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An Operational System For Monitoring Oil Spills In The Mediterranean Sea: The PROMED System

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Abstract

The primary objective of this work was the development of an operational system for early detection of oil-spills, monitoring of their evolution, and provision of support to responsible Public Authorities during cleanup operations, based on Remote Sensing and GIS technologies. In case of emergency, the principal characteristics of the oil spill are defined with the aid of a space-borne synthetic aperture radar (SAR). The transport, spreading and dispersion of the oil spill is subsequently simulated on the basis of wind forecasts of the area. The use of thematic maps of protected, fishing and urban areas, and regions of high tourism allows the better assessment of the impact of an oil spill on the areas to be affected in terms of environmental sensitivity. Finally, reports are generated notifying port authorities, the media, and local organizations to be potentially affected by the presence of the oil spill. The pilot site for testing the PROMED System in Greece is the island of Crete.

Keywords: Oil spills, Operational system, Remote sensing, SAR.

Introduction

The Mediterranean Sea is a frequented sea route allowing access to Southern Europe, North Africa, the Middle East and the Black Sea. The result of this extensive marine traffic is a high risk of oil pollution, both intentional and accidental. In addition to the obvious ecological risks associated with such pollution in a closed sea area, it is in the interest of all nations bordering the Mediterranean to protect their coastal zones as tourism and fishing play an important economic role and both can be seriously affected by marine pollution. It is estimated that around 330 000 tones of crude oil are deliberately and illegally dumped in the Mediterranean Coastal Zone each year. Other figures indicate that there may be as much as 1 million tones dumped each year, demonstrating that too little is known about the full extent of the oil pollution problem in the Mediterranean, a problem that observations of the earth's sea by satellites may help to minimise.

Oil spills spread on the sea surface forming a film, which in extreme cases can be as large as 10 km^2. This film reduces water roughness and can therefore be detected by satellite Synthetic Aperture Radar (SAR) images as dark regions. However, detection of oil slicks in SAR images is a complicated task because objects resembling oil spills (often called look-alikes) occur frequently in SAR images, especially in low wind conditions. Most frequently, look-alikes are produced by organic film, grease, wind front areas, land, plankton formations, rain cell, current shear zones and upwelling zones (HOVLAND, 1994). There are cases, where even the most experienced operator cannot distinguish between a possible oil spill and a look-alike. An operator is trained to discriminate between oil spills and look-alikes based on experience and prior information on weather conditions, difference in shape, contrast to surrounding and background objects and proximity to land.

A single oil spill event in most instances, not only develops very quickly but also causes extensive and, sometimes, irreversible ecological damage. PAVLAKIS *et al.* (1996) have showed that a considerable number of oil spills released from April 1992 until September 1993 were detected along the Mediterranean coastal zone by ERS-1 SAR imagery but were not reported to the appropriate authorities as accidents.

Oil spill contingency planning is an issue of interest and a large number of studies on the subject have been carried out (ASSILZADEH & MANSOR, 2001; THEOPHILOPOULOS *et al.*, 1996; UTHE, 1992; MONK & CORMACK, 1992). This recognizes the importance of early oil spill detection and surveillance as well as the assessment and evaluation of spill evolution by computer simulation, and further management and cleanup operations. Another issue of significant academic research interest has been the possibility of automatic oil spill detection using SAR images (KERAMITSOGLOU *et al.*, 2002; FISCHELLA *et al.*,2000; KUBAT *et al.*,1998; SOLBERG *et al.*,1999; SOLBERG & SOLBERG, 1996), which implies the potential of satellite remote sensing to monitor oil spills effectively in the marine environment.

In this work, an operational system for managing oil spill events, namely the PROMED system, has been developed and described. PROMED was designed to both monitor areas under surveillance for oil spill emergencies using satellite SAR imagery, and to provide quantitative assessment of accident consequences, help users evaluate the available options and effectively implement their decisions. A pilot system was developed for the region of Crete Island, which is particularly vulnerable to oil spills due to the large number of shipping routes that exist in its vicinity. Crete embraces a number of areas included in lists of designated sensitive and/or protected ecosystems, such as Natural Parks, NATURA 2000 biotopes, landscapes of outstanding natural beauty etc. In addition, the Cretan economy relies heavily on tourism and fishing activities, indicating the necessity of effective management of oil spill emergencies.

Method

The architecture of the PROMED system involves an image processing - virtual GIS software with interactive communication and a number of thematic maps of the area of interest, as well as individual software tools that perform all necessary numerical calculations, cartographical and reporting tasks related to the specific management of an oil spill emergency. The core of the system is ERDAS Imagine© 8.4 software (ERDAS, 1997). In addition to the core system the following peripheral tools are incorporated into PROMED: (i) an oil spill simulation model which is necessary for the assessment of the impact of the oil spill on the marine environment and the selection of the specific response to it (General NOAA Oil Modeling Environment- GNOME); and (ii) a meteorological diagnostic model which is necessary for providing the evolution of the wind field in the area.

The system architecture is illustrated in Figure 1. The data pool consists of satellite SAR images for the detection of oil spills, meteorological data used for the simulation of the oil spill and finally, thematic maps of the application area that are used in combination with the output of the simulation module for an impact assessment of the emergency situation. The system operation begins with the oil spill detection module. In the presence of oil spill, meteorological data are introduced to the system and the oil spill features are extracted from satellite images, and fed to the simulation module. Other features include the geographical location of the oil spill centroid, as well as its perimeter and area. Following that, the simulation module predicts the oil spill advection, spreading and dispersion based on the above-mentioned spill and prevailing meteorological situation. For the assessment of the emergency situation, thematic maps of the area are incorporated and, finally, the system enters the reporting module for notifying the authorities responsible for the cleanup operations and other organisations.

The monitoring module imports, processes and displays SAR satellite images. PROMED, through the ERDAS Viewer application,

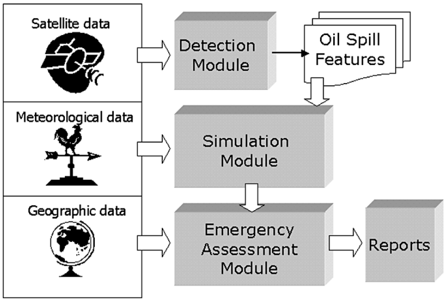

Fig. 1: PROMED architecture.

provides all the necessary image processing functions to enhance the quality and reveal the information relevant to oil spill visual identification. The consequences of an oil spill event relate to marine and coastal pollution, which affect the environment as well as the social and financial activities of the area. Critical aspects that have to be mapped and registered in the geographic database include urban areas, traditional settlements, tourist zones and fishing zones. Figure 2(a) illustrates a detail of tourist zones depicting the number of hotels and hotel beds at each site. The fishing zone extends within 2 nautical miles away from the coastline (Figure 2(b)). Other thematic maps of interest are the protected areas under NATURA 2000, SPA, areas of special natural beauty, archaeological areas and monuments, etc. ERDAS Imagine provides the means to overlap, manipulate and visualise a large volume of such data combined with the information describing the advection and

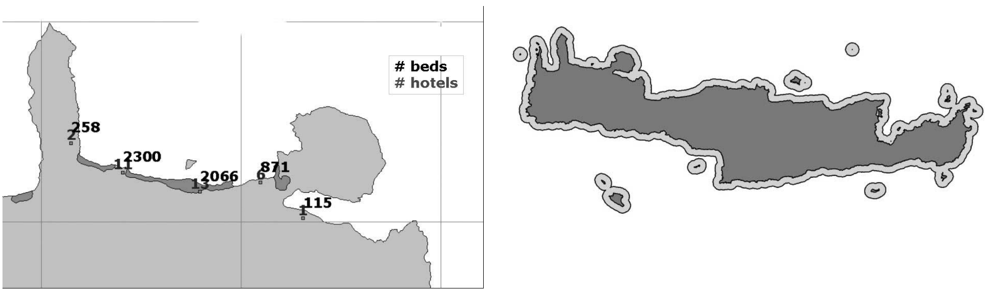

Fig. 2: Thematic background maps of the area of application: (a) tourist zones, (b) fishing zone.

spread of an oil spill, as exported from the oil spill simulation model.

Oil spill simulation is a peripheral tool, necessary for the assessment of the impact of the oil spill and the selection of the type and speed of proper response to it. In general, tracking the movement and spread of the oil spill is a complicated task as a number of physical and chemical processes take place. These processes include pollutants spreading (under the forces of gravity, viscosity and surface tension), advection, horizontal and vertical diffusion, evaporation (influencing mainly the lighter fractions of the mixture of hydrocarbons), emulsification, beaching and sedimentation (POLLANI *et al.*, 2001 and references therein). In addition, of particular concern in relation to oil spills in the coastal zone is the stranding of oil at the shoreline. Finally, slick thickness is a significant parameter for predicting an oil spill's fate. However, there are currently no reliable methods for accurately measuring this parameter using remote sensing methods (FINGAS & BROWN, 1997). In any case, accurate wind forecasts are the single most important requirement for spill modeling (ELLIOTT & JONES, 2000).

For the purposes of the PROMED system, oil spill spread and movement forecast is achieved via the General NOAA Oil Modeling Environment (GNOME), specially customized for the region of Crete. The model estimates the trajectory of spills by processing information provided by the user about wind and weather conditions, together with circulation patterns. Thus the future trajectory of the oil spill is simulated. The forecasted trajectory can be incorporated in the main system in order to evaluate the impact using the various thematic layers, previously discussed.

Finally, the system enters the information module, where three classes of information reports are generated. The report class depends on the recipient: class A reports are very detailed and aim to give the most accurate information to the authorities responsible for the cleanup operations; class B reports are brief and are addressed to the media, whilst class C reports are sent to the local organizations which might be affected by the oil spill. An indicative list of the recipients of each class is given in the chart presented in Figure 3. All three report classes include a number of overlaid thematic maps of the area to be affected by the presence of the oil spill and a table indicating the affected prefecture(s) and providing a list the special characteristics of the area, such as the presence of tourist and fishing zones, protected areas etc. In particular, class A includes detailed information on the present meteorological situation (e.g. wind speed and direction), the exact geographical coordinates (i.e. latitude and longitude) of the oil spill as well as its area (in km^2) and perimeter (in km). The reports are generated using ERDAS Map Composer module.

Results: Application to Region of Crete

Crete lies at the point where the continents of Europe, Asia and Africa meet. It is the fifth largest island in the Mediterranean with an area of 8335 km^2. Crete, especially its northern coasts, is particularly vulnerable to oil spills due to the large number of shipping routes which exist in its vicinity. Furthermore, strong northerly winds prevailing in the Aegean Sea during summer (Etesian winds) would bring the oil-polluted water to the shore more often.

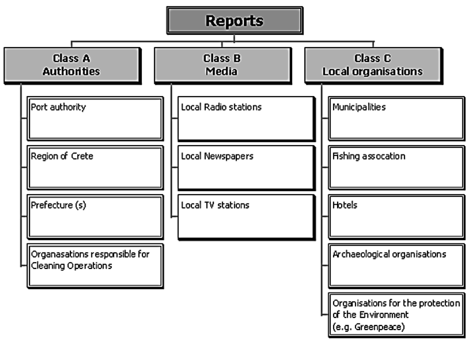

Fig. 3: Report recipients.

There are two important economic activities that can be affected by oil pollution, that would benefit from any measure taken in the direction of oil spill monitoring detection, and containment, namely the tourism and fishing industries. In particular, Crete has 155 km of sandy beaches along its coastline, which attract a large number of tourists every year, mainly from April to October. In addition, the region of Crete embraces a number of areas included in lists of sensitive and/or protected ecosystems, as described earlier. All of the above information is incorporated into the PROMED system via thematic background maps, as previously described.

The areas of the Sea of Crete and Libyan Sea are characterized by heavy marine traffic throughout the year. In particular, navigation through the Libyan Sea (south of Crete) is a common route for tankers and cargo freighters carrying crude oil and other goods to Europe, through the Suez Canal. The frequency of vessels crossing that area, especially of those carrying crude oil, is expected to rise significantly in the years to come, due to the planned Baku - Ceyhan oil duct. Frequent navigation of tankers through this area enhances the possibility of marine pollution by oil-based waste from ships (e.g. sentines) as well as from possible shipwrecks.

The Cretan Sea is characterized by winds blowing from the northern sector, throughout the year and especially during summer due to the dominance of the Etesian wind regime. The Libyan Sea is generally characterized by the same synoptic weather systems as the Cretan Sea, with the exception of the Etesians, that are significantly weaker in this area. Therefore, from a purely meteorological point of view, the Sea of Crete presents a great risk of oil spill accidents that will adversely affect most of the coasts of the island.

PROMED system was validated through a series of archived SAR images. In the following we present one example. A possible oil spill had been detected on the SAR image of 26 of December 1998, as illustrated in Figure 4. The area of interest was magnified several times, and brightness and contrast were optimally adjusted. Following the oil spill location, its perimeter and area had to be defined accurately. The exact coordinates of the centroid of the oil spill in latitude/ longitude as well as in EGSA87 map projection were found to be 24° 41′ E and 35° 35′ N, respectively. The perimeter and area of the

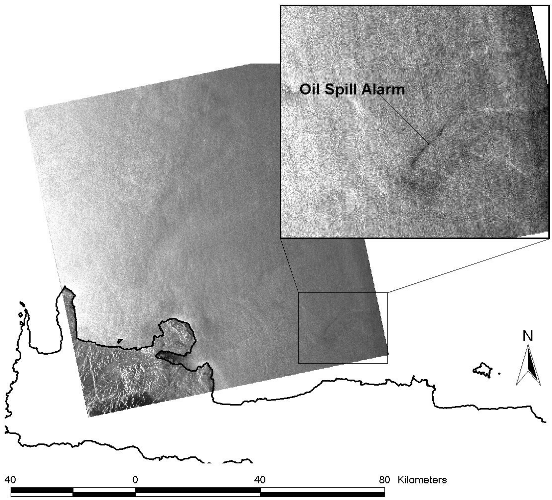

Fig. 4: SAR low resolution image of 26/12/1998 with possible oil spill.

spill were approximately 12.5 km and 2.2 km^2, respectively.

Several accident scenarios were planned, which were incorporated in the GNOME simulation tool. The simulated accidents considered a linear shape (see also Figure 4), different oil spill constituents (such as diesel or medium crude oil) and amount of barrels and weather conditions (constant or variable winds) for predicting the transport, spread and dispersion of the observed oil spill within a specified timeframe. An example of the model output is illustrated in Figure 5. The graph shows a screen depicting oil spill dispersion caused by 500 barrels of medium crude oil for variable winds of ~17 knots of N- NNE direction. GNOME represents the spilled oil as a collection of parcels of the spill (dark points on the screen). The spill transport and spread is depicted at three time intervals as appropriately illustrated on the figure; the total duration was 24 hr. Solid black dots represent the forecasted trajectory whilst gray dots represent the uncertainty trajectory.

The above information was supplied to the core system where it was combined with the geographical characteristics of the region and other data of the system, such as the urban areas, the tourist and fishing zones etc. The results of the accident are included in report classes A, B, and C in an efficient graphical way. The reports could then be sent either by fax or email to the corresponding recipients (Figure 3).

Discussion

To combat oil spill accidents especially in regions close to urban areas or fishing and tourist zones the installation of a system, such as PROMED, could be significantly useful to the regional authorities. It constitutes a combination of Image Processing/ GIS tool with an external set of thematic background maps of the area of application for the better manipulation and visualization of the data, with appropriate tools for simulation of the oil spill transport and fate.

At the beginning of the operation the user can specify the accident scenario for a particular type of oil, provide the appropriate information needed to further quantify various meteorological and regional details, and

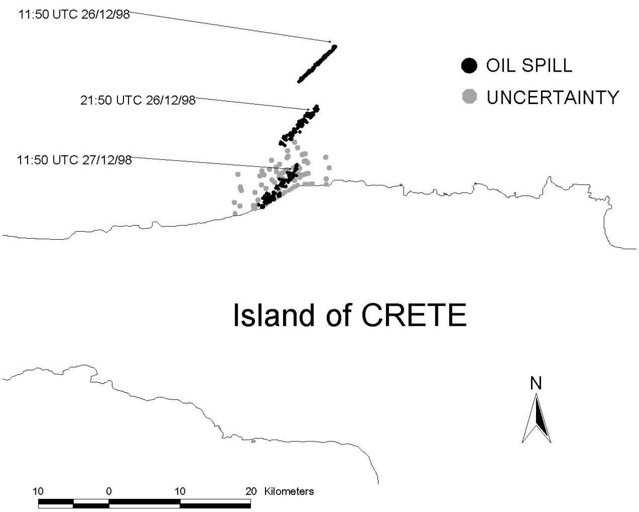

Fig. 5: Simulated oil spill scenario using GNOME software.

proceed to the evaluation of the consequences. The user can subsequently determine the locations and extent of the affected part of the adjacent area; he will then be guided by the system to take actions for the protection of the environment according to the economic activities of this area. Furthermore, under severe and pressing circumstances the system can provide fast and accurate information, vital for the immediate response of the authorities responsible for the cleanup operations.

The system design is of an open architecture, which ensures expandability. In future works, for example, the system can be expanded in order to: (i) incorporate other satellite data, such as ENVISAT and RADARSAT, (ii) monitor forest fires, floods etc., (iii) cover any other geographic region of interest, and (iv) include automatic oil spill detection modules (e.g., KERAMITSOGLOU *et al.*, 2002).

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References

ASSILZADEH, H. & MANSOR, S.B., 2001. Early warning systems for oil spill using SAR images. *Proceedings of the 22nd Asian Conference on Remote Sensing,* Singapore, pp. 358-363.

ELLIOTT, A. J. & JONES, B., 2000. The need for operational forecasting during oil spill response, *Marine Pollution Bulletin,* 40: 110-121.

ERDAS, 1997. ERDAS Field Guide, fourth ed. 1997. Erdas Inc., Atlanta, Georgia.

FINGAS, M.F & BROWN, C.E., 1997. Review of Oil Spill Remote Sensing. *Spill Science & Technology Bulletin,* 4: 199-208.

FISCELLA, B., GIANCASPRO, A., NIRCHIO, F., PAVESE, P. & TRIVERO, P., 2000. Oil spill detection using marine SAR images. *International Journal of Remote Sensing,* 21: 3561-3566.

HOVLAND, H.A., JOHANNESSEN, J.A. & DIGRANES, G., 1994. Slick detection in SAR images. *Proceedings of the IEEE Symposium on Geoscience and Remote Sensing (IGARSS), Pasadena,* CA, pp. 2038-2040.

KERAMITSOGLOU, I., CARTALIS, C. & KIRANOUDIS, C.T., 2002. An integrated fuzzy classification system for automatic oil spill detection using SAR images. *Proceedings of SPIE - The International Society For Optical Engineering, 9th International Symposium of Remote Sensing, 22-27 September 2002, Aghia Pelagia, Crete,* 4883: 131-140.

KUBAT, M., HOLTE, R.C. & MATWIN, S., 1998. Machine learning for the detection of oil spills in satellite radar images. *Machine Learning,* 30: 195-215

MONK, D.C. & CORMACK, D., 1992. The management of acute risks. Oil spill contingency planning and response. In *North Sea oil and the Environment: Developing Oil and Gas Resources, Environmental Impacts and Responses,* pp 619-642. Edited by W.J. Cairns, Elsevier Applied Science.

PAVLAKIS, P., SIEBER, A. & ALEXANDRY, S., 1996. Monitoring oil spill pollution with ERS SAR. *Earth Observation Quarterly,* 52: 8-11.

POLLANI, A., TRIANTAFYLLOU, G., PETIHAKIS, G., NITTIS, K., DOUNAS, C. & KOUTITAS, C., 2001. The Poseidon Operational Tool for the Prediction of Floating Pollutant Transport. *Marine Pollution Bulletin,* 43: 270-278.

SOLBERG, A.H., & SOLBERG, R., 1996. A large-scale evaluation of features for automatic detection of oil spills in ERS SAR images. *Proceedings of the IEEE Symposium on Geoscience and Remote Sensing (IGARSS),* Lincoln, NE, pp. 1484-1486

SOLBERG, A.H., STORVIK, G., SOLBERG, R. & VOLDEN, E., 1999. Automatic detection of oil spills in ERS SAR images. *IEEE Transactions on Geoscience and Remote Sensing,* 37: 1916-1924.

THEOPHILOPOULOS, N.A, EFSTATHIADIS, S.G & PETROPOULOS, Y., 1996. ENVISYS, Environmental Monitoring, Warning and Management System. *Spill Science and Technology Bulletin,* 3:19-24.

UTHE, E.E., 1992, Application of airborne lidar to oil-spill emergency response decision-support systems. *Proceedings of the 1st Thematic Conference on Remote Sensing for Marine and Coastal Environments,* New Orleans, USA, pp. 159-169.