SATELLITE MONITORING OF THE BLACK SEA SURFACE POLLUTION

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ABSTRACT

The results of a long-term satellite monitoring of the Black Sea revealing sea surface pollution by oil as well as manifestations of biogenic and anthropogenic surface films are presented. The basic data are high-resolution radar images obtained by synthetic aperture radars onboard Envisat satellite (till the spring of 2012) and onboard Sentinel-1 satellite (starting from October, 2014). A large amount of experimental data provides statistically significant results on spatial and temporal distributions of these surface films on the sea surface. The regions of the heaviest pollution are outlined. Our findings suggest that certain types of surface pollution detected in sea surface radar imagery are caused by natural hydrocarbon seeps at the Black Sea bottom.

Index Terms **—** Black Sea, satellite monitoring, radar imagery, sea surface, surface films, oil pollution, natural hydrocarbon seeps

1. INTRODUCTION

The Black Sea is a semi-closed sea isolated from the World Ocean. It is bordered by 6 countries with well-developed industries. There are dozens of industrial ports, some of which have oil terminals. The sea carries heavy marine traffic. Shipping activities in the Black Sea, including oil transportation and oil processing in the ports, have a number of negative impacts on the marine environment and the coastal zone. Oil-containing discharges from ships cause the contamination of seawater, shores, and beaches, which may persist for several months. Oil spill pollution is recognized as one of the major threats to the marine environment of the Black Sea.

The authors have more than ten years of experience in satellite monitoring of the Black Sea [1-3]. Presented are the results of long-term Black Sea satellite monitoring that reveal sea surface pollution by oil as well as manifestations of biogenic and anthropogenic surface films. The combined analysis of a variety of data obtained by remote sensing techniques was carried out. A considerable amount of data analyzed allowed us to get statistically reliable results on the spatial and temporal variations of different types of surface pollution manifestations in radar images of the sea surface. The areas of the Black Sea most frequently affected by surface pollution are outlined. The relation between certain types of surface film pollution and natural hydrocarbon seepages in the Black Sea is discussed.

2. TASKS SETTING AND THE MEANS OF DATA OBTAINING

The main focus of the observations was put on detecting anthropogenic and natural surface oil-containing films. The following main types of sea surface pollution films were investigated, specifically, the ones caused by:

- oily wastewaters discharged by watercraft;
- natural marine hydrocarbon emissions (methane seeps);
- increased biological productivity, including chlorophyll life cycle and intensive algal bloom.

Our main data source was high-resolution radar imagery data obtained by synthetic aperture radars onboard Envisat satellite (till the spring of 2012) and onboard Sentinel-1 satellite (starting from October, 2014). Among the many various sensors the Synthetic Aperture Radar (SAR) is definitely the most suited tool for oil spill monitoring, because of its high resolution and independence of cloudiness and solar-light conditions. Nevertheless, detection of sea surface oil pollution based only on SAR data is rather difficult because of the difficulties in distinguishing oil slicks, especially at lower wind speeds, from other phenomena known as oil "look-alikes" [4-5].

Our experience gained from a number of monitoring campaigns shows that this problem can be successfully solved by the combined analysis of satellite data taken in visual, IR and microwave ranges. This data is obtained by different sensors mounted on board of different Earth observation satellites. We used data in visual and IR bands taken by Envisat MERIS, Terra/Aqua MODIS and by scanning radiometers of Landsat-5, 7, 8 satellites nearly simultaneously with the SAR images, in order to facilitate the differentiation between different types of surface pollutants, to reveal meteorological and hydrodynamic processes in test areas, and to determine factors governing pollutants' spread and drift. Meteorological data, required for the analysis of satellite data, were provided by coastal stations.

Fig. 1. Slicks due to algal bloom as seen in ASAR Envisat imagery: (a) subscene (150x150 km) of the ASAR Envisat image collected on 03.07.10 at 17:52 UTC in the western part of the Black Sea; (b) subscene (100x100 km) of the ASAR Envisat image collected on 18.09.10 at 19:32 UTC in the southern part of the Black Sea; (c) subscene (50x50 km), of the ASAR Envisat image collected on 09.06.09 at 07:50 UTC in the north-eastern part of the Black Sea near the Kerch strait

3. MANIFESTATIONS OF NATURAL FILMS ON THE SEA SURFACE

In case of the Black Sea, the detection of oil spills caused by ship discharges is more complicated as compared to other seas due to 1) intensive phytoplankton bloom and to 2) natural hydrocarbons seeps that can be detected in various areas of the Black Sea.

1) The surface of the Black Sea contains a number of slicks resembling oily wastewaters discharged by ships but having some unique features. These features include larger size, specific geometric shape and variation in time and space. Figure 1 gives examples of patterns in radar images acquired over different parts of the Black Sea which are caused by the biogenic films. These biogenic films are produced during complex biochemical processes of life activity in the sea and decomposition of died sea organisms, and thus, such films cannot be considered pollutants. The biogenic films are sensitive to surface currents and reproduce the geometric shapes of local circulation patterns. Under low winds organic films on the sea surface are retained in the form of slicks for a considerable time and start to disrupt at wind speeds of 6-7 m/s and higher. When the strong wind subsides, organic substances come up to the sea surface again and form slicks. Large conglomerations of phytoplankton in the Black Sea are observed during its most intensive "bloom"; the first peak takes place in the period from the end of spring till the beginning of summer, the second – in autumn. That times organic films are produced on the sea surface and most often they cover large sea areas.

2) Slicks of a different type can be frequently seen at the certain regions, particularly in the Kerch-Taman and Bulgarian shelf waters, in deep waters to south-east from the Crimea Peninsula and in Georgian continental slope waters. Geographical distribution of these surface films is characterized by permanent location and correlates with geographical spreading of natural hydrocarbons showings in the Black Sea. The term "natural hydrocarbon showings" in this case includes mud volcano activity, natural gas and oil emersions and gas hydrates. In particular, a relatively small area near the Georgian continental slope became something like a natural laboratory. Four cold methane seeps are located on the sea floor in this area (see Figure 2). Investigations carried out during the field works on the Georgian continental slope [6] demonstrated that the presence of oil traces in bottom sediments is a distinguishing feature typical of these seeps.

We analyzed all SAR ERS-2 and ASAR Envisat images of the Black Sea taken over the continental slope area offshore Georgia and continental slope obtained for the period from January 2010 to December 2011 as well as Sentinel-1 SAR images taken from the October 2014 to April 2015. It was found out that 49.5 % of radar images of the test area for the period 2010-2011 contained slick structures, while in the October 2014 - April 2015 the slick structures were registered in 64 % of images taken over the area of interest.

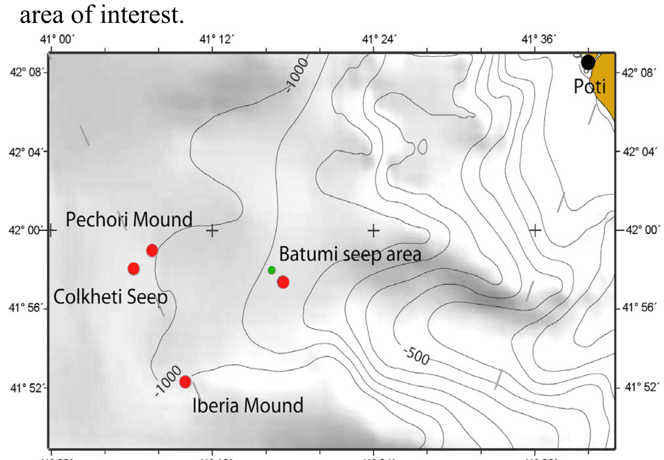

Fig. 2. Location and bathymetry of the investigated seep sites offshore Georgia (after [6])

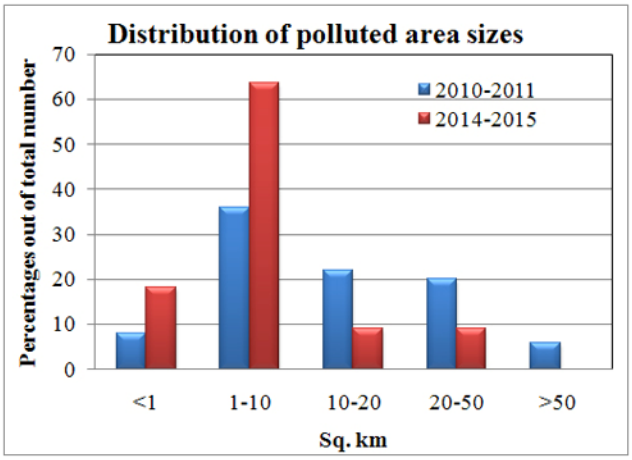

Fig. 3 Size distribution of individual oil pollution areas, caused by natural hydrocarbon seepages from the sea bottom

Size distributions of individual oil pollution areas, caused by natural hydrocarbon seepages from the sea bottom are shown in the Fig. 3. It can be concluded that events of natural hydrocarbon showings are more often registered in radar imagery of the region in 2014-2015 but their individual sizes are smaller than those revealed in 2010-2011. In the majority of radar images taken before 2012 such slicks appear as "coupled" structures. Comparison of slick locations detected in satellite imagery and methane seep locations makes it possible to draw the conclusion that such coupled character is caused by natural hydrocarbons showings from the two closely-spaced methane seeps on the sea bottom: Colkheti Seep and Pechori Mound (refer to Fig. 2). These surface films can stretch along the flow lines of surface currents and reproduce the shape of local circulation pattern.

Consolidated scheme of seepage slicks revealed in the radar imagery in the study area is shown in the Fig.4. Some examples of film pollution detected in SAR images taken over the continental slope area offshore Georgia are shown in Fig. 5.

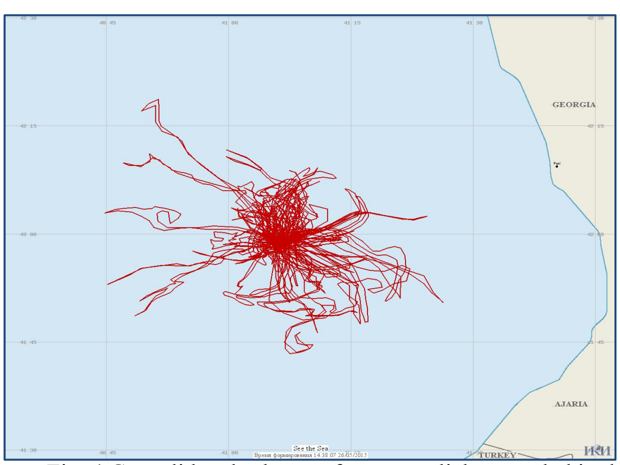

Fig. 4.Consolidated scheme of seepage slicks revealed in the radar images of the study area

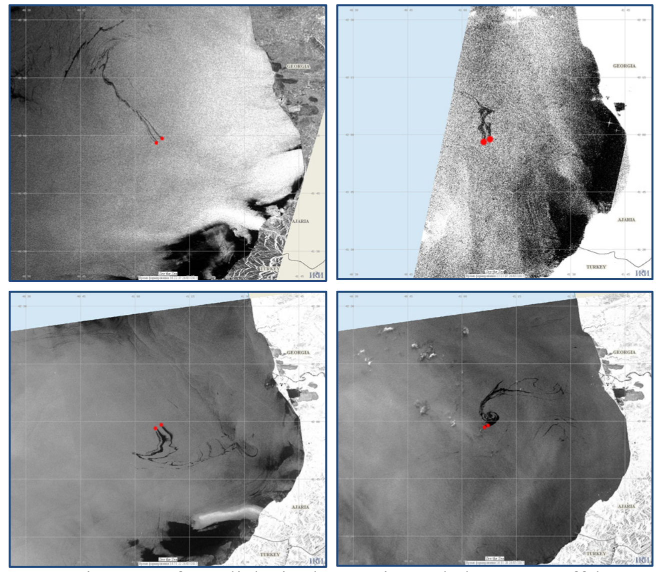

Fig. 5. Surface slicks in the continental slope area offshore Georgia as seen in satellite radar imagery. Subscenes of ASAR Envisat images collected on 27.10.2010 at 07:32 UTC (a), and on 17.09.2011 at 07:21 UTC (b). Subscenes of Sentinel-1 SAR images collected on 08.11.2014 at 15:10 UTC (c), and on 15.10.2014 at 15:10 UTC (d)

4. MAIN RESULTS OF SATELLITE MONITORING OF THE SEA SURFACE OIL POLLUTION DUE TO SHIP SPILLAGES

Fig.6 shows the cumulative map of oil-containing spills revealed from satellite radar data in the aquatic area of the Black Sea for the years 2009-2010. Year-by-year numbers of oil spills detected are 286, 253, and 247 correspondingly. All these pollution events are caused by spillages of oil-containing waters from moving ships. As expected, spillages are concentrated along the main shipping routes such as Istanbul – Novorossiisk, Istanbul – Odessa and Istanbul – Tuapse. Besides these routes, a large amount of spills is observed near the major ports of Bulgaria, Turkey, Romania and Ukraine as well as near oil loading terminals.

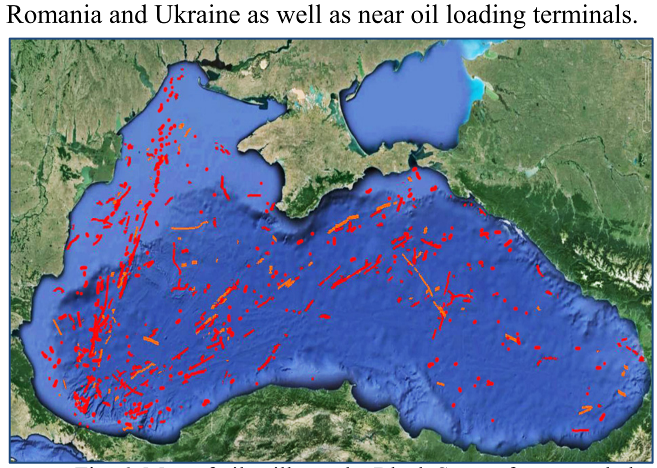

Fig. 6. Map of oil spills on the Black Sea surface revealed from satellite radar imagery in 2009-2011

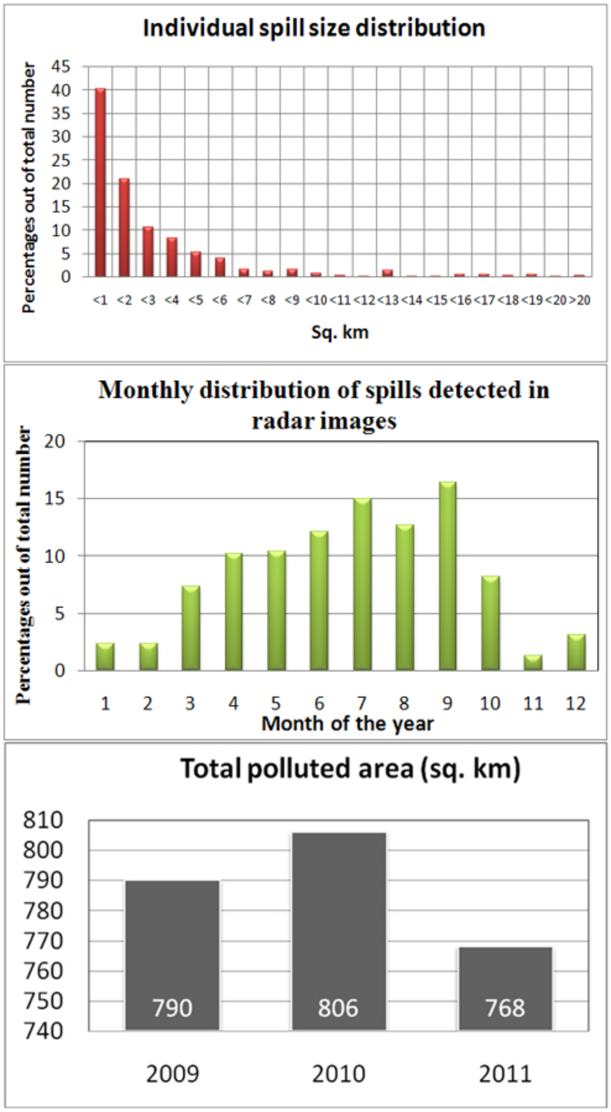

Fig. 7. Statistics on oil spills on the Black Sea surface revealed from satellite SAR data

Some numerical data on oil spills in the Black Sea aquatic area revealed from satellite data is presented in Fig 7. These are distribution of individual sizes of oil-containing spills, average monthly numbers of spills detected, and annual size distribution of total area of the oil pollution.

It can be seen from histograms that over 40 percent of spills detected in radar images do not exceed 1 sq. km, and polluted areas in 80 percent of events are less than 5 sq. km. However, quite often ships discharge wastewaters several times while they are under way and continue dumping wastewaters for dozens of kilometers. Under the influence of the wind and the waves, the film spreads over the sea surface covering large areas.

Larger numbers of spills registered during warm season (March-October) could be explained by better weather conditions favourable for the recognition of spills in satellite radar images.

5. CONCLUSION

The performed observations have demonstrated a clear necessity to implement operational satellite monitoring of water area pollution, which would allow to determine the source of pollution, conduct quantitative assessment of its scale and predict its drift parameters. Satellite data can be recognized as evidence of environmental review assuming that relevant legislation enactment has been provided. In this regard, the degree of quality credibility of satellite images interpretation is of greatest importance as it is used to infer information on anthropogenic pollution of the sea surface. One of the purposes of the paper is to attract the attention of experts specialized in Earth remote sensing to this issue.

6. ACKNOWLEDGEMENTS

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