OIL SPILL MONITORING BY SATELLITE: THE WAYS TOWARDS MAKING A REALITY OUT OF A DREAM

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ABSTRACT: *Despite the good results obtained in a series of experiments performed jointly by satellite image providers and pollution response authorities in Northern Europe, the reluctance to acknowledge the spaceborne data contribution to oil spill surveillance is still considerable. The authors, in part counter pollution professionals, in part experts in satellite imagery interpretation, started to collaborate with background ranging from strong doubts on the suitability of satellite imagery to support pollution control activities, to substantial experience in using radar satellites such as ERS for ocean features detection. Building on their different languages, priorities, and views, they compared satellite imagery with airborne collected information and identified areas where today, unavoidably, using satellite imagery would be disappointing (such as emergency monitoring of major pollution events), areas where satellite imagery can offer a service not satisfied through airplane surveillance (such as wide, synoptic area surveillance together with complementary control of anchorage areas and collection of statistical information on major deballasting routes), areas of potential synergy between satellite and airplane imagery (such as the substantiation of pollution prosecution dossiers). Those conclusions were drawn* inter alia *from the exploitation of SAR images related to over 50 different spill incidents in the Mediterranean Sea.*

Introduction

Oil spill monitoring at sea by naval and aerial means, whether for accidental spills or illegal deballasting, is a well established technique, for which manuals and training sessions are available in a number of languages. In those manuals and sessions, specialised long range surveillance planes equipped with adequate sensors, particularly Side-Looking Airborne Radar (SLAR), are most logically pointed to the most efficient tool for such monitoring. But such planes are costly, both in investment and operational expenses. Additional factors that further reduce their regular monitoring capabilities over maritime routes are maintenance time, staff constraints, range limitations and weather constraints.

OIL SPILL MONITORING OVER THREE DIFFERENT SEAS

Different world regions are far from being equally treated as regards aerial monitoring of oil spills. As an example, the maritime basins of the North, Mediterranean and Red Seas are far from equally treated in terms of number of bordering countries operating surveillance planes, areas surveyed and number of flight hours.

Reports of the Bonn Agreement for "Co-operation in Dealing with Pollution of the North Sea by Oil and Other Harmful Substances" show that eight of the bordering countries of the North Sea (Norway, Sweden, Denmark, Germany, the Netherlands, Belgium, France, the United Kingdom) fly specialised oil slick surveillance planes. The total flight hours averaged 3588 per year over the 5 years 1993–1997, resulting in an average 809 oil slicks reported, i.e., 1 slick per 4.4 flight hours. Results are compared and compiled at regional level, showing a clear need for better intercalibration: in 1997, 70% of the small slicks, the total of which represented 89% of the slicks reported, came from the Netherlands only, whose observations accounted for a significantly higher proportion of small slicks (92%) than those of the other countries (62%)

Only two Mediterranean countries (France and Italy) operate specialised oil slick surveillance planes. Their total flight time seems to hardly exceed 800 hours per year and their results are neither compared nor compiled jointly. They neither fly over the southwest part of the western basin of the Mediterranean Sea, nor over the whole of the eastern basin.

None of countries bordering the Red Sea and Gulf of Aden operate any oil spill-monitoring planes.

Satellite imagery experts have long observed that earth surveillance satellites equipped with Synthetic Aperture Radar (SAR), such as the ERS satellites, have the capability to monitor oil slicks at sea, without the limitations of the planes. Formulating suitable image processing algorithms and testing them on known shipping routes, they have published in the late seventies and all along the eighties a number of highly convincing papers on radar signatures and satellite observations of oil films at the surface of the sea (Alpers and Hühnerfuss, 1988; Sherwin *et al.*, 1977). However, those papers failed to generate consistent interest in the maritime industry and marine pollution monitoring authorities.

The potential contribution of satellite imagery to oil spill monitoring was recently debated at length in several workshops financed by the satellite community and international organisations (Calabresi, 1996). Discussions there concentrated on technical aspects, failing in general to tackle a major question: did the maritime industry and pollution monitoring authorities really have a need for a new oil spill-monitoring tool? For the satellite imagery experts, the answer was evident. The best possible degree of knowledge of any phenomena one wants to analyse, and possibly manage, is an essential starting point for subsequent actions and deeper studies. But a good degree of knowledge might not be sufficient anymore if the domain under consideration is disaster management in general, and, more specifically, a world-wide plague of the importance of oil pollution. Exploiting all available means, from Earth to Space technologies, from human know-how to electronics, from advanced infrastructures to appropriate, specific legislation, in order to achieve that highest level of knowledge, was not seen by the satellite imagery experts as an option, but as a must. So, when a new tool, showed up and volunteered to demonstrate why, how, and when it could help in issues related to oil pollution, it at least deserved full attention, reasonably high level of confidence and no prejudices. Once the familiarisation phase would be over and the first, encouraging results would be obtained, that tool required availability to evaluate, discuss and cross-check those results, positive attitude and co-operation in the validation process, willingness to facilitate a follow up along the always hard road towards operational use.

The targeted potential users saw it differently. The shipping industry had no interest at all in a better and more extensive monitoring of oil spills. The marine pollution monitoring authorities attached little importance to the availability of world-wide spill information. Obtaining less than 1% effective payment of a pollution fine for 100 spills reported by the surveillance planes, they were primarily concerned with improving their evidence and prosecution procedures against offenders in their national waters and with the short term monitoring of slick drift in large, accidental spills. They immediately pinpointed the drawbacks of the new tool, showing that it was little flexible, did not return to the same site frequently enough, could provide misleading information, was inefficient in very calm or rough sea conditions (Bedborough, 1996; Lunel, 1996).

From a pioneering experience to a regional recognition

Dialogue between satellite imagery experts and potential users finally took shape. It was admitted that access to the space-derived information had to be improved, made easier and faster, in order to meet emergency requirements. It was also admitted that space derived information was not a substitution tool, but had to be integrated with other data sources in a dedicated information

CAPACITIES AND LIMITS OF SPACE RADAR OBSERVATION

Space remote sensing of the Earth dates back to the early Seventies, when the first high-technology satellite ERTS-1 (later on renamed LANDSAT) started to provide views of all parts of the world. Since then, a remarkable series of spaceborne instruments have been operated by the different Space Agencies in order to meet the ever more precise requirements of a correct Earth resources management policy. But it is only in recent years that the technical characteristics of sensors mounted on space platforms seemed to better respond to effective needs, especially in the domain of risk prevention and management. Although not especially conceived to meet the operational requirements of an oil spill monitoring system, the ERS (European Remote Sensing) satellites operated by the European Space Agency since 1991 have demonstrated, through an experiment made in Norway first, and by several other initiatives and projects later, that a pre-operational service for oil spill detection and monitoring could be implemented.

The imagery derived from their microwave (radar) sensors not only penetrates clouds but works day and night, covering large areas within a short time. It is suitable for risk map generation, capable to contribute in building up and updating specific database on coast vulnerability, environmental impact of catastrophic oil pollution events and similar. In addition, with fixed installations, such as oil rigs or ships at anchor or on travel, being kept under regular surveillance from space, day and night, a prevention effect should be obtained, resulting hopefully in a reduction of intentional spills.

But a complete understanding of the mechanism for the detection of oil slicks on the water surfaces has not yet been attained. Important factors to consider are sea state, current, and wind speed and weather conditions. In the radar instrument performance, the intensity of a returned pulse is highly dependent on the roughness of the sea surface from where it is returned. The sea waves (gravity waves) are covered with small wind-generated ripples (capillary waves) which reflect pulsed radar energy producing a bright image known as sea clutter. In the case of a completely smooth sea surface with no capillary waves, the transmitted pulse bounces off from the sea and disappears away from the radar sensor. Oil on the sea surface damps a part of the capillary waves, even if oil thickness is only of a few micrometers. It is the difference in return signal between an oil covered and non-covered sea area that makes it possible to detect oil on the sea surface. Many interference are radar-detected as oil slicks, such as biogenic films, fresh water, wind slicks from very calm weather, wave shadows, weed beds, etc. Because of the high number of such interference, radar can be useless in particular situations. Regarding wind speed, this should be comprised between 10/30 km/h to make an oil spill detectable. Data acquisition timing is a limitation to the full exploitation of radar space information in oil spill, especially at latitudes like that of the Mediterranean basin. It can be overcome, though, by taking advantage of the contemporary presence in orbit of more than one radar-equipped mission with subsequent reduction of the revisiting time interval between one passage and the next over the same area.

Space radar can observe and locate ships at anchor or on travel but cannot identify vessel type and name. Here is where the operation of a combined satellite/airplane observation system proves its utility.

system to enable setting up a compound of ready-to-use information. Such a compound had to be based on a large volume of both static and dynamic information, as well as on models making use of suitable meteorological and oceanographic information. Accepting those limitations, Norway stepped into a demonstration project.

The Norwegian model cannot be reproduced all over the world, as it is specific to the needs and capabilities of an offshore oil producer country (it aims primarily at the surveillance of spills by platforms and it benefits from financing from the oil companies exploiting those platforms). But it raised interest over the other northern European countries and the issue of satellite monitoring of oil spill was integrated in the concerns of regional organisation with responsibilities in the matter. A major step forward was made over 1997 and 1998, in meetings of the Working Group on Operational, Technical and Scientific questions concerning counter Pollution Activities (OTSOPA) of the Bonn Agreement for Co-operation in dealing with Pollution of the North Sea by Oil and other harmful substances, and at a joint European Community/Bonn Agreement workshop on Evidence and Law Enforcement in the Event of Pollution further the Release of Oil by vessels. The Technical Aspects session of that workshop, held in December 1997 in Brest, France (Silvestre *et al.*, 1998), included in its conclusions that Satellite SAR imagery is considered to be of the same quality as the known SLAR system. The satellite coverage could, whenever possible, be incorporated into the maritime surveillance operation as an early warning and complementary means of detection. This technical recognition was endorsed by the subsequent meeting of the OTSOPA working group of the Bonn Agreement, clearing the last objections Northern European spill specialists could still have against the technical value of space borne radar observations of oil slicks.

This paved the way towards a further step, now underway: building a constructive technical co-operation between space agencies and national marine spill monitoring institutions over maritime areas benefiting of aerial surveillance through proper calibration and on-site verification of airborne and spaceborne radar spill detection. That calibration achieved, extension of the monitoring to areas without aerial surveillance will become feasible

A spill monitoring demonstration project in the western Mediterranean

The target area selected for this calibration and demonstration work was the western Mediterranean Basin. There are many reasons for that choice. The Mediterranean sea a unique, fragile and vulnerable ecosystem. Evaporation exceeds rainfall and river-supplied fresh water, resulting in a net inflow from the Atlantic Ocean through the straits of Gibraltar. Water pockets would require from 70 to 100 years to be flushed out of such an enclosed sea. Pollution flushing cannot therefore be as relatively easy as in more open water areas such as the North West Atlantic. Besides the natural cleansing process factor that represents a key issue, what makes the situation hard in the Mediterranean is a shipping traffic level among the highest worldwide. As a consequence, deliberate or accidental spillage is an almost constant threat.

Although all countries bordering the Mediterranean have reached a common understanding that oil pollution is a real problem and that a monitoring system should be set up to ensure that the terms of the various international conventions are respected, efficiently banning discharges and preventing dumping from ships in that sea still remains a dream today. The low probability of being seen and prosecuted does not prevent offenders from performing illegal discharges. Adequate control using all existing tools, including space monitoring, should help to enforce laws and regulations. In addition, space-derived information, alone or in conjunction with other data sources, should meet the requirement to urgently generate and subsequently update coastal zone sensitivity maps of both sea and land surface.

However, specific forums, workshops, operational meetings set up in and outside Europe within the Mediterranean Basin environment long failed to convince those concerned. In 1996, it proved extremely hard to convey at ESA ESRIN premises, to a dedicated Thematic Workshop on Oil Pollution Monitoring with the help of ERS Radar, heterogeneous parties belonging to industry, user communities, service provision emergency response and control, ministries and environmental institutions. At a later stage, a unique, common conclusion was reached: as it happens in other applications domains, the technology/operationalisation transfer is extremely hard to achieve.

THE NORWEGIAN OPERATIONAL SERVICE

In 1994, the Tromso Satellite Station (TSS) started offering to customers in Northern Europe a near-real time oil spill detection service based on ERS SAR (Synthetic Aperture Radar) data. Norwegian, British, and Dutch spill monitoring agencies contracted experimental services. In 1996 the offer was improved by upgrading the near-real time information distribution systems. And, when a second space radar capability was established with RADARSAT, TSS started moving into an operational phase: distributing information directly to the Norwegian surveillance aircraft, in addition to normal communication with customers via telephone, fax and electronic networks.

The co-ordination between surveillance aircraft operations and ERS overpasses is facilitated by the orientation of the Norwegian coast, parallel to the ERS orbits: flight plans of airplanes along the coast can be easily adjusted to go and verify a real-time ERS SAR alert.

Space-derived near-real time products were found beneficial for oil drilling platform surveillance by SFT, the Norwegian Pollution Control Authority. A full-scale operational service was set, with financial contribution of the oil industry (Pedersen *et al.*, 1996).

A cost-benefit analysis was carried out, aimed at ascertaining if the largest net social benefits were achieved through an operational oil spill monitoring service using either two aircraft or one aircraft combined with satellite information, to cover twice a week an annually accumulated sea-area of 18 million square km. The cost per square km covered was found to be 46% higher in the two-aircraft option. The social benefits were compared to a reference option without any monitoring, considering four fundamental parameters: the reduction of the probability of an oil spill, the evaluation of spill economic impact, the readiness to contribute in oil spill prevention activities and the willingness to bear the costs of clean up operations. Both monitoring options significantly improved social benefits, in ratios ranging from two to 15 for the two-plane option and from three to 22 in the plane-cum-satellite option, depending on the weighing of the parameters above.

As a challenge to overcome persisting reluctance around and to experiment, ESA ESRIN took the initiative of a joint pre-operational approach for a common objective, which gathered interest from the Italian Coast Guard in early 1997, followed by CEDRE later in the year. All partners in this venture agreed that an exchange and validation of everyone's respective expertise was an absolute requirement. A fast ERS SAR (radar) data processing procedure was implemented and made operational at ESRIN in support to demonstration activities focused on oil slick monitoring in the Mediterranean. The procedure is based on 2–4 weeks advance notice sent by the Oil Pollution Team to Order Desk to plan ERS passes over a given area with high oil slick probability, data acquisition at Fucino Ground Station with generation of relevant quick-look image within 2 hours, transfer to ESRIN via FTP, georeferencing of the image using dedicated software, analysis, interpretation and identification of highly probable oil slicks, and dispatch of the information via fax to the Italian Coast Guard and/or CEDRE (which passes it to the French Customs, operating the French specialised surveillance plane), within a few hours from the original satellite data acquisition. three examples of such images are attached (Figures 1, 2, 3).

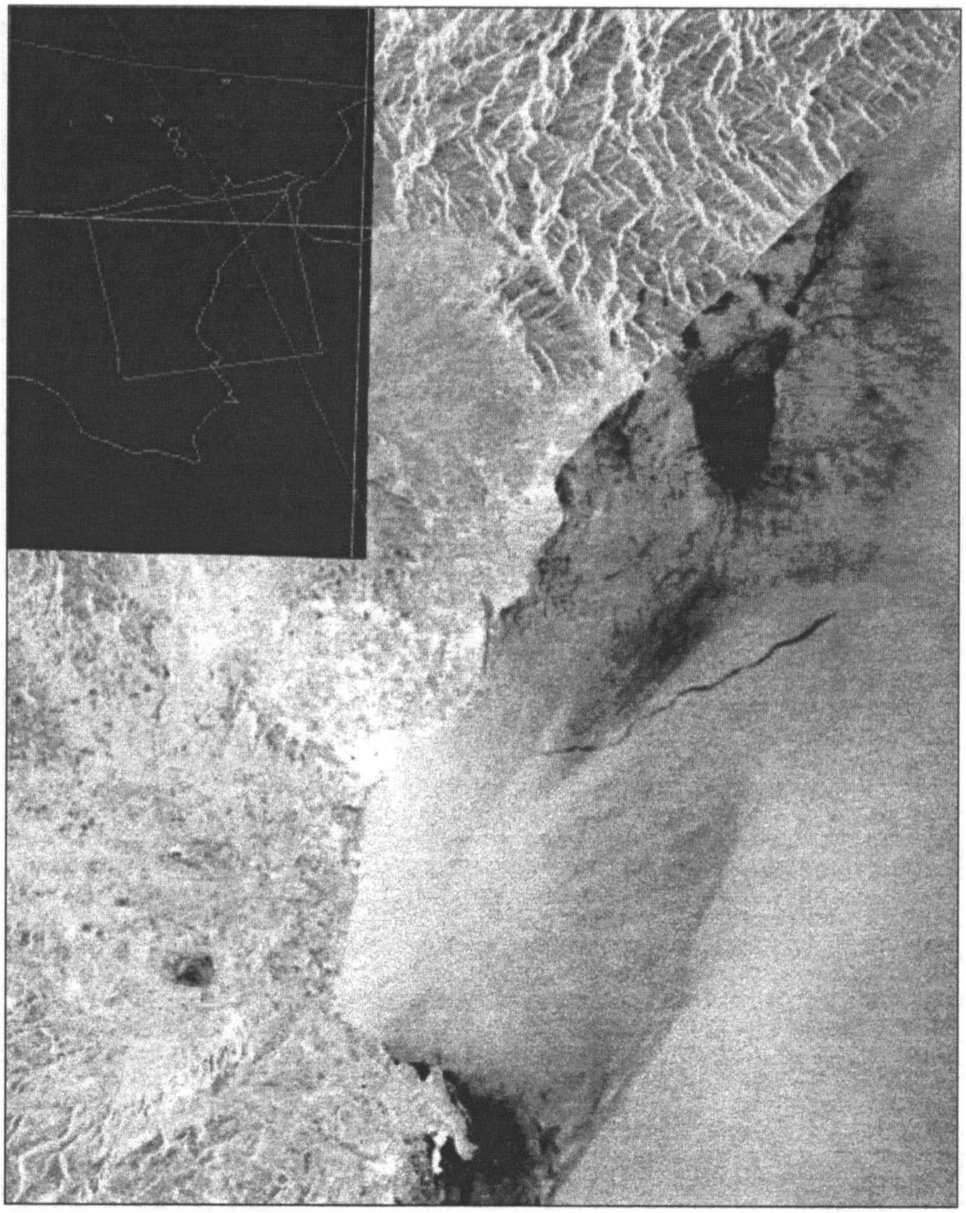

Figure 1. ERS Radar satellite image, East coast of the island of Sicily, Italy, 8 April 1998, 23:16 local time. A 28-km long night spill, in the inset's rectangle, is evident. It was presumably caused by a ship entering the harbour (the spill appears larger at its off-harbour end) a few hours before. Other, more diffuse dark surfaces on the sea are caused by low wind areas. Their shapes and patterns are clearly different from the spill. The round shaped Etna volcano and the city of Catania (in white), down the southern slope of the volcano, show on the land portion of the image. The image was processed and analysed early in the morning after the night acquisition and an alarm message describing the pollution was immediately sent to the Operational Centre of the Coastguard, in Rome. On 9 April, at 16:10 local time a Coastguard plane confirmed the pollution, moved by the currents and wind into a more north-south extension and very diluted (rainbow).

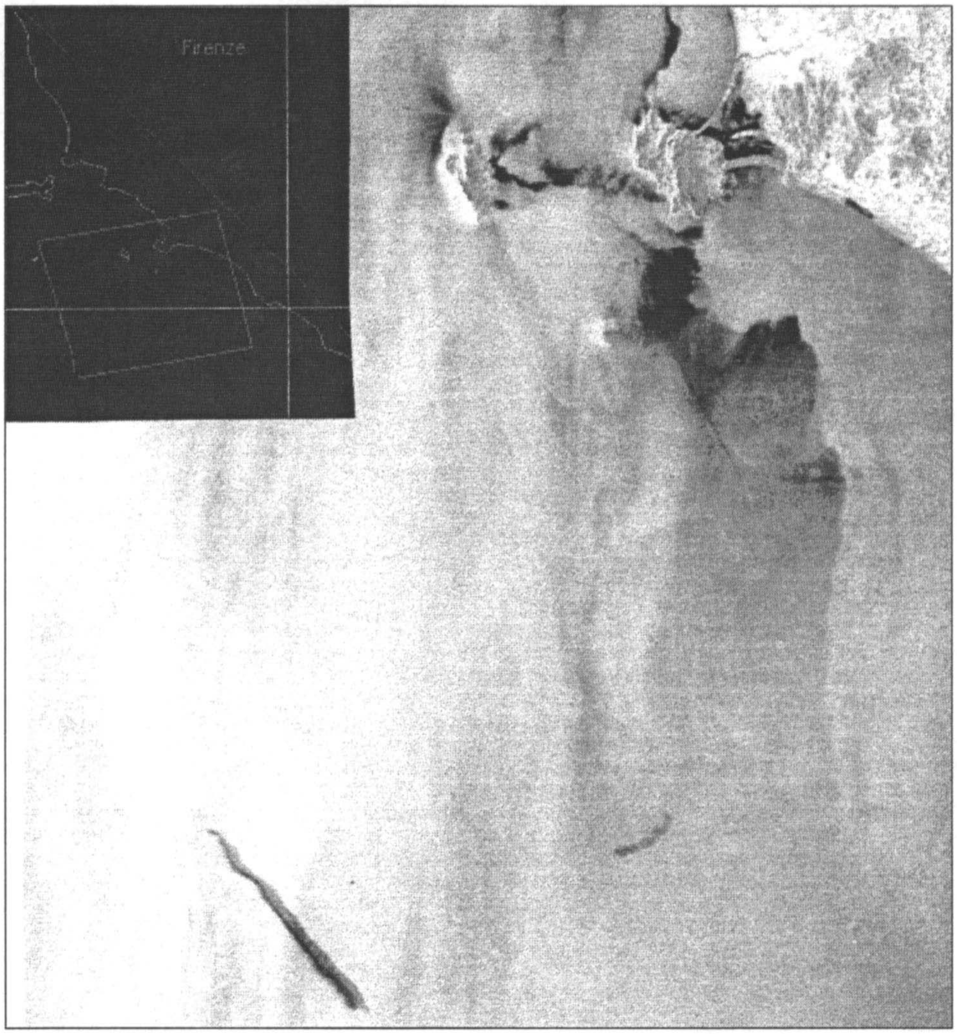

Figure 2. ERS Radar satellite image, Island of Hyères, southern France, 10 June 1998, 12:20 local time. A 17-km long spill, of about 900-m width, is obvious in the inset's rectangle. Another thinner and fragmented spill, 12-km long, marked by the blue line rectangle, is visible at about 20 km from the island of Levant. The irregular thin black streaks near the top left corner of the scene are presumably concentrations of natural oil aligned along current fronts. Such phenomena can be observed quite often in low wind areas. Unfortunately this image was processed only 3 days after the satellite acquisition and no alert was send to the French customs, a surveillance plane of which is based at Hyères airport.

A substantial volume of slicks deriving from accidental oil pollution was detected through ERS SAR in the Italian territorial waters during an approximate 1-year time frame comprised between May 1997 and July 1998. Taking advantage of the night and day observation capability of SAR, 248 images were analysed, out of which 54 (corresponding to 21.8 percent of the total) were found containing oil slicks. The number of SAR-night and day-detected oil slicks amounted to 134, corresponding to an average of 2.4 slicks per image.

Comparison of the above figures with those of Tromso Satellite Station shows the percentage of slicks detected to be 7.3 times higher than the 3% occurrence on the North Sea images (reference time frame: 1 year; total SAR images analysed 6,000; total images showing oil slicks: 200). Main discriminating factors between Northern Europe and the Mediterranean geographic scenario are wind intensity and speed (higher in Northern Europe), sea meteorological conditions (definitely worst in the North Sea), ship traffic volume (more intense in the Mediterranean).

Discussion

The results achieved over that project have now fully convinced the two public services in charge of oil pollution monitoring at sea in French and Italian Mediterranean waters, the Italian Coast Guard and the French Customs, of the complementary of aerial and satellite surveillance. Satellite imagery has started being used in 1998 to generate POLREPs (international report of pollution) passed from one country to another. There is now a chance that a regional map of the reported spills could be compiled at regional level at the end of 1998. An exchange of experience meeting of all parties concerned, with the presence of French and Italian surveillance planes, took place at Fucino airport and Frascati on 28 October 1998. There is also a chance that 1999 would be the first year in which satellite imagery is used in the region as an element of proof in fining an offender, following a path opened by the Singapore port Authority in 1998. But neither the responsible authorities of other Mediterranean countries members of the European Community, namely Spain and Greece, nor those

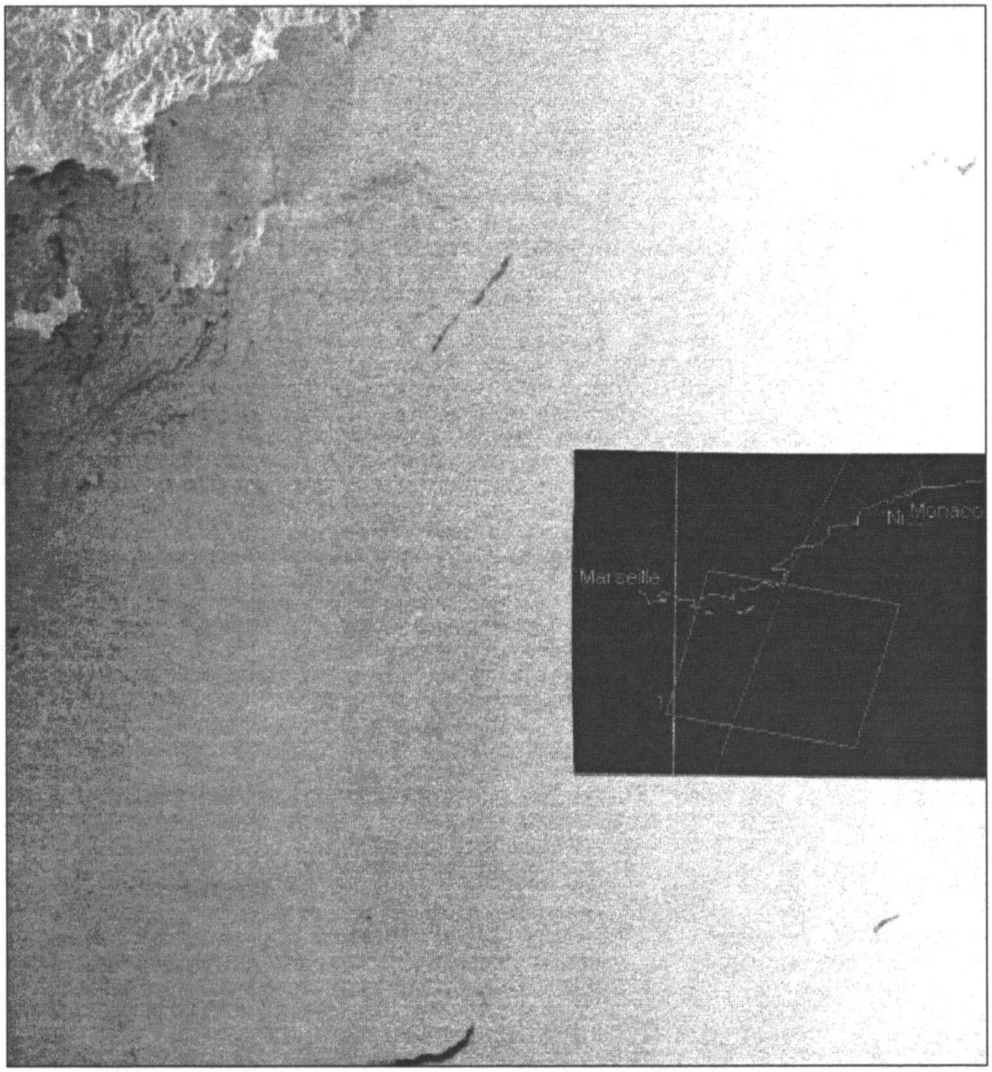

Figure 3. ERS Radar satellite image, Thyrrenian Sea, Italy, 6 October 1998, 23:29 local time. A remarkable spill of 24.3-km length and 1.8-km width, at 90 km from the coast of Tuscany/Italy appears at the bottom of the image (in inset's rectangle). Due to a strong southerly wind, a separation process of the different components of the oil is visible. Another spill of low-density oil, 6.8-km long and quickly spreading northward, is visible in the bottom right of the image. Several ships are present in the image, some of them showing also their wake. In Radar images ship wakes appear normally as a thin and straight dark or bright line, very different from an oil slick. The black areas between the island of Giglio, Argentario promontory and the coastline show the typical pattern of local wind effects of the topography (wind shelter and shadow) that should not be confused with oil spills.

of non-EC Mediterranean countries, have for now shown any interest in embarking in any aerial and/or satellite surveillance.

As pollution knows no borders, and as offenders freely move around the Mediterranean, working together is essential. The authors recognised along their work the outstanding importance of joining complementary expertise to make so that satellite information would be integrated in the elements of proof used against offenders and that the availability of a consistent archive of data collected from ERS SAR over the most common ship routes, main harbours and coastal areas in general would be utilised to its best.

Few main themes have been identified for priority action, such as emergency (i.e., investigation on actual capabilities of space radar, based on real cases), large area surveillance (in order to trace eventual oil ship pollution and to detect and localise ships at anchorage or en route) and support to legal prosecution (integrating airborne and spaceborne collected data to facilitate pollution prosecution acts).

The project partners have also built complementary partnerships with other related international projects presently run in Europe within the European Union framework (Girin *et al.*, 1998), namely OIL WATCH (Oil spill detection and monitoring in the European Union Mediterranean and South West Atlantic Coastal Areas) for CEDRE, ISIS (Interactive Satellite Image Server) for CEDRE and RAMSES (Regional Earth Observation Application for Mediterranean Sea) for both ESRIN and CEDRE. They have also built exchanges of information and intercalibration relations with other projects including in their components the concept of an integrated coastal zone pollution monitoring system taking advantage of satellite information in conjunction with other data sources, namely CLEAN SEAS (concerned with the application of satellite information to the monitoring of all forms of marine pollution), ENVISYS (Environmental Monitoring Warning and Emergency Management System) and DESIMA (Decision Support for Integrated Coastal Zone Management). Among other results of that co-operation, was the finding at the occasion of the final ESA ISIS Application Workshop held in July 1998 at ESRIN, Frascati, Italy, that CLEAN SEAS was reporting a much greater number of slicks per satellite image than the authors, because, as the Dutch aerial observers, CLEAN SEAS reported many more small slicks. This demonstrated again the importance of higher exchange and better intercalibration between all observers.

Those relations identified common interests in strengthening oil spill reporting beyond coastal waters, in order to track the spills as early as possible (to better undertake, if needed, immediate measures to protect the environment and prevent the oil to reach the shore), to provide the best possible elements of proof to pursue the offenders whenever possible (and to increase by all means the cases brought to court), to map polluted water areas routinely (to derive statistical information and set up dedicated archives for easy, quick retrieval and extraction, thus meeting the requirement of timely water quality assessment over wide geographic areas). In addition, it was agreed at the Frascati meeting mentioned above to set up a dedicated Oil Spill Monitoring Forum for a mutual exchange of expertise, information on state of advancement of individual initiatives and projects, crosscheck of respective findings, etc.

An important step towards fully integrating satellite imagery in the daily activity of the French and Italian pollution monitoring services for the Mediterranean has now been made. Extending that step to the whole Mediterranean, and building joint initiatives with other maritime regions of the world is underway. But the task ahead remains formidable. Considerable work and several decades will undoubtedly be needed before all the possibilities of satellite imagery are fully utilised for oil spill monitoring over the major maritime routes of the world.

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