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Oil Spill Monitoring in the Croatian Adriatic Waters: needs and possibilities

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A set of spaceborne synthetic aperture radar (SAR) images and geographic information system (GIS) can significantly contribute to monitoring and identification of oil spills floating on the sea surface. Initially, the GIS has been proven as an excellent management tool for resources assessment, oil spill response and planning, and damage assessment, but the possibilities of GIS mapping also integrate geographical, remote sensing, oil & gas production/infrastructure data and slick signatures detected by SAR. Data from different sources such as nautical charts, geo-databases, ground truth and remote sensing data combined in GIS reveal offshore/onshore oil sources, and estimate the intensity and evolution of oil pollution. SAR and GIS together can significantly improve identification and classification of oil spills, leading to the product - oil spill distribution maps. This approach, applied successfully in different water basins, can also be applied to oil spill monitoring/ mapping in Croatian waters of the Adriatic Sea – it can contribute to understanding the spatio-temporal distribution of oil spills in the Adriatic Sea and be an ideal tool for an oil spill monitoring system. In the framework of the Croatian initiative towards regional cooperation in the Adriatic Sea, such an approach represents a good national opportunity. In this paper, the properties of SAR imagery, as the most reliable source of oil spill information, are described. The possibilities of a combined SAR-GIS approach to oil spill monitoring and GIS databases as a management tools for the protection of the Adriatic Sea are discussed.

Key words: Adriatic Sea, oil spills; monitoring and surveillance; SAR images; GIS; oil spill mapping

INTRODUCTION

The Adriatic Sea is a semi-enclosed sea of the European side of the Mediterranean, covering 138 595 km^2 and containing 35 000 km^3 of sea water (LUŠIĆ & KOS, 2006). It exchanges its waters with the greater Mediterranean through the Otranto Strait at an approximate rate of 3.3 years (FRANIĆ, 2005), although turnover time varies from 1-5 years when determined with different methodologies (MOSETTI, 1983; LUŠIĆ & KOS 2006). With a high and constantly increasing frequency of tankers importing oil to several ports in Croatia and other European countries, the Adriatic Sea is potentially endangered from traffic in general. Ship routes mainly exist along, and to a lesser degree across, the Adriatic axis. Being a country with a heavy reliance on tourism and fisheries, it is economically vulnerable to any kind of pollution. To date, this sea has avoided large maritime accidents. Some pollution accidents have occurred such as the Brigitta Montanari near Šibenik in 1984, Val Rosandra in Brindisi in 1990 and Alessandro Primo near Molfetta in 1991 (CEDRE, www.cedre.fr). Such accidents happen all over the world oceans and can also strike the Adriatic Sea at any time. Since the probability of an accident increases with traffic, the development of an oil spill monitoring system for the Adriatic Sea is a necessity.

Evidently, oil pollution of the sea is a major environmental problem. In order to protect it from oil pollution, the rather sensitive Adriatic Sea was declared a special area under MARPOL (MARPOL, 2009) meaning that any discharge into the sea from tankers and other ships (above 400 t) is prohibited. Although Croatia declared an Environmental and Fisheries Zone (EFZ) in 2004 (Fig. 1) numerous synthetic aperture radar (SAR) images can demonstrate that this law is frequently violated. Some examples are given in the Figure 2.

The Adriatic Sea is crossed by important oil transport routes from the Otranto Strait to the north Adriatic ports (Trieste, Venice, Omišalj and Koper), transporting around 58 x 10^6 t of oil annually (LONČAR & MARADIN, 2009; MZOPU 2010). International shipping activity is increasing because of important industrial centers, especially in Italy. Some of these are also transit ports for Central Europe (Trieste, Venice, Koper and Rijeka), and some new transit ports are gaining significance such as Ploče, Bar and Vlorë.

In spite of the Croatian EFZ declaration, the number of oil spills in Croatian waters has remained high (Figs. 3 & 4). The study

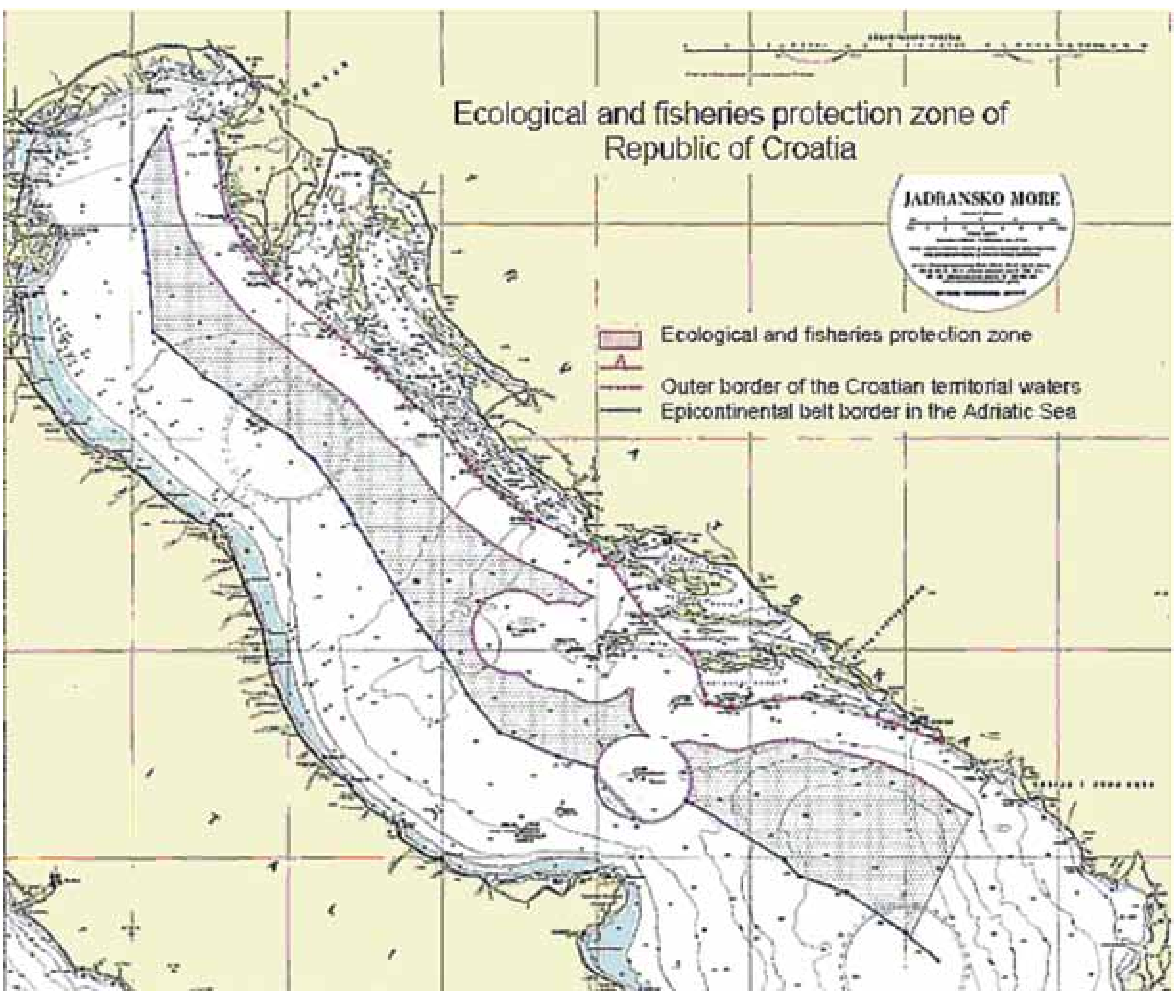

Fig. 1. Environmental and Fisheries Zone of the Republic of Croatia (BAJIĆ & TOMAŽIĆ, 2007)

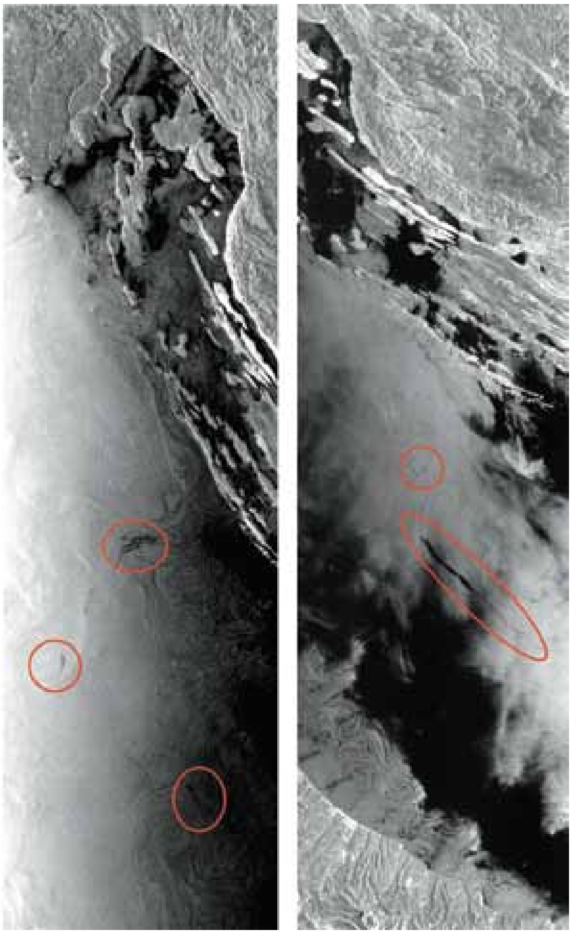

Fig. 2. Ship-made oil spill candidates (in red ellipses) detected in the Envisat ASAR images acquired on 11-09-2008 at 09:18 UTC (left) and on 04-10-2009 at 20:42 UTC (right); the spill area varies from 1 to 60 km^2. © ESA

performed by the Joint Research Centre (JRC, 2006) reported for the Adriatic Sea a total of 257 ship-made oil spills in 1999, 263 in 2000, 184 in 2001 and 244 in 2002 (Fig. 3), with the number of detected oil spills in Croatian waters ranging from 24 to 68 (Fig. 4). That study provided statistics on oil discharges in the Adriatic Sea, although without information on its sources and spatial/temporal variability, proving that continuous oil pollution is ongoing. The released ballast waters in the Adriatic is estimated to be 8 10^6 t in 2003 (KRSTULOVIĆ et *al.*, 2004; MZOPU, 2010), 80% of which was discharged in the Italian Adriatic ports, while the rest is shared between Koper (Slovenia) and the Croatian ports.

The first oil spill monitoring project, supervised by the JRC, was carried out in 1999-2004 (FERRARO *et al.*, 2007; JRC, 2006; FERRARO *et al.*, 2009). For the first time it enabled in the Adriatic Sea a real time detection of oil spills via satellite images and its verification by the Coast Guard. Also, the joint EU-Croatia Adriatic Sea project, AESOP (Automated Electronic System for Ocean Pollution), based on aerial and satellite surveillance of operational pollution, has demonstrated that the study area has been polluted by a considerable number of illegal discharges from ships. There have been EC and ESA funded projects such as RAMSES (Regional earth observation Application for Mediterranean Sea

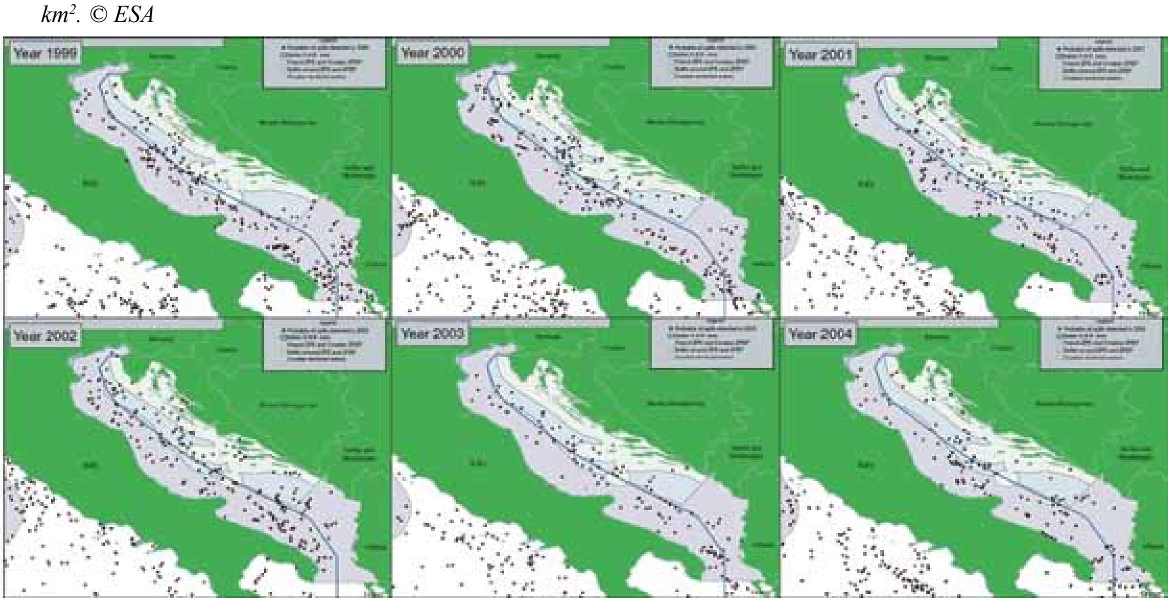

Fig. 3. Oil spills detected in the Adriatic Sea during the 1999 - 2004 period, according to JRC (2006)

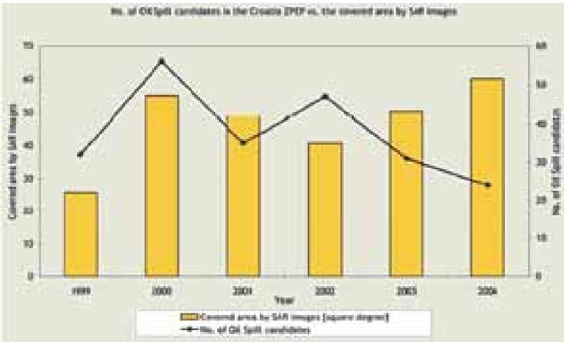

Fig. 4. Number of oil spills in the Croatian Environmental and Fisheries Zone, versus the area covered by SAR images, according to JRC (2006)

Emergency Surveillance, http://ramses.esrin.esa.it), GAIANET (Geospatial Application Intelligent Agent NETwork, http://www.eutist-ami.org/more_gaianet.asp), VASCO (Value Added provision for Slicks and hazardous Cargoes Operational detection, http://www.telespazio.it/vasco) and CLEOPATRA (Chemical Effluent & Oil Pollution Alert and TRAcking, http://www.eurimage.com/cleopatra), as well as the field studies performed by the EC-JRC (European Commission Joint Research Centre, http://ec.europa.eu/dgs/jrc) focused on oil/chemical pollution monitoring/tracking using remote-sensing techniques in the Mediterranean. An exploratory activity has also been carried out, using an Automatic Information System (AIS) to identify the ships via satellite. Such control is essential for detecting those ships responsible for oil spill accidents.

An approach to the oil spill mapping problem was developed by PAVLAKIS *et al.* (1996), who showed the usefulness of a large set of SAR images acquired over the Mediterranean Sea. GADE & ALPERS (1999), after analyzing more than 400 ERS SAR images covering the North Sea, Baltic Sea and the Gulf of Lions, concluded that European waters were polluted mainly by shipping. They, for the first time, compiled statistical spatial maps of oil pollution for European waters. Finally, from these and other studies, it became clear that SAR imagery is very useful not only for locating the areas where ships discharged oil, but also for collecting information about the spatial distribution and extent of oil slicks[1] on a regional scale. As a result, oil spill detection with SAR, following the European Maritime Safety Agency (EMSA) initiative, became a main part of the European Global Monitoring and Environment Security program, the CleanSeaNet project (http://cleanseanet.emsa.europa.eu).

The present paper discusses the technique for mapping oil spills based on SAR imagery as well as the approach based on the use of GIS. This work reflects the experience in this field of the P.P. Shirshov Institute of Oceanology (Moscow, Russia, www.ocean.ru) and shows that, despite the EU analogues, a Croatian oil spill monitoring system is needed, with the approach proposed herein offering a reliable and low-cost solution for that.

MATERIAL AND METHODS

Remote sensing and oil spills detection

Mobile airspace vehicles, airplanes and satellites are proven capable of carrying remote sensing sensors and monitoring oil spills. The progress in oil spill remote sensing has been shown through some review papers (FINGAS & BROWN, 1997). The described applications include optical (visible and laser), infrared and microwave radiometers and real aperture radars or SLAR (Side-Looking Airborne Radar) and SAR airborne or satellite sensors.

Aircraft are expensive and cover limited areas, while satellite optical sensors can produce false detections caused by sun glint, clouds, shallow bottom topography or seaweeds (FINGAS & BROWN, 1997). Traditional sensors like AVHRR, SeaWiFS and MODIS have a low spatial resolution for this purpose with the additional lack of an appropriate methodology. Other available middle-resolution optical sensors like ETM/Landsat, HRV/SPOT LISS/IRS and others provide less frequent observations of limited spatial coverage, and are rather expensive. However, under clear skies many optical sensors also have a good capability for imaging oil spills. Infrared, ultraviolet and microwave radiometers or fluorometric lasers, used only on aircrafts, do

[1] Once oil is spilled, it quickly spreads to form a thin layer on the water surface known as an „oil slick“

not have wide spatial coverage. Since observation conditions are often limited by clouds, all-weather remote sensing is necessary.

The first SAR system based on the synthetic aperture principle was invented by Goodyear in 1951, for mapping the land. While the first use of a SAR on a satellite platform was in 1978 (JPL, Seasat mission), only from the 1990s have considerable contributions to the application of SAR on satellites been made by the USA, USSR, Europe, Japan and Canada.

It is commonly recognized that SAR is one of the main remote sensing instruments for detecting oil spills and monitoring oil pollution in the marine environment. SAR technology has been also widely recognised as the most suitable technique for oil spill monitoring over large marine areas. SAR is an active microwave sensor transmitting a microwave signal towards the sea surface and receiving the backscattering signal. SAR images are capable of capturing 2D distributions of scattering properties of the sea surface. The possibility for the imaging and detecting of oil spills in SAR images is based on the fact that oil spilled on the sea surface dampens the wind-induced, short surface waves, and hence the sea surface roughness (ALPERS & HÜHNERFUSS, 1989; GADE *et al.*, 1998). This results in a dark signature on SAR images (Figure 2). SAR images used for the monitoring of oil spills operate best at incidence angles between 20° and 60°, where the radar backscattering is described by Bragg's scattering theory (VALENZUELA, 1978). For this reason, radar frequencies, incident angles and swath width must cover a domain of the Bragg scattering mechanism to fulfill the requirements of routine oil spill monitoring with SAR. The main SAR-equipped satellites currently available for oil spill monitoring are listed in Table 1.

Table 1. SAR-equipped satellites with data available for oil spill monitoring

Satellite with SAR	Country-owner	Launch	Resolution, m	Swath width, km
Radarsat-1	Canada	14/12/1995	10-150	20 ~ 500
Envisat	EU	1/03/2002	12-150	100 ~ 400
PALSAR/ALOS	Japan	24/01/2006	7-100	20 ~ 350
COSMO-SkyMed-1	Italy	8/06/2007	1-10	10 ~ 200
TerraSAR-X	Germany	15/06/2007	1-20	10 ~ 100
COSMO-SkyMed-2	Italy	9/12/2007	1-10	10 ~ 100
Radarsat-2	Canada	14/12/2007	1-100	20 ~ 500
COSMO-SkyMed-3	Italy	25/10/2008	1-10	10 ~ 100
TanDEM-X	Germany	21/06/2010	1-20	10 ~ 100
COSMO-SkyMed-4	Italy	6/11/2010	1-10	10 ~ 100

From SAR images, oil spills under certain wind conditions can be detected at the sea surface and can be distinguished from other non-film phenomena. However, SAR images are not available on a daily basis and their use is also costly. Oil spill detection is only possible within a narrow range of wind speeds (BERN *et al.*, 1992). Low wind speeds < 2 m/s cause the loss of contrast relative to the background. The minimum wind speed that creates sufficient brightness in the SAR image and makes the oil spill visible is 2-3 m/s. An optimal wind speed is between 3 and 6 m/s (BERN *et al.*,1992). Spills are still visible at wind speeds of 10-12 m/s (IVANOV *et al.*, 1998; LITOVCHENKO & IVANOV, 2006), but at wind speeds > 12 m/s, the spills disappear due to mixing of the water.

There are several categories of oil slicks at the sea surface recognized on SAR images: oil pollution slicks (the thickest slicks), seepage-slicks and natural biogenic films (the thinnest slicks) or man-, geology- and biology-made. The second and third types can be mistaken for man-made oil slicks, i.e. those produced by vessels, rigs or pipelines (ESPEDAL *et al.*, 1998). To be able to distinguish between them the shape, size, area, contrast, edge type, texture, environmental conditions, contextual information about slick position relative to surrounding objects and other oceanic phenomena (internal waves, upwelling, grease ice, algal blooms etc.) must be studied (ESPEDAL, 1998; BREKKE & SOLBERG, 2005).

Oil film characteristics also play an important role in spill detection. The thinnest biogenic slicks are visible on the sea surface at wind speeds of up to 4-5 m/s, but are no longer visible at wind speeds above 6 m/s due to breaking.

For example, seepage slicks and spills of intermediate thickness are still detectable at wind speeds of 6-7 m/s. The thickest films of heavy and crude oil can be detectable up to 12 m/s, or even at 14 m/s (IVANOV *et al.*, 1998; ALPERS & ESPEDAL, 2004). Thus, sometimes the wind speed can act as a filter for oil films on SAR images.

Any kind of oil slick and oil spill are subject to the action of the wind, currents and weathering processes (ITOPF, 2010; IVANOV, 2011). The time for degradation of spills depend on type of the oil, its volume and film thickness and the wind and wave conditions, varying from a day for seepage slicks and ship discharges up to several weeks or even months for crude oil and heavy fuels (ITOPF, 2010).

The slick-ocean backscatter ratio is a complex result of oil film parameters, oil type film thickness, wind speed and sea state. Slick shape and size depend on currents and winds evolution. While crude oil and heavy fuel oil usually remain in relatively compact patches, thin oil films separate into filaments due to currents and wind, and they are all subject to weathering, spreading, advection and mixing as they decay by different processes at the air-sea interface.

Backscatter contrast, shape and size does not discriminate seepage slicks and remnant oil pollution from those of natural biogenic slicks. As oil slicks become smaller, thinner and less distinct, the classification becomes less precise, and the possibility for understanding the source diminishes.

Natural, and thinnest, biogenic slicks can act as tracers for currents and eddies but seepage slicks and oil spills persist over broader wind conditions than the former. In many cases the discrimination of mineral oil patches from natural surface films is possible by their shape and size (ALPRES & ESPEDAL, 2004).

The disadvantage of oil spill detection with SAR is the so-called look-alikes (ESPEDAL, 1998). There is a variety of hydrodynamic and biological phenomena close to the sea surface, and aerodynamic phenomena in the low atmosphere, which can dampen short surface waves, forming look-alike signatures. Typical phenomena in the ocean and in the atmosphere producing look-alikes are: currents, upwelling, ship-made turbulence, internal waves, SST variations, wind stress, precipitation, atmospheric gravity waves, grease ice, algae blooms, floating seaweeds, sperm and eggs of marine animals, and shallow bottom topography.

All these phenomena, under wind conditions of 3-6 m/s can be viewed on SAR images as dark signatures with similar contrast, and even shape and size, to oil slicks. Their presence at the surface may cause false detection. Further information and discussions on the typical appearance and detectably of oil spills on SAR images, the possibility to identify man-made oil spills on a complex image background as well as an overview of these topics can be found in ESPEDAL (1998), ALPERS & ESPEDAL (2004) and CEDRE (2007).

Finally, there are a number of developed semi-automatic and even automatic methods and algorithms allowing the detection and further classification of detected oil slicks (BREKKE & SOLBERG, 2005). However, their applicability faces numerous difficulties related to the evolution of spills and the above-mentioned look-alikes. In these conditions, a GIS based approach can be very useful.

Using GIS to improve mapping and identification of oil spills

A clear and simple concept for a GIS-approach to the oil spill detection problem was formulated by IVANOV & ZATYAGALOVA (2008) and MUELLENHOFF *et al.* (2008). It is based on combining the use of SAR images and existing GIS techniques (Figure 5). Including as much useful information as possible, the probability for identifying oil spills floating at the sea surface imaged by SAR is guaranteed in 90-95% of cases. Moreover, it can be easily built into any oil spill monitoring system because of a common software type used.

In the framework of this GIS approach, a concept-tool for a national oil spill monitoring, surveillance and mapping system is proposed for the Adriatic Sea. It should allow oil spill detection with a high level of confidence, assuring accurate and comprehensive information – in particular:

- for managing information about marine oil pollution and supporting the development of a national monitoring system,
- for oil spill mapping (both accidental or illicit ship discharges) in order to provide spatial information about oil spills in the Adriatic Sea,
- for appropriate emergency management in case of accidental pollution,
- for collection of contextual data, in order to facilitate the organization of a regional database of relevant information including inventories, nautical charts and maps, corporative databases and archives,
- for providing a web-service, in order to make information about oil spills publicly available through a dedicated web-site;
- for communication and training in order to establish contacts with involved partners, to promote collaboration and further development through partnership with national authorities and research organisations.

An example of an oil spill distribution map for the northern Caspian Sea based on analysis of the Envisat and Radarsat-1 SAR images acquired in the June-November 2007 period is given in Figure 6. This monitoring has been jointly conducted by the P.P. Shirshov Institute of Oceanology and R&D Center ScanEx (www.scanex.ru) supported by the Caspian Branch of Lukoil, a Russian oil production company. Within the project framework oil spills detected in SAR images were identified and classified based on information collected in GIS. In

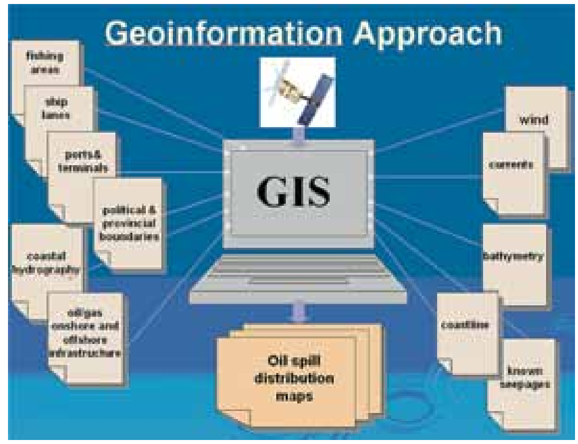

Fig. 5. Geo-information approach to oil spill mapping with SAR images

Figure 6, crude oil spills are shown in black, ship-made spills in red and possible biogenic and river runoff slicks in blue. Information collected in GIS included coastline, coastal features (rivers, estuaries and deltas, and lakes), coastal infrastructure (harbors and ports), political and regional boundaries, offshore gas and oil bearing structures and oil production infrastructure (oil rigs, drilling platforms, oil terminals, regional gas/oil pipelines etc.), bathymetry, ship lanes, marine restricted areas (LITOVCHENKO & IVANOV, 2009). This analysis allowed the revealing the risk zones where the concentration of oil spills and corresponding risk of oil pollution is very high (depicted by red ellipses in the Figure 6). This approach has already been used for oil spill detection/monitoring in different basins with promising results (IVANOV & ZATYAGALOVA, 2008; SHI *et al.*, 2008; IVANOV, 2010A) and also during accidents (IVANOV, 2010B).

On-line implementation of a similar GIS project would enable the managing of oil spill monitoring through the use of imagery, data, maps, additional functions and modules and provides a new functionality and vision of an oil pollution problem. Similar web GIS projects have been implemented worldwide, for example in Russia (http://ocean.kosmosnimki.ru).

Furthermore, in order to simplify oil spill visualization and management, we foresee an integration of oil spill distribution maps with nautical Electronic Chart Display and Information Systems (ECDIS), MaxSea or Transas etc.

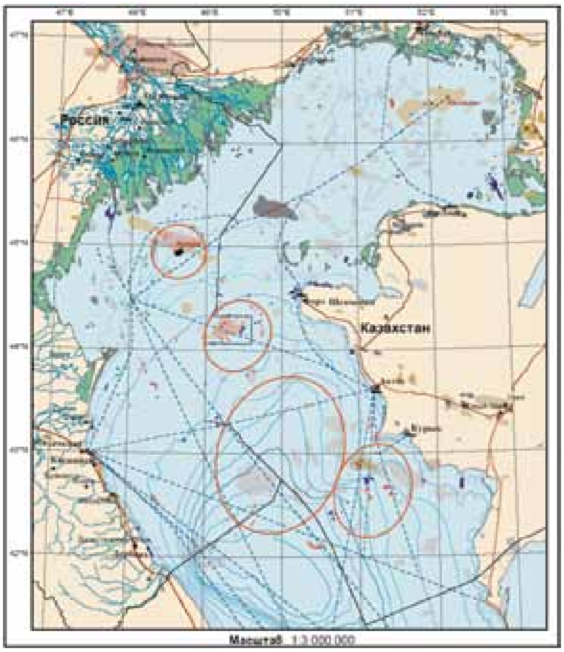

Fig. 6. Example of an oil spill distribution map (scale 1: 3000000) for the northern Caspian Sea based on analysis of the Envisat and Radarsat-1 SAR images acquired in the June-November 2007 period. Oil spills are shown in black (crude oil), red (ship-made spills) and blue (possible biogenic slick or river runoff). Red circles/ellipses show zones where risk of oil pollution is very high (see LITOVCHENKO & IVANOV (2009) for details)

Recent computer and GIS advancements allow such analysis to be performed in a relatively short time.

DISCUSSION

On 12-14 May 2010 in Opatija, Croatia, the first regional oil spill conference, at the level of ministries and other interested parties, was organized. The goal of the conference was to facilitate an exchange of experience and knowledge in the field of preparedness and response to accidental marine oil pollution, primarily between the Adriatic riparian countries, and other European and Mediterranean countries. It was followed by an exhibition of equipment and presentations of services offered for oil spill preparedness and response. The participating countries were Croatia, Slovenia, Bosnia and Herzegovina, Montenegro and Italy from the Adriatic countries and also Tunisia, UK, France, Austria, and Belgium, as well as the international organizations EMSA and REMPEC. The information presented by the Croatian participants indicated that oil spills could be managed in crisis situations in Croatian waters. The existence of the National Protection and Rescue office in Zagreb, the County Operational Center of Primorje-Gorski Kotar (DUZS-PUZS Rijeka) in charge of execution of sea operations, and the National Centre for Search and Rescue (MRCC) confirm that Croatia has taken the first steps to mitigate the consequences of eventual large oil spill disasters. However, constant survey with satellites is not yet incorporated in that system. The possibilities for cooperation with relevant foreign organizations and SAR data providers have not yet been fully explored.

At this conference Croatia has demonstrated its action plans for oil spill accidents and preparedness in different aspects, for example: for elimination of the pollution source, containment of pollution, cleaning of the sea surface and shore with different methods. There was also a discussion about the usage of toxic dispersants or bacteria to degrade oil products in the sea.

According to the fact that a half of the Adriatic Sea is under the jurisdiction of EU countries, through the EMSA CleanSeaNet service, the monitoring exists and its results will be placed at the disposal of Croatia when it becomes EU member. In case of accidents in Croatian waters, at present SAR images could be purchased, but with minimum 12 hours delay, which in some circumstances may be too late.

It has been acknowledged, based on different examples from throughout the world oceans, that oil pollution has left not only short-term but also long-term effects, such as the aftermath of the Exxon-Valdez event and even the Volgoneft-139 shipwreck in the Kerch Strait in 2007 (IVANOV, 2010b). In the Persian Gulf it has been demonstrated that intertidal plants are the most affected by oil pollution, but also the relation between diatoms and dinoflagellates may be altered in the presence of oil (AL-MUZAINI & JACOB, 1995). Prevalently oligotrophic in open waters, the Adriatic Sea is probably more fragile than other seas. Although catastrophic oil-spills could generate ecological changes that require decades for recovery, we cannot ignore continuous alterations as a consequence of the small, slow but constant input of oil through ship discharges. Through SAR images and other remote sensing data it is possible to detect such small oil pollution events on a daily basis. Toxic substances from oil enter in the marine food chain and with bioaccumulation their effects may become permanent. Such oil products kill marine larvae and cause physiological changes in such organisms. Oil films on the sea surface may directly kill marine organisms and also prevent phytoplankton from photosynthesizing and other organisms from getting oxygen. Oil coagulation forms such as tar balls which end up on the shore and may enter the food chain through fish and shellfish. On the southern shores of numerous Adriatic Sea islands there is evidence of such pollution.

It is obvious through the SAR imagery analysis that there are numbers of daily undetected spills whose impact on the marine ecosystem is generally unknown and most probably cumulative. It is not only a matter of large catastrophes that might or might not happen, but about continuous and illicit discharges of oily products from ships that gradually pollute the Adriatic Sea. Comparing oil spill monitoring in Croatia with that in the North Sea or Baltic Sea, the difference is in the better technological level of the coastguards with patrol aircraft, helicopters and vessels capable of multi-sensor monitoring. Through monitoring of ship traffic, which Croatia has already started, the potential of SAR images for the efficient, less costly and flexible control of oil pollution can be established. Incorporating SAR and other monitoring data in GIS, more efficient control and management tools may be developed.

CONCLUSIONS

The presented approach shows that it is feasible to compile not only oil spill distribution maps using SAR imagery and GIS, but to create the core of a national oil spill monitoring and management system. Oil spill maps clearly indicate the marine areas exposed to oil pollution. It is expected that this information will be very useful both for decision makers, environmental protection agencies and experts. An oil spill distribution map is a valuable remote sensing product and is of commercial value.

Aiming at unambiguously identifying oil spills, the GIS must include several highly detailed data sets, such as geographic, oceanographic, geological-geophysical, nautical and industrial features of the Adriatic Sea in greater detail (Fig. 5) (IVANOV & ZATYAGALOVA, 2008). These data sets should be updated accordingly.

GIS is an efficient tool for collection, visualization and analysis of SAR and other information on oil spills in the marine environment. It is well known that their identification and categorization is practically impossible without taking into consideration ancillary additional information which may be integrated and arranged in GIS. Therefore, the use of GIS as a core of the oil spill monitoring system is foreseen. The major advantage of GIS is the ability to extract oil spill parameters such as location, linear size and spill areas. Spatial and temporal information, i.e. oil spill distribution at the sea, its frequency and evolution in time allow the scientists to establish the major cause and source of oil spills, and then outline the risk areas.

Within the GIS-approach, the tasks of analysis, modeling and forecasting of natural processes influencing the drift and spreading of oil spills can also be easily solved on the basis of standard GIS modules or linking it with other useful applications.

GIS can qualitatively and quantitatively characterize not only the spatial and temporal distributions of oil spills, but also environmental conditions of the sea basins as a whole. Such an environment can be created by means of integration in a GIS of different databases on sea water quality, nutrient and chemical composition.

On-line implementation of a GIS approach, enabling oil spills management through the use of satellite imagery, data, maps, additional functions and modules provide a new functionality and vision of a problem.

GIS can collect and integrate the parameters extracted from other satellite images and in-situ measurements. Among the most important are wind fields derived from SAR or Quikscat data, sea surface temperature and ocean color data provided by spaceborne spectro-radiometers, precipitation rates from microwave radiometers and ship detection data based on hi-res SAR images. Ancillary oceanographic and meteorological information provided by research or patrol vessels, buoys and weather stations can greatly increase the probability of effective identification of oil spills from SAR imagery.

Finally, the GIS-approach may be very useful for authorities, managers and technical personnel for supporting management and decision making. Application of developed GIS-technologies for monitoring oil spills in the marine environment will allow not only oil spill mapping, but also tracking the environmental consequences and organizing preventive measures. Taking into account modern tendencies in transportation and even future oil production in the Adriatic Sea, establishing the oil spill monitoring system, based on GIS-integrated databases and satellite imagery seems timely. For these reasons, development of a high resolution GIS basis, covering the Croatian Adriatic waters, which would at the same time provide a powerful tool for decision support and protection of marine and coastal resources is highly recommended.

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Nadzor raspodjele uljnih mrlja u hrvatskom dijelu Jadranskog mora: potrebe i mogućnosti

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SAŽETAK

Kombinacija SAR (synthetic aperture radar) satelitskih snimaka i geografskog informacijskog sustava (GIS) može znatno doprinjeti praćenju i prepoznavanju tankog filma ulja koji pliva na površini mora. U početku, GIS se pokazao odličnim sredstvom u gospodarenju resursa i planiranju zaštite od uljnih mrlja, ali mogućnosti GIS-a postoje i u integriranju geografskih informacija o infrastrukturi za preradu/transport nafte sa satelitskim informacijama od SAR snimaka. Podaci različitih izvora kao što su nautičke mape, geografske baze podataka, mjerenja in-situ te podaci daljinskih mjerenja u kombinaciji sa GIS-om mogu otkriti obalne i morske izvore ulja i odrediti intenzitet i razvoj uljnog zagađenja. SAR i GIS zajedno mogu znatno poboljšati identifikaciju i klasifikaciju uljnog zagađenja, dovodeći do produkta – mapa raspodjele uljnih mrlja na Jadranu. Ovaj pristup, uspješno primijenjen u različitim morskim bazenima može se primijeniti i za monitoring i mapiranje u hrvatskim obalnim vodama na Jadranu, a također može doprinjeti razumijevanju prostorno vremenske raspodjele uljnih mrlja na Jadranu te biti idealan alat nacionalnog sustava monitoriga. U okviru hrvatske inicijative prema regionalnoj suradnji na Jadranu ovaj pristup može predstavljati dodatnu mogućnost.

U ovom su radu opisane osobine SAR snimaka, kao najpouzdanijeg izvora informacija o uljnim mrljama. Raspravljene su i mogućnosti kombiniranog SAR-GIS pristupa nadzoru uljnih mrlja te baza podataka u GIS-u kao sredstva korisnog u zaštiti Jadrana.

Ključne riječi: Jadransko more, uljne mrlje, SAR snimci, monitoring i nadzor, GIS, mape raspodjele uljnih mrlja