical oil marine pollution is one of the most important. In this domain, the bring of space borne remote sensing has been noticeable : first quantitative assessments of chronical oil pollution in the Mediterranean have been achieved by the means of Landsat-TM image processing (Wald, *et al.*, 1983). It has been shown that the annual amount of released oil at sea surface reaches $5\ 10^5\ km^2$, equivalent to the accident of the Haven tanker, every three days.

However, the Mediterranean is well equipped in response, receiving, and archiving facilities and centres : Mediterranean Action Plan (United Nations Environment Program / MAP) centres in Malta (Regional Marine Pollution Emergency Response Center, REMPEC), Split (Priority Actions Program), Tunis (Specially Protected Areas), Sophia Antipolis (Blue Plan for the Mediterranean sea), and Athens (MAP coordinating unit).

The covering of the Mediterranean basin is almost complete. Satellite data receiving stations can be found in Maspalomas (Canaries Islands / ESA), Frascati (Italy / ESA), Aussaguel (Toulouse / CNES), and Lannion (Brittany / CMS). Numerous archiving and processing facilities are also situated in the vicinity of this basin, among which, CTM (Palermo / EEC, UNEP-MAP), Eurimage (Roma), SPOT (Toulouse), CMS (Lannion), JRC (Ispra, EEC), ESRIN (Frascati / ESA).

We present here the general concept and the methodology of an atlas for preparedness and response to marine accidental pollutions in the Mediterranean. The aim of such an atlas is to summarize all of the relevant informations for assisting end users in setting-up emergency plans, and organizing accidental pollution response operations.

2 - Methodology of the Atlas

- Multi-scale
- Risk x Sensitivity → Vulnerability
- Existing data

The basic concept of the atlas is based on a specific multi-scale approach (Denis *et al.*, 1994), allowing to take into account a wide range of phenomena possibly involved in accidental marine pollution, and its transport. The scales to be considered range from the regional scale, *i.e.* the whole Mediterranean basin, to the local, or sublocal (1/5000) scale of the operating maps. The second fundamental concept upon which this atlas is based, is the concept of vulnerability, as a synthesis of the existing risk encountered in a given site, and its sensitivity to the pollutants (Table 1). The general structure of this atlas is organised around these two notions : at each scale, two maps are elaborated, one for the risk assessment (see, *e.g.* figures 2 to 5), and one for estimation of the sensitivity. At a given site, the whole information contained in this data base can be analyzed and synthetized under a vulnerability index. This last approach can be achieved through the implementation of the present atlas in the form of a Geographical Information System (GIS).

Printed
GIS

3 - The bring of space borne remote sensing

The benefits of space borne remote sensing are diferent regarding the type of pollution. In the domain of the survey of chronical pollution, essentially oil spill waste by tankers, space agencies expect significant improvements to come with the increasing number of space borne remote sensing radars. Historically, the space borne remote sensing, and especially the ERS mission has played a key role in the assessment of the impact of oils spill waste in the Mediterranean (Briand, 1993). Regarding this problem, a specificity of the Mediterranean resides in the orientation of the main ship routes : most of the trafic follows routes between west and east, *i.e.* between Suez and Gibraltar. This situation is particularly defavourable for the use of polar platforms (ERS, JERS, Radarsat) for the purpose of survey.

The organization of the response to accidental polutions needs extensive means of survey, with the shortest access delays, and revisit times. Despite of well proven experments, limitations are reported by operators in the domain of the response to oil tanker accidental pollution? The first one concerns the access delays considered as too long, generally two or three days. This remark concerns also the revisit time mainly for optical sensors, space borne radars offering shortest delays. The delivery time reveals also to be crucial, and important means have sometime been deployed in other seas, as in Gulf of Guinea for ERS images, to shorten the delays due to the processing. The late point concerns the reliability of oil spill detection on radar images : the radar signature of other surfactants of anthropic origin, especially in coastal zones, of natural origin (such as algae blooms) is quite similar to the one of oil spills, generating a high rate of false alrm in the detection of oil spill in radar images.

In the more rare case of other type of pollutions, the bring of space borne remote sensing, and especially the ERS program resides mainly, in a similar way, in the assessment of the climatological conditions for the transport and the dilution of the pollutant. Water quality assessment, especially in the coastal zones, will be significantly improved with the future missions of space borne imaging spectrometers (SeaWifs, MERIS, OCTS).

The preparedness needs the knowledge of a great variety of informations that will help the end user for the operations : meterological and oceanological data sucah as current climatology (using SST derived from ATSR imagery, or derived from models using altimeter data), swell, sea surface wind climatology, and cloud cover, and geographical informations describing the sensitivity of a site, as the state of the coastal environment, water quality assessment, ground cover ...

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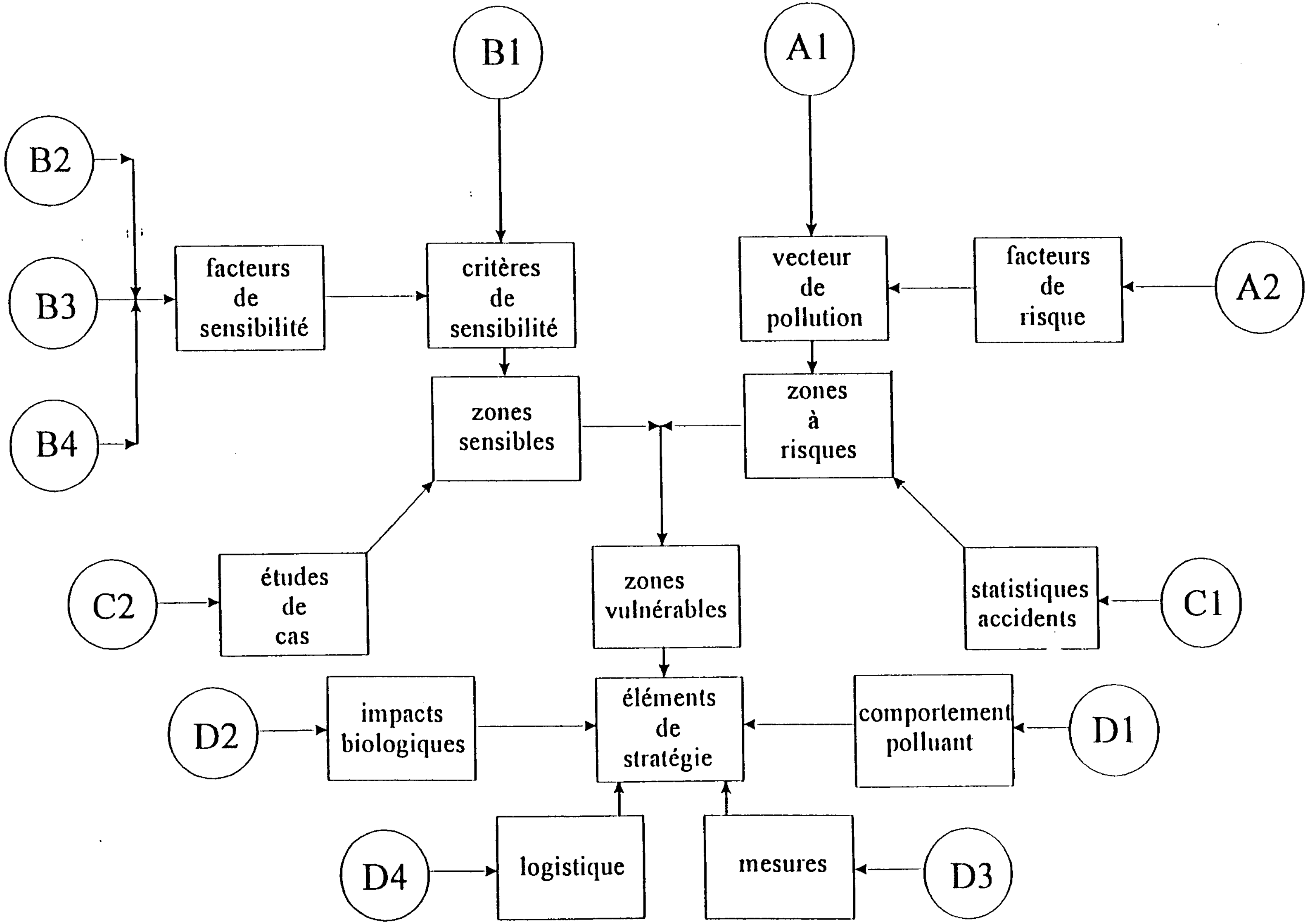
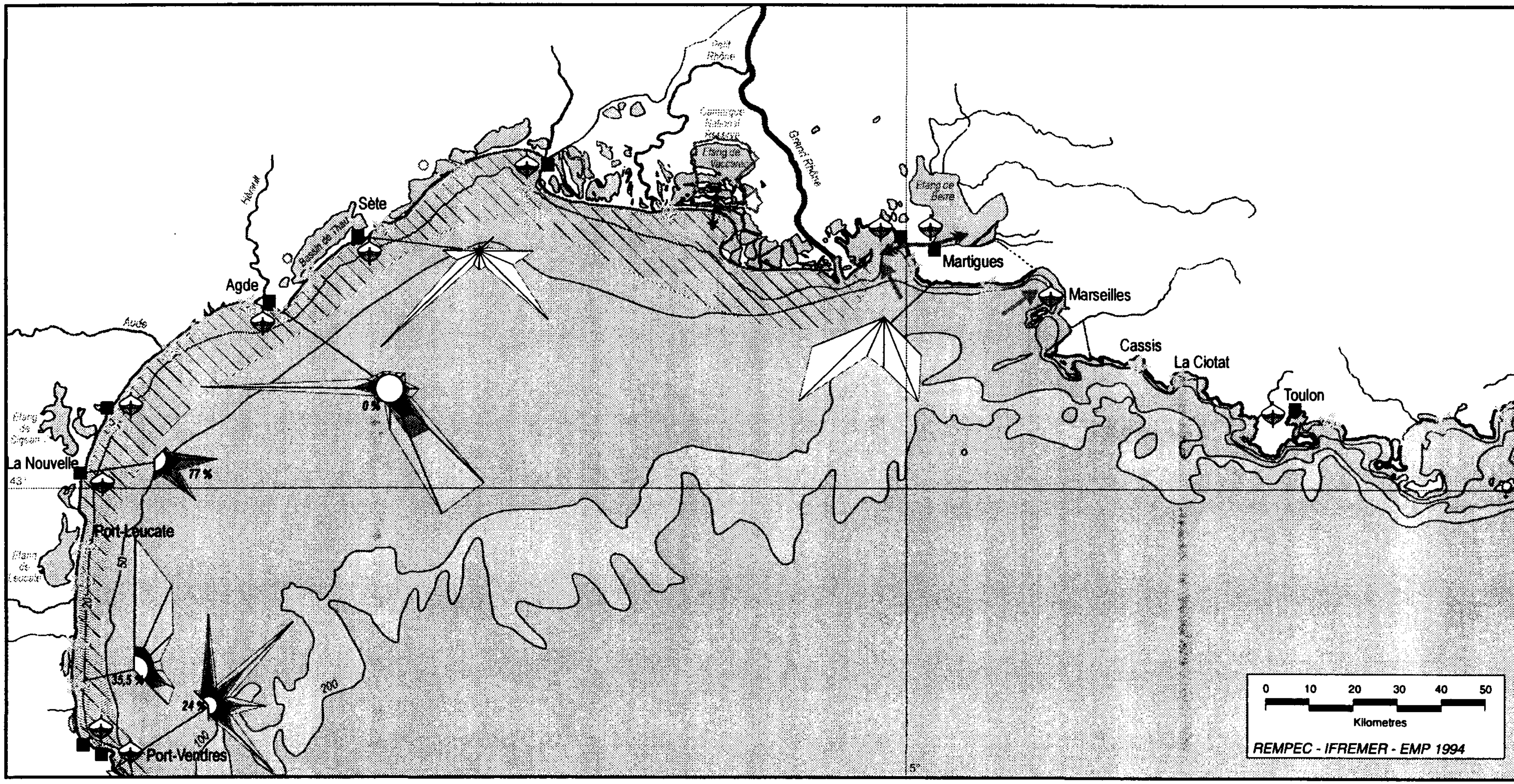
TABLEAU I : METHODOLOGIE DE L'ATLAS - SCHEMA GENERAL DES DONNEES



MEDITERRANEAN ATLAS FOR PREPAREDNESS AND RESPONSE TO ACCIDENTAL MARINE POLLUTION

Map S2



Coastline type
- low coastline with dunes
- abrupt rocky coastline
- specially protected area

Environment - Fish
- main fish nurseries
- sea-lagoon exchange area
- migrations of the young

Utilization of coastal areas
- fishing port
- touristic area (seaside resort, marina, ...)

Sea surface agitation (swell)

frequencies: 0, 10 %, 20 %

24 % : calm weather

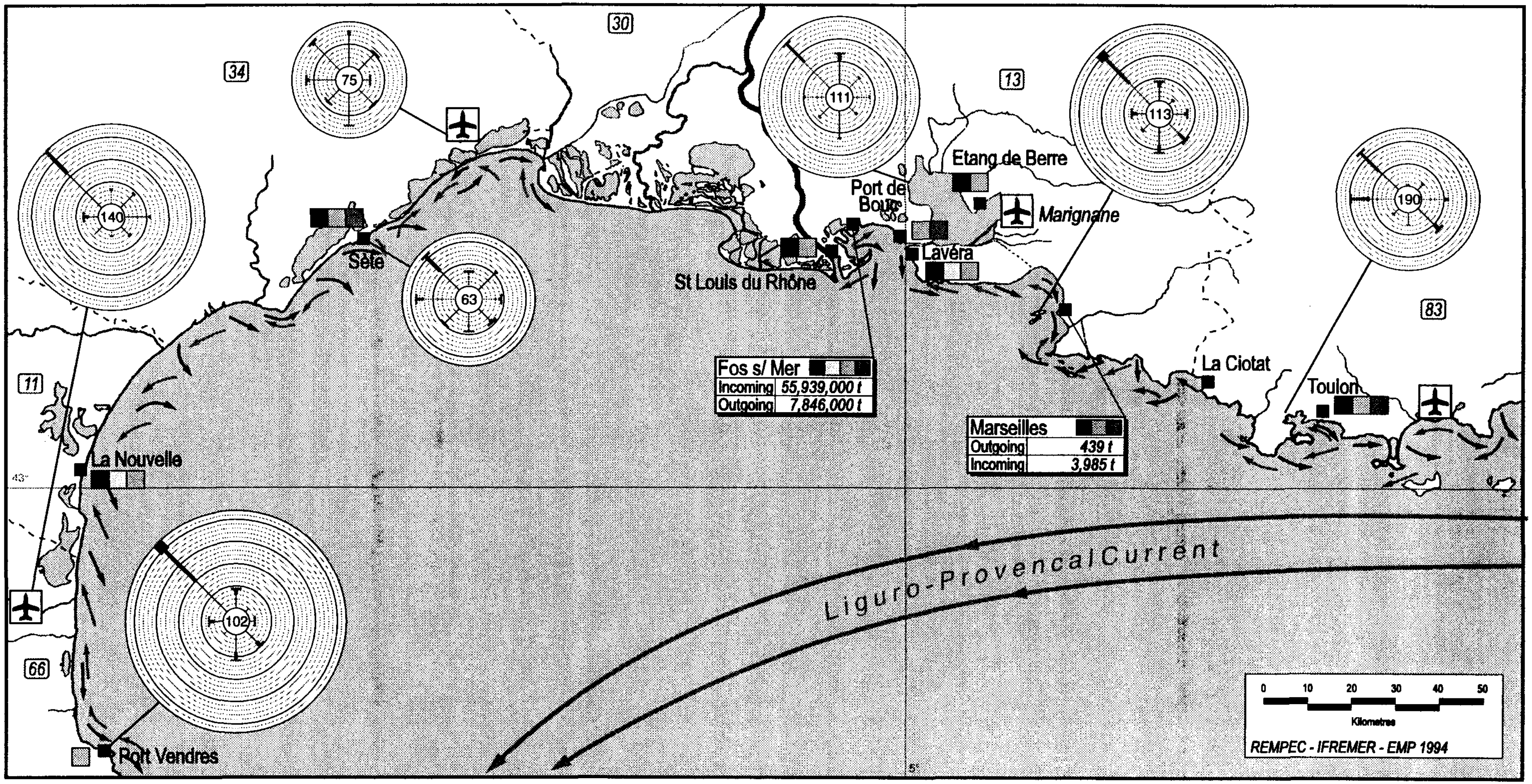
amplitude: 0, 0,5, 1,25, 2,5, 4, 6 metres

UNEP - PNUE

IMO - OMI

MEDITERRANEAN ATLAS FOR PREPAREDNESS AND RESPONSE TO ACCIDENTAL MARINE POLLUTION

Map S1



Ports and maritime traffic

Oil

Natural gas

Liquid bulk

Solid bulk

Oil traffic (crude and refined)

Marseilles	
Incoming	439 t
Outgoing	3,985 t

Winds and currents

- *Permanent current*
- *Drift current, East wind*
- *Drift current, West wind*
- 15 8 m/sec *Average ‰ wind frequency in different directions* *(Primary ticks : 100 ‰ - central value : calm weather)*

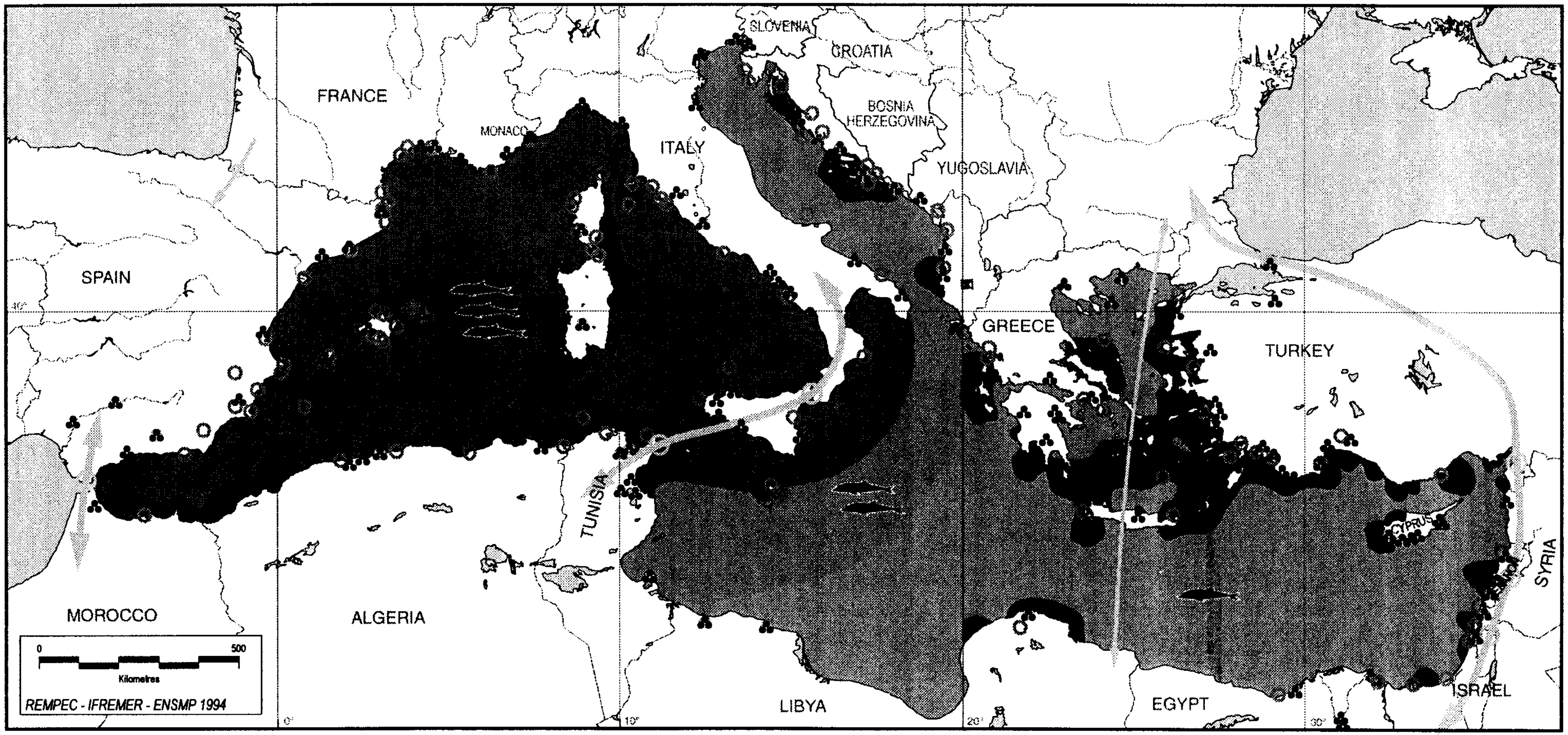
- *Airport*
- 13 *District boundaries and number*
- *Approach lane*

UNEP - PNUE

IMO - OMI

MEDITERRANEAN ATLAS FOR PREPAREDNESS AND RESPONSE TO ACCIDENTAL MARINE POLLUTION

Map R2



Protected species

- *Cetaceans - all species present*
- *Cetaceans - many species present*
- *Cetaceans - a few species present*
- *Cetaceans - transit zones*
- *Monk seals*
- *Sea turtles*
- *Migrating birds - main routes*

Special sites

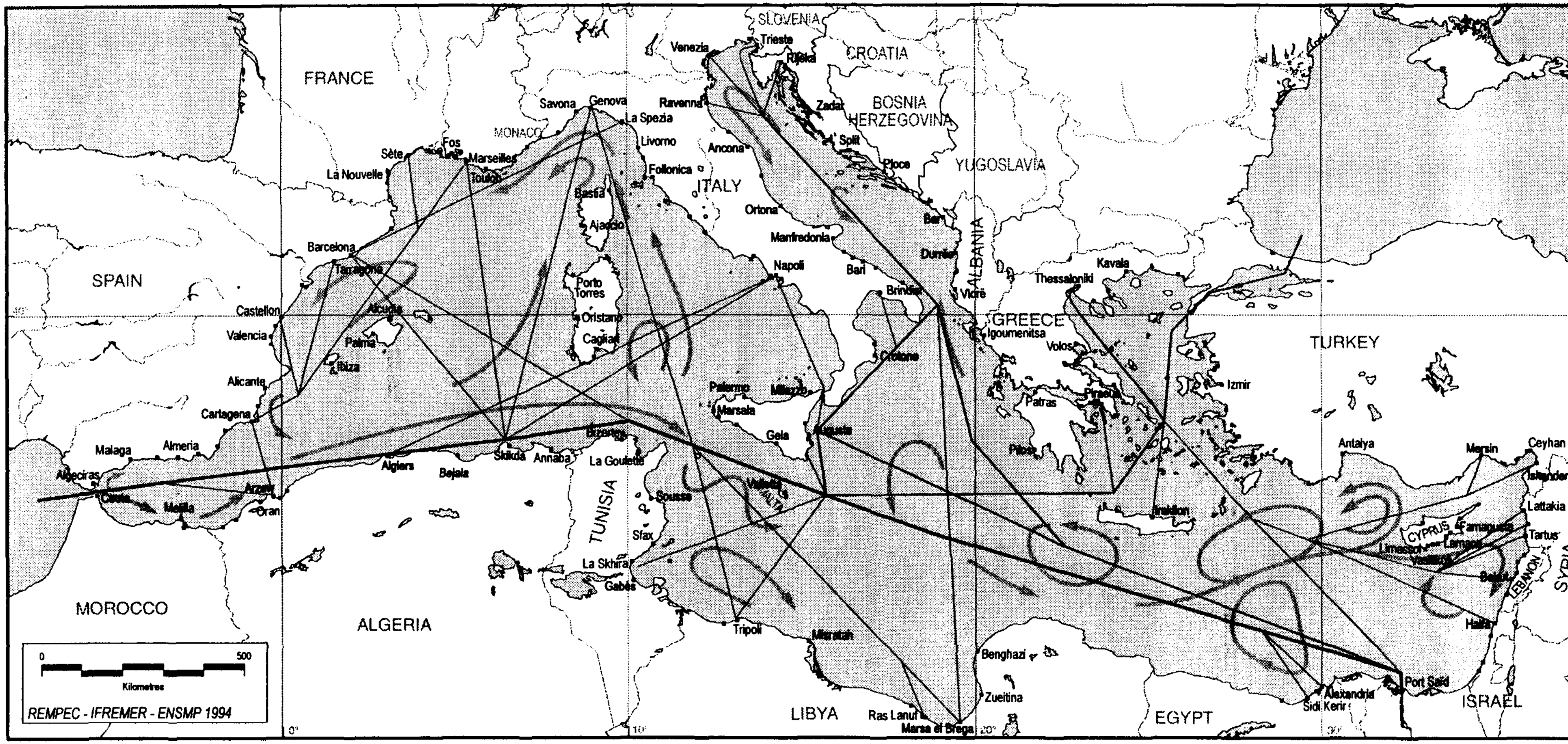
- *Specially protected areas (SPA)*
- *Historical sites*
- *World Heritage sites*

UNEP - PNUE

IMO - OMI

MEDITERRANEAN ATLAS FOR PREPAREDNESS AND RESPONSE TO ACCIDENTAL MARINE POLLUTION

Map R1



Routes and ports

- *Main oil/gaz/chemical bulk ports*
- *Main maritime routes*
- *Secondary maritime routes*
- *Traffic separation lanes*

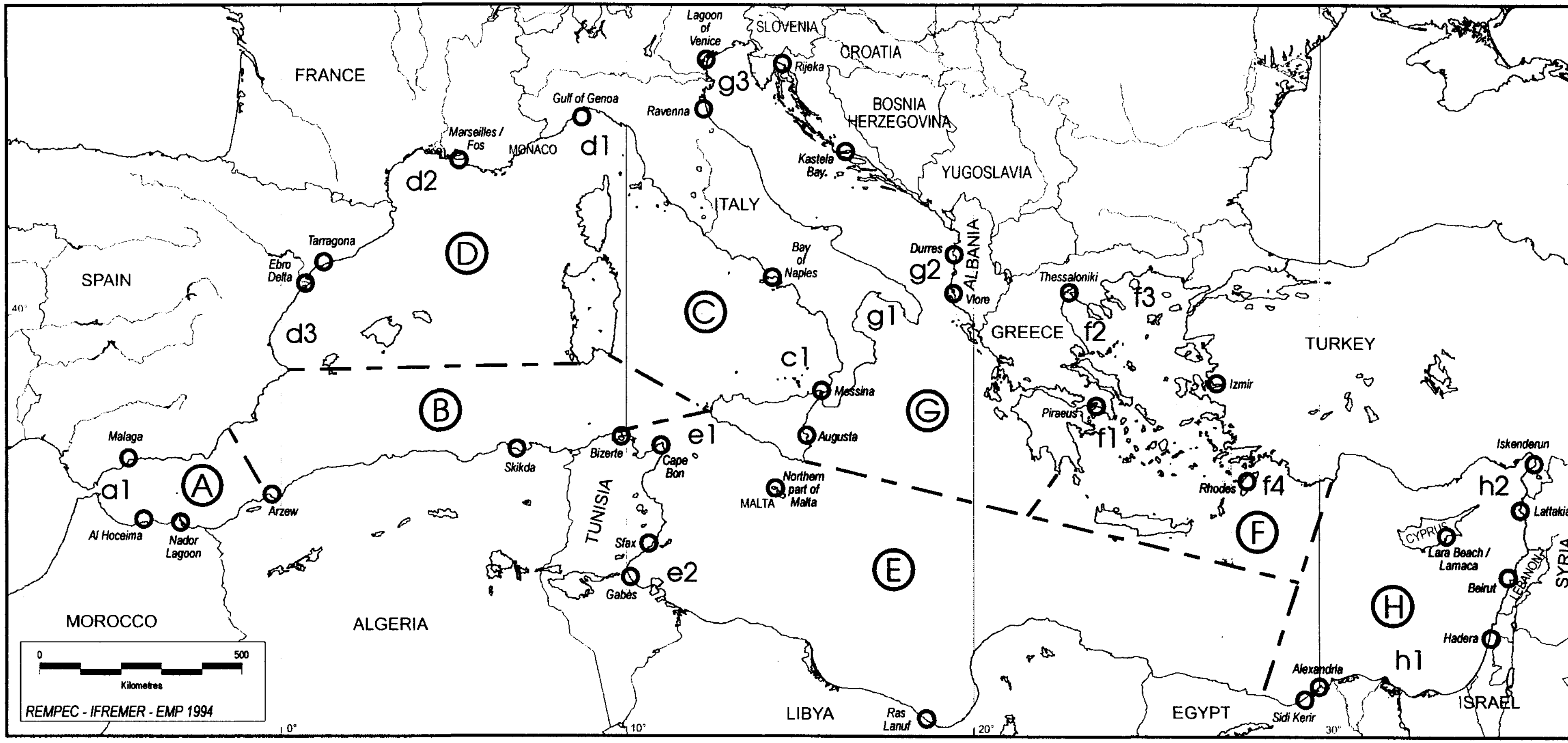
Sea Currents

- *Main permanent currents*

UNEP - PNUE

MEDITERRANEAN ATLAS FOR PREPAREDNESS AND RESPONSE TO ACCIDENTAL MARINE POLLUTION

Regional zoning map



(B) *Identification of Basins*

e2 *Identification of Sub-basins*

Malaga o *Identification of critical areas (local scale)*

UNEP - PNUE

IMO - OMI

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

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1 Introduction

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 project. These studies were called 'CEO Application Proof of Concept Studies'.

An Application Proof-of-Concept Study on utilisation 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 Centres (NSC) national ERS-1 application program.

The project consortium was composed by Tromsø Satellite Station (TSS, Norway), Telenor Research and Development (TNR, Norway), Swedish Space Corporation (SSC, Sweden) . TSS has been the prime contractor for the study.

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
- Value Adding Companies

The users can be divided into three main categories: National Pollution Control Authorities (NPCA), Value Adding Industry (VA) and Research & 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 has been established and the user requirements and feedback assessed. This paper presents the user feedback obtained during the study.

2 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. national pollution control authorities and oil companies. The requirements of the pollution control authorities are to obtain information in near real-time, i.e. within less than 1 hour, 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&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 Figure 1.

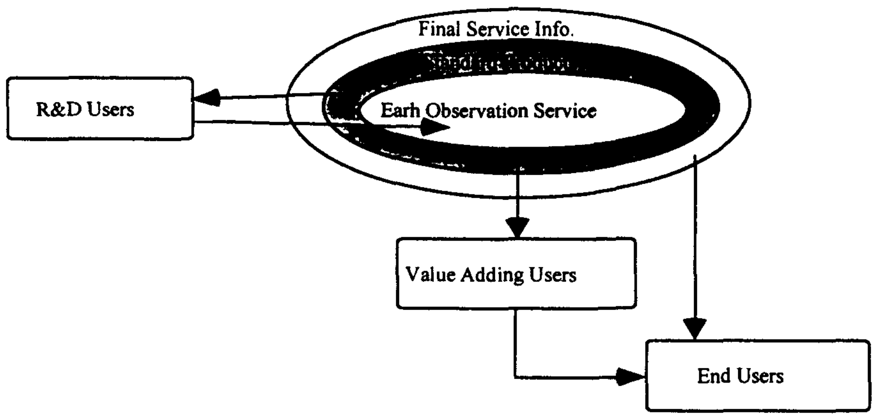

Figure 1: Relationship between the oil spill service and the existing main user groups.

The interaction frequencies with the users varies from weekly with the pollution control authorities, to only a few times annually with the R&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 10 seepage candidates have been identified. None of these candidates have, however, been confirmed by any in-situ observations. 8 of the candidates were detected at very favourable wind conditions (i.e. wind speed less than approx. 5 m/s). 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 characterised 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&D activities.

3 User feedback analysis

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

3.1 Product issues

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

The users are from North Sea and Baltic Sea countries and can be divided into three main categories: National Pollution Control Authorities (NPCA), Value Adding Industry (VA) and Research & Development (R&D) users. NPCA have three main interests concerning oil spill detection: Early warning, Legal prosecution and Off-line applications. The last one is for documentation, statistics, planning and long-term environmental planning. Oil companies are considered to belong to the VA group.

3.1.1 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. Authorised 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

3.1.2 Problems

The NPCA users in general emphasise that their main problem is not to detect oil spills but furthermore to get evidence that can be accepted in court. This may need a change in the court evidence valuing concerning illegal discharging from ships. None of the prosecutions based on aircraft oil spill detection lead to a conviction in the HELCOM area during 1994.

Satellite data only is not regarded to be sufficient as 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 is not possible to estimate 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 does currently not allow a reliable discrimination between thick and thin slicks.
- Classification such as determination of crude oil type can't be obtained from SAR-data.
- Currently three levels of probability is used by the TSS Oil Spill Detection Service. To discriminate 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 only from SAR-data, especially for moving targets such as ships. However, for fixed targets such as off-shore oil rigs identification is possible.
- Type of crude oil is not possible to assess from SAR-data.
- The transformation into a compressed bit-map format has caused loss of radiometric information, of which the final impacts upon the data applicability both for operational monitoring and R&D usage are not fully understood yet.

3.1.3 Solutions

The two previous sections have presented user product requirements and problems related to these requirements. In order to develop further the user community, attention must be paid to try to solve the problem areas. The objective must be to meet user requirements based upon a joint solution utilising satellite data and additional data and information. This section discusses possible solutions to the problems listed in the previous section.

- Estimation of pollution volume is regarded as one of the important issues. This can hardly be done from satellite. An indication of a possible solution is discussed in the next point.
- The satellite information can be used as a guidance 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 to get high quality samples will increase with shorter time between satellite acquisition and delivery of indication to the end-user.
- If there is a natural slick, and in-situ observations from the same area have detected algae bloom then it would probably be possible to assess the area of the algae bloom slick. Please refer to the Service requirement about "Proven confidence".
- Legal discharges from other sources than ships may be possible to assess with a GIS as an aiding tool in the analysis. E.g. when the position of a discharge indicates that it comes from a previously known source giving pollution/pollution-like features. All other slicks not possible to sort out in the analysis have to be inspected and investigated by other available means.
- 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 sinner.
  - By using a GIS to identify a possible source. In this case it is the same problem as in the "Illegal discharge detection" above.
- Classification of natural seepage requires that oil samples are analysed in a laboratory.

3.2 Service issues

3.2.1 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 for the oil spill in order to identify and catch illegal polluting sources for legal prosecution. Satellites can not 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. No gaps in data availability are accepted by the users.
- *Near real-time aspect:* The time between satellite observation and information provided to the end user is a critical factor. Even a one hour time delay has been expressed as a too long time for this kind of service. A very short time delay will increase the possibilities for 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 minutes after satellite overpass.
- *Acquisition planning information:* The available planned acquisition period for ERS-1 and ERS-2 is currently three weeks. Due to 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 Value Adding Industry 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 is widely used, and it should therefore, if possible, be avoided to install new hardware to become a oil spill service user. 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 regular monitored for a limited time period.
- *International cooperation:* Operations of satellite based systems for pollution monitoring is 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 on 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, ..)
- Highest priority, many users want to be "the first one served".

3.2.2 Problems

Use of satellite SAR for detection of oil spills at sea is a new application, and many of the users are neither convinced about the cost effectiveness, nor 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 utilisation of satellite data only do not provide the end user with all the information they require. A final identification of the pollution type and source is not possible, and the satellite based information can not 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 spill.

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. At a 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 two hours after acquisition. Many users express that this alert time is too long for their application.

The most experienced users already make efforts on aircraft operations in co-ordination 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 requirements 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 organisation*, in addition to national activities. The main problem is, however, that currently there exists no international institute or organisation 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 program.

3.2.3 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 optimisation 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 the daily/weekly contacts 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 mean for information transmission. These means can be hence used instead of WWW for providing all kind 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 (outside this study) and the results show that for monitoring of illegal oil spill 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 mean for convincing other/new users about the service reliability and confidence.

3.3 Communications Issues

Distribution of service information to the users is another important task dealt with during this study. Service information in this term means both information about planned acquisition, 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.

The users dealt with can be divided into three main categories, each having different impacts upon the service communication issues. One common requirement is, however, that the oil spill detection service offered by Tromsø Satellite Station, must rely on communication solutions that meets the requirements of the different categories.

3.3.1 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 is 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.

3.3.2 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 experienced problems include:

- Existing communication systems differ from user to user. Available communication services include :
  - Telephone
  - Fax
  - E-mail
  - World Wide Web (Internet)
  - 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 in some cases been experienced. Phone/fax messages to some of the users in Eastern Europe have been very delayed or even missed.
- The TSS mail system is based upon Internet. Due to this configuration it is neither not possible for TSS to control, nor to receive an automatic receipt confirming that the collections distributed via SARA arrives at the users. A manual confirmation from the recipient is therefore needed. This is one disadvantage for the e-mail configuration, e.g. compared to use of ftp or complete X.400 based mail systems for data distribution.
- Due to 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 a flexibility to adapt to special user systems.
- Network capacity is variable, and do not meet the requirements of the near real-time users. A delivery time of several hours have been experienced for 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 attachment to the e-mail message.

3.3.3 Solutions

In order to provide service information to the users, efforts has been made on solving the communication problems during the study. The solutions to some of the main problems include:

- 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 minutes has been experienced within the Internet mail system, while the additional delay in the internal network within the user's organisation was 70 minutes giving a total delivery time of 87 minutes 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 optimise 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, 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.
- Problems with no receipt when and if an e-mail message has been received have been tried solved by asking the users to send an inquiry if e-mails are not received when expected. Some users have e-mail systems where a receipt is issued automatically when the e-mail is received.
- MIME support will be available at most gateways in the near future.

3.4 Benefits

3.4.1 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:

- 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 National Pollution Control Authorities 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 and 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 also "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
  - prevent environmental damage

- By introducing EO data in the surveillance services, improved *management* of surveyed waters may be obtained. The monetary impacts this will bring to society is however difficult to estimate.

- Improved development of environmental *impact assessment plans* leading to improved water quality in territorial waters.

- By making 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.

4 Conclusions

The study has demonstrated that it has been difficult to obtain new users without extensive user approaches. Use of WWW and traditional information and marketing have not given any new user contacts, nor resulted in any new user connection to the service. On the other hand, the CEO study has given the team the opportunity to visit users and also offer them access to the service free of charge for a limited time period. As a result six potential/new users are connected 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 the cost effectiveness, nor the information reliability and quality. An operational monitoring service only based on utilisation of satellite data do 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 can not be used for legal prosecution. Satellites are considered to be one of several means of providing an operational service for early warning of oil spill. A fully operational monitoring service should 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 technology developments can be considered a platform suitable for further application development.

The main challenge for the Oil Spill Detection Service is the realisation of a real market where users are willing to pay full service cost. The users do not yet trust the quality of the satellite based services.

The development of the market is one of the major objectives of the CEO Programme, in particular of two of its Components :

User Support, that comprises the actions and measures to help the user to benefit from EO to meet his or her professional goal

Application Support, to stimulate the production of information from Earth Observation data, in response to customers needs, and draw more customers into the system.

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/.

Earth Watching from Eurimage

An "eye" on the world

The oil pollution case

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Each year ships and industries cause big damages to the weak marine ecosystem releasing oil or pollutants in the rivers and in the sea, causing also damages to the coastal environment.
The marine environment, also far from the coasts, is polluted by mineral oil mainly due to these cases:

- after tanker accidents, when large amounts of oil are spilled into the sea
- by ships during "*normal operations*" by illegal oil spillage
- by natural oil seepage

In the first case, during these emergencies one of the biggest problems is to obtain an overall view of the phenomenon, getting a clear idea of the extent of the slick and, if possible, predicting the way the it will move.

In the other cases performing aerial surveys on large areas (e.g. the Mediterranean sea) to control the presence of oil are very expensive and limited to the daylight time. Satellite imagery can help greatly in this field, showing the probable spills in very large zones and then guiding the aerial surveys for the final assessment.

Eurimage has developed the Earth Watching service for two main reasons: to supply satellite data and pertinent information quickly in cases of natural disasters; and to demonstrate the benefits of remote sensing applications during emergencies, through images and articles. In short, Eurimage's Earth Watching program is all about stimulating awareness.

Satellite data can provide an overview of the situation quickly, as large areas can be covered in one pass, indicating zones already or probably affected and those in danger.

The European Space Agency's ERS-1 and ERS-2 satellites carry a Synthetic Aperture Radar (SAR) instrument, which can collect data independently of weather and light conditions. This instrument offers the most effective means to monitor sea pollution: oil slicks appear as dark patches on the SAR images because the dumping of the backscattered signals, due to the oil, in the affected areas.

Once alerted, the Earth Watching team quickly processes the data (within one day) to produce simple black and white images that can be used by the mass media and by the civil protection authorities to examine the situation. Image interpretations are prepared to accompany the images, and colour or interpreted versions are prepared (within a few days) for use by magazines, etc.

The Earth Watching Structure

The Earth Watching Team is very small: just four, who, on receiving the alert, stop their normal work and start collecting information about the disaster through press agencies and through the Eurimage distributor network (39 distributors located in 27 countries covering Europe, North Africa and the Middle East). At the same time a satellite acquisition plan is made and the team prepare a fast data reception channel.

Once an image is generated, a low resolution image (whole or part) is put on Internet where it is accessible through the standard World Wide Web graphical interfaces (e.g. Mosaic or Netscape). Laser copies are quickly sent to newspapers and, if a magazine or TV station is interested, a photographic product is created. Normally the team are able to produce an image within 5-6 hours from acquisition.

To better help people understand the image (most people are not very familiar with SAR images), an interpreted image is made, showing coastal reference points (if present within the image, as towns, capes and rivers) or highlighting the slick area(s).

In order to promote the use of Remote Sensing data and demonstrate their possibilities, the Earth Watching team try also to setup, with the help of the European Space Agency, demonstration projects as the mediterranean coastal survey. Today it is not yet possible to have a daily complete coverage of the Mediterranean basin, but a good acquisition planning allows to cover the whole area within 12 - 13 days, with many areas covered several times. The use of both ERS-1 & 2 satellites allows to save one day, or, to have two complete coverages with an additional day. The use of other radar satellites (like JERS-1 and Radarsat) can drastically reduce the needed time.

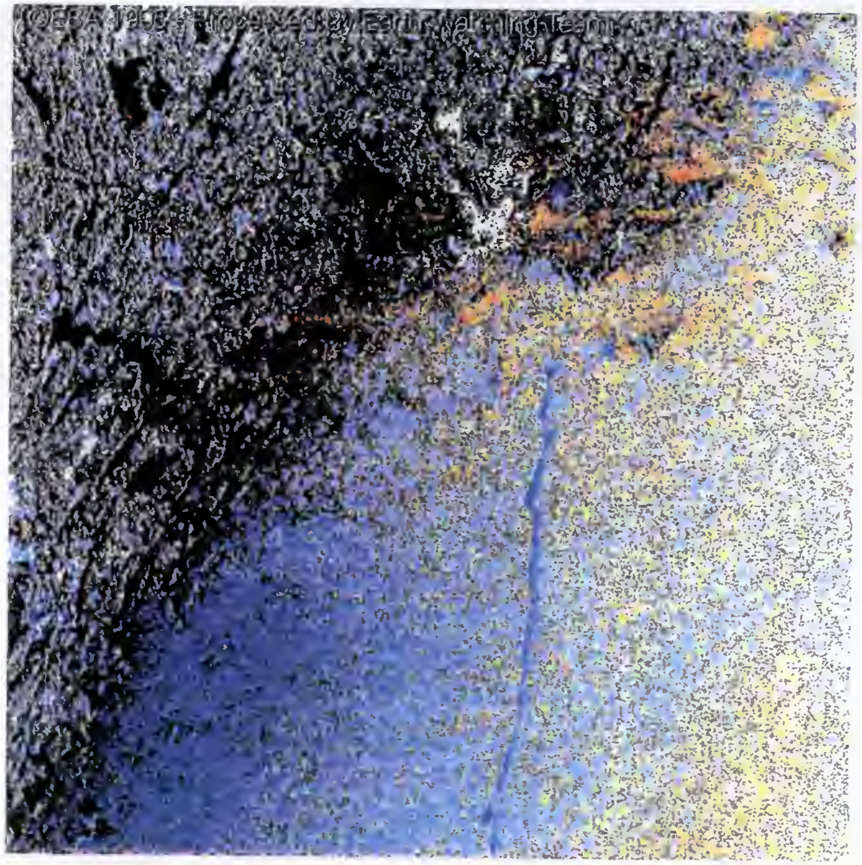
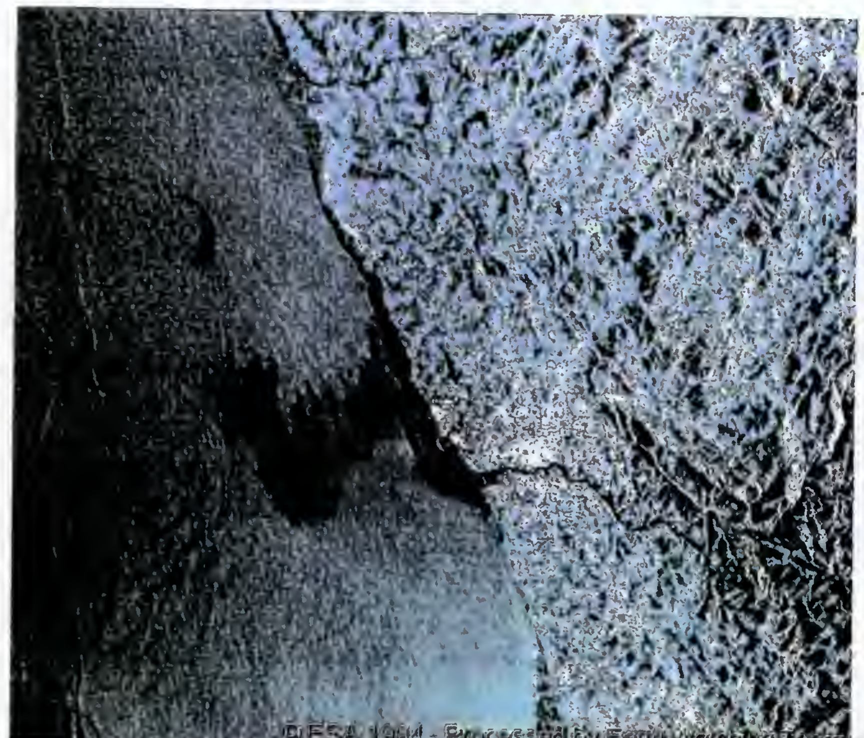


Fig.1 Helsinki (Finland) - May 1995

This composite image is obtained by superimposing two SAR scenes: the first acquired on the 27 May 1995 by ERS-1 and the second by ERS-2 the day after. An artificial channel derived from a combination of the two images (known as the first principal component) has been added to aid the discrimination of change.

The image shows the Finnish capital of Helsinki lying on the Gulf of Finland, (the city is the large white area). It clearly shows a long oil spill near the centre of the image. This spill is the result of an oil tanker flushing its tanks with sea water after leaving Helsinki harbour. The variation in colour of the water surfaces is caused by different wind conditions on the two acquisition days.



On the 2nd October 1994 a Panamanian-registered oil tanker, the Cercal, struck a rock on entering the harbour of Leixoes (the harbour of Oporto), releasing about 1,000 tonnes of crude oil into the sea.

This ERS-1 SAR image was acquired two days after the accident. The spill can be seen floating along the coast and out to sea. The coastal city of Oporto, lying near the centre of the oil spill, appears as a cluster of white dots. The rainy and foggy weather that prevailed in that region of Portugal at the time of the accident made it very difficult to evaluate the spill from an aircraft.

Fig. 2 Oporto (Portugal) - October '94

Milford Haven Oil Spill

On the 15th the oil tanker "Sea Empress" struck the rocks of St. Anne's Head, near Milford Haven.

80.000 tonnes of crude oil were release in a period of 10 days

Winds pushed the black tide southwards and eastwards into the Bristol Channel

ERS-1 acquisition strip
25th February 1996

ERS-2 acquisition strip
26th February 1996

From Skokholm Island to Carmarthen Bay the sea was covered by oil; the nature reserve of Lundy Island (lying 50 km to the South) was also hit

The first available passes from the ERS satellites were on the 25th and 26th February.

Wind conditions during the two acquisitions were very different and some slicks appeared only in one

Mil;ford Haven Oil Spill

Zoomed area of oil spill from ERS-1 acquisition strip, 25th February 1996

Zoomed area of oil spill from ERS-2 acquisition strip, 26th February 1996

Demonstrations

DETECTION OF OIL SPILLS IN THE STRAIT OF TUNIS
(A case Study)

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Abstract

In the framework of the ERS Thematic Workshop, Oil Pollution Monitoring in the Mediterranean, held in ESA/ESRIN Frascati, 25/26 March 1996, a one-off experiment was conducted with the objective to assess the magnitude of ship traffic and related pollution in a crucial area of the Mediterranean Sea, namely the Strait of Tunis between Cap Bon and Sicily, using the Synthetic Aperture Radar onboard the ERS satellite.
In order to have the same data coverage available as during the Workshop a 2 months period in the 3-day repeat cycles of ERS-1 was considered, i.e. from 30 January to 27 March 1992. In this period 14 scenes were acquired. Prior to the analysis, the PRI images were reduced to 8bits, 9x9 low-pass filtered and resampled to 100 by 100 m pixel size equivalent.
The interpretation was performed in collaboration with experts at the Tromsø Satellite Station and was done only visually. Four out of 14 scenes were acquired in high wind speed and show neither ships nor natural or man-made ocean features. In 6 images one or more slicks were detected. For most of them their probability to be man-made was judged to be medium to high. A great number of ships could be spotted, demonstrating the extraordinary density of ship traffic in this area.

A report is in preparation. It will be made available on request, at no cost, together with the low resolution digital images and the interpretation-file.

IDEAS

A TOOL FOR THE MANAGEMENT OF DATABASES OF GEOGRAPHICALLY REFERENCED INFORMATION AND THE INTERACTIVE DISPLAY AND ASSESSMENT OF RETRIEVED DATA.

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1. INTRODUCTION

Remote Sensing sensors flying on spacecrafts and aircrafts have transmitted on the ground a huge amount of information and digital images of the Earth. Many centres in the world have accumulated in their storages thousands (or millions) of images. In most cases these images are integrated by information of different kind, linked by the common geographic reference.

As a consequence of such accumulation, these centres need tools

- to catalogue the information
- to assess their quality
- to support the user in the data selection and retrieval
- to locate data on the storage medium

ACS has developed an integrated tool (named IDEAS) to answer these needs. IDEAS allows the storage of information into databases and provides a management tool to interactively handle the information.

IDEAS includes:

- a database (IPSDB) for georeferenced items of any kind, images associated characteristics, and
- an interactive tool to manage the database, to select information and inspect data and images.

IDEAS allows a user to navigate through the information stored in the database, to select the geographic area of interest, to inquiry the database for the availability of data with specified characteristics, to retrieve and display information and images, to assess data quality and to prepare production requests.

The activity is performed in a very easy and rapid way, using an advanced graphic user interface. This aspect is linked with the optimisation of the software data retrieval and the power of the selected workstation, leading to an integrated product with unrivaled characteristics.

Two typical uses are foreseen for IDEAS:

- as a cataloguing facility for the remote sensing stations and for the remote sensing data distribution centres, where IDEAS answers to the images browsing need, retrieving information on the data availability, on the quality, providing the user with quick looks of the selected passes, and supporting the setup of production requests.

- as a management system for database of images geographically distributed, with selection and retrieval capability. IDEAS allows the retrieval of information associated with geographic locations. In this case the application is linked with ACS image analysis tool ("IPS") for the retrieved data exploitation and processing.

IDEAS is also a very flexible product. Being completely in-house developed, it can be easily adapted to specific customer requests, spanning from the addition of a new satellite to the output in a user defined format. ACS is ready to improve the product to cope with new specifications.

2. IDEAS HIGHLIGHTS

Stored information

IDEAS and its database can handle different kinds of information. They span from satellite images to annotation and texts, through aerial photos, GIS data, reports. They all can be stored and managed, provided that they can be geographically referenced. IDEAS keeps the mutual relations between objects.

Map Database

IDEAS allows an easy navigation on a worldwide database of vector data to locate the geographic area of interest. Based on the Digital Chart of the World (DCW), one of the most recent and complete map database, the navigation tool allows the display of more than seventeen layers of geographic information, from coastlines and state boundaries to the drainage and hypsography. Main strata have sub-layers to separately display information of different importance. Vector database is stored on disk. A minimal part (coast-lines and state boundaries) are kept in memory; the amount of data on disk can be tailored according to user needs. As example, one can have maximum data density for the area of interest (e.g. the station coverage area) and lower for the rest of the world.

Satellite data organisation

Satellites data are organised per acquisition segments. A segment, formally defined for satellites like SPOT and ERS, is a continue strip of satellite data, detected by the on-board sensor with homogeneous parameters (e.g. looking angle or calibration gain) and acquired by one station. IDEAS manages, for each segment, descriptive information and quick-look images, providing a complete tool for the inspection and quality assessment of the available data. The display of a segment is supported by a continuous scrolling of the image along the track, for accurate positioning of the image.

Multisatellite Capability

IDEAS can handle data from different satellites. Presently implemented are: SPOT, ERS, LANDSAT, J-ERS1, RADARSAT. The database handles indifferently georeferenced strips and pass description from any satellite; specific display functions have been developed to cope with the different characteristics of the satellites. As tipical example, for SPOT scenes, the software handles the GRS and the non standard scenes (Shift Along Track), as typical of the SPOT environment.

Graphic capabilities

The great advantage IDEAS with respect to applications with similar features resides in the advanced graphics interface between the user and the application. Based on MOTIF-style windows, the user interaction, completely mouse driven, is simple and easy-to-use. Several windows are available, each containing homogeneous information. The fully resizabler colour map window can be enriched with the available data layers, according the user selection, for a better understanding and reading of the image location. The user can associate and save them as a new configuration.

3. IDEAS FUNCTIONS

Following is a list of functions implemented in the interactive management of the information database.

- ♦ definition of the geographic area of interest
  - •- geographic area definition:
    - -by drawing polygons on the screen via mouse
    - -by drawing "rectangles" on the map
    - -by entering geographic co-ordinates
    - -by reference to files of co-ordinates
    - -by satellite reference grid
  - •- re-use a previously defined area
  - •- save/delete a defined area

- ♦ selection of the information retrieved from database:
  - •- information kind (image, text, vector, dataset...)
  - •- calendar definition on time window

- •- satellite parameters definition
- •- acquisition parameters
- • -quality of the data

- ♦ zooming and panning on the cartographic map (as in the picture below)
- ♦ catalogued information searching
- ♦ display/remove segments or scenes (interactive function executed by mouse clicking)
- ♦ display selected pass description information
- ♦ product definition
- ♦ production order preparation
- ♦ generate catalogue reports for the satellite operators
- ♦ print inquiry results
- ♦ assign colours to vector layers and objects.

Automatic Slick Detection and Information Dissemination using ERS SAR
(A Pre-Operational Experiment)

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Abstract
Oil pollution detection using spaceborne Synthetic Aperture Radar imagery has been investigated by many organisations in recent years. Automatic detection has been pioneered by EOS Ltd and DRA with the development of the Oil Slick Detection Work Station (OSDWS). An attempt to demonstrate the operational potential of using SAR images for routine slick detection has been organised in collaboration with AEA Technology, DRA Farnborough (West Freugh) and the U.K. Marine Pollution Control Unit. All this work is being funded through investment by each of the organisations involved. The OSDWS software has been installed at the West Freugh receiving station where images are being processed to identify and locate oil slicks. Output from OSDWS is transferred via fax or email to AEA Technology where it is input into an Oil Spill Prediction Model, output from which is then forwarded to the Marine Pollution Control Unit (MPCU) in Southampton for investigation. It is intended that a library of detected slicks and verification details will be built up in order to evaluate the viability of the service in an operational sense. This pre-operational phase will last for six weeks from the beginning of February 1996.

Brief history of slick detection using SAR

Aircraft are currently used to monitor or police the vessels that might be polluting coastal seas but they are constrained in their effectiveness by their range and search area. Ships, in the vicinity, are only capable of rapid response to a specific location once positional information of a potential slick has been gleaned from other sources. Satellites offer one potential solution to this problem of providing regional coverage of seas. Optical sensor systems are limited in their ability to detect oil slicks on the surface of the water and are hampered by cloud cover. In contrast Synthetic Aperture Radar (SAR) systems have an all weather day/night capability which enables them to monitor the state of the oceans in detail. Research has demonstrated the potential of slick detection using ERS-1 SAR data and the difficulties associated with minimising false alarms. Such false alarms are due to natural surface features which exhibit reduced levels of radar backscatter similar to those of an oil slick.

Slick Characteristics

Surface oil on the ocean reduces the radar backscatter due to the damping effect the oil has on the water. However this effect is limited when the wind speed and sea surface state rise to levels where the damping effect is insignificant and the radar backscatter is lost in the complex radar returns from the ocean. Also the effect is lost when the sea is very calm and there is no backscatter to damp.

After segmentation, potential slicks were identified using a number of criteria. The most important of these was an assessment of the fractal nature of the edges of the slicks. The relatively smooth edges associated with slicks provide a convenient discriminating factor which can be measured as the ratio of surface area to circumference.

Another feature of the slicks that has been noted is linked to the dispersal of the oil from the initial point at which it was released and the way in which the release occurs. In those cases where a large amount of oil is released over a short period of time the thickness of the oil tends to vary from the initial point and thus the damping effect. The dispersal pattern also, in very low sea-states, tends to follow prevailing tide, current and wind conditions. It is therefore possible to predict, given

knowledge of the above parameters, the likely dispersal pattern for a specific type of oil using prediction models such as that produced by AEA Technology. However there are a number of slick features in the water that exhibit similar signatures to those observed in real oil slicks.
These areas in the sea with low levels of radar backscatter are often caused by a range of natural features, such as coastal sea which is sheltered from the wind, features arising from shallows as well as those caused by plankton blooms and surface films. These natural phenomena often result in large numbers of possible slicks being identified in segmented ERS-1 imagery.

Automatic Slick Detection using ERS SAR imagery

The characteristics of an oil slick in SAR imagery as described above enable an expert image interpreter to identify such features by visual inspection. However this is a labour intensive task and tends to be rather subjective. One might argue that the subjectivity provides the best discrimination but for an operational role where statistics may be required, a more impartial solution may prove to be more quantifiable. To this end EOS Ltd investigated the potential for automatic slick detection and established that by segmenting a SAR image and defining a range of discriminatory attributes a reasonable degree of accuracy could be achieved. So by integrating these components a software system called the Oil Slicks Detection Work Station (OSDWS) was developed. This system was developed for the DRA Space Department under contract with the British National Space Centre.

Following the successful completion of the OSDWS system it was necessary to perform some evaluation of its potential role in an operational environment. First some validation and verification was attempted using information provided by the Marine Pollution Control Unit of Southampton. EOS were provided with details of slicks sighted during routine patrols from which a search was undertaken to identify available ERS-1 SAR data for those times and areas. This was not entirely successful as very little coincidence occurred i.e. where the aircraft were patrolling the satellite was elsewhere and vice versa. Therefore a different strategy was adopted where End User Evaluation programmes were set up with the intention of using experienced image interpreters who were involved in routine visual identification of oil slicks in SAR imagery (for research or operational purposes) to compare their findings with the results from OSDWS.

The End User Evaluation programme involved three organisations; the Joint Research Centre, Nigel Press Associates/Treicol and the Rijkswaterstaat in Holland. All of these organisations are experienced with slick detection using satellite based SAR imagery and so were able to provide expert interpretation of the results from OSDWS.

On the whole the results were successful though the main problem lay with the number of false alarms. This led us to consider improvements to the slick attributes having found that some of them were heavily correlated and therefore over-weighted those contributory factors. Consideration was also given to contextual information such as relationships between similarly shaped features. For instance a wind/wave slick effect is often comprised of similarly shaped targets arranged in a near regular pattern.

Further Development

In addition to our own development, the Oil Slick Detection Work Station, developed by EOS Ltd, has been used as the basis for developing technologies in Canada. MacDonald Dettwiler Associates are involved in this work and are undertaking the following activities to further explore the potential for automatic slick detection.

The main objective is to develop a methodology to analyze the image properties and context for discriminating between hazardous sea-surface objects and normal sea phenomena. The first application to be developed is oil slicks detection with SAR imaging. This involves developing a machine learning method which will learn rules to distinguish properties of oil slicks from properties of slick look-alikes. In addition the successful methodology will be adapted to the detection of other hazardous materials or phenomena causing environmental harm. A classification scheme to summarize the observable properties of all ocean surface phenomena will be used to "learn" the classification rules. This will be augmented with human expertise. Methods will be adapted to include RADARSAT imaging as a source of evidence to allow for low-incidence angle imaging and wide-swath imaging.

By developing an automated slick detector with a high degree of detection accuracy and classification accuracy a cost-effective system for continuous surveillance of the oceans surface could be achieved. A region detection method combined with a multivariate input to the machine learning system shows promising results in the ability to separate regions representing oil slicks from non-oil slick regions. A comprehensive classification system has been met with encouragement from scientific advisors to the project.

Pre-Operational Service Experiment

In conjunction with AEA Technology and DRA a pre-operational demonstration project has been set up to supply the MPCU with prompt oil slick information from the West Freugh tracking station. This has been achieved by processing ERS SAR data of U.K. coastal waters received at the station and sending the results directly to AEA, where the information is assessed and any likely targets forwarded to MPCU. The Oil Slicks Detection Work Station has been installed at West Freugh for this purpose. The procedure is as follows:

1) Images received at West Freugh for the areas of interest are visually inspected for oil slicks.

2) If a target is identified that is a possible oil slick the image will be processed using OSDWS.

3) Once the image is processed the results can be viewed in the OSDWS display window Depending on the number of slicks detected, they can all be displayed. If there is a large amount then a few can be selected for display (i.e. the most likely targets).

4) Once a satisfactory display of slicks is achieved a chart output should be obtained from the menu on the main OSDWS panel. This chart can then be faxed to AEA.

5) If the slick(s) look particularly interesting a screen dump should be obtained using the Sun utility "Snapshot", it should then be converted to "tiff" format and emailed to AEA..

6) The individual slick details can also displayed and sent to AEA Technology.

7) Slick details are then input to the spill prediction model at AEA TEchnology and the path of the oil calculated.

8) Where appropriate information is then forwarded to MPCU.

The results of this experiment will be used to provide information to guide the future development of automatic slick detection as well as identify the data delivery needs.

Mediterranean

The Mediterranean has its own particular problems and considerations when it comes to the environmental impact of oil spillages. Apart from the obvious ecological hazards presented by oil slicks reaching the shore, many countries bordering the Mediterranean rely on tourism for a significant proportion of their national income. Ideally ecological concerns should be sufficient to encourage counter-measures, unfortunately it is more often economic threats that prompt swift action.

During work on slick detection, at EOS, it has been noted that in many cases the images of the Mediterranean provided the highest levels of hits and generally the lowest proportion of false alarms.

This could be due to the quality of the images that were provided for this work or attributable to the particular factors of the Mediterranean (e.g. salinity, closed sea, relatively calm, generally warmer than open seas, etc). Nonetheless it is interesting to note it lends itself particularly well to survey by satellite. This fact should be exploited to provide an operational service to supply regular slick details to each of the Mediterranean countries.

Coverage

One of the major problems with satellite monitoring is the lack of frequency with which areas are repeatedly surveyed. Both ERS satellites are currently in 35 day repeat cycles thus monitoring a particular slick or spill over a few days is not possible. However the opportunistic detection of slicks can provide a complementary service to the routine aircraft surveys and assist with the targeting of these resources. Information that can be derived from longer period monitoring is the occurance of "spillage patterns", where it may be noticed that a particular area is regularly the victim of deliberate spilling.

Environmental agencies responsible for determining the extent of such pollution need regular and consistent surveying of particular areas in order to obtain a statistical measure of the problem. Satellite remote sensing can provide this type of survey without the problems encountered by the aircraft such as bad weather, or being re-directed to another area. EOS Ltd are undertaking research in collaboration with the National Environmental Research Council (NERC) on the use of remote sensing sampling to determine the characteristics of populations of oil spills and other transient ocean surface features.

SAR data can provide useful synoptic information in the event of a pollution disaster such as the running aground of the Sea Empress off St Annes head in Wales. It was unfortunate that it was not possible to commission the ERS satellite in time for the pass the day after the spill started; it would have provided an interesting comparison with the scenes from the 25th and 26th February when the oil had spread a significant distance.

Radarsat will provide a further source of data and with its ability to provide images of varying resolution and swath will allow optimised detection possibilities. In particular the shallow incidence angles can improve detection of oil spills. The standardbeam mode will provide coverage similar to ERS but in addition (depending on the size of the slick) the lower resolution ScanSAR modes will provide larger area coverage.

Overall the opportunities and possibilities for oil slick monitoring from satellite are good. Although at present the ability to undertake such monitoring operationally is limited due to the constraints of coverage, without ERS-1 there would have been no opportunity to test and experiment with the technology and pre-operational services. Radarsat is now taking this a stage further as a fully commercial operation with the objective of satisfying the users needs. If users are prepared to accept the current limitations and support the pre-operational services, it is unlikely to be long before instruments are launched which provide the type of resolution and coverage required for their specific needs.

OIL SPILL MONITORING BY USE OF RADAR SATELLITES AND AIRCRAFT

Tromso Satellite Station in collaboration with Norwegian Pollution Control Authority, Norway

OIL SPILL MONITORING BY USE OF RADAR SATELLITES AND AIRCRAFT

Tromso Satellite Station in collaboration with Norwegian Pollution Control Authority, Norway

A project for use of ERS-1 SAR data for detection of oil spill at sea was initiated in 1991 as part of the Norwegian Space Centre´s (NSC) national ERS-1 program. Based on this activity, a near real-time service has been established by Tromsø Satellite Station (TSS) according to requirements forwarded by the Norwegian Pollution Control Authority (SFT) - a Governmental expert agency under the Norwegian Ministry of Environment.

The main objective is to serve the end users with information on possible oil spills within two hours after satellite overpasses. Today´s service is a first step towards a fully operational system covering Norwegian and adjacent waters. The operational service will use both satellite and aircraft data in combination with other observations.

ERS-1 SAR image of an oil field in the North Sea acquired in July 1994. Bright spots represent rigs and ships, dark features possible oil slicks or other deposits. © ESA/TSS, 1994

Total oil spill service coverage area (blue) and national priority area (red). ERS SAR data within the area is analysed in near real-time.

Total coverage of ERS-1 SAR data applied for the service during second half of February 1995.

National Service Operations
Utilisation of ERS SAR data is implemented in the national system for oil and chemical pollution reporting in Norway. The satellite element represents an extension of the existing governmental surveillance aircraft patrols coordinated by SFT. The service operations at TSS include a near real-time analysis of ERS SAR data from Norwegian waters, and information directly to SFT on possible oil spills within two hours after satellite overpasses. The primary service area has been defined by SFT, which is responsible for observation verifications.

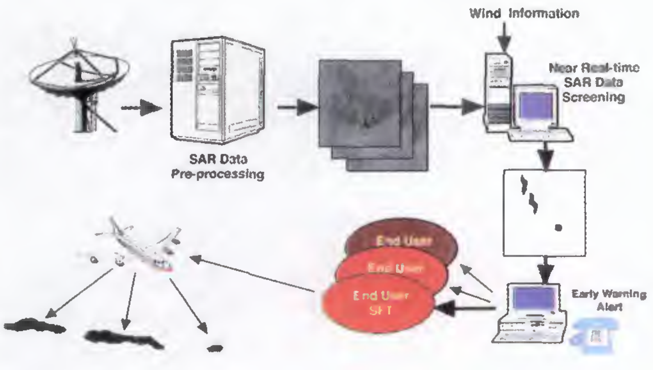
In 1995, the SFT surveillance aircraft operations are coordinated according to the ERS overpasses. TSS informs SFT and the surveillance aircraft crew about the planned satellite acquisition schedules, and receives the flight plan in return. The data analysis at TSS is also scheduled according to the flight plan. SFT has an agreement with the Norwegian Meteorological Institute regarding use of an oil drift model as well as meteorological assistance whenever an oil spill is identified.

Extended Service Operations
Due to a co-operation with other North European countries and research needs, the total coverage area has been extended. TSS analyse ERS SAR data from waters belonging to other North European countries, thus providing a limited coverage outside Norway. On an experimental basis national authorities are either notified directly, or through SFT, about possible oil spills.

Service Advantages
The large coverage area in combination with the near real-time capabilities of TSS represent the main advantages of this service. The ERS data infrastructure at TSS processes a 100x100 km SAR image within 6-8 minutes. Even though ERS-1 is an experimental satellite, an acceptable coverage has been obtained. On average 300 ERS scenes each covering 100 square kilometres from the service area are analysed per month.

Automatic detection of potential oil spills was earlier considered to be mandatory for this service. Algorithm for this purpose has been developed and verified. Experience have, however, shown that this is not a mandatory requirement for the time being. Whereas the automatic slick detection is executed within a few minutes and anyhow needs a manual interpretation, 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.

Detection capabilities
The use of the SAR low (100 meter) resolution images has demonstrated the ERS-1 satellite´s capability to detect even very thin pollution layers in low wind speed of 3-4 m/s and thick oil emulsions at higher speeds of 10 m/s. Detected pollutants include: crude oil emulsions, run-off water from acid-pitch depository on land, drilling fluid from off-shore oil rigs, waste from fish production plants, and fish fat remaining at the sea surface after fishing trawler catches.



Oil spill service concept model, from reception and analysis of data at TSS, through early warning alert and aircraft operations by SFT.

SFT surveillance aircraft, LN-SFT. Photo: SFT/Fjellanger Wideroe a.s.

Two SAR detection capability problems have been experienced: - 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 sea water and no surface effect is detected by the SAR (e.g. the "Braer" disaster).

Rain cells have also been detected from the SAR data, and may cause interpretation problems. The service reliability is improved through extensive training of the operators at TSS, and through the use of additional (e.g. meteorological/wind) information.

Natural Oil Seepage
Another activity is detection of natural oil seepage from the seafloor by use of SAR data. More than 150 SAR images have been analysed, and 10 seepage candidates identified. None of these candidates have, however, been confirmed by any in-situ observations. A new signature pattern appearing as small (approx. 0.3 x 0.3 km) patches stretching out in the wind/current direction was discovered. This signature is associated with seepage droplets reaching the surface at different times.

This activity has been carried out based on the requirements of oil-companies.

Service Development Phases
The present service is a result of national priorities and projects involving end users. Since the mid 80´s the use of satellite radar data for near real-time marine applications has been given a high priority within the Norwegian space policy. The objective has been to provide information at the users´ site in near real-time, i.e. within one hour after the satellite overpass.

The Norwegian oil spill detection project was 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 founded by international sources, and the end user represented by SFT has participated in the project from the very beginning. A steering committee chaired by NSC, with participants from SFT, Norwegian Defence Research Establishment (NDRE), ESA, Marine Spill Response Corporation (MSRC), the oil companies Statoil and ESSO and TSS has existed during the period. Co-operation with other governmental pollution control authorities in Europe (The Netherlands, Germany and UK) has also been developed.

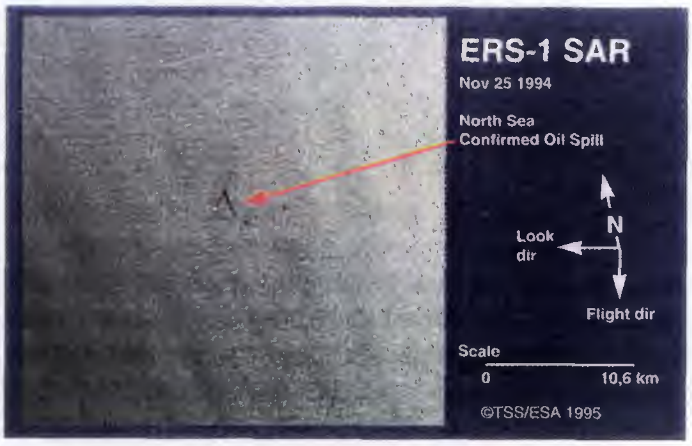
A phased development model has been applied. The project results have achieved large international attention:

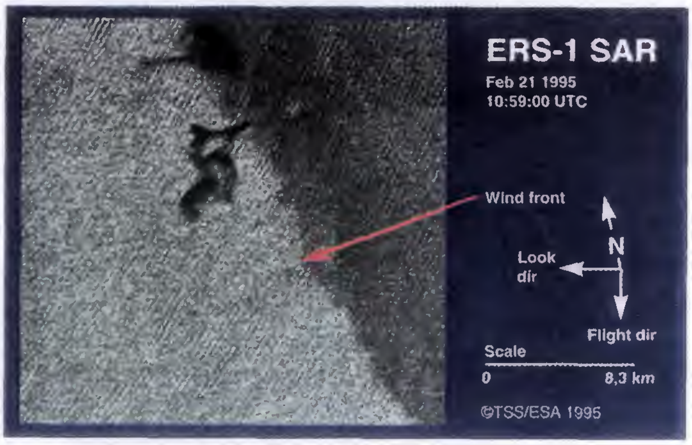
<u>1991</u>: Evidence of the capability of the ERS-1 SAR to detect oil at the ocean surface.

<u>1992:</u> Demonstration of detection capabilities and the dependence upon the wind conditions and the sea state.

<u>1993:</u> Regular formal requests from SFT to offshore oil exploration companies for explanation of satellite observations. Detection of various types of pollutants.

<u>1994:</u> Project transferred from research to operational unit. ERS SAR images are analysed on a routine basis at TSS, and observed possible oil spills are forwarded to the SFT national 24 hours notification focal point.





ERS-1 SAR image data examples:
Confirmed oil spill (upper), candidate spills, ships, wind front (middle), and a seepage candidate (lower).
© ESA, TSS, 1995

Future Development

The results obtained so far have shown that there is still a need for continuous service improvements. The service infrastructure chain needs to be upgraded. The new radar satellites (RADARSAT, ENVISAT) will improve the repetitive coverage, but a full understanding of the detection capabilities need to be developed.

The costs per unit covered by satellite is below the cost obtained from traditional aerial surveillance systems. It is, however, important to emphasis that satellite data will not fully replace other monitoring platforms.

However, it has been shown that aircraft operations can be more cost effective by the use of satellite data for pre-mission planning.

TSS covers large parts of the Northern European waters, and has an infrastructure capable of near real-time operations. Today, an end user in Northern Europe can receive information about possible oil spills within their territorial waters within two hours after SAR data acquisition. TSS could therefore play a central role as a satellite data handling facility within an operational North European oil spill detection service.

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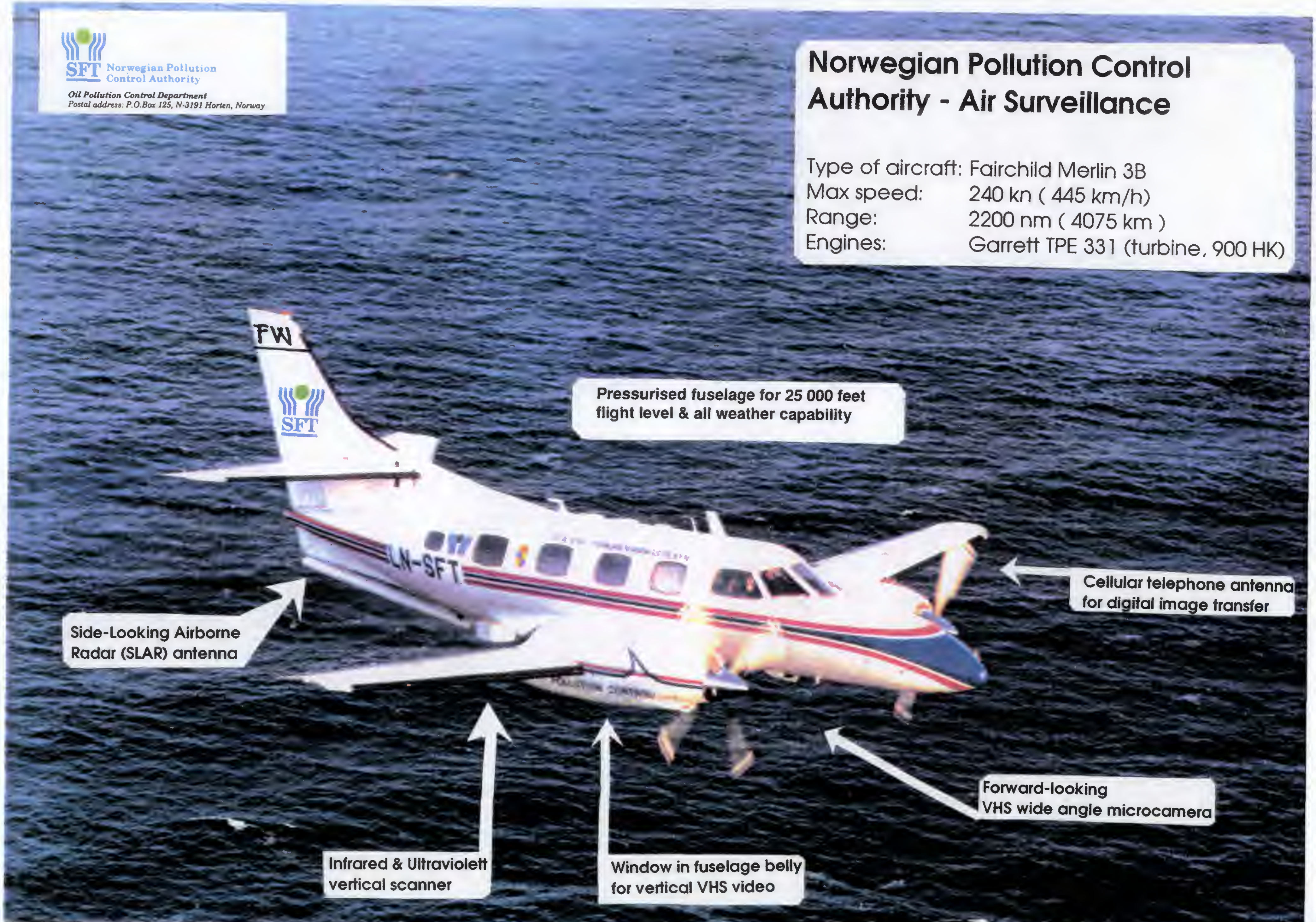
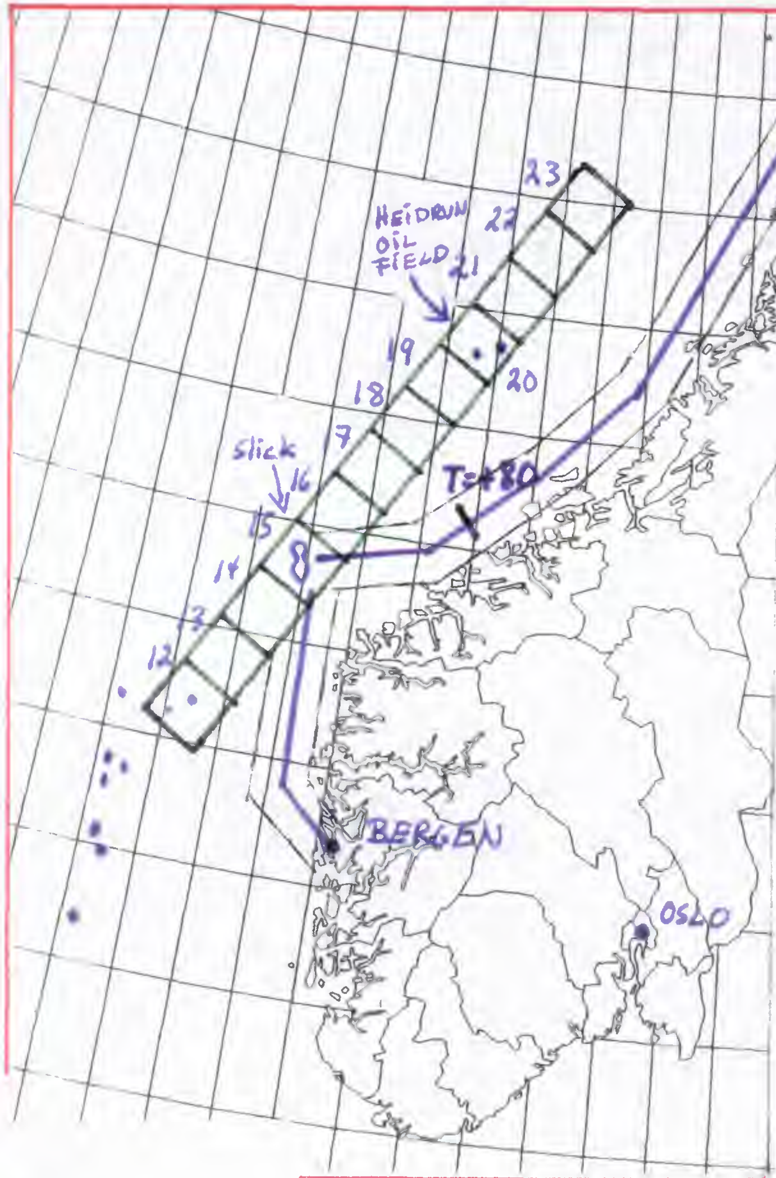


SFT Norwegian Pollution Control Authority
Oil Pollution Control Department
Postal address: P.O.Box 125, N-3191 Horten, Norway
Norwegian Pollution Control Authority - Air Surveillance
Type of aircraft: Fairchild Merlin 3B
Max speed: 240 kn (445 km/h)
Range: 2200 nm (4075 km)
Engines: Garrett TPE 331 (turbine, 900 HK)
FW
SFT
LN-SFT
Pressurised fuselage for 25 000 feet flight level & all weather capability
Cellular telephone antenna for digital image transfer
Side-Looking Airborne Radar (SLAR) antenna
Forward-looking VHS wide angle microcamera
Infrared & Ultraviolett vertical scanner
Window in fuselage belly for vertical VHS video



AIRCRAFT-SATELLITE CO-ORDINATION

T= 0 min	SAR image download start
T= + 2 min	SAR image download end
T= +20 min	Frame 20 completed - No indication Heidrun oil field
T= +30 min	Aircraft take-off Bodø airport
T= +35 min	Frame 23 processed & assessed then frame 22, 21, 19, 18...
T= +80 min	Pager call to aircraft from TSS slick detection frame 15
T= +85 min	Phone-call from aircraft to TSS flight plan changed
T= +110 min	Pollution confirmed
T= +115 min	Aircraft call SFT officer on duty
T= +180 min	Aircraft landing, Bergen

Total surveillance coverage: 168 000 km^2

SFT Norwegian Pollution Control Authority

Oil Pollution Control Department

Postal address: P.O.Box 125, N-3191 Horten, Norway

DAY 2

SESSION 3

Continuation of DAY 1

- Contributions
  (in order of presentation)

SESSION 4

- Posters

SESSION 5

- Contributions
  (in order of presentation)

THE USE OF SATELLITES TO DETECT OIL SLICKS AT SEA

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INTRODUCTION

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

a) 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

b) 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 other (greater) source of oil pollution which is land based, entering the marine environment via rivers.

This presentation 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.

2 THE ROLE AND RESPONSIBILITIES OF THE MPCU

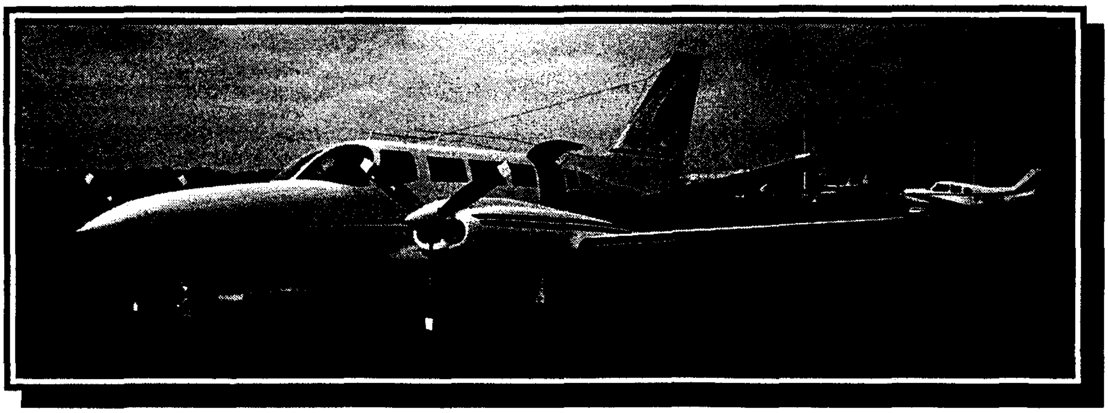
2.1 The MPCU was established to provide the UK Government's response to an oil or chemical spill from a ship at sea. It also provides assistance to Local Authorities who are responsible for cleaning oil from the coastline. The MPCU develops and implements the UK's National Contingency Plan for dealing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

2.2 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.

2.3 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.

3 CURRENT AERIAL SURVEILLANCE

3.1 The MPCU has two Cessna 404 aircraft on contract fitted with Side Looking Airborne Radar, Ultraviolet and Infra Red detectors, a still camera and video.



CESSNA 404 REMOTE SENSING AIRCRAFT

3.2 Side-way Looking Airborne Radar (SLAR)

3.2.1 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 centimetres, and the reflection is used to build up a radar 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.

3.2.2 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.

3.2.3 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.

3.3 Ultra-violet 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 micrometers. 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.

3.4 Infra-red Line Scanner (IR)

3.4.1 The IR is very similar in operation to the UV, and the two are normally operated together. It detects infra-red radiation with a wavelength of about 10 micrometers 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 millimetres) will warm up more rapidly than the surrounding sea and show up white on the display.

3.4.2 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. Infra-red systems can be mislead by other temperature effects, such as cooling-water discharges and should therefore always be used in conjunction with other sensors.

3.5 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.

3.6 Video Camera

3.6.1 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.

3.6.2 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.

3.7 Systems

3.7.1 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.

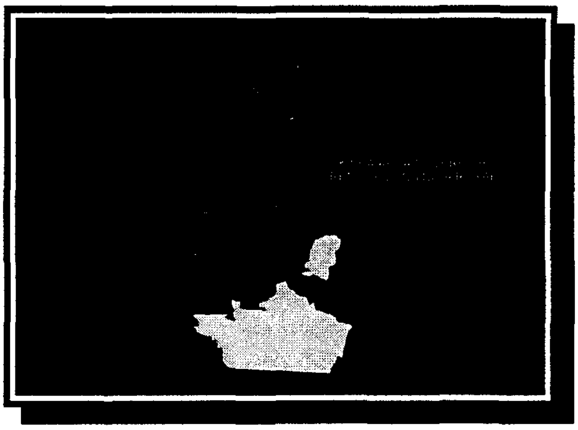
3.7.2 The computer can also provide some limited in-flight processing facilities, typically expanded views of areas of the screen, and facilities for selecting targets to provide navigational instructions for moving the aircraft to the target.

3.7.3 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 on to the pictures.

3.7.4 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.

3.7.5 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.

3.8 Operational procedures



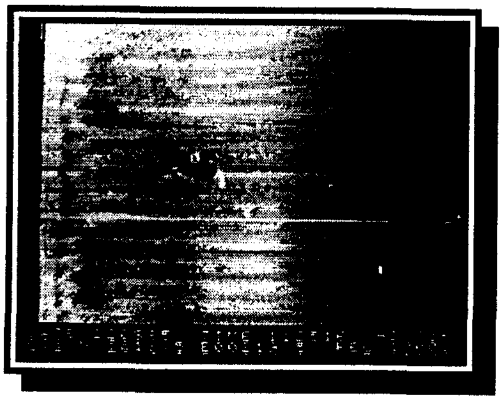
3.8.1 UK waters are divided into a number of patrol areas of roughly equal size. These areas are patrolled on a random basis but with more patrols in the areas of known activity, such as area M where most of the UK's oil production platforms are located and areas C, D, and E which cover the busy shipping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

3.8.2 When on patrol the aircraft proceed at 290 km/hr knots at a height of 1000 meters using SLAR only. When an image is detected the aircraft drops to 300 meters and investigates the slick using UV and IR. If a vessel is associated with the slick the aircraft drops to 100 meters to identify the vessel and obtain pictures/video.

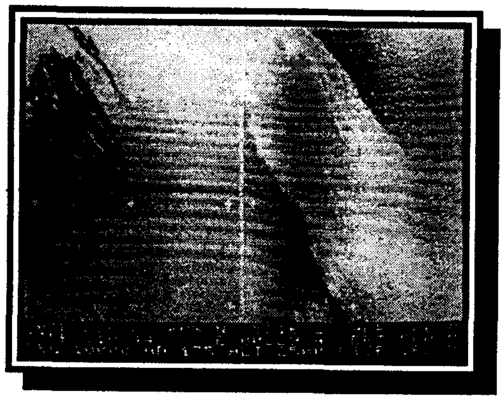
3.8.3 Possible offenders are imaged and photographed using the techniques set out in Chapter 23 of the Bonn Agreement Counter-Pollution Manual. It is important that the photographs and the imagery show that the vessel is the only possible source of the oil. The vessel's name is photographed, if possible, 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.

3.8.4 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.

3.8.5 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 below are of a test spill of a approximately 10 tonnes, the IR shows the "structure" of the slick which has started to break down into windrows (wind is bottom right to top left).



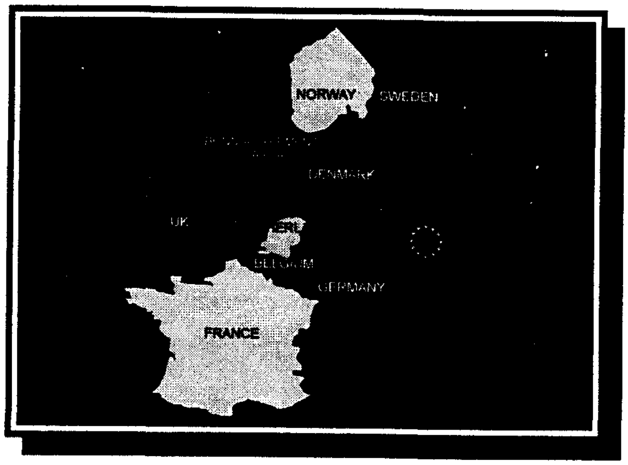
SLAR IMAGE



IR **UV**

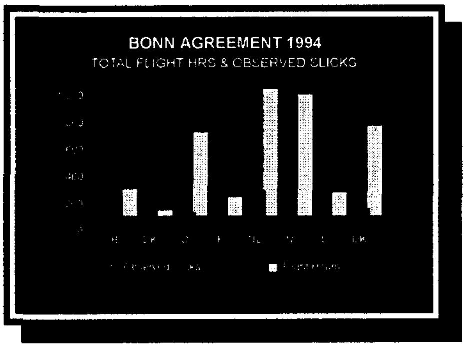
3.9 BONN Agreement

3.9.1 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 have agreed a co-operative approach to aerial surveillance, and this is set out in Chapter 4 of the Bonn Agreement Counter-Pollution Manual.

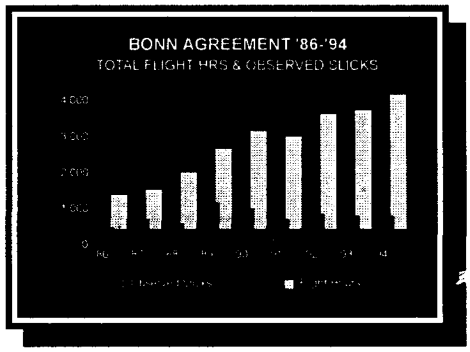


3.9.2 Over the years a large body of data has been collected for aerial surveillance in the North Sea. The charts below show the data for individual Bonn Agreement countries for 1994 (1995 figures are being compiled) and the total data for 1986 to 1994.

BONN AGREEMENT DATA



BY COUNTRY



TREND

4 PERCEIVED WEAKNESSES

4.1 Weather/Visibility

4.1.1 Weather and visibility will affect the ability of the remote sensing aircraft to detect slicks for two reasons:

i) 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 can not fly is quite small; and

ii) weather conditions will affect the ability of the sensors to detect slicks and identify offenders.

4.1.2 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.

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

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

4.1.3 Although IR will detect slicks for a few hours after sunset, neither IR nor UV can 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.

4.2 Number of hours flown

4.2.1 The UK waters currently patrolled cover some 360,000 km^2. When on patrol the aircraft flies at 290 km/hr and covers 24 km on each side using SLAR. Therefore the aircraft can survey some 14,000 km^2/hr. Assuming a slick will persist for 24 hrs, then to ensure that all slicks are detected would require 26 hrs to be flown each day - assuming 6 hr patrols this would require some 4 aircraft.

4.2.2 The total yearly hours required would be some 9400. Infact we fly some 800 hours (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 employed with more hours flown in some areas than in others.

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

5 POSSIBLE USES OF SATELLITE MOUNTED SAR

5.1 Collection of statistical data

5.1.1 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.

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

5.2 During major oil spills

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

5.2.2 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 leading to a distraction for those carrying out clean-up operations.

5.2.3 During the recent SEA EMPRESS incident in Wales SAR images were obtained but were not used to direct response operations. The image shown below shows oil in locations consistent with the observations of the remote sensing aircraft.

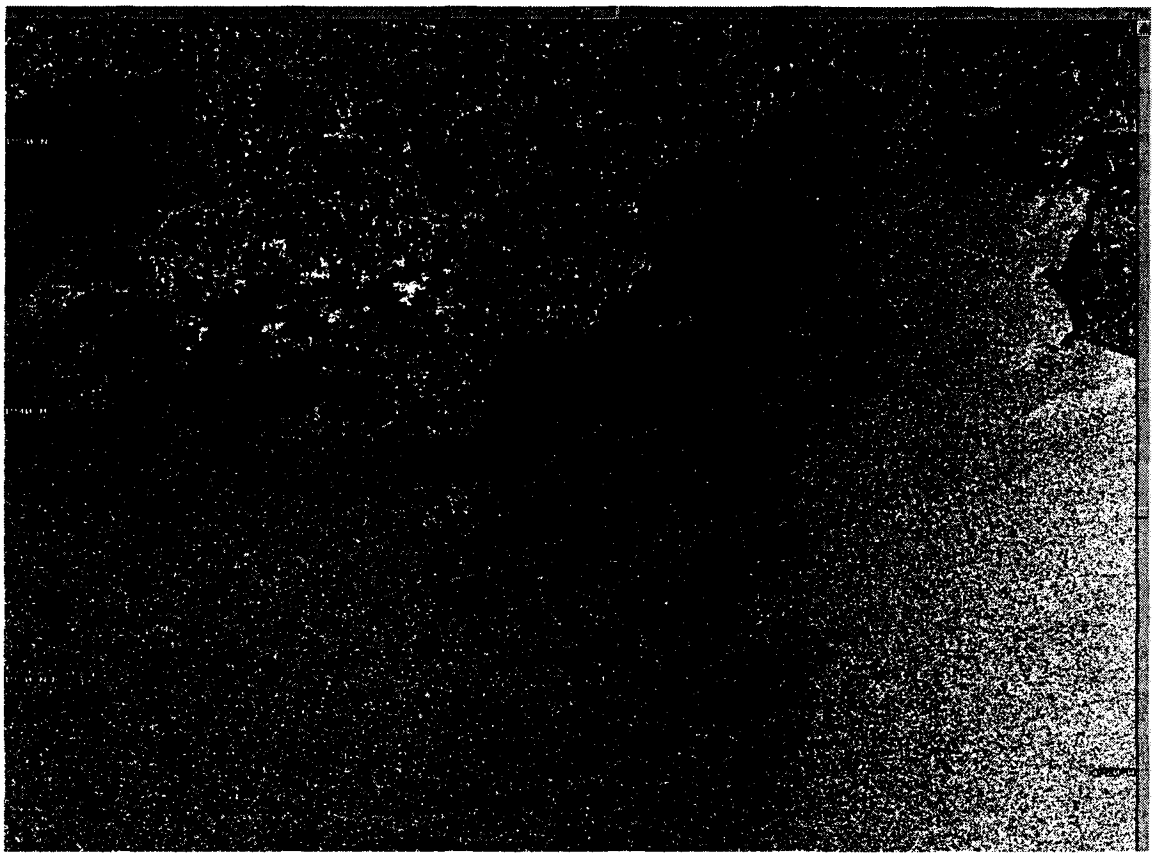


IMAGE FROM RADARSAT FEBRUARY 21st 1996 at 06:45 UTC
(wind 8 m/s Northerly)

5.2.4 However, other images showed "dark" areas where no significant oil had been detected (25 February) and "dark" areas where oil could have been (26 February).

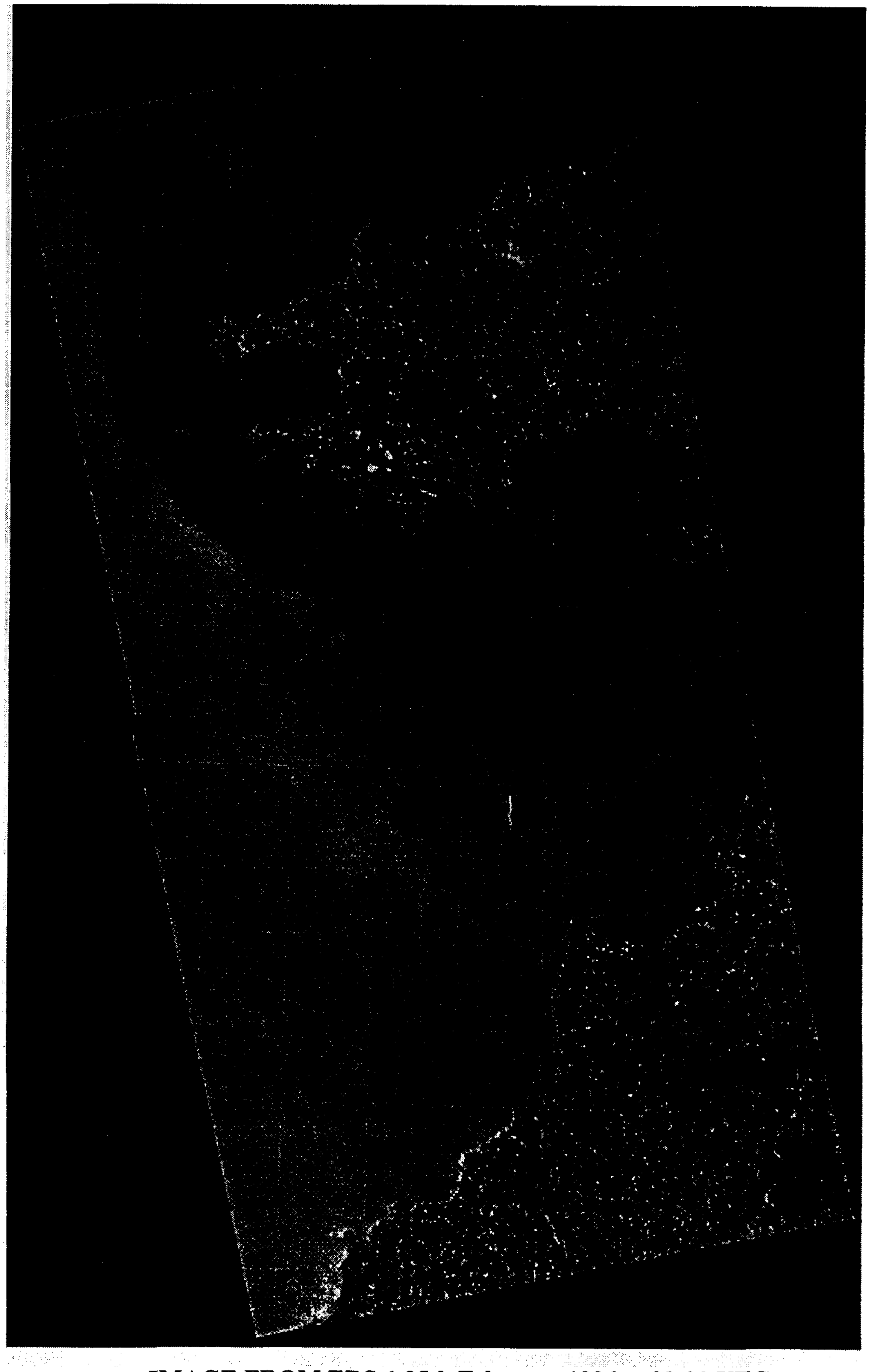


IMAGE FROM ERS-1 25th February 1996 at 22:23 UTC
(wind 7m/s Westerly)

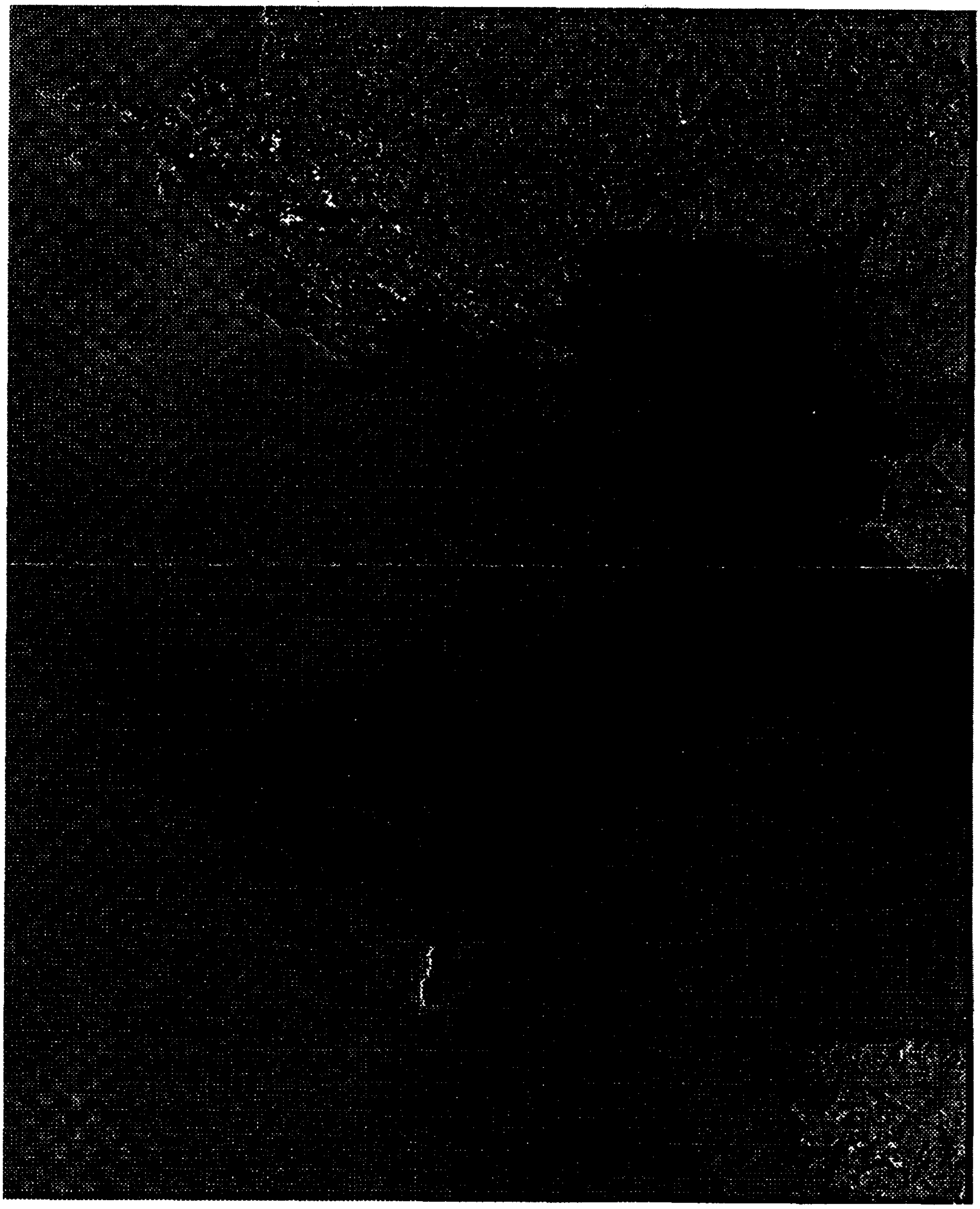


IMAGE FROM ERS-2 FEBRUARY 26th 1996 at 22:23 UTC
(wind 4 m/s Southerly)

5.3 Detection of illegal discharges

5.3.1 Satellites can detect slicks at sea, however they can not 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 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.

5.3.2 From para 4.2.2 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.

6 USER REQUIREMENTS

6.1 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 hour (it may take the aircraft upto to 2 hours to arrive on 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.

6.2 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.

6.3 As mentioned in para 4.2.3 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.

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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Abstract

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

The above mentioned system including a Bispectral Scanner System DAEDALUS AA2000 and a Multispectral Scanner System DAEDALUS DS 1268 makes possible a quickly and effective survey both of shorelines and large areas off-shore for environmental (oil pollution detection and evolution. control of oceanographic and biological parameters). geological (soil erosion. coastal assessment) and police purposes (identification and appraisal of illegal releases. prevention and repression of unauthorized building). including the processing and interpretation of real time data.

Satellite platforms (ERS 1. ERS 2) may be taken into account for surveillance duties. although in the case of operational activities. a comparison with the data elaborated by the airborne remote sensing system must be done.

The planning of such a programme should not be carried out without a keen cost-benefits evaluation.

ITALIAN COAST GUARD HEADQUARTERS

PLANS AND OPERATION BRANCH

THE COAST GUARD REMOTE SENSING ACTIVITIES AND THE USE OF SATELLITE PLATFORMS FOR MARINE POLLUTION ABATING.

1. The Italian Coast Guard - Generalities.

It is a branch of the Italian Navy giving support to the Ministry of Transport and Navigation by absolving the Administration's institutional duties.

It is a highly professional and specialized organization carrying out, besides specific activities of military nature, maritime police activity in co-operation with different national Administrations. It operates in such fields as the management of harbours and civil maritime personnel, the control of national fishing activities, the surveillance of sea-going merchant ships and pleasure boating, the issue of maritime certificates, the control of archeological patrimony.

Anyway, prior to all the above mentioned activities are Search and Rescue, safety at sea, protection of marine environment.

2. Surveillance and defense of marine environment.

The Italian Coast Guard can deploy about 300 marine craft, including 60 long-range vessels, 140 short-range boats with different features, 137 coastal short-range boats and 13 anti-pollution craft.

Resources available include also twelve fixed-wing patrol aircraft type PIAGGIO 166 DL3 and four helicopters type AUGUSTA AB 412, whose number is expected to increase in the future up to 21.

2.1 Remote sensing programme .

The importance of remote sensing has grown in the last years, especially in relation to surveillance of both marine and coastal environment: an experimental program is being implemented by the Coast Guard, which has given encouraging results despite some bureaucratic obstacles.

Actually, the evolution of national legislation concerning the protection of marine environment made the specific competence of Coast Guard personnel even more urgent in such activities as the control and abating of man-induced pollution and the management of protected marine environments.

That is the reason why a development of both operational and professional components of the Coast Guard is necessary.

Fixed-wing aircraft have been equipped with different types of sensors so as to perform the quick monitoring of large marine areas and extended strips of land with low costs. The aim of aircraft deployment is both ecological (i.e. oil pollution detection and sea health) and geological (erosion. territory set-up) and judicial (control of unlawful waste. prevention and repression of unauthorized building).

The keyword in the development of the mentioned programme has been from the very beginning the production of a highly qualified aircraft for marine sourveillance): the PIAGGIO 166 DL3 is equipped with an aerial camera system VINTEN 618 made up of two 70 mm. cameras installed on the port side of the aircraft and in such a way that their axis are oriented 80° and 40°30' in relation with the surface. allowing 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 in function of aircraft speed and altitude.

The multispectral scanner system DAEDALUS DS 1268 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 so as to be processed by a special software for the utilization of required information.

Processed imagery show in false colours some physical parameters (temperature. radiance. reflectance). giving the opportunity to analize the features of the sea stretch observed.

The bispectral scanner system DAEDALUS AA2000 works on two channels in the infrared and ultraviolet bands. with a 86° digitalized field of view and a 5 mrads geometric risolution. It was especially designed for the surveillance of coastal zones involved in oil spill pollution. Oil slicks may be easily detected thanks to their high reflectance in the ultraviolet band. Besides. a difference of emissivity between adjacent healthy and polluted surfaces in the infrared band is to be noticed.

DAEDALUS AA2000. differently from DAEDALUS 1268. was not intended to make the digitalization of imagery: by the way. it produces a hard copy onboard the aircraft.

For a rational use of both systems the S.T.A.I. (Remote sensing service - Servizio di Telerilevamento Ambientale e Istituzionale) has been recently established in the Italian Coast Guard Headquarters.

This service arranges and schedules remote sensing missions carried out by CG aircraft. processes and reads the data that are source of important information as far as the defense of marine environment and the surveillance of all activities in- and offshore.

Further S.T.A.I responsabilities are the standardization of remote sensing procedures, the production of operational issues and the familiarization of airborne teams with equipment and sensors efficency maintenance procedures.

After the S.T.A.I was established, missions have been managed in co-operation with the Civil Protection Department - 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 anthropized areas and about warp shifting due to tides in the proximity of shorelines.

Last Dicember, Coast Guard aircraft monitored in co-operation with the Ministry of Environment the Lagoon of Venice, from Malamocco harbour to Chioggia harbour for the evaluation of the effects of an oil pollution originated by a fortuitous break in a pipeline.

The data processing showed the spreading and the thickness of the oil slick and represented at the same time a valid aid for the allocation of antipollution resources coordinated by the Harbour's Master Authority of Venice.

2.2. Coastal environmental monitoring program from airborne and satellite platforms.

The Italian Coast Guard elaborated in co-operation with the Aerospace Enginnering Department of "La Sapienza" University in Rome an experimental project for the monitoring of sea surface close to the italian coast line.

The program is based on both data collected by ERS satellites' S.A.R 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 program consists of:

1) the planning of periodic aircraft surveys for the evaluation of coastal water quality and the detection of pollution in marine waters. The surveys are carried out by means of the Italian Coast Guard aircraft equipped with a Remote Sensing system:

2) the implementation of a systematic monitoring of oil slicks by means of SAR sensors mounted on ERS satellites (through the study of quick looks available shortly after the transit of the satellites):

3) on scene missions aimed at a detailed analysis of waters affected by oil slicks detected by ERS satellite quick looks by deploying CG aircraft and marine craft belonging to different Government's Administrations.

Periodic aicraft surveys

Coast Guard aircraft equipped with sensors are particullarly designed for periodic missions (for instance twice a year. so as to collect data before summer and in autumn) for the evaluation of coastal water quality. Calibrated algorithms may be used in order to estimate the presence of chlorophill. suspended sediments. suspended organic particles with a previous algorithms calibration mission.

Such surveys allow to detect waste water discharges by means of the DAEDALUS AADS 1268 CZCS sensors in the thermic infrared band.

They could be aimed only at the monitoring of chlorophill α along the italian coast line in the first year of the programme development just as experimental stage. They could be then carried out for the evaluation even of organic particles (this second stage would need a calibration campaign of water quality parameters).

Systematic utilization of Satellite Remote Sensing

Similar to the marine pollution monitoring system established by the Norwegian Coast Guard. a ERS imagery acquisition system in favour of the Italian Coast Guard and a quick looks delivery system to the S.T.A.I. might be created.

The fast processing of imagery delivered to the Coast Guard would produce in no more than 3 hours a quick look for the stretch of sea observed with a resolution below 100 mt.

The Italian Coast Guard could analyse the quick looks shortly after the satellites passed. finding out dark slicks on sea surface representing presumibly oil slicks.

On scene evaluation of possible oil slicks detected by ERS satellites.

The third operative stage of the coastal monitoring system with reference to Coast Guard structures and requirements starts whenever an oil slick is presumibly detected at sea. The data collected must be such to justify the delivery of an aircraft P 166 DL3 that must verify the real presence of pollution in the referred area.

The utilization of the DAEDALUS AA 2000 UV/IR is at this point particularly important. as it detects effectively a floating oil slick and makes the datum immediately available to the specialized staff on board the aircraft.

Besides, satellite imagery acquisition allows to track the shifting of the slick for many days and shows all coastal waters affected by it. It makes also possible to control the dispersion of the slick on a sufficiently large scale, so as to be sure that the entire oil slick observed has been abated.

In case of low ceilings on the areas where the presence of pollution must be checked, satellite aid reveals itself absolutly necessary if the aircraft must fly at low altitude.

At last, it must be said that the acquisition of imagery reporting a possible oil spill authorizes the deployment of further aircraft and marine craft for a better evaluation of it on scene and, at the same time, for its abatement.

2.3 Oil slicks monitoring

In case of relevant oil spills, up-date data on its evolution are continuously required, so as to give prompt response and to modify strategies purposly studied as the emergency develops.

It is given for sure that oil spreading in the sea depend largely both on influence of weather conditions and different external dynamic agents, and on the specific components of each single hydrocarbon.

Experience shows that forecast mathematical patterns, even the most elaborated, need confirmation through a continuous and systematic monitoring of the scenario.

For all these reasons, unless satellite platforms are available for the monitoring of the affected area with restricted time parameters (less than 12 hours), the better aid is represented by an aircraft equipped with radar and optic sensors.

On the other hand, our observations are confirmed by the norwegian experience using a system based on extremely frequent satellite detections.

3. Conclusions

A satellite and airborne coastal monitoring model is based essentially on tools and sensors presently operating. It aims at a better utilization of existing platforms, but cannot offer any solution to some operative problems that remain open question:

- poor temporal repetitiveness of satellite lookouts;
- lack of satellite electro-optic sensors giving such a on-earth-risolution to allow a significant study of water quality;
- strong disturbance on airborne electro-optic sensors generated by ceiling and fog on scene.

Actually, the last difficulty may be avoided, as satellite lookouts of clouded areas make it possible for an aircraft to divert directly on the area affected by the pollution detected by the satellite. Quality water evaluation, on the other side, cannot take place by using microwave sensors. Water parameters monitoring missions require in any case good weather conditions.

Poor temporal repetitiveness of satellite lookouts and low on earth-risolution of satellite electro-optic sensors, depending on the altitudes of the orbits, represent a more serious question to solve. Without increasing the number of satellite passages and with no chance of improving the features of imagery acquired by satellite sensors, an effective coastal monitoring system in the Mediterranean Basin able both to detect most marine weathering and to deploy immediately all resources available for the eventual abating of pollution is hardly obtainable.

The hypothetical pattern suggested should be carefully evaluated in terms of costs-benefits, considered that satellite imagery presently are too expensive.

Anyway, the project may benefit from international co-operation, which means that Mediterranean Basin communities might subscribe an agreement for mutual utilization of the system.

Such a solution, besides directing the efforts, both financial and scientific, of all Mediterranean countries towards the protection of marine environment, might allow the access to the utilization and management of satellite data at low cost.

INDEX OF ITALIAN COAST GUARD MAIN TASKS

EXCLUSIVE AND PRIMARY COMPETENCE

- Search and rescue at sea
- Environmental protection and marine pollution response
- Harbour traffic control
- Harbour security
- Ship security
- On and offshore Maritime police
- Fishing activities regulation and surveillance
- Merchant fleet control
- Pleasure craft control and policing
- Protection of pipelines and off-shore oil platforms in the exclusive economic zone
- Coastal patrolling
- Archaelogical patrimony under-water surveillance

SUPPORT COMPETENCE

- Anti-immigration patrolling at sea
- Partecipating in maritime operations in case of natural calamities or national emergencies

REMOTE SENSING SCANNERS

- 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 lenght (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

- 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 lenght (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

Ministero dei Trasporti e della Navigazione
Comando Generale delle Capitanerie di Porto
REPARTO V P.O. - S.T.A.I.

concessione S.M.A. n.5 del 5 GEN 95

Ministero dei Trasporti e della Navigazione
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concessione S.M.A. n.5 del 5 GEN 95

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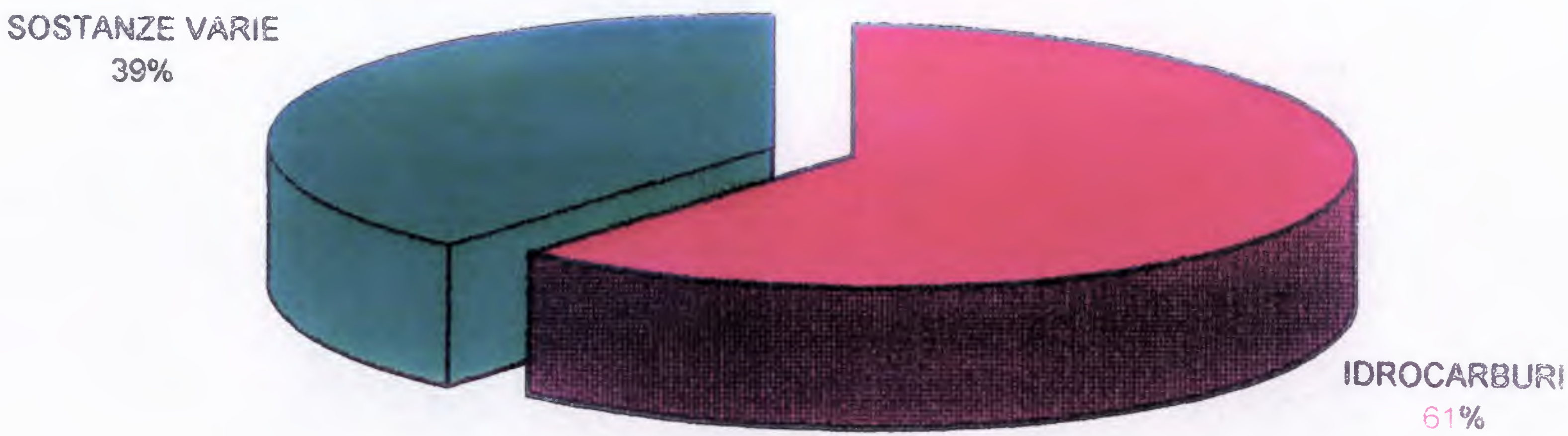
concessione S.M.A. n.554 del 12 DIC 95

SUDDIVISIONE PER TIPOLOGIA DI INQUINAMENTO



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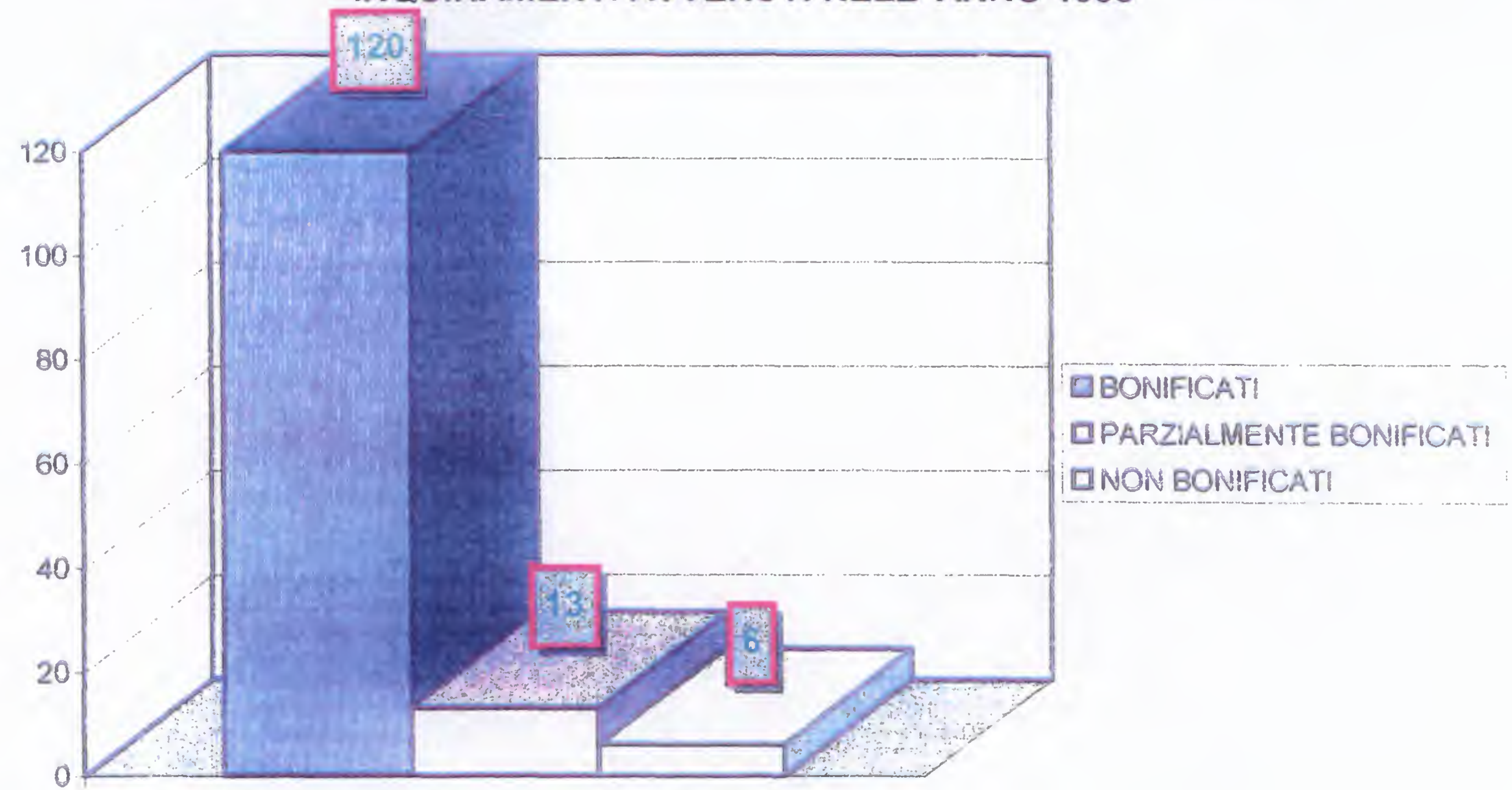

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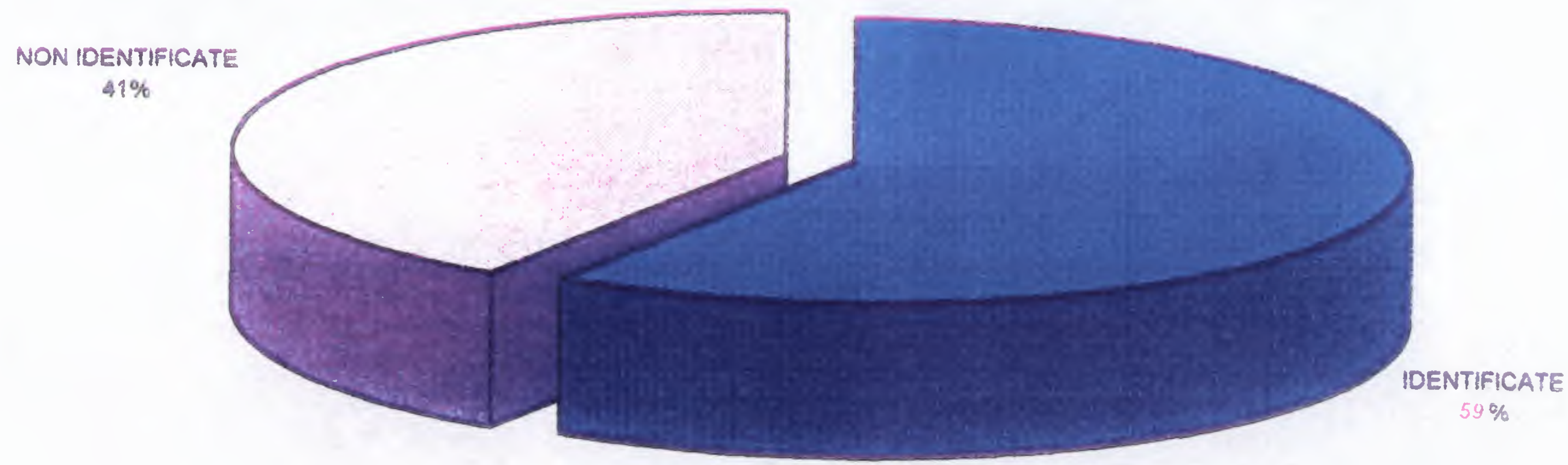

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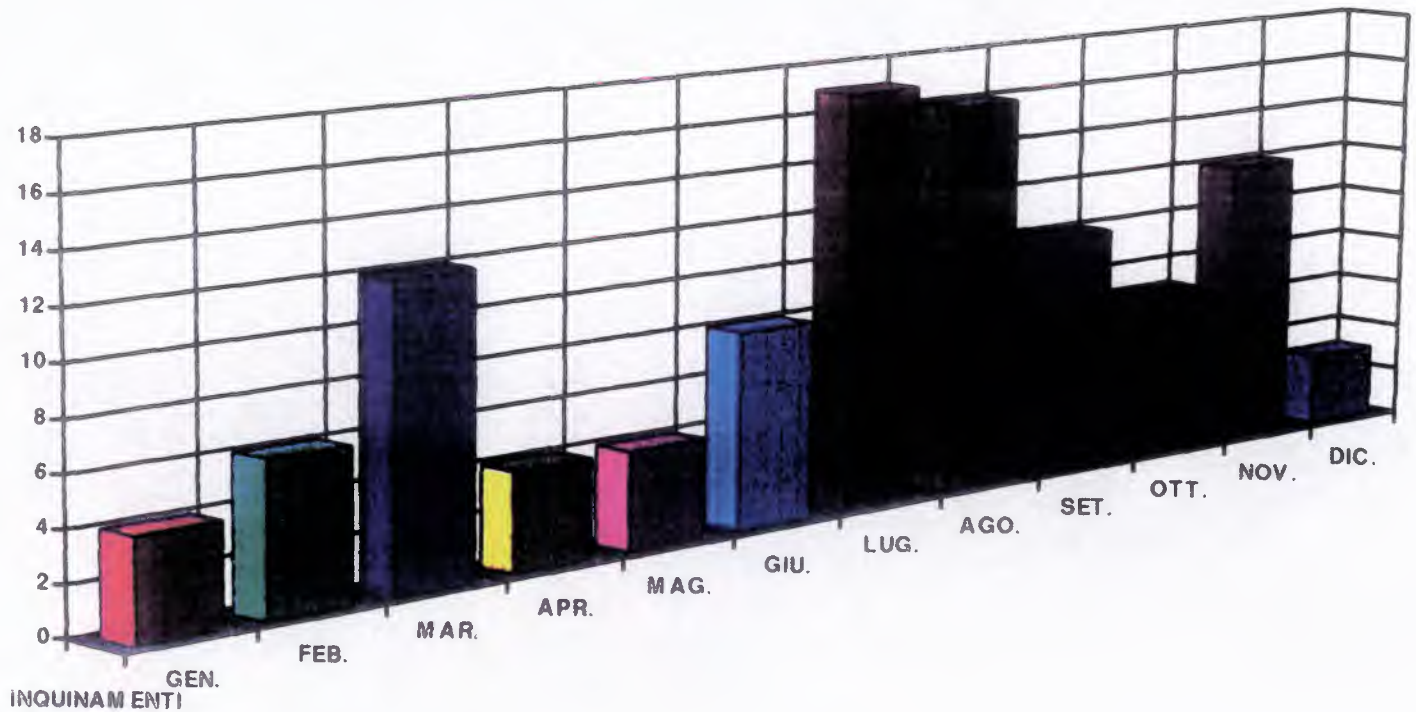

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Posters

Fast SAR images screening for oil slicks detection

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Fast SAR images screening for oil slicks detection

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Abstract

In this study we present a methodology for a fast screening of oil slicks in Synthetic Aperture Radar (SAR) images. Usually this task is performed by a pre-processing of SAR images to enhance some feature, and then by visual inspection of the images. Slicks are recognised as dark areas with shapes of particular characteristics.

Several parameters influence the degree of evidence of oil slicks in an image, the wind speed being the most important one. In an early stage oil slicks are usually easily identifiable by their shapes and edges. With the time, depending on currents and wind, the edges loose their sharpness and the contrast between the polluted and not polluted sea surfaces decreases. The shape of an oil slick also appears more indented and frayed.

A detection process based on the recognition of the shape of slicks requires a lot of computation effort, and should include an exhaustive list of parameters of physical and morphological characteristics of slicks. The approach we propose is based on locally determined statistical and morphological analysis of a SAR image. It results in reliable hints of slicks, with the possibility to assess their position and extension.

The algorithms have been developed in the framework of a software package for SAR image processing (SARIP V.1.1, copyright 1995 by Space Engineering), and the performances have been evaluated using a PC Pentium 100MHz with WindowsNT and the SARIP V.1.1 as a library of IDL, analysing sets of 1000 x1000 pixel SAR images (product PRI).

The result of a complete analysis of an image is performed in about ten minutes and provides a first level of oil slicks detection, namely processed images with:

- noise reduced by speckle filtering
- edge detected
- contrast enhanced
- ship wakes enhanced.

Subsequently slicks can be easily identified and measured.

A support decision system to minimise disaster cost in high risk areas

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A Support Decision System to Minimize Disaster Cost in High Risk Areas

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Abstract

The architecture and the overall design concepts are presented of a system able to support decision makers during the occurrence of large oil spills in areas subject to high environmental risk due both to the closeness of a likely dangerous site (e.g. an oil terminal) and the special features of the area itself (e.g. the case of Venice near the oil terminal of Porto Marghera); there are a lot of such "troublesome" areas in the Mediterranean.

The referenced support decision system will use data from satellites as the main input of the elaboration chain and other data (e.g. from aircraft and from local sensors) as integration.

1. Introduction

A number of accidents to tankers and, more in general, in oil terminals/offshore have occurred in the last years testifying the risk the European coastal zones are subject to and highlighting the difficulties in managing environmental disasters.

A remarkable share of the economic and environmental damages caused by the frequent oil-spill disasters seems to be due to the delay in decisions, observed by the crisis units. Delays were due to the intrinsic "inertia" of the relief system, owing to the lack of an on-line tool allowing a fast response and a valid, real time, support to decision makers.

2. Objectives

The system proposed in this project could reduce or even minimize the collective costs through the evaluation of different elements concerning:

- the final destination of the spilled oil;
- clean-up and environmental remedy techniques;
- the damages in bio-mass and human health;
- the missing incomes of the concerned area.

The system aims at achieving a provisional capability in the occurrence of disasters in areas subject to high risks such as those close to oil terminals or tankers routes.

Purposes of the project are:

- to show the capability of achieving a faster disaster response due to the on-line availability of the service;
- to expertise personnel in the usage of an on line instrument;
- to develop a flexible tool capable of reproducing the probable scenarios that can occur during marine environmental disasters;
- to develop a risk analysis methodology.

3. *System description*

The proposed system uses satellites images as input data; use of aircraft data as well is envisaged as a support.

The proposed system features the following operational scheme (pictorially shown in figure 1).

Once the satellites raw data relevant to the zone under control have been received by the ground receiving station, they are immediately sent to the processing stage located at the elaboration centre where real time image processing is performed.

A number of different relevant figures are to be extracted from processed images and concern not only the basic slick position and characteristic (extension, shape, etc.), but also, if available, winds and currents maps as well as sea surface temperature profiles, to be used by the local elaboration stage.

Afterwards, images and other satellite data (winds and temperature maps) are transmitted to the workstation located at the relevant local elaboration centre.

The scope of the local elaboration (whose flow chart is shown in figure 2) is to perform a provisional analysis of the spill behaviour (through a simulation of oil spill spreading) and, consequently, a real time damage evaluation in order to identify the most appropriate intervention methodology. Of course such simulations/evaluations strongly depend on the peculiar characteristics of the local environment, local geography and bathymetry, economics and the available intervention means.

The final output is directed to decision makers to achieve a fast decision support. It is very important, therefore, to take great care of the end user/machine interface.

The core of the project will consist of a system created to evaluate the overall cost of non-intervention and to compare it against the cost of different clean-up solutions. This will be performed by two subsytems as explained in the following.

3.1 Simulations of oil spreading

The local workstation gets remote sensed data as well as in situ measured data as input of a program that simulates the "spreading" of the slick and its moves under the local winds and streams evolution and the local morphology.

System operations rely on models concerning the oceanographic and atmospherical conditions, the dispersion of smoke clouds, the behaviour of oil spots and its biodegradability [1].

The implemented procedure consists of two mathematical models:

- the first one is a finite elements model and reproduces the hydrodynamic evolution of the marine basin;
- the second one is a lagrangian model describing the pseudo particles evolution in the motion field determined by the first model.

Coupling both the models allows to simulate the behaviour of a dissolved (or suspended) substance being transported and spreading over the motion field. The number of particles per unit of area can give indications about the spilled substance concentration.

3.2 Damage and cost evaluation

This stage is referred to as the "risk analysis" procedure and implements a number of models each representing a class of the possible damages the disaster can cause. These models should rely on databases taking into account data coming from the marine and the coastal environments monitoring.

More specifically, the model should operate on thematic cartography about:

- local bathymetry;
- actual coastal usage;

- residential complexes;
- industrial complexes;
- protected areas;
- fisheries areas;
- shellfish farms;
- areas of special interest (for tourism, hydrology);
- maps of the local human concentration.

Such data and cartography have to be processed to achieve a realistic provision of the disaster cost as a function of the possible interventions on the oil spill.

A model of the local environment and of the expected impacts that the disaster can cause on it, can quantify the environmental damage, whose cost can be estimated as that needed to restore the environmental situation as it was prior to disaster occurrence.

The last step of the decision process is to examine the intervention forces available in situ so that to decide the kind and the guidelines of the intervention on the oil spill, taking into account the indications and the constraints arising from all the previous elaboration steps, so that to minimise the expected disaster cost. The output orientates clean-up and environmental remedy techniques in different directions and intensities which also consider the economic value of the concerned area.

This kind of evaluation can use techniques of cost-effeciveness analysis in support to public decision processes related to management of existing systems.

In particular these costs concern:

- technical clean-up and environmental remedy;
- missing incomes from tourism;
- missing incomes from fishing and water-cultures;
- damages to public and private properties;
- damages to boats and fishing equipment;
- damages to wild life, non-marketable bio-mass;
- damages to human health.

Notice that costs of intervention must consider not only the technical clean-up costs, but also the sum of damages and missing incomes that have already occurred. In non-intervention, technical clean-up costs must be excluded but the damages and missing incomes will be much higher.

Considering the legislation (OPA, 1990) on oil spills the damager must repay a fixed sum. The system described above might choose an alternative whose total cost is lower than the total repayment, therefore the damaged subjects could gain a higher compensation.

4. Conclusions

The proposed system aims to fulfil the lack of an on-line tool allowing a fast response and a valid, real time, support to decision makers in the occurrence of a disaster due to a large oil spill in a high risk area. The system operations have the goal to minimize the overall disaster cost (including environmental impact, damage to industrial activities, tourism, etc.) to the community, by choosing the best intervention strategy among those available.

The system is developed by an industrial team formed by four signs, namely :

- TER (former N.C.I.-Space & Research Dept., Italy) responsible for the project management and the overall architecture including the issue related to risk analysis;
- ISMES (Italy) that develops the provisional models of oil spreading;
- GEOSPACE (Austria) responsible for image processing issues;
- SMA (Italy) contributing for sensors and network issues.

At time, simulations of oil spreading have been developed for the study case of the Venice Lagoon, near the oil terminal of Porto Marghera [1]; the results show clearly that very different situations can occur, starting from the same simulated spill, when different weather conditions are present, so that in one case a fast intervention is mandatory while, in another one, the best intervention is non-intervention!

These preliminary results give evidence to the necessity of a on line decision support system in order to be able to effectively combat a disaster due to an oil spill in such areas.

Reference

[1] ISMES Report (1992) "System Engineering applied to Environment Degradation in the Adriatic Sea"

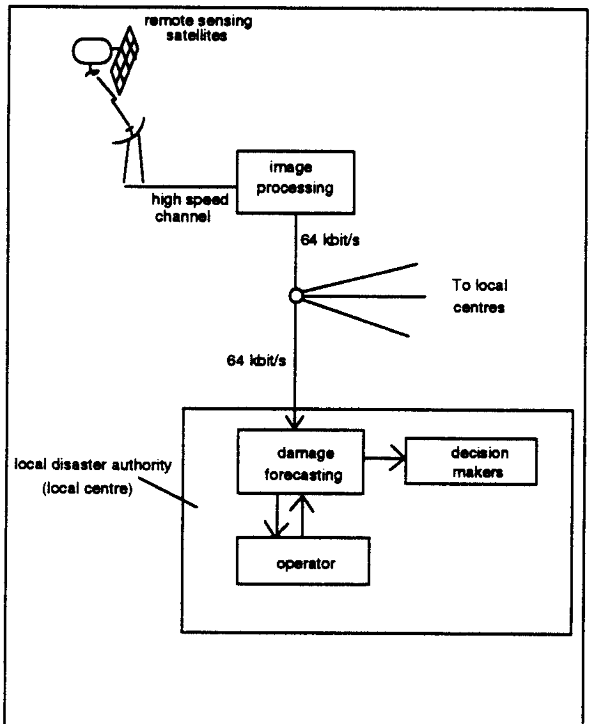

fig. 1: simplified architecture of the system

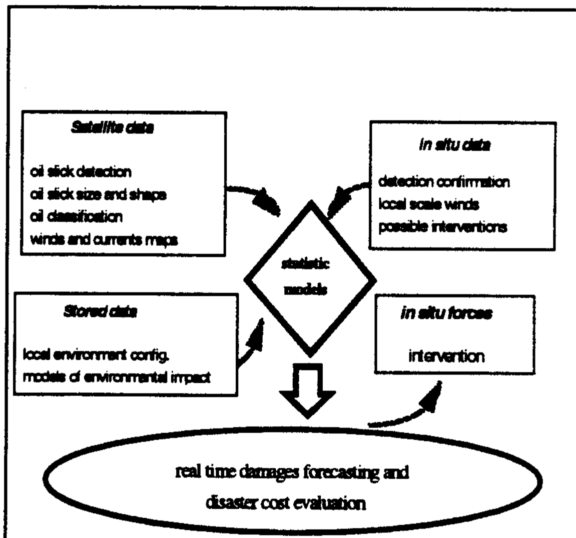

fig.2: concept of the elaboration stage

SESSION 5

The Mediterranean Action Plan initiative for the protection of the Mediterranean sea from oil pollution

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The Mediterranean Action Plan initiative for the protection of the Mediterranean sea from oil pollution

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Abstract

The Mediterranean Action Plan, legally supported by the Barcelona Convention for the protection of the Mediterranean sea against pollution - to which all the Mediterranean bordering Countries and EU are contracting Parties - has been committing itself since 1975 in the protection and development of the Mediterranean basin.

Four Protocols concerning the prevention of and the protection from oil pollution have already been adopted

The MAP Coordinating Unit and five Regional Activity Centers (RACs) are actively cooperating for the implementation of actions for the protection of the Mediterranean environment and the sustainable development of the coastal areas of the Mediterranean.

Among the RACs, the REMPEC - Regional marine pollution Emergency response Center for the Mediterranean sea, based in Malta, is operational for assistance in case of emergencies at sea; whilst the RAC/ERS - entrusted with the use of remote-sensing techniques and methods for the environmental monitoring of the Region, based in Palermo, Italy - has carried out several projects and would shortly committ itself in activating joint efforts for oil pollution detection.

The MEDPOL Programme - Coordinated Mediterranean Pollution Monitoring and Research Programme - has started in 1975 and is still in progress for the assessment of the coastal water quality in the basin.

All these initiatives will be presented, specifically emphasizing the importance of setting up a wide cooperation effort aimed at the oil pollution monitoring by applying to the remote sensing techniques, in the framework of the legal and operational context of the Mediterranean Action Plan.

THE CTM RAC/ERS IN THE FRAMEWORK OF THE "MEDITERRANEAN ACTION PLAN"

In the framework of the **Mediterranean Action Plan (MAP)**, in 1993 the CTM, following the request of Italy made by the Italian Ministry for Foreign Affairs, was recognized - by all the Mediterranean Countries and the EU, Contracting Parties to the Barcelona Convention - **Regional Activity Center for Environment Remote Sensing (RAC/ERS)**.
In this role the CTM started to be operational for the study and observation of the Mediterranean environment, for the technical assistance to all the Mediterranean Countries e for the development of concrete cooperation among the remote-sensing Organizations in the basin.

The MAP and the Barcelona Convention

The **Mediterranean Action Plan** originated on the occasion of an Intergovernmental Meeting convened in 1975 in Barcelona (Spain) by the Executive Director of the **United Nations Environment Programme (UNEP)**, where sixteen States bordering the Mediterranean adopted an Action Plan for the protection and development of the Mediterranean basin.
Its legal framework - known as the **Barcelona Convention** - was subsequently adopted in the final act of the Conference of the Plenipotentiaries convened by UNEP in 1976.
Since the beginning, the UNEP has been designated as the Organization responsible for carrying out the secretariat functions for the Convention and for acting as the coordinator of the activities agreed upon within the framework of the Mediterranean Action Plan.

Today, **all the Mediterranean coastal States and the EU are the 21 Contracting Parties** to the above Convention, which is the **only existing legal framework** for cooperation among them in the Mediterranean area.

Five protocols, which are binding for the signatory States, have been adopted till now: Protocol for the prevention of pollution of the Mediterranean sea by dumping from ships and aircrafts; Protocol for cooperation in combating pollution of the Mediterranean sea by oil and other harmful substances in cases of emergencies; Protocol for the protection of the Mediterranean sea against pollution from land-based sources; Protocol concerning Mediterranean Specially Protected Areas; Protocol concerning pollution resulting from exploration and exploitation of the continental shelf, the sea-bed and its subsoil.

The MAP Phase II

More recently, in 1995 the Contracting Parties , with the aim of better orienting the Mediterranean Action Plan and of extending it to the coastal ares of the basin, adopted the **MAP Phase II**, "for the Protection of the Mediterranean Environment and the Sustainable Development of the Coastal Areas of the Mediterranean"

Coordinating Unit and Regional Activity Centers of MAP

From the operational point of view, the **Coordinating Unit** - based in Athens - and the 5 **Regional Activity Centers (RACs)**are today actively cooperating in the framework of the MAP for the implementation of actions, following the recommendations adopted by the Contracting Parties in the occasion of Ordinary meetings held every two years.

Each Regional Activity Center relies on advice and cooperation of 21 **Focal points**, nominated by each Contracting Party to orient its action.
Moreover, the plans of each Center, as well as all the activities within the MAP, are discussed and approved by the **Technical and Socio-economic Committees** of MAP, then are submitted to the Contracting parties to the Barcelona Convention for the final approval. They are so implemented following the decision of the 21 Mediterranean Countries and the EU.

The RACs are presently:

- the Regional Activity Centre for Environment Remote Sensing (CTM-**RAC/ERS**), based in Palermo, Italy;
- the Regional Activity Center for the Blue Plan (**RAC/BP**), based in Sophia Antipolis - France, for perspective studies and observatory function on Environment and Development;
- the Regional Activity Center for the Priority Actions Programme (**RAC/PAP**), based in Split - Croatia, for Integrated Coastal Areas Management;
- the Regional Activity Center for Specially Protected Areas (**RAC/SPA**), based in Tunis - Tunisia;
- the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (**REMPEC**), based in Malta.

The Coastal Area Management Programmes - CAMPs

Among the initiatives of the MAP, a remarkable role is played by the Coastal Area Management Programmes - CAMPs, devoted to the study of environmental concerns in areas threatened by environmental degradation or changes.
The CAMPs are launched following the adoption of the Contracting Parties and are set up on the basis of an official agreement between the hosting Country and the MAP
The CAMPs for Kastela Bay, Izmir and Rhodes have been already carried out.
Presently, the CAMPs for Egypt, Tunisia and Albania are currently being developed, while the CAMPs for Malta, Morocco, Israel and Algeria have already been adopted and are going to be started.
All the RACs are involved in and contribute to their development, accordingly with the specific field of expertise of each of them.

CTM

CENTRO DI TELERILEVAMENTO MEDITERRANEO

UNITED NATIONS ENVIRONMENT PROGRAMME
MEDITERRANEAN ACTION PLAN

RAC/ERS UNEP

REGIONAL ACTIVITY CENTER for ENVIRONMENT REMOTE SENSING

The CTM-Centro di Telerilevamento Mediterraneo (Mediterranean Remote sensing Centre) has been established in the role of Regional Activity Center for Environment Remote Sensing (RAC/ERS) in the framework of the Mediterranean Action Plan (MAP/UNEP) in occasion of the 8th Ordinary Meeting of the Contracting Parties to the Barcelona Convention and its related Protocols, held in Antalya, Turkey - October 1993.
Since then the following projects have been conceived, planned and set up, in compliance with the mandatory task of fulfilling the Mediterranean Countries' requirements:

COSMOS - **C**riteria for an **O**perational **S**etting-up of a **M**editerrranean **O**bservation **S**ystem, to investigate the priority common requirements of the Coastal Countries in terms of environmental parameters which may be monitored by applying to the use of remote-sensing.

RAIS - **R**emote-sensing **A**ctivities **I**nventory **S**ystem, to create a data-set of activities, structures and resources in the field of remote-sensing, in order to draw an analytical picture of the potentialities and experiences as a whole in the basin, which could be exploited for coordinated initiatives.

DAPHNE - Observation, study and classification of vegetated and non-vegetated areas in all the Mediterranean coastal region - relying on daily images from NOAA/AVHRR satellite - to continuously monitor their conditions and changes in time and space.

CAMPs - Coastal Areas Management Programmes:

ALBANIA: to monitor and analize, on a periodical basis, the most recent evolution of the coastal strip through multitemporal high resolution observations from SPOT satellites, in order to provide real and updated information for the planning and control of those areas.

FUKA-MATRUH (EGYPT): to apply a methodology for land analysis and classification -supported by Landsat satellite images - focused on the identification of homogeneous areas as for vegetation, soil, geomorphology and hydrology, to be used for the setting-up of a system for the production of land suitability maps.

SFAX (TUNISIA): to draw a characterization of coastal sea circulation through the application of a numerical model integrated by sea surface temperature maps from NOAA Satellite, in order to support the assessment of the capacity of the sea dynamic to disperse the pollution from land.

Towards an Operational Hazard Warning System in the Mediterranean

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Towards an Operational Hazard Warning System in the Mediterranean

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Since the Seasat mission in 1978 it has been evident that oil slicks can be imaged from space using Synthetic Aperture Radar (SAR). Now, almost 20 years later, with 4 SAR's - two of which are European - currently in flight, there is still no operational system for monitoring or regulating the dumping of oil at sea. Satellite Observing Systems, through projects such as 'Clean Seas' and 'AMIS', is seeking to establish the techniques and tools along with the necessary expertise to monitor pollution in a number of key test sites in the Mediterranean, the North Sea and the Baltic. These projects, which are supported by the European Space Agency and the European Commission, will establish prototype operational pollution monitoring and alarm systems over 3 sites, including the Gulf of Lyon, in the Mediterranean. It is hoped to add a further three sites as the projects develop, to examine the Strait of Sicily, the Gulf of Otranto and the Nile Delta .

Such a series of repeat radar surveys concentrating on a manageable number of Mediterranean sites of strategic importance, backed by temperature and colour imagery over the same areas, will form the elements required for assessing the effectiveness and in particular the reliability of a prototype alarm system. In addition to the scientific aims of the projects the commercial viability of such an operational system will be examined to establish whether satellite based monitoring can reduce the financial as well as environmental impact of pollution from all sources in a cost effective and reliable manner.

Introduction

The deliberate dumping of oil in the Mediterranean is illegal. It is estimated that around 330,000 tonnes of oil are deliberately and illegally dumped there each year [1]. Other figures indicate that there may be as much as 1,000,000 tonnes dumped each year, perhaps demonstrating that too little is known about the full extent of the pollution problem in the Mediterranean, a problem that Earth Observation may be in a position to solve.

The synthetic aperture radar on board the ERS-1 satellite records the surface roughness of the areas of ocean that it images, that roughness is a direct result of the surface tension of the water and the wind speed. A film of oil has the effect of changing the surface tension of the surface imaged by the SAR, leading to a weaker Bragg reflection of the radar signal to the satellite. Areas of ocean covered with a thin film of oil can therefore be observed from space.

The problem facing the Earth Observation industry in this respect is therefore how to develop techniques necessary to turn the chance anecdotal observation of what is suspected to be a deliberate slick into a legally watertight operational system capable of policing the marine environment and thereby acting as a serious deterrent to those responsible for this form of pollution.

Satellite Observing Systems are leading two projects which aim to provide the scientific backdrop for the operationalisation of this marine remote sensing technology. The first project, supported by the European Commission and the European Space Agency, is Clean Seas. Clean Seas will deal directly with the problems of marine pollution in three test sites in the Baltic, the North Sea and the Gulf of Lyon in the Mediterranean. The second project is AMIS (Automated Marine Information System) which will examine oceanographic monitoring to reach a better understanding of how spaceborne measurement of surface roughness, colour, temperature and slope might be combined to eventually form a fully integrated marine information system.

This paper describes the objectives of these two projects and examines some of the issues related to the establishment of an operational pollution monitoring system based on satellite observations

Oil as a marine pollutant

The seas and oceans of the world do an excellent job of storing and in many cases destroying the pollutants that the industrialised world wants to get rid of. Some seas are better at this job than others and some pollutants are more easily destroyed than others. A vegetable oil spill in the middle of the North Atlantic in January will generally have a short life expectancy as the actions of wind, wave and bacteria attack the slick. The same cannot be said for other types of pollution such as plastics which in many environments can persist for centuries. Similarly, some areas of the world are not as well suited to the job of waste repository as others. In particular the Mediterranean, a semi-enclosed basin with little tidal flushing, is one of the seas least able break down the oil, sewerage and chemical pollutants pumped daily into its waters, yet it is one of the most actively polluted.

Hydrocarbons are vital to the economies of all the nations of the world and for the vast majority, these fuels must be transported across great distances by sea before they can be used. Inevitably not all of the estimated 100,000,000 tonnes of oil loaded into tankers *each day* in the North Sea, the Middle East or any of the other oil production areas ends up being delivered to the consumer at the other end [2,3]. Some is lost in large, dramatic spills such as that from the Sea Empress on the South Wales coastline which has the immediate effect of killing waterfowl, mammals and other sea life while also inflicting more insidious harm in the form of long term disruption and pollution of the food chain long after the clean-up operations needed to remove the cosmetic damage. These dramatic and newsworthy accidents are a disaster for the local environment but may represent just a quarter of the total input of oil from ships into the oceans each year [4]. For example, of the 200,000 tonnes that a tanker might carry, 700 tonnes will remain stuck to the sides of the storage tanks after delivery of the oil [1]. This oil must be disposed of before the next load can be taken on board and one of the easiest and cheapest ways of doing this is simply to dump it at sea on the return journey.

Oil is an extremely toxic substance, containing between 100 and 200 known carcinogens in every 5 tonnes released into the oceans [1]. A significant proportion of all oil dumped in the sea is to be found in the Mediterranean despite the fact that since 1983 it has been illegal to dump oil in the Mediterranean. It is evident, however, that such dumping is still widespread, inflicting a heavy cost on a delicate environment as well as damaging the tourist and fishing industries.

Practicalities of operational pollution monitoring

Enforcement of the Mediterranean Action Plan [6] is reliant on accurate information on the fate of oil transported through the Mediterranean. The majority of this information comes from inspection of vessels and from monitoring exercises. Information on possible violations may be obtained from port records of loading and unloading of oil as well as residues from the cleaning of tanks. In addition, under the MARPOL 73/78 convention [7], ports have the right to inspect any ship without the necessary certification relating the prevention of pollution, issued by the flag state of the vessel. The only time a port state can disregard an International Oil Pollution Certificate which is valid for five years, is when the port authority has "clear grounds for believing that the condition of the ship or its equipment does not correspond substantially with the particulars of that certificate."

Monitoring of dumping of oil at sea is also difficult, for two reasons: firstly aircraft and coastal patrol boats have limited visibility and cover only a small proportion of a country's Exclusive Economic Zone (EEZ) every day; secondly, even when a slick is detected it is usually extremely difficult to prove which ship in a busy shipping lane was responsible for the dump. Even in quiet areas, unless the ship is actually observed and photographed discharging oil at sea, it is unlikely that there will be anything more than prima facie evidence of the crime.

Oil pollution monitoring from space

Satellite remote sensing has the potential to increase the financial risk to ship operators of dumping oil in controlled areas. Synthetic Aperture Radar in particular has been shown to image oil slicks from a variety of naturally occurring sources as well as accidentally and deliberately dumped slicks. To supply an effective pollution monitoring service however, a number of technical, practical and political obstacles must be overcome. For example, oil is not the only substance which can lead to a slick-like signature on a SAR image; biogenic films are produced by plants and animals and further information must be retrieved on the size, shape and position of a "dark patch" before some of the other possibilities can be eliminated. The practical difficulties of pre-operational satellites mean that while occasional snap-shots of the sea surface can be obtained (every 35-days in the case of ERS satellites), there are substantial periods of time in between when no SAR data can be acquired. Finally, there is the problem of identifying the vessel responsible for the spill. Despite the fact that large ships can clearly be located in a SAR scene, they cannot be positively identified. Identification will only be possible in conjunction with legislation that allows for the compulsory remote identification of shipping, for example via an on board transponder.

Satellites do, however, have a part to play in oil pollution monitoring, within the context of part-time surveillance and long term statistical surveys of key areas. In addition, there is the potential to refine current technologies and analysis techniques to the point that effective use can be made on an operational basis of co-ordinated missions carrying instruments such as the ERS SAR. To this end, Satellite Observing Systems, in collaboration with a number of leading research centres throughout Europe, have embarked on the Clean Sea and AMIS projects.

Towards an operational system

There are three stages to the successful operation of a pollution monitoring system:

- the reliable identification of possible pollution incidents;
- accurate prediction of the fate of those pollutants;
- and the identification of the original source of that pollution.

Pollution detection and tracking: Clean Seas

Clean Seas is a research project funded under Framework IV of the Environment and Climate programme of the European Commission, and supported by ESA through the provision of data over three test sites. The objective of Clean Seas is to co-ordinate the research needed to deliver the expertise and techniques that will be required for operational oil pollution monitoring. The three test sites include an area of the Baltic between Gdansk, Stockholm and Helsinki, the southern North Sea at the entrance to the English Channel and finally in the Gulf of Lyon in the Mediterranean.

The philosophy of the experiment is to monitor repeatedly the state and condition of the sea surface over a manageable number of key sites and to build up an archive of satellite and 'in-situ' derived observations. This will enable the compilation of key signatures and characteristics of naturally occurring surface phenomena in the area as well as the occasional pollution incident. To assess the reliability of the Earth Observation results, ground truth will be obtained from a number of sources, such as aircraft and ship board observations. In this way, the reliability of existing techniques may be assessed while the development of new and improved methods can be guided by the experience gained from the repetitive scrutiny of these sites.

Oceanographic context of pollution: AMIS

Once an oil slick has been identified, there are two elements which will lead to the output of useful information from the raw input data. The first of these is how that slick will develop; how it will be carried by the winds, tides and current that are prevalent at the time as well as how the slick will spread and fragment. To achieve this, a thorough understanding of the oceanography in each site must be obtained and appropriate models developed. This is the realm of the second research project, investigating the synergy between different sensors and different satellite missions as well as the integration of the features which they observe into a single description of the current oceanographic state of each test site. The AMIS project aims to take the first steps towards an Automated Marine Information System by examining at least four test sites in the Mediterranean: in the Gulf of Lyon, the Strait of Sicily, the Gulf of Otranto and at the outflow of the Nile Delta. By establishing the scientific basis for such a system, it is hoped that by observation of different aspects of the dynamics of the ocean surface, models can be developed which incorporate the full capability of the network of different satellite missions observing the marine environment. As with the Clean Seas project, this will involve extensive ground truth monitoring to validate the satellite based observations as well as provide direct measurements of the full meteorological conditions during each observation. In this way an understanding of the limitations and reliability of each sensor can be established and incorporated into the oceanographic output from the system.

Commercial development of an operational system: ?

These two projects alone represent a considerable investment by the organisations, agencies and funding bodies involved. In the case of marine oil pollution the long term aim must undoubtedly be a fully commercial system based on dedicated instruments flown as a co-ordinated network of missions. While there is little doubt that a satellite based pollution monitoring system is technically feasible, can it supply the information required at a cost that represents a real saving in terms of the need for less terrestrial based monitoring or an improvement on the reliability and coverage of the techniques currently employed?

In order to demonstrate an advantage in using satellite based operations, the scale of current operations must be assessed and quantified in order that these may be compared with the costs of developing and installing a dedicated system. These two may easily be assessed in terms of the money spent either globally or on a regional scale. To assess the success or failure however it is important to examine the cost of the pollution itself and that is considerably more difficult.

The total financial cost of the Exxon Valdez disaster in Prince William Sound in Alaska in 1989 was an estimated $2 billion in clean up costs and $1 billion in out of court settlements [5]. In the case of operational discharges, unless the polluter can be positively identified and successfully prosecuted, the cost is borne by the holder of the EEZ. Pollution has a financial cost in a number of ways, most directly through the need to spend money on preventative measures such as airborne patrols as well as indirectly through the damage to the marine environment and its consequent effect on the sustainability of fishing and the perceived water quality for tourism. The Mediterranean in particular is at risk because of its strong reliance on the tourist economy in many areas where fishing has already declined as the main source of revenue. Of all the oil transported in the world, an estimated 22% travels thorough the Mediterranean which in the 10 year period between 1977 and 1987, resulted in 94 accidents, 55 of which spilled oil [6]. In addition, there were 46 reports of operational discharges - a figure likely to grossly underestimate the full extent of the problem due to the limited surveillance available. It has been estimated that around 330,000 tonnes of oil is spilled either deliberately or accidentally from ships in the Mediterranean each year [6]. To an area which receives approximately 30% of the world's tourists (over 100 million visitors each year) [7], this represents a considerable risk to the reputation of the Sea as a whole as well as to the beaches were such spills come ashore. According to one estimate [7], as much as 20% of all operational discharges of oil globally may be released into the Mediterranean, an area representing just 7% of the world's ocean surface. Since this estimate in 1979, the MARPOL 73/78 convention has lead to a reduction in the quantity of oil discharged into the sea during transportation and a considerable investment has been made in reception facilities for dirty ballast waters and other oily residues. As has been shown by numerous SAR images over the Mediterranean, however, a considerable amount of oil is still being dumped by ships at sea and with several nations bordering the Mediterranean still not contracting to the MARPOL 73/78 convention, there are wide variations in the provision of treatment and reception facilities. This implies that protecting the coastline and economy of areas within the Mediterranean must rely on active deterrence of polluters within each EEZ. This makes the provision of reliable monitoring systems of great importance if they can be linked to identification of the vessels observed.

The development of an operational pollution monitoring systems is therefore linked not only to the practicalities of providing daily SAR coverage or even being able to identify every single slick-like feature within those images but more importantly it requires the political will to restrict access only to that shipping which can be identified remotely. In the mean time, satellites have an important role to play in the gathering of reliable statistics on the scale of operational discharges into the Mediterranean and thereby to provide the evidence to support the introduction of transponder or other system to positively identify polluters.

Review

The Mediterranean is an area identified as being particularly sensitive to oil pollution from shipping and as such, all dumping of oil and contaminated ballast and tank cleaning waters is prohibited. It is estimated, however, that around 330,000 of oil is introduced into the Sea by shipping each year. This is equivalent to 2 or 3 full tanker loads or one Sea Empress disaster every 10 weeks. On a pro-rata basis, if the financial costs of this pollution were proportional to the costs incurred by the operator of the Exxon Valdez in 1989, the oil industry would face an annual bill of over $10 billion for polluting the Mediterranean. Even if only 0.1% of the oil released into the sea comes ashore each year, that would equate to a cost of $10 million, to say nothing of the long term cost to fishing and tourism.

On the other hand, in open ocean MARPOL 73/78 allows for up to 1/30,000 of a tankers cargo to be "lost" in transit. Considering the volume of oil transported through the Mediterranean each year, this figure would amount to 250,000 tonnes annually, just 25% less than the estimated total. These two numbers can be compared in two contrasting ways; if the limit of 1/30,000 is viewed as a practical limit for leakage of oil from a tanker at sea then these figures may be viewed as perhaps being as good as can be achieved. If this is the case, the cost of attempting to enforce the MARPOL 73/78 regulations would be out of proportion with any improvement in the levels of pollution that might be realistically achieved. Alternatively, figures released by Chevron indicate that in the whole of 1993 they spilled a total of just 1.5 barrels of oil, equivalent to loss of 1/300,000,000. It would therefore seem fair to surmise that there is legitimate room for improvement in the transport of oil around the world. The conclusion, therefore, must be that far more oil is dumped into the Mediterranean than is either necessary or unavoidable. Economically, the result is not so clear cut as this requires accurate information on the full scale of the problem in terms of the volume of oil spilled, where and when. With this kind of information, limited resources can be used at sea level to police favoured dumping areas and thus reduce the incidence of deliberate dumping. Satellites are well placed to deliver just this kind of information now and this will be a key objective of the Clean Seas programme. In the longer term if there is the political will to launch operational satellite systems supported by remote vessel identification then an operational hazard warning system for areas such as the Mediterranean may not only be possible but may even prove itself to be cost effective.

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ENVISYS: Environmental Monitoring Warning and Emergency Management System

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1. Introduction

Each year the environment is exposed to a series of major hazards like oil spills, forest fires, floods, etc. A single such event causes major damage to the ecological system and often develops very fast. Users report that in order to reduce the effects to a minimum it is of the utmost importance to be able to detect and report such events as quickly and as accurately as possible. Today recent developments within Telematics technology makes it possible to monitor and report many such events in a much more efficient way.

Oil spills is a major source of marine pollution. The amount of oil spill from rinsing of tankers and "natural losses" in the Mediterranean alone is estimated to 600,000 tons yearly (three times the Amoco-Cadiz pollution). The problem is correspondingly large along the European Atlantic coast. Today, it is impossible to enforce laws that regulate such oil spills since there are no effective monitoring systems.

2. ENVISYS Project

ENVISYS is a recently started international cooperation project, partly financed by EU DG XIII in the framework of the Telematics for the Environment Programme. Its primary objective consists in 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 will therefore provide a basis for several independent, commercial products that can also be used separately in other contexts. What should be emphasized is the availability of large quantities of satellite data, the primary data source of the ENVISYS project before the end of the century. This will bring clearly the results of the project (as well as of similar projects) from the domain of R&D to the domain of commercial exploitation.

The project will built demonstrators in three European countries by integrating existing remote sensing techniques (based on Synthetic Aperture Radar imagery), communication tools, Geographic Information Systems, Data Bases and multimedia tools.

The demonstators will provide automatic detection of oil-spills, based on intensive research work realised during the preparation phase of a relative pre-operational service in Norway by the Norvegian Space Center, the Tromso Satellite Station, the Norvegian Computing Center and the Norvegian Pollution Control Authority. The demonstrator will be tested and verified in two Mediterranean regions, the South Aegean Sea (Cycladic Region) and Gigraltar area, as well as in the Finisterre Region (Galicia, Spain).

In this way, the knowledge and experience acquired during the Norvegian experiment, will be transferred and tested in South European areas, selected due to frequent problems of oil pollution and characterised by different difficulties and operational requirements.

3. Project Objectives

The objectives of the ENVISYS project are the following :

1. To integrate into a fully operational system existing remote sensing, communication and software intensive technologies, as well as existing public infrastructure, for the sea monitoring, detection of oil spills due to human activities, issue warning to responsible public authorities, and provide decision support to the said authorities during clean up operations.

2. 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

3. To investigate the applicability of similar concepts and techniques in other physical disaster phenomena, most notably forest fires and floods.

4. Expected results

As a measurable result, the project aims to detect a very high percentage of slicks created during demonstration time, constrained only by satellite coverage of the area in question (in terms of time). Achievement of these results with current satellite coverage, implies the systems viability as a very powerful tool for public agencies responsible for such disasters, on a day by day basis, as 24 hours coverage from satellites is anticipated in the imminent future.

Apart from the direct monitoring functions, the existence of a sea monitoring system, will have 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 the ENVISYS technology will be regional, national and international authorities responsible for enforcing national & international law for marine environment. Secondary users are organizations and industry taking part in verification, assessment, and the clean-up activities. ENVISYS project will be focused to provide assistance directly to the involved Environmental Authorities, enterprises and institutions related to the environment protection.

5. Basic technologies to be used

ENVISYS will create 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 (Synthetic Aperture Radar) is based on the dampening effect oil has on capillary and short ocean surface waves. In order to discriminate from "look alike" phenomena, (which prevent up to now automatic tools) higher-level analysis based on special characteristics for oil-slicks has been tested to a limited degree, and showed 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 & 2 data as well as other non European satellite data as soon as they become operational.

Geographical Information Systems

Geographical Information Systems (GIS) shall be 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 monitor these operations. Currently, commercial GIS systems provide very powerful modelling tools which make such tasks feasible and quite practical.

Data bases

In order to support public authorities in their clean-up operations, various types of data (images, maps, statistical data etc.) mainly related to the demonstation areas will be 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, under-water flora, touristic regions)

Chimical products used in clean-up operations asoociated 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 few hours from the satellite passing). In order to provide that, fast data communication links from the satellite ground stations to the system operations site are essential. The ENVISYS project will use high speed leased lines of up to 2Mbits/s for this purpose, during the demonstration period. Such infrastructure today, is available in - and between - every EU member state. Therefore the availability of telecommunications infrastructure seems to be assured, and only operation cost questions in the case of a future permanent operation have to be examined, related with the possible use of new broadband telecommunications links (e.g. ATM networks)

.

Likely developments

The types of emergency situations covered by ENVISYS are totally dependent of frequent remote sensing data from appropriate parts of the electromagnetic spectrum. The remote sensing sector is steadily growing, and it is no doubt about that access to remote sensing data will just increase. The European ERS-1 satellite will be followed by ERS-2 this year, and the Canadian Radarsat will also be launched this year. The large European remote sensing platform Envisat will follow in 2-3 years, and there are plans for numerous other commercial remote sensing satellites within ten years. This will ensure satisfying data access and frequent coverage, which strongly support the potential for ENVISYS to be an important tool for environmental emergency monitoring in the future.

6. System characteristics

The system will contain the following features:

- Synthetic Aperture Radar (SAR) remote sensing data collection and processing (a typical image product will cover an area of 100 km x 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 near-by 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:

- 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 & multimedia tools to efficiently inform the operator for a 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 operation. Among the planning tools is a simulator for different scenarios of the emergency development. The simulator will make 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 geographical information system (GIS), multimedia functions and report generators.

The application-specific modules

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

· External remote sensing system. ENVISYS will be 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 will use 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.

7. Methodology

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

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 to be taken consists of the following steps :

1. ***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 appropriateness of the existing work for incorporation in the final system will be conducted. In addition, a detailed report of currently available satellite imagery products shall be produced with relation to the demonstrator sites.

2. Given the necessities for satellite imagery collection and processing, as well as the user requirements, a ***detailed system architecture*** shall be 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) should allow the incorporation of ready modules, in addition to the off-the-shelf tools.

3. The next step will be the ***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 data material only. The results were quite good and demonstrated that oil-slick screening is possible, but the results also indicates that the methods must be refined, tested on a larger data material and made more robust to avoid unnecessary manual inspection.

- Integration with GIS. A commercially available GIS tool will be an integrated as part of the system. The GIS tool should be available on different types of platforms (i.e. PCs and UNIX workstations), and integrated with a window manager suitable for a multi-media environment (e.g. Microsoft Windows or Motif).

- Integration of image data and GIS system. The GIS system selected should have this facility already built-in.

- Integration of other data types. In addition to satellite imagery ENVISYS will be using several other sources of data input. The project will monitor 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 must have 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 system exist available on both PCs and UNIX platforms.

The demonstrator will be 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 will be tested, but not necessarily together. This means that for instance the preprocessing and hazard detection modules and the communication between them can be tested in Norway while the modules for integration of imagery and other data types with GIS and multi-media systems could be tested in Greece.

4. The next stages are the ***verification and demonstration*** phases.

The precise test criteria to be used in the evaluation of the different stages will be established as part of the user requirements analysis, but some of them will be:

- Capability to detect 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 amount of false alarms. Most of these can be 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 will be far too costly. It is recommended to base detection verification on statistical sampling of data from other sources, e.g. reports from coast-guard aircrafts and ships.

- Efficiency as a tool for assessment, information, and management. This must be tested for all emergency categories ranging from minor oil spills to major catastrophes. Within the verification period, no major catastrophes will - hopefully - 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 can be taken care of by using 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 must be taken into account both in learning to use the system and in using it once it is there.

SMALL SAR SATELLITE CONSTELLATIONS FOR TRACKING OIL SPILLS

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ABSTRACT

The present paper examines the key issues related to three main problems regarding oil pollution ; (1) the early detection of oil spills in the case of accidents , (2) the tracking of oil slicks motion to support containment and/or clean-up intervention , (3) and the identification of culprits in the case of intentional discharges, for monitoring and law enforcement purposes. The paper also explores potential and affordable solutions to resolve these major problems through the employment of small satellite constellations embarking SAR payloads. The key features that enable an effective monitoring of both oil spills and detection / identification of the responsible ships for such damaging to the environment actions along maritime routes most susceptible to oil pollution , are also discussed in some detail considering as a specimen area the Mediterranean Basin.

1. INTRODUCTION

Oil spills, whether due to accidental or intentional actions, are seriously hambering the environment and specifically its quality and quantity of marine resources, causing directly and/or indirectly huge economic damages. This is especially accentuated in the case of "closed" seas , such as the Mediterranean Basin, which exhibits a water renewal cycle of about 90 years long, and other regions where the water circulation is somewhat limited. In general , oil spilling in an "open" sea , such as oceanic regions, is of less concern due to the fact that ocean water mass , with its vast circulation , dilutes the oil damaging effects. In fact , tanker tank washing operations are currently permitted in open seas. A recent international legislation in the matter , has imposed the adoption of filtering devices aboard the new generation of tankers so as to render safer and less worrysome the problem caused by the tanks clean-up in both open and closed seas. Therefore , in the near future , the problem of oil pollution is expected to be drastically reduced , except in the case of wreckage and/or major accidents both in open and closed seas.

Thus, the aim is to deal with two basic problems ; (1) tanker accidents resulting to damaging oil spills and , (2) clean-up operations of tankers, without filtering equipment provisions , not complying with international regulations and order. In the first case , the coordinates and the condition of the tanker in distress are usually known and therefore would be relatively easy to support operationally the oil spill monitoring effort. In the second case , there is a great interest in the activities of detecting and monitoring , which are mostly directed toward the effective support of the Law Enforcement effort so as to tackle illegal discharges and relative actions that jeopardize the marine environment . In addition to the identification and tracking of illegal discharges and their assessment , in terms of environmental damage risk ; the most challenging effort is to provide solid evidence in identifying the culprit for Law Enforcement purposes.

2. THE USE OF SATELLITE SYSTEMS IN CASE OF DISASTERS

Tanker wreckages may occur either close to a coast or far. In the first case , and if certain environmental conditions allow , an assessment of the oil spill extend and potential damage, as well as post disaster oil spill tracking and monitoring , can be performed by airborne missions , provided , that the subject coasts belong to countries which dispose 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 extend and for the tracking , monitoring and control 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 ; this information can be used to command the satellite , so that , its resources will be directed to look at the disaster area with a minimum delay. The detection of an oil spill , resulting from a tanker's wreckage may be required the first 12 to 24 hours by the time the accident has occured. In addition , subsequent revisits of the disaster area are required , at an interval of every 24 hours or less, to monitor oil slick migration due to local currents and support tracking operations and predictions regarding its future direction.

Due to the high revisit frequency required by the above assumed operation; a single satellite system will not be adequate to satisfy all mission performance, related ,requirements for this effort. This is true especially when performance requirements are related to **Mission Reliability and Availability**, since a single system total failure will prevent mission continuity until a spare satellite is launched. Therefore, a system of at least two satellites in orbit shall be necessary in order to satisfy the required mission performance requirements for oil spill tracking and monitoring. Since the mission will also require all weather and day-night capabilities, so as to meet the needed high revisit frequency operational profile, therefore, each satellite should be equipped with a **S.A.R.** sensor for this purpose. Resolution-wise , oil spill detection and tracking would require about 30 to 50m capability although a better resolution of 10-15m , as demonstrated by the ALMAZ satellite, would be more suitable to evaluate oil slick boundaries. Any frequency band ranging from **S** to **X** could be adopted, although a preference for the **X-band** results from a number of pre-operational tests. Such SAR sensors can be easily installed on small size and relatively inexpensive satellites (Ref. [1] , [2]).

Assuming a mission scenario which includes sites at high latitudes, it can be chosen a sunsynchronous dawn-dusk orbit to provide definite advantages in terms of better sun illumination conditions compared to those provided by the non-sunsynchronous inclined orbits, leading to simpler and cheaper satellite configurations (Ref. [3]). Figure 1, of this paper , shows the revisit interval performance of two SAR satellites in a sunsynchronous resonant orbit of about 570 Km altitude, spaced apart by 90° in mean anomaly at a North Sea scenario over a latitude band between 45° and 65°. In addition , it is assumed that both SAR access arcs, included between 20° and 55° off-nadir, will be available via satellite roll tilting (Ref. [4]) which is quite easily performed with a small satellite , thanks to its small inertia. Figure 1 shows that, with both satellites operating, one gets an average revisit interval always less than 13 hours and with peaks of 24 hours at the highest latitude of 65°. If one of the two satellites fails , one still gets a peak revisit interval of less than 15 hours over a reduced coverage which is included between 52° and 62°.

In the particular case of the Mediterranean Basin , the tanker routes are concetrated along specific paths dictated by maritime navigation regulations in force for the area (Ref. [5]). Figure 2 shows the monthly passage of tankers, while Figure 3 shows the whole maritime vessel traffic in the Mediterranean of all types of ships. The tanker traffic density varies from 10 to 20 per day concetrated mostly along the route Gibraltar to Cairo and with 2 to 3 passes per day along the Italian coasts facing the Tyrrhenian and Andriatic seas. The approximate width of these routes varry from 50 to 100 Km. The assessment of the two-satellite system has been performed by computing the revisit interval over 10 evenly distributed points along the most densed path (Gibraltar - Cairo) and 4 points along the Tyrrhenian and Andriatic routes. Figure 4 shows the computed performance for , case 1 : both satellites operating and case 2 : one failing. In the first case , the mean revisit interval is about 12 hours with exceptional peaks of 24 hours. In the second case, a maximum of 24 hour revisit interval is guaranteed for the 85% of the observation points. Therefore, in order to guarantee a continuous service with at least one observing chance per day , for any site , along the assessed routes and secure high mission performance reliability and availability (in Orbit Fail-Safe Performance) , it is required to have more than two satellites.

In the case of bad sea conditions, oil spill detection becomes very dificult operation because of the water and oil mixing. For accidents occuring far away from coasts this may cause delays in the assessment of the oil slicks, since the operation must be haulted for better sea conditions. On the other hand, for accidents occuring close to the coasts , under bad sea conditions, it will be preferable ,depending on the sea state index , the utilisation of airborne sensors. It is , therefore, necessary to introduce the concept of the **Totally Integrated Monitoring Systems** combining Satellite and Airborne Missions in a technically complementary mode.

3. UTILISATION OF SATELLITES FOR CLOSED SEA BASINS SURVEILLANCE

Herein, there are two main problems to consider, namely : (a) the detection of illegal oil discharges at sea for monitoring purposes, (b) the identification of the culprit, which is a considerably more complicated task than the former. Herein, a reference case, it will be considered the Mediterranean Basin scenario as introduced in figures 2 and 3.

3.1 Detection of Illegal Oil Discharges

For the detection of illegal oil discharges , one has to consider the distribution scenario of the tanker routes shown in Figure 2. of this paper. This consideration reduces considerably the area to observe for law infrigements.The detection and monitoring , of newly formed oil spills , is sufficient to be performed once a day , concetrating on the area of high trafficked tanker routing (where the probability of discharging is greater) and then comparing the newly acquired image data with that obtained in the previous days in order to verify the presence of new spills and the motion of the old ones. To provide an example of the data volume necessary for the above described work, it is assumed to limit the observation in the areas of Tyrrhenian, Adriatic and Gibraltar-Cairo routes as shown in Fig.2. The total length of the traffic paths are about 6000 Km and 120 Km wide each, corresponding roughly to 200 images of 60 x 60 Km. These images must be received, processed, compared with the archived ones and interpreted, thus giving rise to a considerable amount of effort.

The satellite orbit choice should preferably match the orientation of the major traffic paths. This dictates the launch of satellites preferably in inclined orbits (Ref. [1],[2]) which are suitable to cover both the Tyrrhenian and Adriatic routes, as well as , those of Gibraltar-Cairo. An important difference , with respect to the monitoring of a disaster area , is that the location of illegal spills along these routes is not known “a priori”. Therefore , a “blind surveillance” must be performed which will exclude the possibility of spacecraft roll tilting and thus the capability to view alternatively on both sides of the spacecraft. “Blind surveillance” will require the spacecraft to continously observe within one access arc, roughly defined between 20° and 55° with respect to the local nadir , prepointing electronically the instantaneous swath , which could be of the order of 120 Km, to patch the tankers’ lanes during the satellite overpasses. Under this assumption, a number of constellations have been evaluated. Figure 5 shows the feasibility of three SAR satellite constellation performance in 40° inclined orbits, spaced by 120° apart in

RAAN. This constellation configuration permits a mean revisit interval of less than 15 Hours and peaks of 21 Hours. In case of one satellite totally failing, the constellation will experience a partial degradation in terms of revisit frequency capability with peaks raising to 24 hours and thus still acceptable in terms of mission performance. Figure 6 shows the outcome of three satellite combination at the 40° inclined orbit with the two satellites in a resonant sunsynchronous orbit as discussed in para. 2. It can be seen that , with all satellites functioning , there is a certain improvement in the mean peak revisit intervals. In the case of a failure , the achievable performance depends on whether the failed satellite belongs to the two-satellite constellation or to the three - satellite constellation in inclined orbit. Figure 6 shows the performance in the latter case which is also the worst. It can also be seen that there is still an average improvement in the mean revisit intervals , but for few points along the Gibraltar-Cairo route. However, the peak revisit interval still remains at 24 hour level similar to the constellation performance shown in Fig. 5.

3.2 Identification of the Culprit

In addition to the identification and tracking of oil spills, it is also necessary to identify the culprit which is responsible of such illegal actions and vast damage. The latter is much more complicated than the first because it will be necessary also to detect and identify a whole variety of ships in transit and correlate them , in terms of responsibility , 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 commercial ships and thus providing for a stronger radar tracing signature. Therefore, it appears feasible to implement a detection algorithm capable to distinguish between tankers and other vessels. It is also true that , a high resolution SAR of - e.g. 3 to 5m geometric resolution- will be capable of identifying tankers given the availability of their profile,signature and/or dimensions. It is also known that , the tankers have a low crusing speed and thus can be easily tracked . The tracking can be performed by sampling the area around the preferred paths at regular intervals. Nevertheless, even at 15-20 knots vessel cruising speed , a sampling time , considerably less than 6 hours, seems necessary for ship route restitution and tracking. Data , concerning departure time from harbours and destination schedule of tankers in transit , are normaly available by the port authorities and contribute considerably in the identification of the vessels.

The above , can introduce the prospectives for a series of feasible law enforcement actions. In fact, the integration of oil spill detection capabilities and the information regarding the spill position and shape , the vessel traffic data in the observed data , the departure time and destination of all candidate tankers, could allow the identification of the responsible ship(s). For example, an ERS-1 SAR image acquired on June, 09, 93, near the city of Cadiz, has revealed a ship spilling oil. According to the records of Cadiz harbour authorities, it was ascertained that only one ship had left the harbour in the evening of that day.

A potential procedure for detecting illegal oil discharges at the sea and identifying the culprit , may be summarised as follows :

(1) Perform routine surveillance of the most trafficked tanker routes, using coarse resolution SAR sensors having a medium swath width capability compatible to the ship route lanes (in the order of 100-120 Km);

(2) Use SAR imagery for : (a) detecting new oil spills , (b) detecting ships above a minimum radar cross section value in order to avoid false alarms , (c) sorting out tankers using thresholding algorithms or other selection criteria , and (d) determining the vessel position at the time of image taking ;

(3) Utilise a SAR high resolution mode (in the order of 3-5m over a narrower swath of 30-40Km) to support positive tanker identification. This operational mode could be

commanded in near real-time by Ground Stations utilising attended quick look processors. As an alternative, mode switchover can be preset the tanker route prediction from measured position points and motion estimates, obtained from previous passes. **Note: it would be highly desirable to perform automatic tanker detection on board the satellites in order to support automatic switchover operations. This is still not within the current spaceborne SAR capabilities , however, this could be introduced in the near term.**

(4) Correlate the tankers position datapoints to derive the routes actually followed;

(5) If a new oil spill is detected, interpolate back from the actually followed routes to derive which tanker was closest to the oil spill at any time between two subsequent satellite passes; and

(6) Fuse the above data with ships / routes database , available from the appropriate harbour authorities, to support the identification of the culprit.

Fig.7 shows a more comprehensive block diagramme of a possible Maritime Traffic Surveillance System which aims to cope , not only with the **Warning Phase** of the operations (detection and tracking of oil spills) in order to intiate law enforcement actions, but also to handle the **Post-event Phase** (Relief) which deals with the forecasting of the oil slick motion (utilising meteo and oceanographic data), and the triggering of an emergency management system in charge of alerting the appropriate harbour authorities to start-up oil spill containement and clean-up operations.

Fig.7a shows , in a summarised form, the authors' concept and main functions of a future **Totally Integrated Maritime Traffic Surveillance System (TIMTSS).** The proposed TIMTSS introduces a higher , operation-wise concept , to that of Fig.7 and it is composed of three basic functional sub-systems, namely:

(1) **SPACE INFORMATION AND COMMUNICATION SYSTEM (SICS)** , which comprises (a) a Small SAR Observation Satellite Constellation , providing imagery information services, (b) a Telecommunication Satellite System, providing rugged telecommunication services between the surveillance and law enforcement field operations groups and the Maritime Traffic Surveilance Integrated Management System , and (c) a Meteo Satellite System, providing environmental information services to forsaid operations. **Note: The services (b) and (c) may be obtained by existing systems.**

(2) **CONVENTIONAL INFORMATION AND SURVEILLANCE SYSTEM (CISS),** which comprises (a) Airborne Sensorial Surveillance System(s), providing complementary, to satellite , services and operational support to field groups, (b) Ground Sensorial Surveillance System(s), providing continuous vessel traffic information to operations, and (c) Maritime Intelligence and Information System, providing confidential vessel traffic and identification information to operations.

(3) **MARITIME TRAFFIC SURVEILANCE INTEGRATED MANAGEMENT SYSTEM (MTSIMS),** which comprises (a) a Data Receiving, Elaboration, Archiving and Distribution System, providing totally integrated information for intervention planning , monitoring, and control operations, (b) a Maritime Traffic Surveillance Integrated System, providing planning, command, and control services to field units in the area of their operational jurisdiction, and (c) a Maritime Traffic Surveillance Logistics Support and Training System , providing total ground support for targeted Mission Readiness and Availability, and training services in order to develop operational efficacy and up-to-date expertise.

It is important to note that , the system described in Fig.7 is part of the TIMTSS. In itself, the TIMTSS is similar to a common C3I system with the addition of an Earth

Observation system. In turn and thanks to this addition, the proposed TIMTSS becomes conceptually a C4I (Command, Control, Communication, and Computer Information) system. The TIMTSS concept may be implemented at Continental level (e.g. Europe) with regional management sub-functions converging to a common effort. This will permit to utilise an Observation Constellation in orbits for Global coverage instead of a regional one given that the other contributing systems are still part of the Total System configuration.

Returning back to the regional satellite observation system concept; sush a system will be more complex if has to support also the identification of the culprit. This is because it will require to perform, in quite short revisit intervals, the vessel identification and tracking operations. Specifically, the Mediterranean Basin scenario will require for such operations several small satellite constellations in inclined orbits of about 40° inclination. It was evaluated that a double access arc is necessary to ensure reasonably short revisit intervals (6 hours or less) without utilising a too large number of satellites. However, since no roll steering manoeuvers can be reastically implemented when patroling the Mediterranean (roll steering manoeuvers would, in fact, reduce too much the time left for image taking), the baseline approach would be to equip each satellite with two SAR antennas looking laterally and perform beam switching in accordance with predetermined sequences matched to the crosing of the traffic lanes by the overpassing satellites. The addition of a second antenna would increase satellite complexity and costs, but however, it is still feasible to employ a small, 600Kg or less, satellite for this purpose. Each satellite would, thus, be capable to nearly simultaneous viewing the two access areas symmetrically located about the local nadir and included between, typically, 20° to 55° off-nadir. Each antenna would feature electronic beam steering in the elevation plane to position a f.o.v. of about 120 Km - when projected on ground - anywhere within the two symmetrical access arcs.

With these assumptions they were assessed, parametrically, the performance and feasibility of constellations comprising from 2 to 6 small satellites in either all inclined or sunsynchronous or a combination of both for the most trafficked lanes as defined in Fig. 2. They were taken as a reference, ten regularly spaced points on the Gibraltar-Cairo route , four on the Tyrrhenian, and four on the Adriatic route.The results are summarised in Table 1, providing the mean value of both the average and peak revisit intervals over the preset points for the nominal case (all satellites operating) and the degraded case where one satellite is considered innoperative. Assessing the performance in the latter case is very important considering the operational nature of the service and the delay in restoring the constellation integrity. Table 1 shows that only constellations with three or more satellites can satisfy the specific mission requirements. A constellation with 4 satellites exhibits much better perfomace than the one with three, especially in the case of one satellite innoperative. In the case of 5-satellite constellation , the obtained performance improvement results to be marginal when compared to the 4-satellite constellation and therefore the cost of the fifth satellite does not satisfy the Performance-Cost return ratio. Therefore, the final choice must be based on the trade-off among the 3-satellite and 4-satellite constellation configurations. The added complexity, in terms of SAR instrumentation and ground processing, will be the price to pay in order to implement the law enforcement activities in addition to the simpler task of tracking illegal oil slicks in the Mediterranean. However, the implementation of the proposed technical concepts may be strong deterrents to law infringements and , thus, might be worth while to be adopted.

4. USING SATELLITES IN THE RELIEF PHASE

Following an oil slick detection, as a result of intentional or unintetional action, satellite remote sensing may be used as powerful means to support the Relief Phase of operations directed mainly to damage containement and / or clean-up activities. The "observation variables" that are the most significant during the Relief Phase (Ref. [6]) are the following :

(1) Oil Spill Size. Remote sensing , as being the most efficient way to detect oil spills, is able to provide a synoptic view of large area, 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 ; they are used to estimate the oil spill dimensions. Landsat data is currently used to detect oil presence. However , systems such as Landsat are inadequate, due to their low revisit frequency characteristics, to perform operational oil spill monitoring. SAR sensors can be used for oil spill tracking in all-weather and day-night conditions, to delineate its boundaries, but do not provide information on oil thickness, volume and type; X-band seems to be the best for oil slick detection. Not all current and planned 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 hours), though data from various satellite systems might be combined to provide inputs for prediction models.

(2) 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 0.1mm.

(3) Oil Classification. Lidar fluorosensor can be used to measure thicknesses less than 10mm and to discriminate between oil types. Nevertheless such sensors have not yet reached a good maturity for space applications.

(4) Wind Fields. Wind field maps, if available, may support oil slick motion predictions thus facilitating its tracking. In addition, microwave scatterometers are able to measure both the surface wind speed and direction. ERS-1 AMI can measure surface wind speeds in the range of 0.5-30 m/s with an accuracy of about 2 m/s 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 every 1 to 2 days, rather than the required few hours. Other data sources include passive microwave imagers and altimeters (wind speed only, not direction). At local level the scale is too small for space based measurements with high spatial and temporal requirements; so their operational use is highly questionable.

(5) Currents (Speed and Direction). Significant data sources are the precision altimetry packages and SAR. 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.

(6) Sea Surface Temperature. Sea surface temperature data can be used to derive marine current characteristics and profiles in order to predict the spill extension behaviour. 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° range respectively and 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 to 24 hours can be achieved. In principle, AVHRR can meet the requirements, although in practice,cloud cover will prevent complete sub-diurnal coverage of the European region.

A summary of the above instrumentation characteristics and their relevance to the Relief phase , is given in Table 2. However, not all of the above instruments will have the same priority and not all considered tasks should necessarily 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, it should be recalled that many existing satellites already provide information that can be used to support the modeling of marine cyrrents, and the assessment of meteorological and environmental conditions. Therefore, a dedicated satellite system should primarily address those unusual performances which are highly specific of the relief phase, with the greatest emphasis being addressed on the measurement of the oil spill extent, shape, and the important parameters for oil slick motion tracking. In this context, a SAR satellite constellation, as discussed in para. 3.2 above, having the required revisit interval performance and resolution characteristics, it seems also well suited to support relief phase operations. Nevertheless, such satellite system may also carry auxiliary packages, if compatible with the non-sunsynchronous orbit. Furthermore, TIR sensors may also worthwhile to be investigated for use in the characterisation of sea currents. In addition, the enhancement of the SAR sensor multimode operation (e.g. adding a wavemode for surface wind characterisation) could be also considered within the scope of the primary mission.

5. THE GROUND SEGMENT AND OPERATIONAL CONSIDERATIONS

The control and operation of the prospected satellite system will be performed by a Ground Segment that should be designed for decentralising the operations, relevant to North Sea , Atlantic Coasts and the Mediterranean Basin, through a common satellite management center. A proposed configuration may include:

(a) a satellite management center , including a TTC station located in Central Europe ;

(b) three data receiving stations with one handling satellite passes over the North Sea and two receiving data from satellite passes over the Mediterranean Sea. Fig.8 shows an example of coverage with data stations located close to Stockolm, Marseille , and Cyprus respectively.

(c) two processing centers; one co-located at the northern data receiving station and the other co-located with one of the two Mediterranean data stations.

Data stations, TTC stations and Processing Centers would be all interconnected, as shown in the block diagramme of Fig.9. The above prospected set-up can easily be a part of the Totally Integrated Maritime Surveillance Management System described previously (Ref. also Fig.7a).

The Processing Centers (Pcs) should be designed taking into account the following operational requirements :

(a) the Pcs shall 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 justify the presence of massively parallel processors to speed up considerably all computing tasks and support the automatic interpretation activities, such as the oil slick detection, vessel detection, sorting and identification, and even data fusion.

(b) shall allow minimal archiving requirements. In fact, all data is very volatile and it should be temporarily archived for i.e. a week. Only a small number of data (regarding relevant to major events) could be permanently archived.

6. TECHNOLOGY CONSIDERATIONS

In defining an effective satellite system for oil spill and, possibly, for law enforcement, a number of advanced technologies and system concepts should be considered, both on board and on the ground, since they will affect the overall cost-effectiveness of the design. Some of these are briefly reported herein, as follows:

(a) the use of directive, mechanically steerable, antennas for satellite data transmission will enable the system to transmit SAR sensor data at up to 180 Mbit / sec - as required for example by the high resolution mode which supports the vessel identification, to ground data stations equipped with small (order of 3m) diameter antennas (Ref [7]);

(b) applying advanced, non-linear, high gain compression algorithms directly to the I / Q SAR sensor data streams generated on-board, which may lead to important reductions in the data trasmission rates, thus facilitating the data reception by small terminals. Such techniques are presently under study in Italy ;

(c) applying massively parallel computing to the ground SAR data processing, will enormously speed up image restitution by a factor of 60 to 100, as recently was experimentally verified by Alenia Spazio SpA. The large data volume associated to this application- see para. 3.1 above - will maket it important to rely on this technology ;

(d) automatic features extraction algorithms seem particularly attractive to handle the large daily data volume, taking into account the repeatitivity and specificity of the processing and interpretation tasks. Here also massively parallel computing can considerably help.

Concerning the small satellites, there are several interesting new technologies developed by European and non-European companies, that can considerably reduce the satellite production and integration costs.

7. AN OUTLOOK OF THE SMALL SAR SATELLITE

The small SAR satellite required to meet the mission needs considered herein may be very similar to the one shown in Fig. 10. The Ref. figure shows an artist 's view of the X-band SAR satellite which is being designed for the Trinational CO.S.M.O. system (Italy-Greece-Spain) Ref. [7],[8]. This system will be launched in a transverse sunsynchronous orbit. When flying in an inclined orbit, the solar plant - including the array - must be modified to cope with the variations of the sun vector with respect to the orbital plane. Minor modifications may be generated from the specific SAR payload requirements, especially from the antenna side. However, as long as, a SAR instrument will have to be accommodated on board the satellite, it will be very difficult to conceive a spacecraft considerably smaller than this, which is aimed to have a launch mass of 550 Kg (including the propellant) and life cycle of 5-years at 500 Km altitude.

The estimated recurring costs for such satellite (more than 3 production units) is of the order of 20-35 MUS$ each, depending on the payload peculiar requirements and optional features dictated by each specific mission. Launch costs for this type of satellites are estimated to be around 15 MUS$ (for each) depending on the launcher type, market conditions and competition.

8. CONCLUSIONS

The main problem with oil spill detection and monitoring, is the acquisition and processing of remotely sensed data, for use in containement and/or clean-up operations, with a limited delay from the occurrence of the event. Revisit intervals of 12 to 24 hours are required to cope with the dynamics of accidental or intentional oil spills at sea; short delivery times (order of 1 hour or less) are also essential for data availability. An effective and highly performant ground processing network should be thus forseen to reduce delays through parallel computing. The observation capabilities must satisfy both daylight- nighttime and all weather requirements , which imply the use of SAR instrumentation. Constellations of dedicated small SAR satellites are feasible and can provide excellent coverage of the high risk areas mainly in Europe.

Moreover, enhanced constellations can be designed to cope with the more challenging task of identifying tankers responsible for illegal oil spills in closed sea basins and supporting law enforcement actions. 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 Management System.

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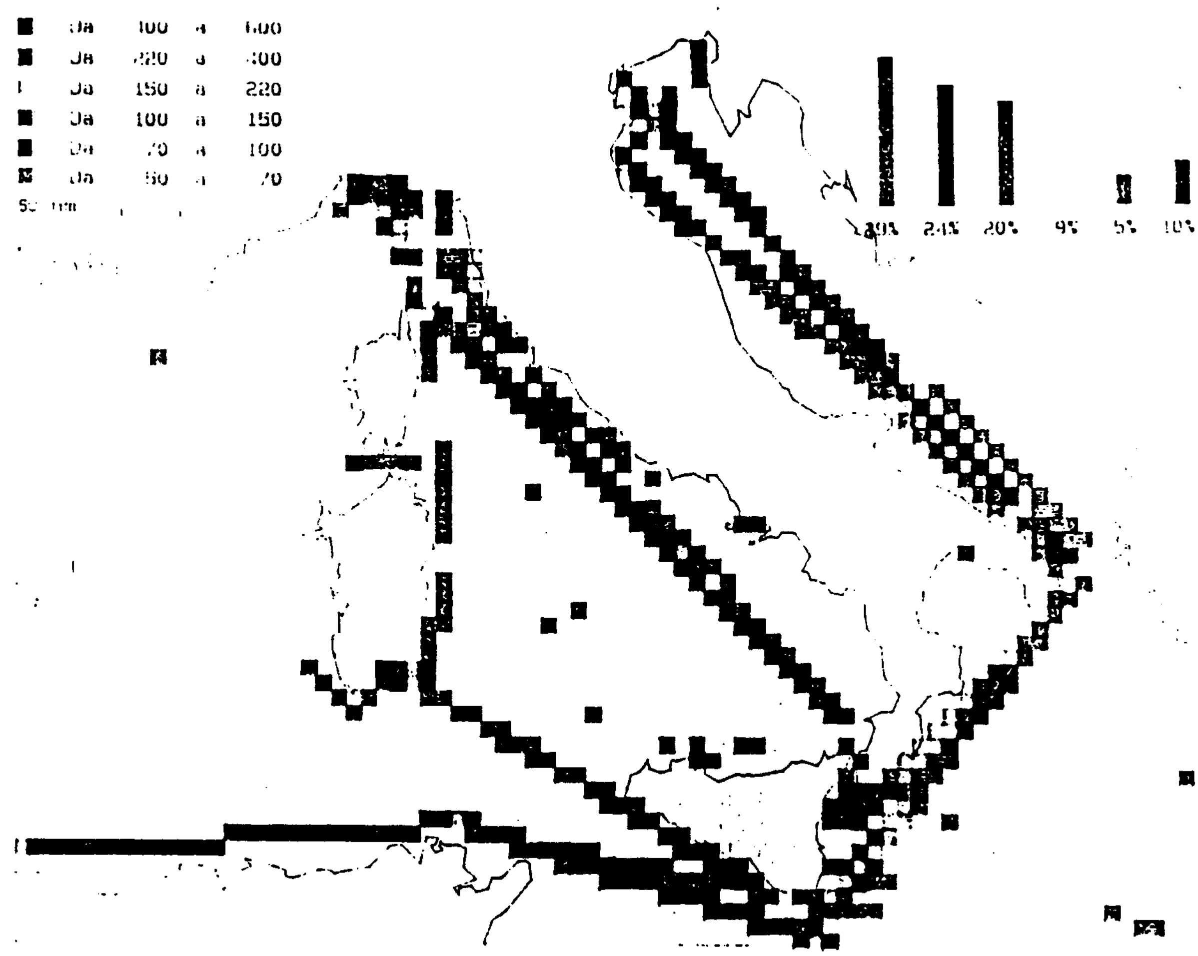


Fig. 2 Tankers' routes in the Mediterranean Basin, showing the major lanes: Gibraltar-Cairo, the Tyrrhenian route, the Adriatic route

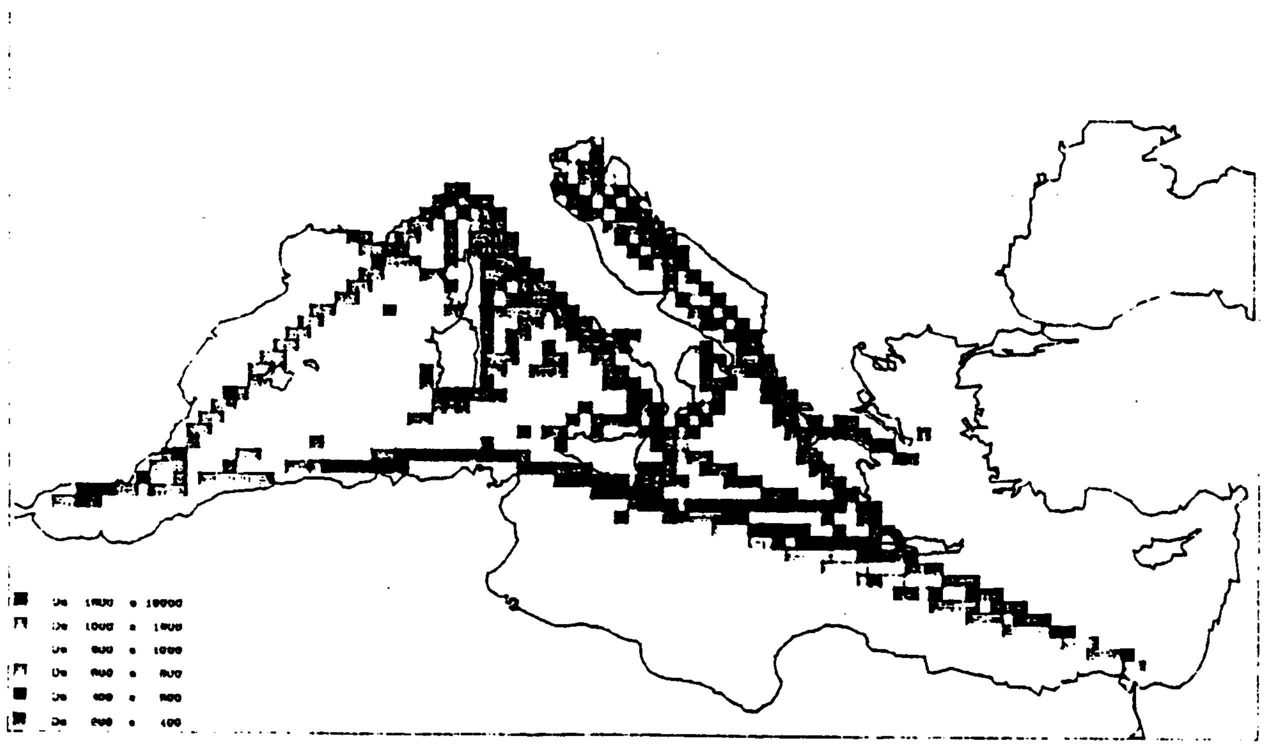
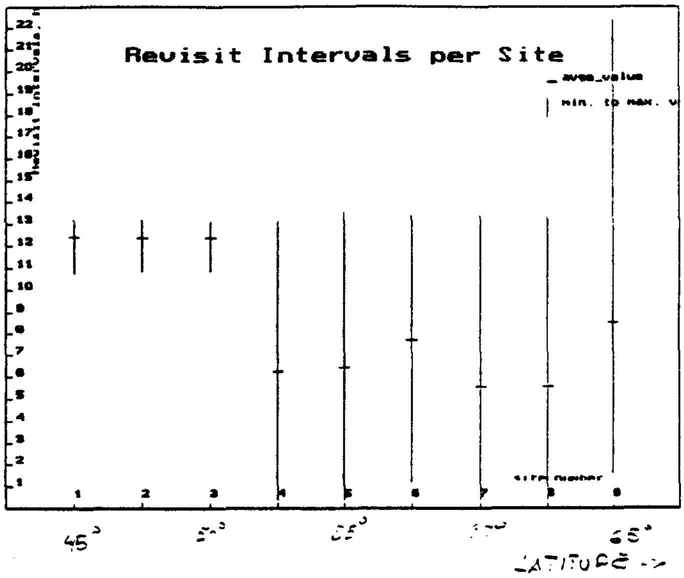
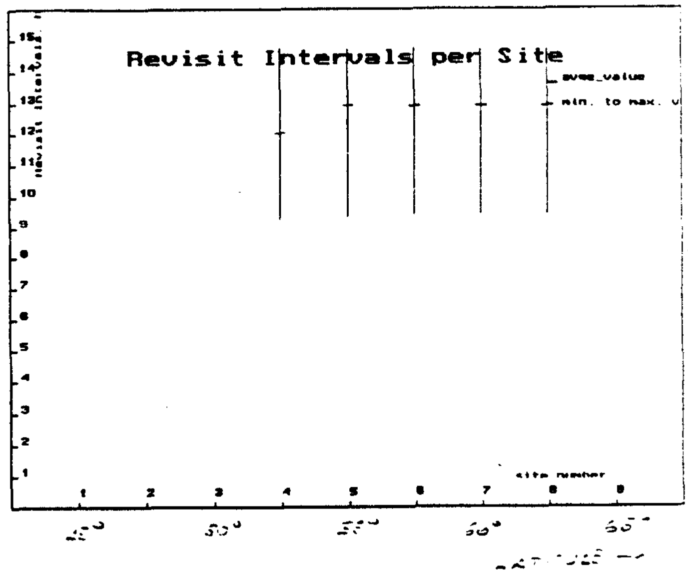


Fig. 3 Distribution of all ships in the Mediterranean Basin

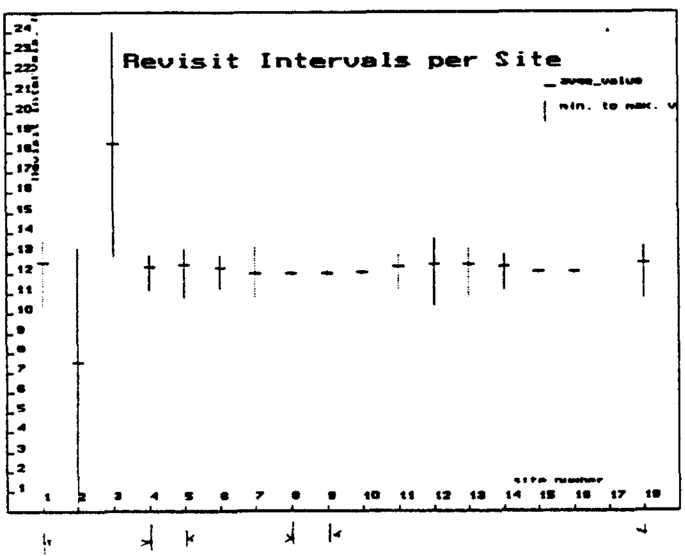


nominal case



1 satellite failed

Fig.1 Performance of a two-satellite system in a resonant sunsynchronous orbit over a 45°- 65° latitude band (North sea).



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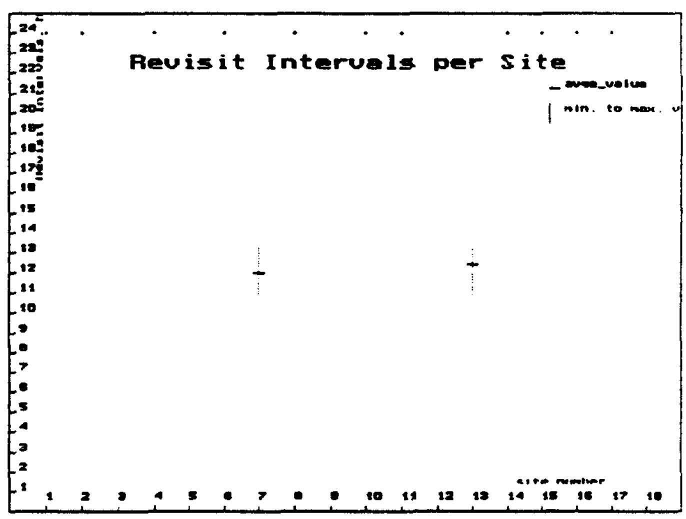
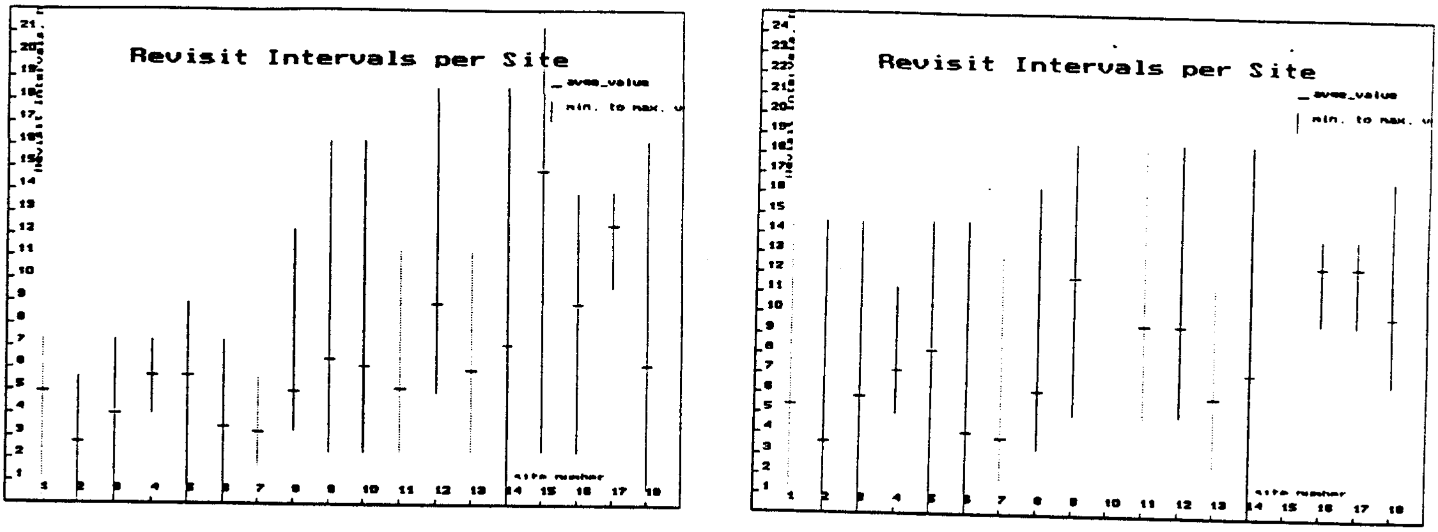


1 satellite failed

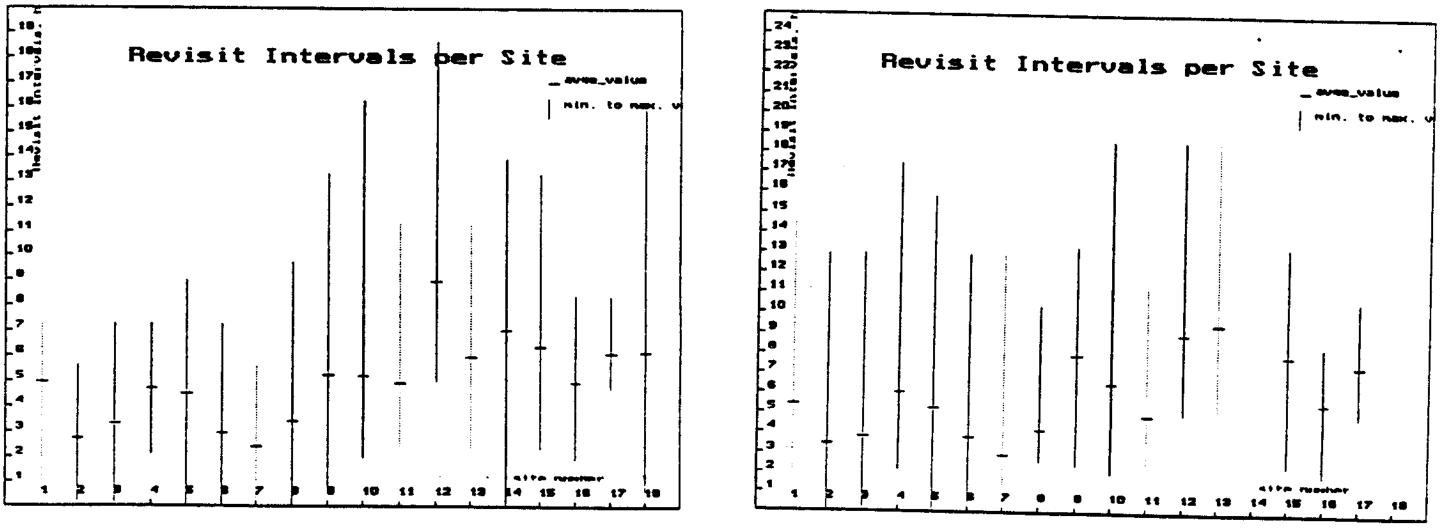
Fig. 4 Performance of a two-satellite system in a resonant sunsynchronous orbit over 18 sites in the Mediterranean Basin (4 points each on Tyrrhenian and Adriatic routes, 10 points on Gibraltar-Cairo route)



nominal case

1 satellite failed

Fig. 5 Performance of a constellation of three SAR satellites in 40° inclined orbits (120° spaced in RAAN), over 18 points along the major tankers' routes in the Mediterranean Sea



nominal case

1 satellite failed

Fig. 6 Performance of the constellation in Fig. 5 plus the two satellites in a sunsynchronous resonant orbit shown in Fig. 1 and Fig. 4, over 18 points along the major tankers' routes in the Mediterranean Sea

Constell. Type	Nominal case Mean Rev. Int.	 Peak Rev. Int.	One satellite failed Mean Rev. Int.	 Peak Rev. Int.
• 4 sat. In S.S.O (≈ 570 Km alt.)	5.45 hrs	12.25 hrs	8.73 hrs	13.5 hrs
• 2 sats., 40° incl.; 180° spaced in RAAN	5.17 "	11.25 "	n.a.: performance falls below minimum acceptable	
• 2 sats. in SSO + 2 sats., 40° incl. 180° spaced in RAAN	3.93 "	10.26 "	5.1 "	11.7 "
• 3 sats.; 40° incl.; 120° spaced in RAAN	4.34 "	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 satellite can position the f.o.v. within a 20°-55° off-nadir

Table 1 Parametric evaluation of constellations for the Mediterranean Basin scenario

Indicator for Relief	Sensor	spectral bands	required revisit	current revisit	required resol.	current resol.	time-liness	archiv.
Oil Spill size	Opt.(UV) -VIS/NIR MWpassive SAR	0.3 mm .4-1.75mm 5-94 GHz X band	2 - 6 h	- monthly daily monthly	10 m	 30 m 3-60Km 30 m	2-6 h	Yes
Thickness and Volume evaluation	Passive MW Laser fluorosensor	5-94 GHz .35-.7 m (128 ch.)	2 - 6 h		-		-	
Oil classification	Laser fluorosensor	.35-.7 m (128 ch.)	-		-			
Wind Fields (at local scale)	Scatterom.		3-6 h	1-2 days	.1-1Km	50 Km	2-6 h	
Currents (at local scale)	Altimeter SAR	Ku, S band C-band	3-6 h	monthly monthly	10 m	7-15Km 30 m		
Sea Surface Temperature (at local scale)	TIR	10-12mm	6 h	6 h	100 m	1000m		

Table 2 Use of Satellites in the Relief Phase

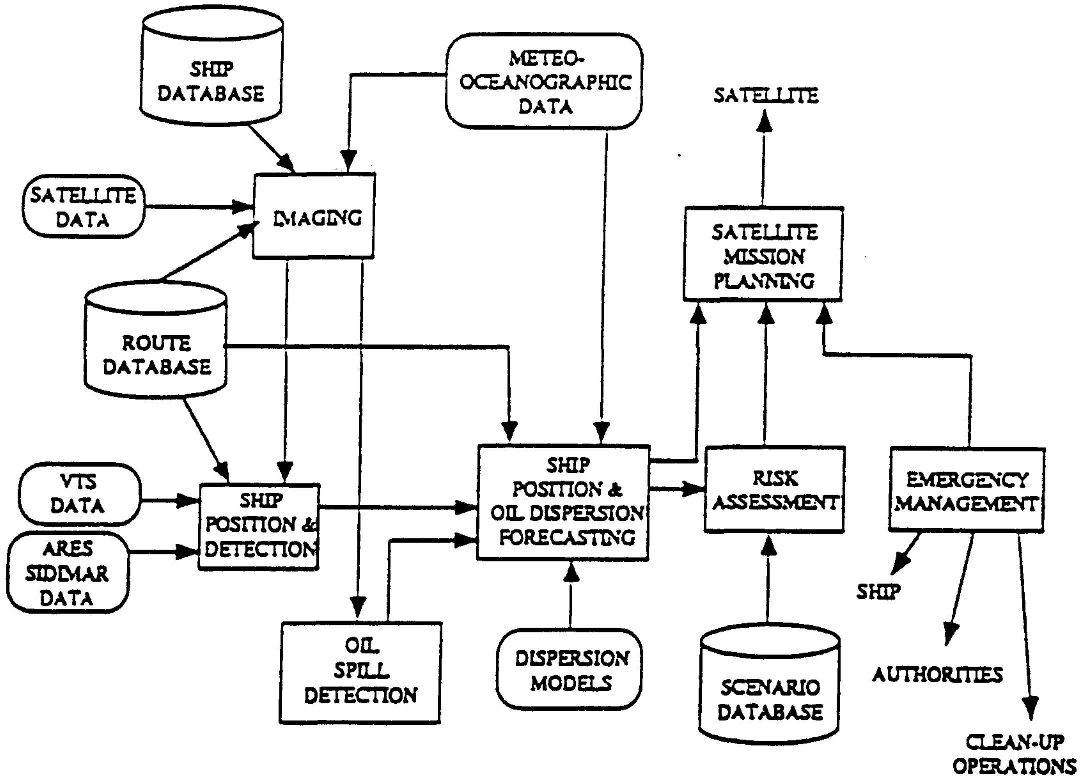


Fig. 7 System Block diagram of a possible Maritime Traffic Surveillance System

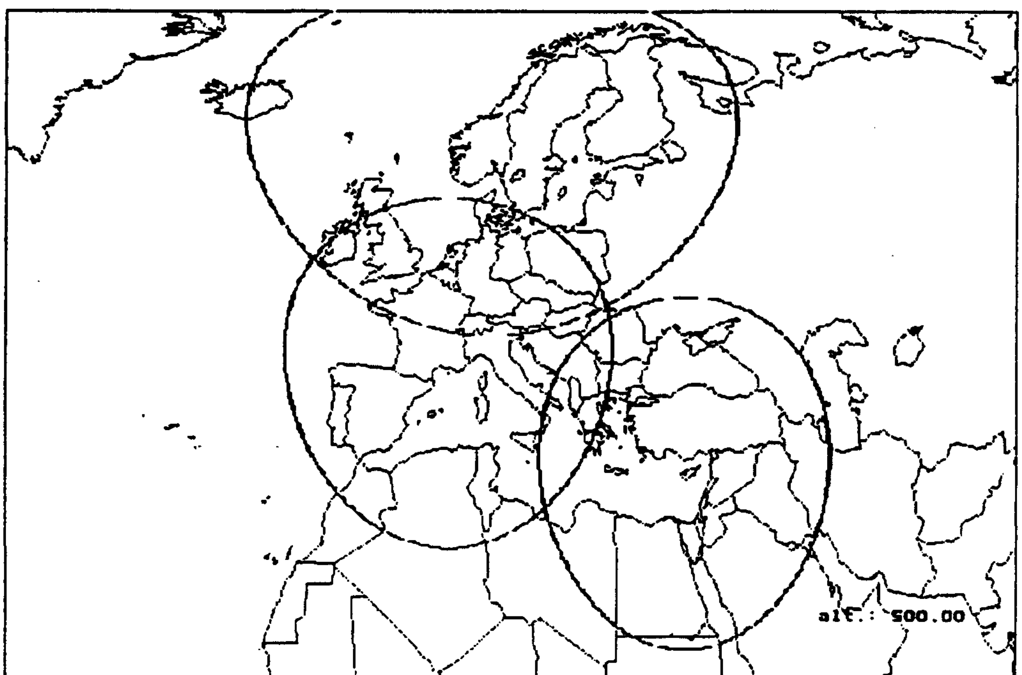


Fig. 8 Three Data Receiving Stations (Stockolm, Marseille, Cyprus) for North Sea and Mediterranean Basin coverage. Minimum elevation angle: 10°

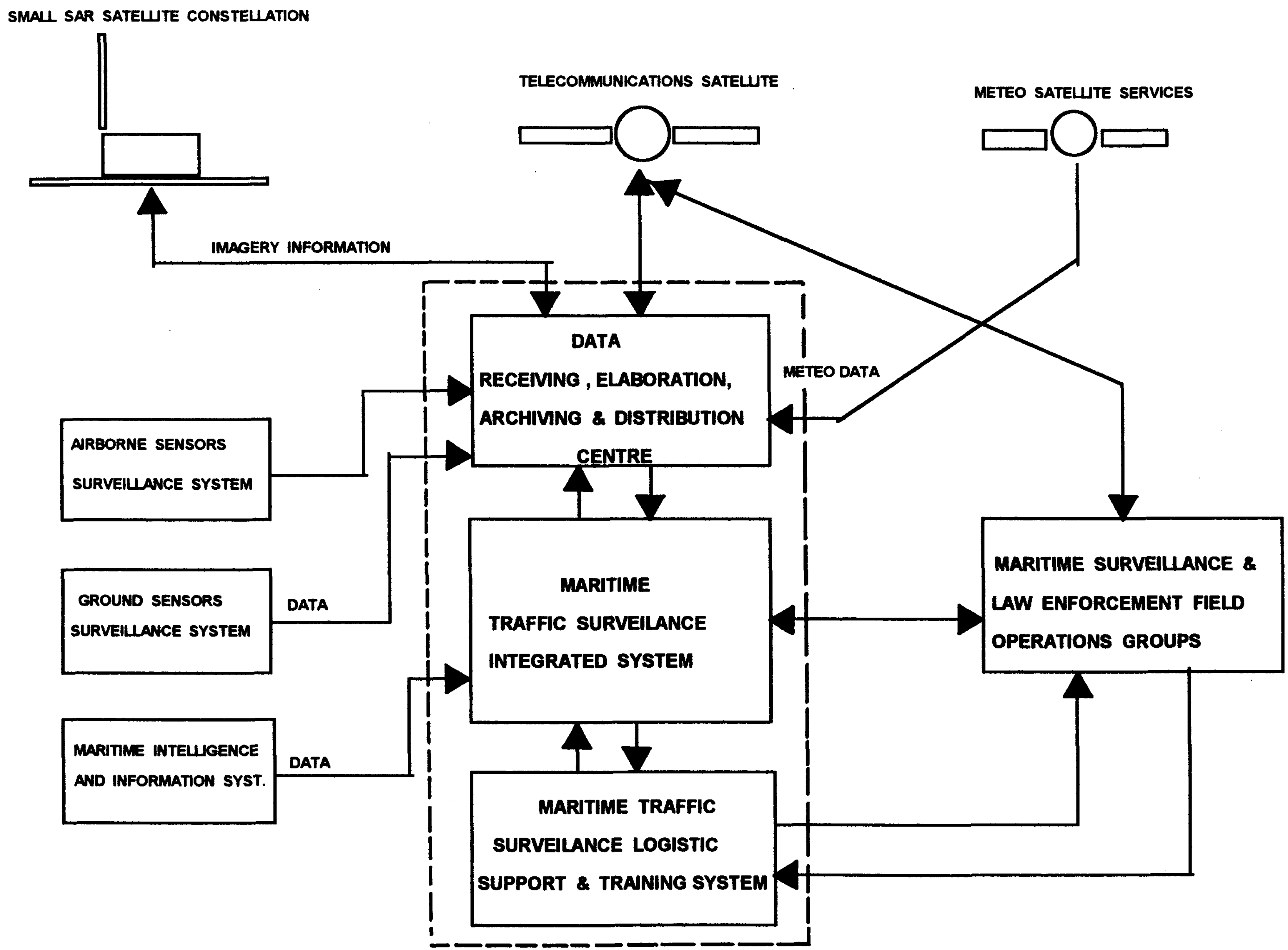


FIGURE 7a TOTALLY INTEGRATED MARITIME TRAFFIC SURVEILLANCE SYSTEM - MAIN FUNCTIONS BLOCK DIAGRAMME

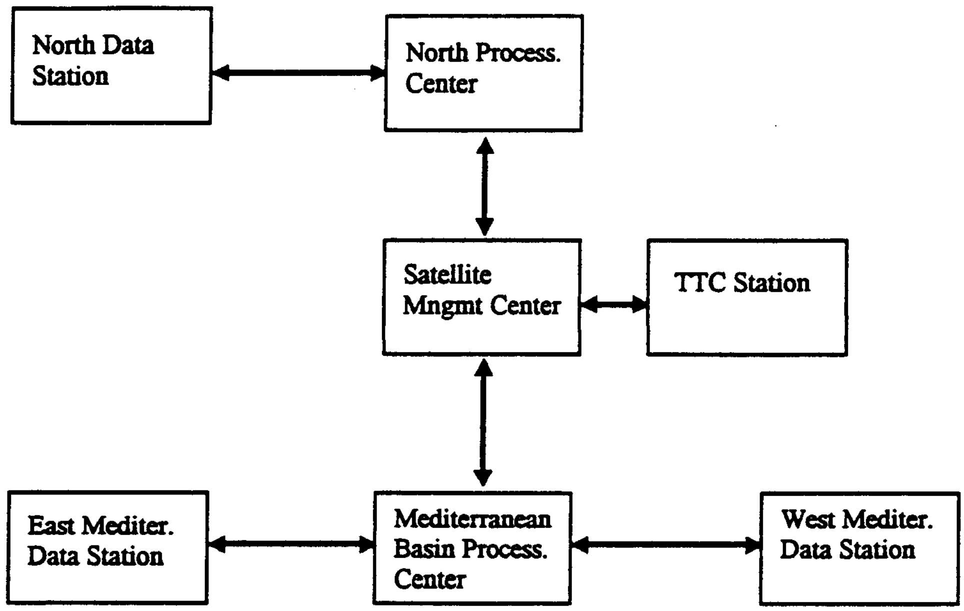


Fig. 9 Satellite System Ground Segment Block Diagram

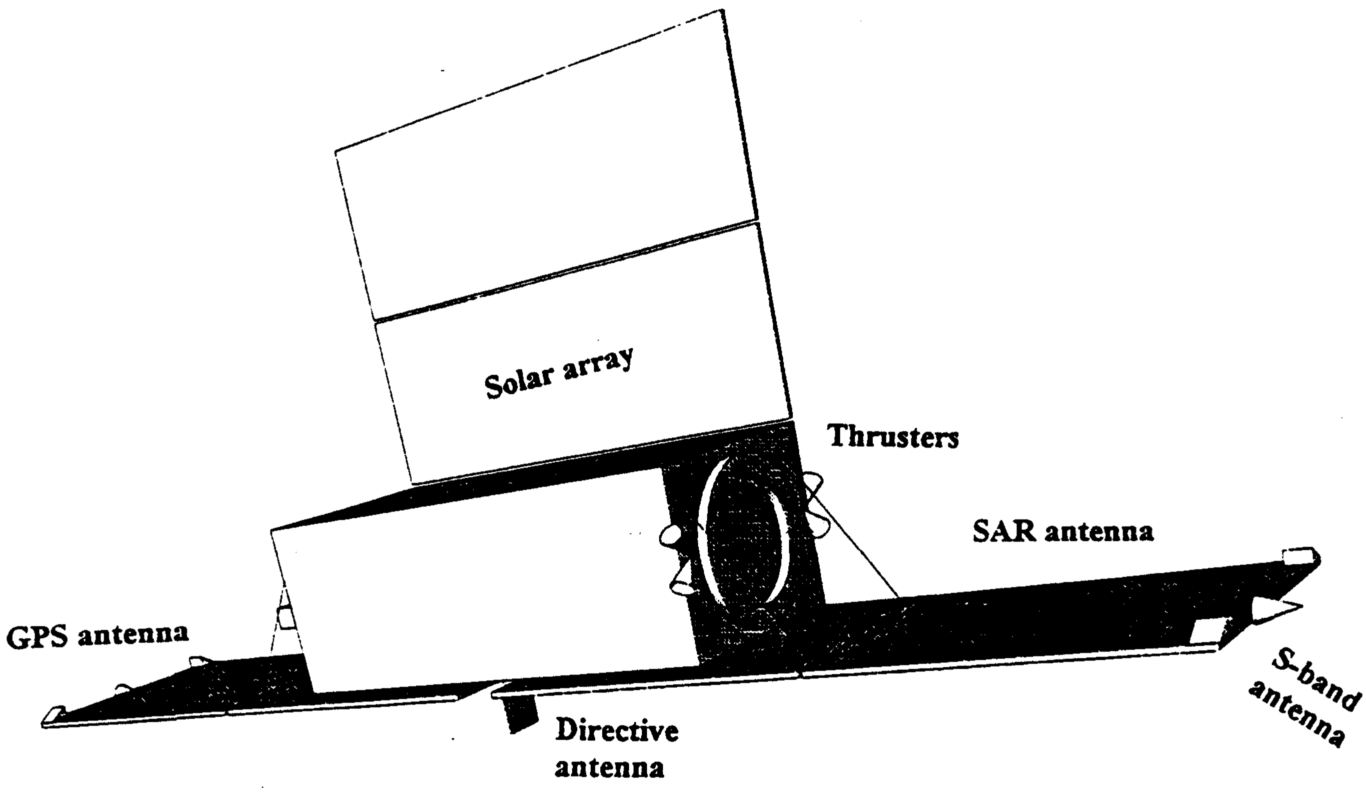


Fig. 10 Artist's view of a representative (COSMO) SAR satellite

ERS SAR Image samples of oil spill detection in the Mediterranean

Côte d'Azur, France

The ERS-1 SAR image shows Côte d'Azur between Monaco in the North and Bormes in the South. It is a multitemporal image resulting from the following three acquisitions recorded at 10.20 GMT: 13 September 1991 (in blue) - 19 September 1991 (in green) - 25 September 1991 (in red). Colours are linked to changes in backscatter within the relatively short time period under reference. Nevertheless, backscatter on the sea may change rapidly because of the wind regime, whilst, on land, changes of such magnitude cannot be explained by vegetation growth but only by meteorological phenomena (rain-fall, freezing and similar). The magenta colour on the sea indicates stronger winds on 13 and 25 September. The horizontal blue/magenta line is a wind-front announcing the arrival of a weather change on 25 September. The magenta feature towards the lower right corner is an oil slick which occurred on 19 September. The same slick reached the coast (lower left) on 25 September, and is visible as a green/bluish line.

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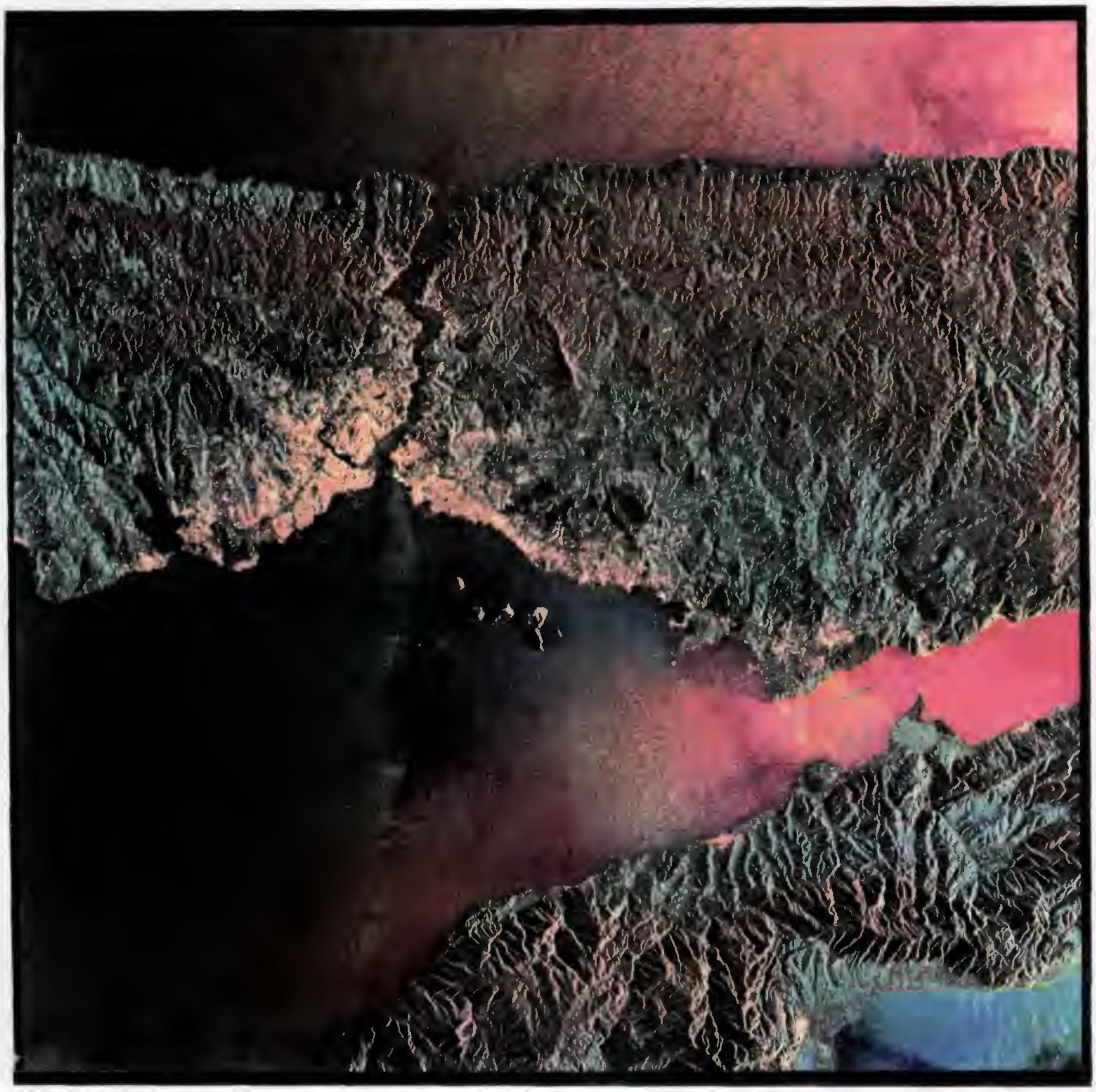

Bosphorus, Turkey

The scene shows the Black Sea to the North, the Marmara Sea to the South and in-between the Bosphorus separating Europe and Asia. The heavily populated areas of Istanbul and Üsküdar at the southern end of the Bosphorus are well imaged in white. Also visible are the two bridges connecting both parts of Turkey. The multitemporal ERS-1 SAR scene represents an area of 100 by 100 km and is composed of: 20 April 1992 (in blue) - 16 November 1992 (in green) - 25 May 1992 (in red). Just South of Istanbul many coloured points in the sea can be recognised. These are ships at anchor. The red points are the ships there on the 25 May 1992; in green are the ones of 16 November 1992, etc. The colours of the sea merely reflect the wind situation during the data acquisition. The prevailing magenta colour would mean that the 25 May but especially the 20 April were rather windy days. Some slick-like features are present, such as the cyan-coloured streak (25 May) in the Bay to the East, which is most probably man-made.

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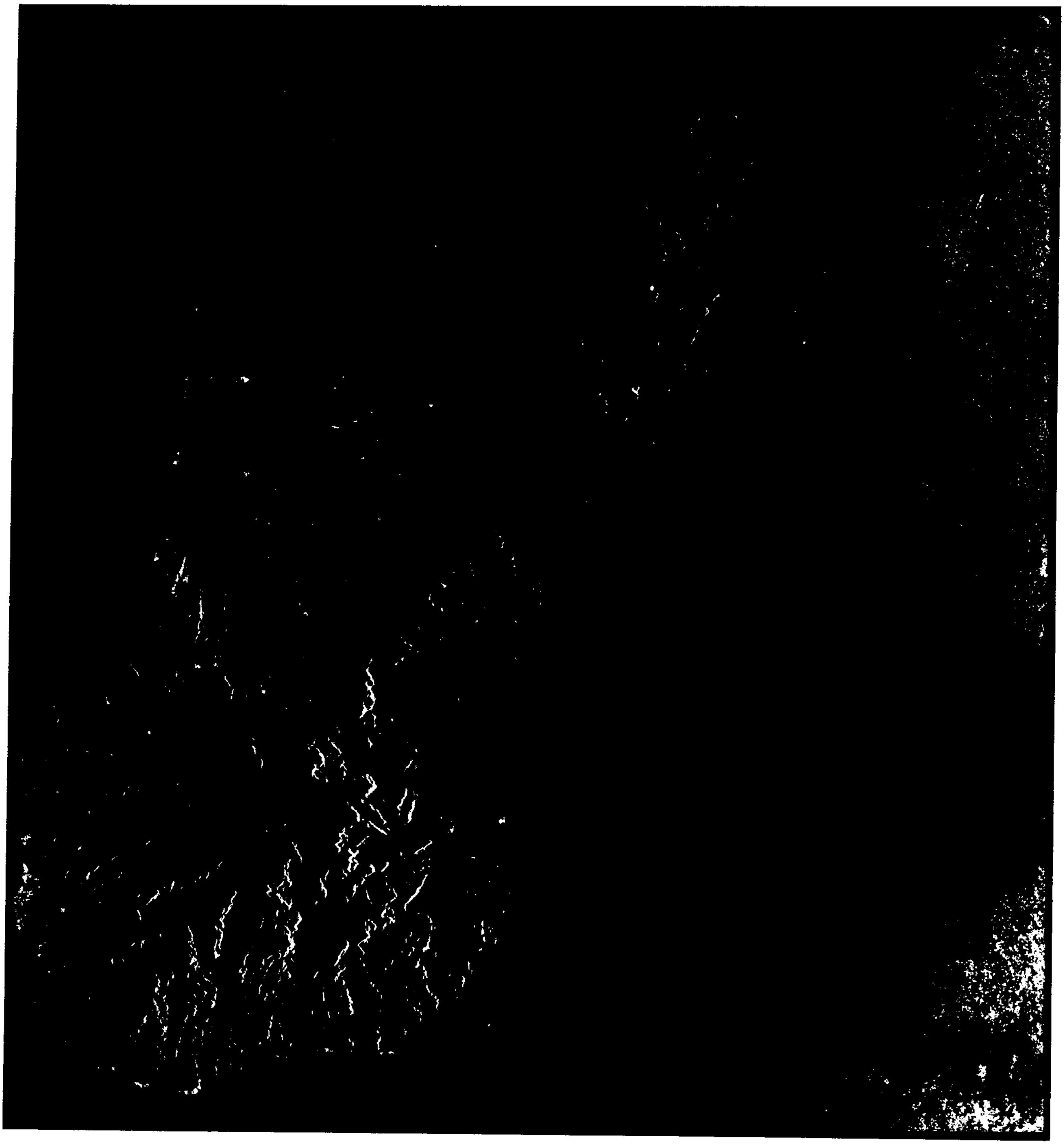

Calabria, Italy

The most southern tip of Italy as seen by the ERS-1 Imaging Radar on 31 August 1994 at 9.48 GMT. It is a meteorological situation with low wind favouring the appearance of all kinds of surface phenomena. There is a clear difference in the atmospheric conditions on both sides of the Peninsula. On the Tyrrhenian side apparent cool air produces an unstable atmosphere, and consequently a characteristic pattern. On the Ionian side, instead, a local wind regime prevails. Most of the black linear features are probably natural oil films produced by micro-organisms. However, the large, compact black feature at the image bottom is most likely a man-made oil slick. This feature shows sharp edges and a straight form.

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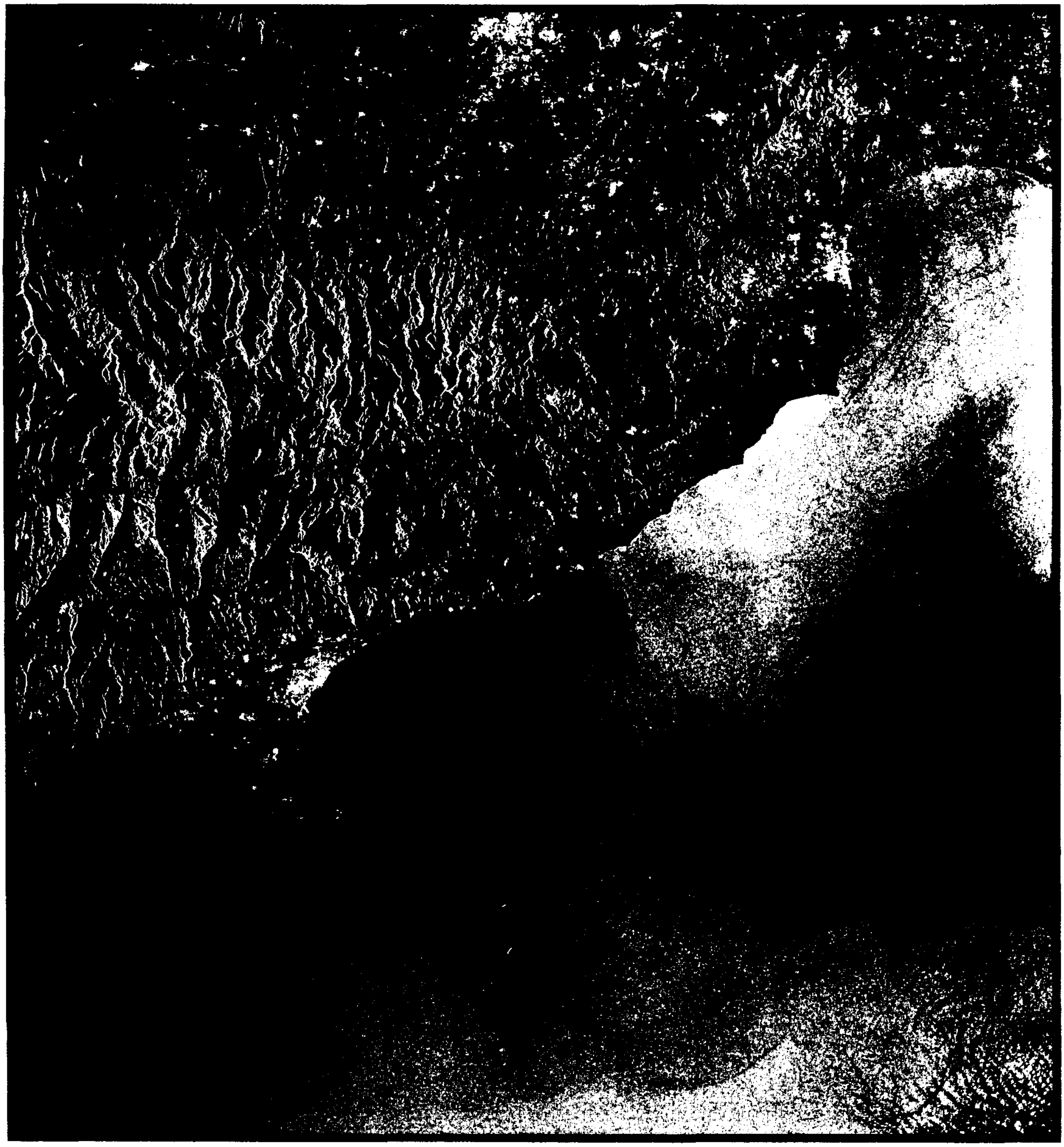

Cyprus

This is an area in the Eastern Mediterranean, where oil spills caused by ships can frequently be observed, especially at the entrance to the Suez Canal. In the ERS-1 SAR scene acquired on 26 August 1992, the South-Western part of the island of Cyprus is imaged. Nicosia is visible at mid-top, whilst Limasol on the coast can be identified in the lower half of the image. Due to low wind over the sea, many different features become evident. Natural slicks are present in the Gulf of Larnac (right top corner) and also along the right edge of the frame. However, the other dark features in the lower part of the image are most probably man-made, especially the straight and extended ones.

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Strait of Gibraltar

Internal waves propagating from the Strait into the Mediterranean, a very usual phenomenon in this area, is shown in this 100 by 100 km image by ERS-1 SAR of 1st January, 1993 at 22.39 GMT. At each high tide such wave types are triggered over the Camarinal Sill. They consist merely of areas of alternating roughness, not caused primarily by wind but by vertical and horizontal currents. Light wind amplifies the effect, whilst the waves may not be visible when winds are stronger. These well developed internal waves have travelled through an oil slick, about 40 km long, modifying its shape in the Western part. Other features in the image are induced by wind. A wind front is visible just South of Gibraltar. The same can be observed more to the South, where the wind is blowing out of the valleys into the sea, forming fan-like features. The many dark irregular linear features are presumably natural oil films, accumulating in areas of up-welling.

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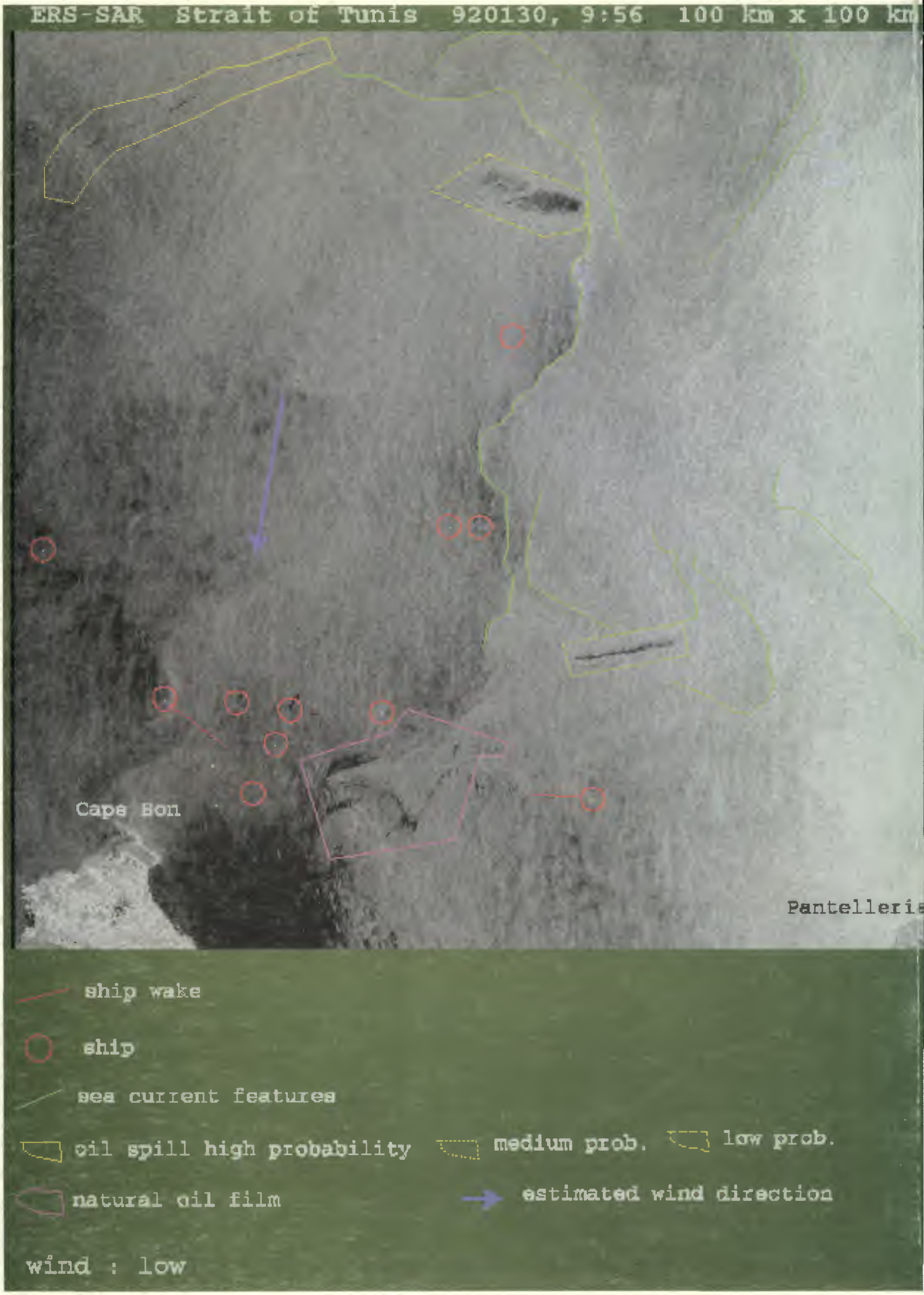
ERS-SAR Strait of Tunis 920130, 9:56 100 km x 100 km
Cape Bon
Pantelleria
ship wake
ship
sea current features
oil spill high probability
medium prob.
low prob.
natural oil film
estimated wind direction
wind : low