ABSTRACT
Geographic information systems (GIS) can significantly contribute to correct interpretation of the slick signatures visible on synthetic aperture radar (SAR) images. Initially GIS is proven to be an excellent management tool for resource assessment, oil spill response, planning and damage assessment. GIS approach to a problem of oil spill mapping includes integration of the geographical, remote sensing, oil & gas production/infrastructure data and slick signatures, detected by SAR, in GIS. Compiled from data of several sources including nautical maps, geodatabases, ground truth and remote sensing data, GIS allows retrieval of key information, i.e. predict spill locations, reveal offshore/onshore sources, estimate intensity of oil pollution. SAR and GIS technologies can significantly improve identification or even classification of oil spills allowing making the final product - oil spill distribution maps. This approach has been applied to oil spill mapping in the Sea of Okhotsk, Black Sea, and Gulf of Thailand. Conclusion is done that combination of GIS to be an ideal solution to understand spatial/temporal distribution of oil spills in the marine environment and is considered as a core of oil spill monitoring system.

1. INTRODUCTION
Now oil spills in the sea are considered to be a serious environmental problem. Every day illegal discharges from ship and accidents at sea with oil spilling do occur. The ITOPF database contains information on about 10,000 oil spills in 1970-2001 from tankers and oil carries [1]. Oil pollution as a serious environmental disaster often leads to significant, long-term impact on the environment, ecology and socio-economic of the polluted area. Fortunately major oil spills are of public concern and usually under control of pollution authorities. On the other hand small oil spills occurring in open sea due to ship operations are usually uncontrolled, unaccounted in oil spill balance and have smaller public concern.
Spaceborne synthetic aperture radar (SAR) is proven to be very useful in oil spill detection and monitoring. Wide coverage provided by SAR-equipped satellites such as European Envisat gives a good opportunity for development of operational oil spill applications.
However, SAR has a number of limitations, which to some extent restrict it coming into operational service. Among them are low revisit time especially in low latitudes and a narrow range of wind speeds available for spill detection [2]. So-called, look-alikes (false targets) caused by natural phenomena occur in the upper ocean and lower atmosphere [3], and impossibility to measure any physical parameter of oil film.
Recent use of SAR imagery in real-time oil spill detection systems are associated with attempts to more fully automate oil spill detection and identification. Such systems usually combine hardware, software, remote sensing technologies, geoinformation and communication subsystems, and provide key information for further analysis and decision making [4].
GIS is now widely used for spill planning and response because they support integration and preparation of geospatial information on the location, nature and sensitivities of different resources with rapid access [4]. Developments in geospatial and remote sensing technologies have also assisted improvements in GIS systems for oil spill management [4]. Recent examples include the use of real-time multisensor satellite information, development of internet-based GIS systems, which better support sharing of GIS information among users and the public, and oil spill drift models [5-7].
Applied to our task it is considered to be a geoinformation technology for acquisition, storing and retrieving data and images, as well as for processing these data into information for researchers, environmentalists and decision makers. GIS is especially useful in oil spill sensitivity mapping, planning and response because these systems allow the integration of information from many different sources and allow the displaying this information [4].
A number of key marine basins is covered by different-level GIS systems [4]. While these systems continue to be supported and developed with additional analysis tools, linkages are now being developed using the web-GIS technology to make information accessible and encourage a more universal approach. A number of other GIS applications is developing worldwide; many of them are limited in geographic coverage and were originally developed independently [8-9]; For example, several GIS applications are intender for monitoring of seepage and abandoned oil wells [10-11].
Fig. 1 illustrates, why it is necessary to use a GIS to improve oil spill detection and identification. The Envisat image acquired over the North Caspian Sea (left panel) shows an oil spill located close to unknown bright object that can be a ship, platform or rig. To know this exactly we need to collect additional information. A picture taken from a vessel (right panel) two days before confirmed that this object is the Lukoil’s Astra oil drilling platform. If position of the Astra platform is defined. In a GIS, an “owner” of oil pollution can be easy defined.
Wide use of a GIS for identification and classification of oil spills in the marine environment is limited. The approach directed on improvement of oil spill detection/identification in the sea with use of SAR images as a main source of information has been developed. SAR images and extracted oil spill signatures integrated into GIS significantly improve possibilities of oil spill monitoring system. Moreover, the GIS, as shown below, is considered to be a core of the oil spill monitoring system allowing integration of all available data and information and making the final product - oil spill distribution maps for end users/decision makers.

2. GEOINFORMATION APPROACH

In our approach we consider GIS as a tool for improving oil spill identification and classification in SAR imagery. A number of limitations of SAR for oil spill detection have been recognized. SAR system relies on the detection variations of the sea surface roughness. Oil films can be detected as dark patches relative to the surrounding water as they dampen the wind-generated short surface waves. Detectability of oil spills in SAR images depends on both the wind, sea state and oil parameters [2]. Detection is also difficult because SAR doesn’t measure any film characteristics and possible in a narrow range of wind speeds [2]. Despite development of automatic and semi-automatic methods of SAR image analysis, visual (manual) methods of analysis still predominates. The operational service provided today also relies on visual methods [12].

Slick signatures on the SAR images of the sea surface are often classified into three types: natural slicks, look-alikes, and man-made oil spills. They can be created by a variety of phenomena. The natural slicks are biogenic films of biological surfactants formed from material produced by plankton and fishes. The term “look-alikes” unites all slicks looking like oil slicks, which are produced by phenomena in the upper ocean and low atmosphere and detected by SAR as dark patches. They include low wind areas, rain cells, upwelling, current shear, internal waves, algae blooms, shoals, floating vegetation, grease ice, etc. Crude oil and refined products released into the sea form man-made oil spills.

The signatures of the first and second types can be mixed with those of oil spills produced by vessels, rigs or pipelines. Discrimination between look-alikes and oil spills includes analysis of slick appearance (shape, size, area, dB-contrast, edge type, texture), environmental conditions (wind, currents, precipitation), contextual information about slick position relative to surrounding objects (ships, ship lanes, rigs, platforms, natural seeps) and other concomitant oceanic and atmospheric phenomena (internal waves, upwelling, grease ice, algae blooms etc.) [3]. Because operational spill detection service based on SAR images is still depends on an operator’s experience, such complicated analysis is considered to help in removing look-alikes from consideration. It is suggested, therefore, that GIS approach and use of geographic, remote sensing, contextual and other ancillary information can make an important aid to correctly interpret the slicks signatures, providing a framework for analysis. Sketchy GIS approach to oil spill mapping is depicted in Fig. 2.

A GIS database for the marine basins can be compiled from data of several sources. Vector shoreline and bathymetric data can be obtained from the national geophysical data centers or by digitizing detailed nautical maps, or extracted from global topographic models, e.g., ETOPO. Oil-gas production infrastructure can be compiled from data of regional/local archives, atlases or corporative databases; main ship lanes can be also obtained from nautical maps. Fishing/aquaculture areas, coastal and marine restricted, protected and vulnerable zones are responsibility of corresponding authorities. All datasets and geographic information have to be compiled together and placed into a generally used geographic projection using ESRI GIS-software.

A general system view is depicted in Fig. 3. As seen, such a system could be composed of the data integration subsystem based on a GIS and three subsystems responsible for: acquisition and processing SAR and other remote sensing data & images; collection in situ measurements and contextual information; and backup, and archiving of information. Amongst data of remote
sensing satellites necessary for verification are data on the sea surface temperature (SST), chlorophyll concentration and algae blooms provided by the visible/infrared sensors are essentially necessary. Wind and wave fields and rain rates over the ocean can be retrieved from data of microwave scatterometers, altimeters and radiometers. Collected remote sensing and in situ data and measurements can be further used as an input to oil spill drift models.

3. VALIDATION OF THE METHODOLOGY

GIS providing an efficient storage, retrieval, analysis and visualization of geographic, environmental and industrial information is considered to support oil spill monitoring and identification. Fig. 4 displays a window of the GIS constructed for oil spill applications in the Caspian Sea. Such GIS was created using different sources, e.g., maps, charts, satellite images, raster and vector digital data and textual information. On Fig. 4 displayed are only layers related to oil production and transportation; they are: lease blocks, oil shipping routes, pipelines, oil & gas fields and bearing structures. One can load a set of SAR images into the GIS and display any information, which necessary for support of identification of oil slick sources, and make a decision in the area of oil spill incident.

In order to validate a methodological approach, a number of projects has been carried out. In these projects mapping of oil slicks/spills were undertaken in the Sea of Okhotsk/Japan Sea, Caspian Sea, Black Sea, Yellow/East China Sea, and in the Gulf of Thailand (GOT) by the use ESRI software. These results have been obtained within the projects being carried out in cooperation with governmental and non-governmental organizations.

In the following sections the main results of these applications in a number of marine basins are briefly summarized, comparison of obtained result with existing knowledge about oil contamination is done, and questions of the practical use of a geoinformation approach to mapping oil pollution are discussed.

3.1. Offshore Sakhalin

Within this project the waters surrounding Isl. Sakhalin in the Japan Sea and Sea of Okhotks were included into the area of interest. This test area was chosen in order to detect any oil pollution in the sea that might originate from ships, fishing operations, oil production and river runoff; possible natural sources of crude oil, i.e. oil seeps were also considered. Idea of this study was to show advantages and limitations of SAR imagery and GIS-approach for researchers and environmentalists as well as to collect preliminary information about distribution of oil slicks ahead monitoring and compare it with ground truth data.

Most of SAR images in this study were used as images of low resolution, so called, quick-looks. Manual method has been used for analysis of collected SAR scenes. Analysis of integral map shown in Fig. 4 together with ground truth observations (not presented here) reveals that there is multiple oil pollution of different types in the waters surrounding Isl. Sakhalin.

Oil pollution of the Sakhalin coastal zone comes mainly from two sources, i.e. oil production and shipping (including fishing) activity. Spills produced by these activities can be found in any part of the coastal zone, especially along the east coast and episodically along the west seashore. Large oil slicks were detected in the waters of Aniva Bay and Terpeniya Bay; their sources are considered to be various; some of them having linear forms left by passing ships.

One of important sources of oil contamination in the northern Sakhalin is abandoned wells and collectors, where in time of the USSR oil was produced, as well as present-day oil production. This pollution usually goes to the sea with river runoff during spring after snow melting, and summer/autumn during rain periods. Probably, the other source is fish seasons, when large amount of fishing and fish-factory ships approached the coasts of the Sakhalin; practically all these ships discharge the bilge/engine room waters as well as fish waste into the marine environment. It is also reported that one possible source of pollution are derelict stores of combustible and lubricating materials on the abandoned frontier posts.

Among pollution sources we considered natural onshore oil seeps discovered on the eastern coast of the island.
Other likely possible source of the natural oil is seepage on the eastern shelf of Isl. Sakhalin related to the oil fields in the Sea of Okhotsk.

3.2. The Northeast Black Sea

The NE part of the Black Sea belonging to Russia has a high risk of oil pollution. This is due to an increase of transportation of crude oil and refined products through marine routes. This transportation is still rising due to increased oil production and consumption. Moreover, soon many oil tankers will transport their oil cargo through the Black Sea waters that implies that the total amount of petroleum products passing the Black Sea and, in turn, oil pollution will rise greater. Unfortunately, modern estimates of oil pollution balance for the Black Sea have a big spread in values. For instance, input of oil into the marine environment from ships (including ballast, engine room and bilge waters) are estimated to be from 10 % to 30-60% of total marine oil pollution. Within this project a small marine area in the NE Black Sea has been chosen in order to detect any oil pollution indeed associated with tanker operations. In our analysis only high resolution ERS-2 and Envisat SAR images have been used. In order to get a maximum confidence in oil spill detection this analysis has been done by manual and semi-automatic methods with wide use of ground truth data (wind, currents, SST and chlorophyll concentration) and subsatellite verification [13]. In this project the SAR images were collected during short period in August-September 2004, processed and entered as a vector layer into prototype of a GIS. Verification of majority detected oil spill has been done through the video surveys from a helicopter. Spatial distribution of oil spills detected on SAR images covering the test site in the Black Sea is shown in Fig. 6. Analysis of the presented map allowed to clearly recognize the marine area on a way to the Novorossiysk port, where ballast waters usually discharged. The most polluted marine area is limited by 44º-44º25′ N latitudes and 36º45′-37º40′ E longitudes (frame on Fig. 6) and considered to be a latent place for discharge of oily ballast waters. In total 22 oil spills were identified, but the largest spills, however, were detected on the areas of major ports (Novorossiysk).

3.3. The Gulf of Thailand

The GOT covering an area of about 320,000 km² and 1840 km long coastline is a semi-enclosed marine basin, which coastal areas support mangroves, coral reefs, sea grass beds and diverse fish stocks. There are four large rivers entering the GOT in the Bangkok Bight with seasonal fluctuations of the freshwater discharge and contaminant concentrations. Water quality in the GOT is lower than acceptable standards and is deteriorating due to increasing inputs of oil and chemical pollutants [14]. This pollution comes from the increased use of oil products in agriculture, aquaculture and from municipal sewage. Oil contamination from tankers has been reported from time to time, and oil spills occurring in the in the GOT caused serious environment damage. The GOT has been chosen in order to detect any marine oil pollution associated with ship traffic, fishing activity or oil and gas production. In this pilot project we try to show a relevance of GIS approach for mapping oil spills over such large area of the Southwest Asian Basin. The ERS-2 and Envisat SAR images were collected with low resolution as quick-looks, whereas only few images in full resolution were available. Because of low resolution of collected SAR scenes, manual analysis with participation of training operators has been used. Fig. 7 shows spatial distribution map of oil spills in the GOT, created with help of GIS, where major oil spills and risk areas are clearly seen. The oil spills in the GOT were basically detected in the navigation areas, along main ship routes and at the mouths of the large rivers such as Chao-Praya, Tha Chin, Mae Klong and Bang Pakong, in the Bangkok Bight. The oil pollution in the central area of the GOT is due to oil discharges from ships. The most polluted waters (large concentration of oil spills) were revealed in the southern part of the GOT at the border of territorial waters between Thailand and Malaysia. Comparison of our results (Fig. 7) with results obtained in [14,15] showed an efficiency of the given approach for mapping of oil spills in this basin.

4. CONCLUSION AND DISCUSSION

REMARKS

The presented and discussed approach shows that it is feasible to compile oil spill distribution maps using the SAR imagery and GIS. Oil spill maps clearly indicate those marine areas, which are exposed to oil pollution. It is expected this information to be very useful both for decision makers of pollution authorities and experts of environmental agencies. Oil spill distribution map is a valuable remote sensing product and is of commercial value. A professional GIS for mapping and identification of oil spills and their sources has to consist of the following data sets (see also Fig. 2): (1) detailed coastline, (2) coastal hydrography (rivers, their estuaries and deltas, lakes and lagoons), (3) coastal settlements, harbors and ports, (4) political, provincial, territorial and EEZ water boundaries, (5) onshore and offshore gas & oil bearing structures and oil production infrastructure (oil rigs, drilling platforms, oil terminals, refineries, regional gas/oil pipelines etc.), (6) bathymetry contours, (7) average current field, (8) international and local ship lanes, (9) oil seep locations, (10) fishery & aquaculture areas, (11) marine restricted areas, (12) coastal and marine protected areas/coastal & marine wildlife resources, (13) recreational resources... this list is not completed yet and one can include as many information as need.

One of the major advantages of GIS is the ability to allow extracting oil spill parameters such as location, linear size and spill areas. Spatial and temporal information, i.e. oil spill distribution at the sea and its evolution in time allow the users to establish the major cause and source of oil spills, and then outline risk areas. Furthermore main findings and ideas resulting from this study could be formulated as follows:

1. GIS itself is an efficient tool for collection, visualization and analysis of information on oil spills in the marine environment. It is well known that their identification and categorization is impossible without bringing in of additional information that can be also integrated and arranged in GIS. Use of geoinformation approach as a core of oil spill monitoring system is foreseen.
applications in the Caspian Sea; displayed are: lease blocks, oil transportation routes, pipelines, oil and gas fields, revealed and perspective structures.

Figure 4. Window of the GIS constructed for oil spill applications in the Caspian Sea: displayed are: lease blocks, oil transportation routes, pipelines, oil and gas fields, revealed and perspective structures.

Figure 5. GIS-based map showing distribution of multisource oil pollution in the waters surrounding Isi. Sakhalin (Sea of Okhotsk and Japan Sea).

Figure 6. Map showing distribution oil spills related to tanker operations in the north-east part of the Black Sea revealed in August-September 2004.

Figure 7. Oil spill distribution map for the Gulf of Thailand based on processing and analysis of the ERS and Envisat SAR images.
2. Within GIS-approach the problems/tasks of the analysis, modeling and forecasting natural processes influencing the drift and spreading of emergency oil spills can be also successfully solved. This can be done on base of use standard modules available in the GIS-software or specially created and linked with GIS. Examples of developed modules for oil spill drift modeling are presented in [5,6].

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

5. GIS and GIS-approach providing resources and information for pollution authorities are considered to be very useful for managers and technical personnel to support management and decision making. Application of the achievements of GIS-technologies to monitoring oil spills in the marine environment will allow not only getting spill distribution, but tracking the environmental consequences and undertaking the prevention measures.

6. Taking into account modern tendencies in oil production & transportation on the European/Russian shelves, it is obvious a need of creation all-European monitoring system based on GIS-integrated databases and satellite imagery. Completely integration of all kinds of information, systems and resources on a European level, within a single monitoring system is also foreseen. Out of comments is development of the high resolution GIS covering all European seas, which provides Europe and Russia with a very powerful and integrated decision support tool helping to protect marine and coastal resources. In our opinion, one of successful regional attempts is the Australian Oil Spill Response Atlas Project [6].

7. On-line implementation of a GIS project, enabling to manage oil spills through the use imagery, data, maps, additional functions and modules provides a new functionality and vision of a problem. Such GIS project for the northern Caspian Sea is ready to start, see soon at www.scanex.ru.

8. Of course, a GIS, as a data integration system, is open to collection and integration of those parameters, which can be extracted from remote sensing data satellite image and in situ measurements (Fig. 3). Most important among them are: wind field derived from the SAR or Quicksat data, SST and ocean color data provided by sensors onboard NOAA, Terra & Aqua satellites, rain rates provided by SSM/I and TMI microwave radiometers, ship detection results based on SAR images. Ancillary oceanographic and meteorological information provided by research/patrol vessels, buoys and weather stations can greatly raise probability of effective identification of oil spills in SAR imagery in GIS.

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