Multi-Sensor Satellite Survey of the Surface Oil Pollution in the Caspian Sea
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ABSTRACT

The results of long-term satellite survey of the aquatic area of the Caspian Sea are presented. The patterns of surface oil pollution of the Caspian Sea are described and analysed. It is demonstrated that surface oil pollution is often caused by natural causes, namely by natural hydrocarbon seepages and mud volcanoes activity on the sea bottom. A combined analysis of oil film signatures in satellite radar and optical imagery data is performed. Mapping of the main types of surface pollution of the Caspian Sea is performed and areas of the heaviest pollution are outlined and analysed. Dependence of radar signatures of sea surface oil patches on the wind/wave conditions is investigated. The large amount of the data available allowed us to make some generalizations and obtain statistically significant results on a spatial and temporal variability of various sea surface film manifestations in SAR images. The impact of dynamic and circulation processes and natural factors (current meandering, vortical activity, temperature and wind patterns) on spatial and temporal distributions and intensity of oil films is studied. The connection between manifestations of natural seepages and mud volcanoes and earthquake activity in South Caspian and adjacent areas is established.

Keywords Caspian Sea, satellite monitoring, sea surface, satellite radar imagery, oil pollution, oil pollution, natural hydrocarbon seeps

1. INTRODUCTION

The unique and rich with natural resources Caspian Sea has no natural connection with the World Ocean and is the largest inland body of water in the world. It contains about 3.5 times more water, by volume, than all five of North America's Great Lakes combined. The Caspian is a lake by its geographical definition although it is not a freshwater lake. Average salinity of the Caspian Sea water contains 12.85‰. (an average ocean water contains 35 ‰). Low salinity of the Sea is caused by large river inflows. Over 130 rivers provide inflow to the Caspian Sea, with the Volga River being the largest, but it has no natural outflow other than by evaporation. The Caspian has characteristics common to both seas and lakes, but its size, hydrometeorological conditions, currents, water level oscillations, flora and fauna are more characteristic for seas.

Surface oil pollution of the Caspian Sea is often caused by natural causes, namely by seepages from oil and natural gas fields on the sea bottom. From the late 19th century, Azerbaijan pioneered the development of shelf and offshore oilfields, and it was the first country to suffer from surface pollution. The Caspian Sea pertains to the world largest oil bearing regions. Total oil reserves of the Caspian Sea region are estimated at above 250 billion barrels1, which puts it in second place after the Middle East. The main sources of the Caspian Sea surface pollution are considered to be offshore oil production as well as the natural oil seeps at sea bottom. According to some estimations2, about one million tons of oil is annually leaked to the Caspian Sea.

A satellite monitoring is an effective way of monitoring sea surface outside of ports and oil terminals. It allows for continuous monitoring of oil pollutions over a vast area of offshore waters including territorial waters of neighboring countries. The latter is particularly important for monitoring trans-border transport of the pollutions by sea currents. The primary type of contamination, which was the main focus of research in the field, is the pollution of the sea surface by oil-containing films3. European countries have being quite successful in preventing major sea surface pollution and establishing a system for monitoring sea surface using aerial and satellite surveillance4.
Many countries cannot afford an adequate monitoring program. None of the Caspian countries (with the exception of Russia) carry out satellite monitoring of the aquatic area of the Caspian Sea.

The authors of this paper have more than five years of experience in satellite monitoring of the Caspian Sea. This article presents the results obtained during these observations. 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 significant results on the spatial and temporal variations of different types of surface pollution manifestations in satellite images of the sea surface.

2. THE DATA USED

Data in visual, infrared and microwave ranges provided the basic material for the analysis. This data is obtained by sensors mounted on board various Earth observation satellites.

The surface pollution and sea dynamics monitoring was based on a combined analysis of satellite imagery obtained by sensors installed on various satellites and operating in different bands of electromagnetic waves. 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 many available sensors, the Synthetic Aperture Radar (SAR) is definitely the most suited tool for surface pollution monitoring, because of its high resolution and its insusceptibility to cloud and solar light conditions. Nevertheless, detection of sea surface oil pollution based solely 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".

The basic radar data is complimented by other satellite data on the sea surface and water condition, such as sea surface temperature, suspended matter and chlorophyll-a concentration, meso-scale water dynamics etc. 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 various 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.

3. DETECTION OF OIL PATCHES ON THE SEA SURFACE IN RADAR IMAGES

3.1 Basics of radar detection of sea surface oil pollution

The SARs are the most important data source for satellite monitoring of sea surface for pollution due to the following reasons:

- twenty-four-hour operation capacity, insusceptible to solar light conditions
- radar measurement can be performed under any weather conditions, as the atmosphere is nearly transparent for SAR microwave radiation
- dielectric property of water at microwave frequencies is homogeneous, and the fluctuation of scattered signal is induced solely by sea surface roughness, which facilitates satellite imagery interpretation
- high spatial resolution of advanced SARs allows to accurately detect even insignificant oil pollution

Satellite monitoring of oil pollution of the sea surface is based on the capability of satellite-borne radar imagery to reveal sea surface areas (so-called film slicks) covered by surface films. Surface films cause a reduced interaction of ocean waves and wind as well as an attenuation of the resonance gravity-capillary component of surface waves. In this case, smooth areas (slicks) appear on the sea surface and form areas of reduced backscattered signal in a radar image.

It should be stressed, that the wave damping may be related not only to oil films, but also to biogenic films, land-shadowed areas near coasts, rain cells, zones of upwelling, young ice, and oceanic or atmospheric fronts. The contrast between a spill and surrounding water, and therefore the probability of detecting pollution films, depends both on the amount and type of oil as well as on environmental factors such as wind speed, wave height, sea surface temperature (SST), currents and current shift zones.
The discrimination of anthropogenic and natural (biogenic and mineral) films is one of the most difficult tasks. Our experience gained from a number of monitoring campaigns shows that this problem can be successfully solved by a combined use of satellite data taken in visual, IR and microwave ranges. The key problem consists in combining data sources varying in physical, spatial resolution and image dimensions.

Over the course of experiments, the correlation was investigated between radar backscattering caused by oil films and sea surface conditions, such as waves, wind speed and direction and the condition of near-surface layer of atmosphere. As a result, the optimal conditions for satellite monitoring of sea surface pollution were specified, namely wind speed – 3-8 m/s, and wave heights – up to 1.25 m, stable stratification of the atmosphere – ocean boundary layer.

Furthermore, the near-surface wind was identified as the most important factor affecting the reliable detection of oil pollution on the sea surface via radar imagery. All these results are based on the satellite data obtained over the oil-producing area “Neftyanye Kamni” (translated as “Oil Rocks” in English, and hereafter we will use the name Oil Rocks for convenience) in the Central Caspian. The major shelf oilfield, Oil Rocks, was discovered and developed in the late 1940s, produced 10 million tonnes of oil annually. Oil films are always present on the sea surface in that area covering areas of 200 – 1000 sq. km. However, sea surface pollution in the vicinity of this drilling platform is caused not only by “dirty” oil production techniques (the oil production and oil-well drilling, the underwater oil-rig repair, oil outflow during pipeline breaks). Even before drilling started at Oil Rocks in 1949 the sea surface in this area was famous for its natural oil slicks. It is now believed that the oil pollution around this platform is caused not solely by man-made discharges and leaks, but is rather a result of natural seeping activity at the sea bottom. The amount of the oil ingress to the sea in this area can vary between 100 and 500 tons per day. The oil patch size, its spread and evolution depend on the meteorological conditions. The oil-producing area Oil Rocks can be used as a natural laboratory for studying the effect of wind conditions on oil patches as well as on formations of oil slick signatures in radar images.

3.2 Dependence of radar signatures of oil patches on the sea surface wind/wave conditions

We noted that essentially all the SAR images taken at moderate wind speeds (3-8 m/s) over the Oil Rocks oil production area included oil slicks. The Envisat ASAR imagery taken in 2009-2011 was compared with that obtained by Sentinel-1 SAR in 2014-2015. It was found that the amount of surface oil slicks manifestations in radar images remains practically the same during both observation periods. Oily films floating on the sea surface appear in radar images as dark patches occupying large areas among the bright (rough) sea surface and evolve under the influence of currents and local winds. The reduction in the Normalised Radar Cross Section (NRCS) within a slick can reach 2 - 11 dB depending on film thickness, oil concentration and wind speed as well as on the type of sensor and polarisation. Figure 1 presents characteristic examples of oil slicks seen in radar images taken over the Oil Rocks platform under moderate winds. The graphs depict variations of radar signal along the marked transects.

![Figure 1](http://proceedings.spiedigitallibrary.org/ on 11/23/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx)
At high wind speeds (exceeding 9-10 m/s) both oil and biogenic polluting films are disrupted by wind and waves, and cannot always be identified in radar images. A radar image taken under less than favourable wind speed of 11 m/s in presence of convective processes in the atmosphere-ocean boundary layer is depicted in Figure 2a. A combination of strong wind and waves inhibits the formation of an oily slick. Wind field variations caused by convective processes in the near-surface marine atmosphere produce prominent cellular structure in the radar image so that oil slick cannot be easily identified in this image. One can only see a very small dark area of decreased radar backscatter in the immediate vicinity of the oilrig.

Active atmospheric processes resulting in a considerable variation of the near-surface wind field can also negatively affect the detection of surface films in radar images. The atmosphere is transparent for radar signal and atmospheric processes are displayed in radar images only via inhomogeneities of the gravity–capillary component of the sea-surface wave field. Resulting from mesoscale processes, wind field variations modulate short gravity waves at the sea surface resulting in the inhomogeneities of the backscattered radar signal distribution. We found that imprints of atmospheric phenomena may cover the major part of some radar images and the variations of introduced radar signal intensity are rather high. This often makes it impossible to identify manifestations of oil patches on the sea surface. In Figure 2b a Sentinel-1 SAR image taken over the oil-producing area Oil Rocks is depicted. Quasi-periodic modulations of radar signal can be observed in this image. These oscillations appear to be reflections of surface wind fluctuations connected with atmospheric gravity waves propagating in marine atmosphere. Note that in this case the radar signatures of mineral oil floating on the sea surface are very weak, about of 1.5 dB (see the graph in Figure 2b). We found out that areas of oil patches detected in radar images under strong winds and disturbed near surface atmospheres are significantly smaller than those detected under moderate winds. Hence, it is possible to underestimate sizes of polluted areas based solely on radar data, if active atmospheric processes are present.

In the low wind conditions oil patches spread out and occupy large areas, extending far beyond the oil-extracting platform. On the other hand, under weak-to-no-wind conditions the capillary-gravity component of the sea surface wave field may not develop. This results in attenuation of backscattered signal. Moreover, in radar images obtained under weak near-surface wind there are usually a large number of low backscatter areas that are not related to the presence of oil-containing films on the sea surface. The existence of these low scattering (dark) areas in radar images increases the “false alarm” probability in oil pollution monitoring. Hence sizes of polluted areas derived from radar data taken at low wins can be overestimated.

In Figure 2c an Envisat ASAR image taken over the oil-producing area Oil Rocks at low wind is depicted. The area of the slick around the oil drilling platform is approximatly 835 sq. km. To the south of the platform one can still see an area of moderate wind. A lot of spiral eddies are visualized via biogenic films. These biogenic films can be found virtually everywhere on the vast sea surface, mostly in warm seasons. They are caused by marine organisms and seaweeds, primarily phytoplankton and zooplankton, as well as bacteria. Biogenic films are very sensitive to surface currents and typically form the shape of a local circulation pattern.
For this study we examined all ASAR Envisat images of the Caspian Sea obtained over the Oil Rocks in the period from January 2010 to December 2011 as well as Sentinel-1 SAR images taken from the October 2014 to June 2015. It was found that 69.3% of radar images of the test area contained signatures of oil patches near the oilrig. No slick structures were seen in the remaining images because high/low winds prevented them from being detected by SAR. The corresponding statistics is shown in Figure 3.

Distribution of individual sizes of oil slicks near the oil-drilling platform detected in radar images is shown in Figure 4. From the diagram, it follows that the characteristic areas of this patches are from 300 to 600 sq. km, while sometimes their areas may exceed 900 sq. km. It should be stressed that these areas are retrieved from radar imagery, which depends on the wind/wave conditions and these areas may differ from real areas measured in situ.

Monthly mean oil patch sizes detected in radar images was calculated as well. This distribution is shown in Figure 5. It can be inferred from this diagram that oil patches sizes detected in radar imagery in cold period – from October till April are relatively small. This can be explained by the larger number of days with predominantly high wind speed observed in the study area in this period. In Oil Rocks during the cold season (from November to March), when the intensity of atmospheric circulation increases, the average wind speed reaches 7.5 m / s. Storm winds can often be observed in this period16.

![Figure 3. Statistics on visibility of oil patches in the Oil Rocks oil producing area in dependence on near-surface winds.](image3)

![Figure 4. Distribution of individual sizes oil patches in the Oil Rocks oil producing area detected in radar images of the in 2010.](image4)
4. JOINT ANALYSIS OF RADAR DATA AND DATA OF OPTICAL SENSORS

Some ambiguities in the interpretation of radar data and detection of oil slicks on the sea surface can be solved by the combined use of satellite radar data and data taken in visual (VIS) and near-infrared (NIR) electromagnetic ranges. Joint analysis of radar and optical images can be very effective. Optical images, especially obtained in a sun glint zones can provide additional information on the processes and phenomena on the sea surface in the low wind areas. These are the areas where returned radar backscatter is low, and the ocean surface may appear featureless and uniformly dark across a radar image.

Sunglint refers to the reflection of solar radiation from the sea surface observed by optical (VIS/NIR) sensors when sunlight’s incidence angle is equal to the angle of reflection. The presence of inhomogeneous roughness - surface waves - gives rise to a set of small tilted facets reflecting sunlight at a variety of different angles and directions. The size and shape of the sun glint pattern depends on the probability distribution of the slopes of the facets caused by the sea surface roughness, the direction of the incident sunlight and the sensor viewing angle. Thus, differences in the sea surface roughness variance in the sun glint region manifest themselves as variations in the image brightness. In the sunglint region, areas covered by films appear brighter because the surface film reduces the sea surface roughness and a greater number of local elements are present, reflecting light to the sensor. It should be added that the oil film on the VIS images may be visible even better than in the radar images, since the observed contrasts are caused not only by smoothing surface waves by oil slick, but also by the differences in the optical characteristics of clean water and the oil film.

The Envisat ASAR image in Figure 6a depicts vast dark areas of decreased radar backscatter caused by low near-surface wind. It is impossible to accurately identify oil patch areas in this image. However, adding optical data taken by Landsat 5 TM sensor in the sun glint region to the analysis allows to solve this problem – i.e. to reveal oil patches and to exclude areas of the calm wind.

Figure 6b depicts a fusion of a false-color Landsat 5 TM-derived image and Envisat ASAR radar image. The areas of oil film coverage are seen in optical image as characteristic iridescent patches with a darker halo, in accordance with the film thickness unevenness.
Figure 6. An example of joint analysis of optical and radar data. a) A part of a HH-polarized Envisat ASAR image acquired at 06:50 UTC on 19.07.2010 under low wind conditions; b) a fusion of the Envisat ASAR radar image and Landsat 5 TM-derived false-colour image obtained over the same area close in time.

Figure 7 depicts a comparison of the optical and radar images taken over the Oil Rocks oil-producing area almost simultaneously. In Envisat ASAR image an oil patch spreading in north-west direction is distinctly seen. In Landsat TM-derived image obtained in the sunglint region not only oil films at the sea surface are well pronounced, but elements of the sea water mesoscale dynamics can be observed, in particular one can see an eddy in the coastal area visualized via variations in the suspended matter field. This eddy does not manifest itself at the sea surface and is not visible in the radar image.

Figure 7. Near coincident data Envisat ASAR and Landsat TM taken over the Oil Rocks area. A part of an Envisat ASAR image acquired at 06:36 UTC on 29.07.2010; b) a part of a false-color (R- 2090-2350 nm, G-770-900 nm, B-630-690 nm) Landsat TM image acquired at 07:03 UTC on 29.07.2010.

Data taken by satellite sensors in VIS/NIR bands of electromagnetic spectrum provides a significant value for marine observation systems. A limitation of this data remains the weather conditions, as a cloud cover may prevent radiance penetration and solar illumination. The combination various types of remotely sensed data acquired at different electromagnetic wavelengths and its joint analysis can significantly improve the effectiveness of sea surface oil pollution detection.
5. MAP OF THE CASPIAN SEA SURFACE OIL POLLUTION

Satellite data taken over the Caspian Sea was analyzed in order to accurately detect oil films pollution on the sea surface. Contours of every oil patch were outlined and patch areas were calculated. As a result, a comprehensive map of sea surface pollution by oil films was produced. According to this map, shown in Figure 8, two areas of the heaviest pollution are identified. Those are the area of Absheron and Baku archipelagoes (I) as well as the Western edge of South-Caspian depression (II). Later in this paper we discuss main features of surface oil pollution in both of these areas.

![Map of the Caspian Sea surface oil pollution](image_url)

Figure 8. Map of oil spills revealed from satellite radar imagery in the central and southwestern Caspian Sea in 2010.

The anthropogenic pollution caused by oil-containing waste water discharges from ships is also detected in satellite radar images of the Caspian Sea surface. The radar data analysis showed that ship discharges are concentrated along the main routes of the oil transportation in the Caspian Sea, namely in the directions of Aktau-Makhachkala, Aktau-Neka and Aktau-Baku. As opposed to what was observed in other enclosed seas, illegal discharges in the Caspian Sea are not the main source of sea surface film pollution, although unfortunately their amount grows year-to-year.

6. SURFACE POLLUTION IN THE AREA OF ABSHERON AND BAKU ARCHIPELAGOES: DEPENDENCE OF OIL FILM SPREAD ON LOCAL WINDS AND CURRENTS

As discussed above, the main source of the open sea surface pollution in the area of Absheron and Baku archipelagoes is the ingress of the oil caused by the oil production and oil-well drilling, by oil outflow during pipeline breaks as well as by oil outflow from natural seepages at the sea bottom. The tasks of satellite monitoring of sea surface pollution and of sea state are closely related because pollutants become part of marine environment and evolve according to its intrinsic mechanisms. The most important factors which influence the size, extent and spreading of oil films on the sea surface are local winds and surface currents. The system of surface currents in the area near the Oil Rocks platform is rather complicated and unstable. The highest current speeds in the Caspian Sea (up to 10 cm/sec) are observed in this area. Our observations show that during the initial phase of oil patch evolution, the oil moves and spreads mostly under the influence of local winds. During the second phase, the oil can be entrained in a local current, travel long distances or be involved in a vortical motion. Examples of these two-phase movements are shown in Figure 9.
Figure 9. Examples of oil patch evolution under the influence of local winds and currents. a) a part of a Sentinel-1 SAR image acquired at 02:43 UTC on 05.01.2015. Total area of the slick – 205 sq. km; b) a part of an Envisat ASAR image acquired at 06:42 UTC on 01.08.2010. Total area of the slick – 445 sq. km; c) a part of an Envisat ASAR image acquired at 06:36 UTC on 24.06.2010. Total area of the slick – 325 sq. km.

Consolidated map of oil patches revealed in radar imagery in the vicinity of Oil Rocks is shown in Figure 10. It can be inferred from this map that a total aquatic area covered by oil which is released to the sea in the immediate vicinity of the oil-extracting platform reaches approx. 6260 sq. km, which is a great threat to the ecology of the Caspian Sea.

Figure 10. Consolidated map of oil patches revealed in radar images near the oil-producing platform Oil Rocks in 2010.

7. SURFACE POLLUTION IN THE SOUTHERN CASPIAN: OIL SLICKS OF NATURAL ORIGIN

Surface manifestations of mud volcanoes and seeps at the Caspian Sea bottom are known for a long time. The largest number of mud volcanoes (more than 300) and the biggest ones are concentrated at the north-western edge of the South-Caspian depression. The majority of South-Caspian depression mud volcanoes is in the seepage stage of their lifecycle and is discharging mud, water, gas and oil. Intensification of activity of the underwater volcanoes and seepages results in contamination of the sea surface by oil and mud patches. Sometimes, mud volcanoes manifestations may serve as an indicator of oil and gas reserves, so these phenomena attracts the attention of researchers. Their manifestations in radar images is discussed in 20,21

The characteristic examples of oil film pollution detected in the sea surface radar images taken in south-western part of the Caspian Sea are shown in Figure 11.
Figure 11. Mud volcanoes manifestations on satellite images via surfacing oil slicks.

a) Part of Envisat ASAR image taken on 19.06.11 at 18:32 UTC;
b) Part of Envisat ASAR image taken on 28.05.11 at 18:38 UTC;
c) Part of Envisat ASAR image taken on 26.05.11 at 06:59 UTC;
d) Part of a color-synthesized image (channels 3, 2, 1) of Landsat 7 ETM+ taken on 28.05.11 at 07:13 UTC.

The analysis of spatial variability of surface manifestations analogous to those shown in Figure 11 revealed that their geographic distribution correlates with that of localization of underwater mud volcanoes. In Figure 12 a map of the South Caspian basin mud volcanoes locations is shown, with red rectangles indicating radar images depicted in Figure 11.

Figure 12. Map of mud volcanoes in the South Caspian basin [22]

We have analyzed all radar images of the aquatic area of the Caspian Sea near the South-Caspian depression taken in 2009-2011 and displayed surface manifestations of mud volcanoes. A correlation between seepage manifestations in radar images and the earthquakes in the South Caspian and neighboring areas was studied.

A strong correlation was discovered between seepage manifestations in the satellite images and earthquakes of magnitudes 3-4 on the Richter scale. For instance, according to Azerbaijan Republican Center of seismological service, an earthquake of magnitude 3.90 was detected at the Caspian bottom at a distance of 166 km from Baku on 27.05.2011 at 04:55 UTC. The next day (28.05.2011), surface traces of mud volcano manifestations were found on the Envisat ASAR radar images (see Figure 11b) as well as on Landsat 7 ETM+ optical images (see Figure 11d).

Scientific publications on the subject provide substantial evidence that eruptions of mud volcanoes are caused by earthquakes. Since epicenters of earthquakes are typically located at a distance from volcanoes, seismic waves are taking some time to reach volcanoes. This results in volcanoes awakening not immediately at the day of the earthquake but several days or even weeks after the earthquake, depending on a distance from an epicenter, an earthquake magnitude and a depth of an earthquake.

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8. CONCLUSIONS

Based on the satellite remotely sensed data two areas of the heaviest surface pollution of the Caspian Sea are outlined. These are the area of Absheron and Baku archipelagoes as well as the Western edge of the South-Caspian depression.

It is shown that oil patches with areas 300-500 sq. km are quite common for the area of Absheron and Baku archipelagoes near the Oil Rock oil-producing site. It should be noted that sizes of oil slicks retrieved from radar imagery heavily depend on wind/wave conditions and may differ from real sizes measured in situ. Sizes of polluted areas derived from radar data taken at high wind speed and/or in presence of active atmospheric processes are typically underestimated, while sizes of polluted areas derived from radar data taken at low winds – overestimated.

A map of oil patches discovered in radar imagery in the vicinity of the oil drilling platform Oil Rocks is created. It is shown that a total aquatic area affected by spread of oil released in the sea in the immediate vicinity of the oil-extracting platform reaches approx. 6260 sq.km.

Oil slicks are frequently seen in radar images taken over the South-Caspian. Geographical distribution of these surface films is characterized by their persistent locations and strongly correlates with geographical locations of mud volcanoes and natural hydrocarbons showings at the sea bottom. A correlation was discovered between these manifestations in satellite images and earthquakes of magnitude 3-4 on the Richter scale.

The presented results demonstrate a need to implement operational satellite monitoring of the Caspian Sea surface pollution, which would allow to reveal the source of pollution, obtain a quantitative assessment of its scale and predict its drift parameters. Combined analyses of various satellite data will contribute to a more comprehensive interpretation of the data and help develop a better understanding of the sea surface oil pollution pattern. Special emphasis is placed on joint analysis of data obtained in different ranges – visual, infra-red, microwave – at different spatial resolutions by sensors mounted on specialized remote sensing satellites of the Earth. It is recommended that the satellite imagery should be correlated to the map of potential regular pollution sources (oil-drilling rigs, underwater pipelines oil and gas seeps and mud volcanoes at the sea bottom, etc.) for more reliable interpretation.

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