MULTISENSOR SATELLITE MONITORING OF OIL POLLUTION IN NORTHEASTERN COASTAL ZONE OF THE BLACK SEA

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ABSTRACT The new approach to the problem of oil spill detection consisting in combined use of all available quasi-concurrent satellite information (AVHRR NOAA, TOPEX/Poseidon, Jason-1, MODIS Terra/Aqua, QuikSCAT) is suggested. We present the results of the application of the proposed approach to the operational monitoring of seawater condition and pollution in the coastal zone of northeastern Black Sea conducted in 2006. This monitoring is based on daily receiving, processing and analysis of data different in nature (microwave radar images, optical and infrared data), resolution and surface coverage. These data allow us to retrieve information on seawater pollution, sea surface and air-sea boundary layer conditions, seawater temperature and suspended matter distributions, chlorophyll *a* concentration, mesoscale water dynamics, near-surface wind and surface wave fields. The focus is on coastal seawater circulation mechanisms and their impact on the evolution of pollutants.

KEY WORDS: oil spill detection, satellite pollution monitoring, coastal zone, Black Sea, synthetic aperture radar

INTRODUCTION

Oil pollution is a major environmental hazard for the ocean. There are two main sources of oil pollution in oceans: major disasters such as oil-tankers sinking and chronic events such as illegal tank cleaning or bildge pumping. It is impressive to note that the amount of oil spilled annually worldwide has been estimated at a level greater than 4.5 millions tons, equivalent to one full tanker disaster every week (Migliaccio et al. 2006).

As for the study area, serious ecological situation has built up in the region of Novorossiisk where the lagest Russian port on the Black Sea with an annual oil export of about 32 mln. tons is situated. In the coming 10 years the export is expected to triple (Lavrova et al. 2006a). The situation is aggravated by the fact that the shore zone of the northeastern Black Sea is a unique environmental complex and the only Russia's recreation area on the Black Sea.

Awareness of the dramatic effects caused by sea oil spills has promoted a series of research projects. A satellite-based remote sensing system is capable to ensure a relatively low-cost high-standard observational system. Within such a framework, synthetic aperture radar (SAR) is best suited for the detection of oil slicks on sea surface because slicks modify seawater viscosity producing a strong impact on short waves mesuared by SAR (Bulatov et al. 2003). Besides, SAR images can be acquired regardless of cloud cover or sun illumination. However, operational oil spill detection by SAR runs into problem distinguishing oil slicks from look-alikes, such as organic films, wind shadows, rain cells, zones of upwelling, and seaweed in bloom. Therefore, reliable automatic detection of oil spills on the basis of SAR data is not yet achieved.

A wide range of papers is devoted to different aspects of using SAR data for oil spill detection, such as advantages and disadvantages of SAR-data (Girard-Ardhuin et al. 2003), using different algorithms (Girard-Ardhuin et al. 2004; Migliaccio et al. 2006), distinguishing sliks of different nature (Brekke, Solberg 2005), experience of pollution monitoring in different regions (Lavrova et al 2006a,b; Litovchenko et al. 2006), automatic oil spill detection (Solberg et al. 1999), etc.

In the present paper a new approach to this problem is suggested. This approach consists in combined use of all available quasi-concurrent satellite information and was tested during operational monitoring of seawater condition and pollution in the coastal zone of northeastern Black Sea conducted in 2006. This monitoring is based on daily receiving, processing and analysis of data different in nature (active and passive microwave radar images, optical and infrared data), resolution and surface coverage. These data allow us to retrieve information on seawater pollution, sea surface and air-sea boundary layer conditions, seawater temperature and suspended matter distributions, chlorophyll *a* concentration, mesoscale water dynamics, near-surface wind and surface wave fields.

OPERATIONAL WATER CONDITION MONITORING

Since April 2006, Scientific Research Centre of Space Hydrometeorology "Planeta" jointly with Space Radar Laboratory of the Space Research Institute realizes operational satellite monitoring of seawater condition and pollution in the coastal zone of the northeastern Black Sea and the Azov Sea. This monitoring is based on the receiving, processing and analysis of different satellite images. Their amount runs up to 180 per month.

These data include:

- synthetic sperture radar (SAR) or Advanced Synthetic Aperture Radar (ASAR) images obtained by satellites ENVISAT and ERS-2 of the European SpaceAgency;
- optical characterictics the near-surface layer of the sea (sensor MODIS, satellites Aqua and Terra);
- sea surface temperature fields (sensors MODIS and AVHRR, satellites Terra/Aqua and NOAA);
- sea level anomalies (altimeters, satellites TOPEX/Poseidon, Jason-1, ENVISAT);
- velocity and direction of sea surface wind (satellite QuikScat).

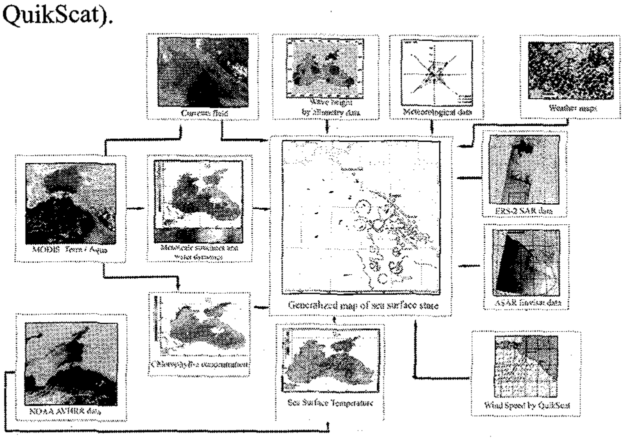

Figure 1. Scheme of the satellite monitoring of seawater condition in northeastern coastal zone of the Black Sea

The principal scheme of joint application of ll the above data for seawater condition monitoring is presented in Fig.1. The resulting product in graphical form is shown in Fig. 2. It summarizes information retreived by data processing and fusion analysis techniques and focusing on seawater turbidity, in particular due to high concentration of phytoplankton, mesoscale seawater circulation, such as oceanic eddies, hypothetical route of the Rim Current, and anthropogenic and biogenic pollution, including oil spills. Such charts are drawn once a decade and give an overview of the sea state over the period.

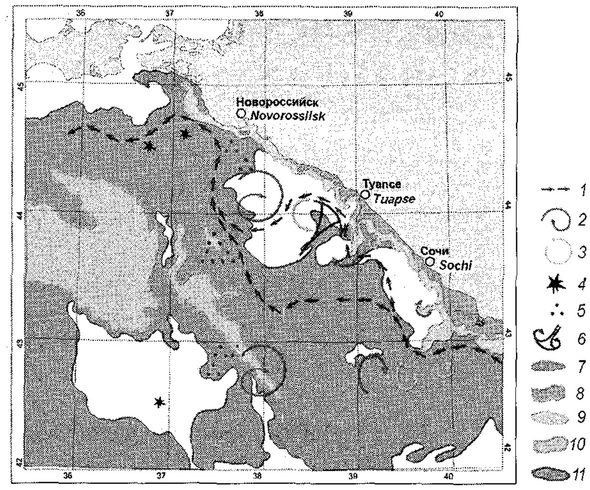

Figure 2. Seawater condition chart for 1st decade of June 2006: 1 – hypothetical route of the Rim Current; 2 – anticyclonic eddy; 3 – cyclonic eddy; 4 – oil slick; 5 – biogenic films; 6 – mushroom flow; 7 – river discharge; 8 – high turbidity waters; 9 – medium turbidity waters; 10 – higher chlorophyll *a* concentration; 11 - medium chlorophyll *a* concentration

DISTINGUISHING OIL SPILLS

SAR images are the basic element of oil spill monitoring data bank. Oil spills appear as dark patches in SAR images because of the damping effect oil film has on sea surface ripples, which results in lower backscatter registered by the radar (Fig. 3). The instrument advantages are high ground resolution (25 m for ASAR ENVISAT Narrow Swath) and data availability regardless weather or sunlight conditions.

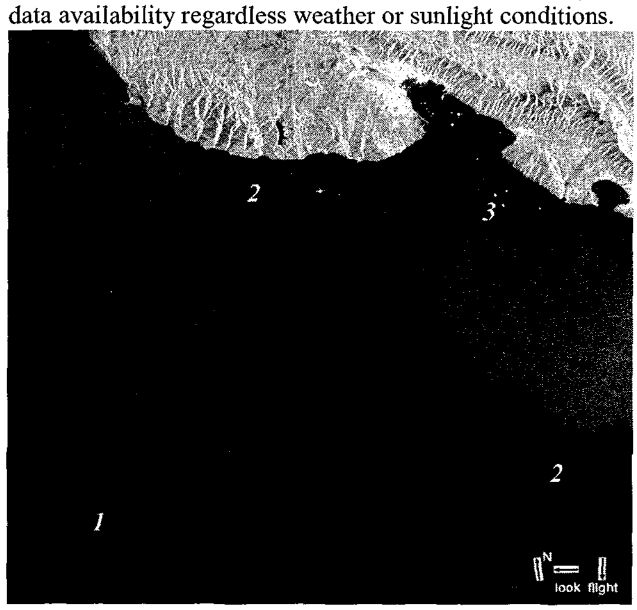

Figure 3. ASAR (ENVISAT). 22.08.2006. 1 – oil slicks; 2 – natural organic films; 3 – ships

The *contrast* between a spill and surrounding water depends on many environmental factors such as wind speed, wave height, sea surface temperature, current field. They also determine spreading, drift and weathering of oil on the sea surface. Hence, reliable *oil spill detection* demands a large amount of supplementary data.

Because of a strong dependence of oil slick detectability in SAR data on near-surface wind speed and direction confronted with the lack of ground-based wind data, there is a great need for satellite data on wind field. At present, data obtained by QuikScat is employed. Unfortunately, its resolution is rather low (25 km) and insufficient to reveal local small-scale wind field features.

Chlorophyll *a* concentration charts derived from MODIS data help to distinguish between oil spill and natural organic film manifestations in SAR images, which are easily confused, especially during seasonal aggressive phytoplankton boosts.

Biogenic and antropogenic films can be directly visible in MODIS optical images, provided they fall into sun glint zone. (Fig. 4a,c). Their appearance is similar to SAR data imprints. Beside well-known limitations of optical data availability and necessity for sun glint, optical data interpretation is affected by a specific look-alike – cloud shadows (Fig. 4b).

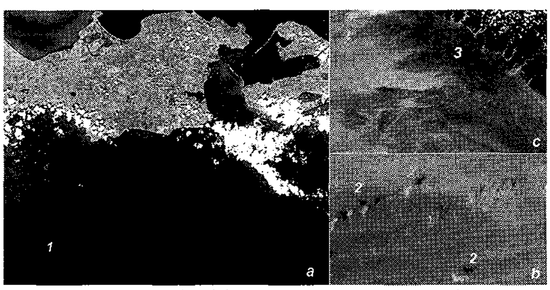

Figure 4. Optical images from MODIS (Aqua). a – 19.07.2006; b – 05.07.2006; c – 21.06.2006. 1 – oil spill; 2 – cloud shadow; 3 – natural films

UNDERSTANDING LOCAL SEA SURFACE DYNAMICS

An important aspect of oil pollution monitoring is forecasting spill evolution, drift and weathering. The key success factor here is the knowledge of local water circulation patterns including surface gravity waves, current fields, zones of divergence and convergence, small- and mesoscale vortical structures.

Satellite infrared and optical data can help to reveal seawater trajectories when there are some tracers in the water such as suspended matter including phytoplankton (Fig.5), or contrast of water characteristics, for instance, surface temperature.


Figure 5. Elements of large- and mesoscale water circulation. MODIS (Aqua). Optical image

The more images different in physical nature are received the more complete is the picture of water circulation. Figure 6 shows two images derived from simultaneously acquired MODIS data. In the first one (chlorophyll *a* concentration), one can distiguish a cyclonic eddy only, while the second image (water-leaving radiance) reveals that this eddy is part of a mushroom flow.

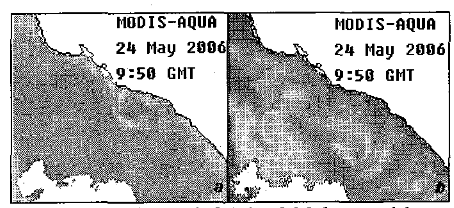

Figure 6. MODIS (Aqua) 24.05.2006. a – chlorophyll *a* concentration, b – water-leaving radiance

Comparison of two or more consequent images also appears fruitfull in the case when some long-living structures can be identified in them. For example, Fig. 7a,b shows the evolution of a cyclonic eddy registered in two infrared images taken with a 5-day interval.

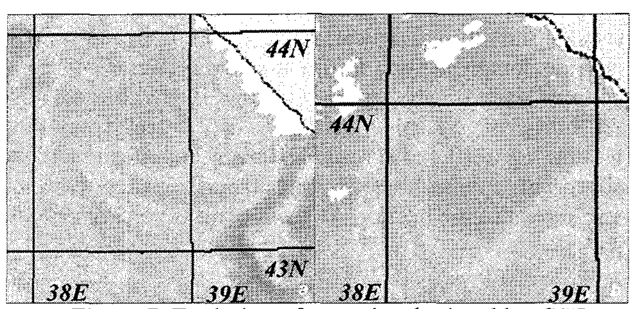

Figure 7. Evolution of an anticyclonic eddy, SST (NOAA-18). a – 29.04.2006, eddy diameter is 100 km; b – 05.05.2006, eddy diameter is 70 km

Unlike infrared and optical data, seawater circulation in SAR data is reflected due to the presence of biogenic or antropogenic surfactants on the sea surface. High resolution of SAR images makes it possible to detect vortical structures as small as a few kilometers in diameter (Fig. 8) or fragments of mesoscale eddies.

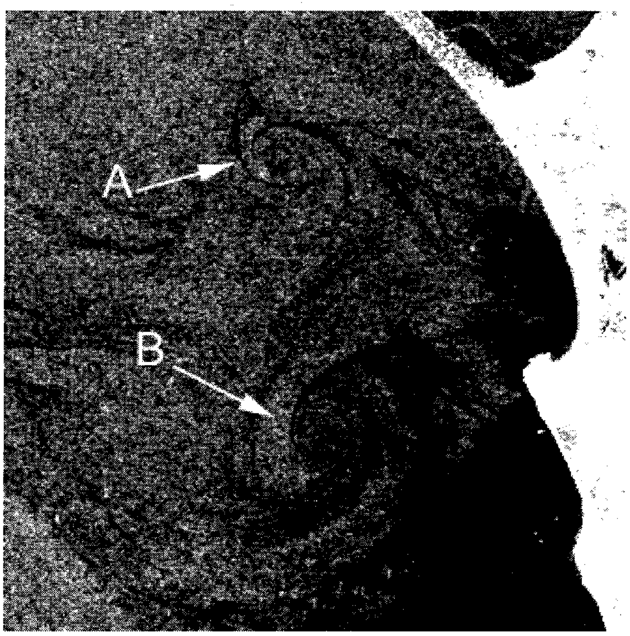

Figure 8. Two cyclonic eddies with diameters 3.75 km (A) and 3 km (B). ASAR (ENVISAT), 15.08.2006

Information on sea waves and sea level anomalies derived from altimeter data can also be useful for the prediction of oil spill evolution, although on a limited scale because of low resolution.

CONCLUSIONS

Operational monitoring of seawater condition and pollution in the coastal zone of northeastern Black Sea conducted in 2006 have demonstrated high potential of multisensor approach to satellite monitoring of oil pollution. Different satellite microwave, optical, infrared and altimeter sensors provide complementing information on seawater and near-surface layer of atmosphere making it possible to raise reliability of oil spill detection and forecast of their weathering, drift and spread. The main imperfection of the suggested approach is significant discrepancy between resolutions of the basic (SAR) and complementary satellite data.

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