
USE OF SPACE INFORMATION ABOUT THE EARTH STUDYING SEAS AND OCEANS FROM SPACE

Oil Pollution in the Kerch Strait Based on Five-Year Monitoring with Synthetic Aperture Radar: Current Status and Main Sources

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Abstract—The results of the five-year (2017–2021) monitoring of oil pollution in the Kerch Strait and its pre-strait regions are analyzed. The synthetic aperture radar (SAR) images of the European Sentinel-1A and Sentinel-1B satellites, both real-time and archived, representing valuable material for searching, detecting, and studying the character of oil pollution caused by spills of crude oil, petroleum products, and other oily substances, have been used for monitoring. During monitoring, 2597 oil slicks with a total area of 1120.4 km² are detected on 481 SAR images. The main sources of pollution have been identified, in descending order, they are cargo transshipment areas in the strait, the port of Taman with its berthing complex, and prestrait anchorages in the Sea of Azov and the Black Sea. In addition, natural seep manifestations in the adjacent Black Sea shelf have been discovered, they create a natural hydrocarbon background that should be taken into account. Based on the monitoring results, a tendency towards an overall decrease in spills is revealed, despite their growth in 2016–2019. Monitoring with SAR using the geoinformation approach has shown its high efficiency for the problems of real-time and retrospective analysis of the satellite imagery data concerning oil pollution.

Keywords: Kerch Strait, oil spills, SAR images, satellite monitoring, oil pollution sources

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INTRODUCTION

The Kerch Strait is an important marine area of the Azov-Black Sea basin undergoing a high human-induced load, not only due to active navigation, but also to the intensely developing turnover of goods. In recent years, the volume of cargo turnover has been accumulating at the ports of the strait, which leads to an increasing number of passing ships that in either case affects the ecological state of the waters in the strait (Fashuk and Petrenko, 2008).

The coast of the Kerch Strait, which is fully developed, is in fact an anthropogenic–technogenic landscape. The commercial port of Kerch and the ports of Kamysh-Burun, Kavkas, and Krym are on the coast of the strait, while the port of Taman is in the Black Sea prestrait area (Fig. 1). The coasts of the strait are connected by Crimean Bridge used for highway and railway services. The Kerch Strait is shallow-water; therefore, the Kerch-Yenikale canal was dug to make navigation possible between the Black Sea and the Sea of Azov; the ports of the strait are connected to it by auxiliary ship channels. Moreover, the strait itself hosts production facilities, so-called cargo transshipment areas (Fig. 1). The construction of Crimean Bridge in 2016–2019, together with dredging works

in the strait area, is an example of an extremely high human-induced load on the strait waters.

All these factors significantly affected the hydrological and hydrobiological regimes of the strait, as well as the overall state of the ecosystem of the offshore area. Therefore, monitoring is necessary to reveal the most polluted areas and further control the improvement of the ecological situation (Fashchuk and Petrenko, 2008; IO RAS, 2016; Ivanov et al., 2021).

Remote sensing (RS) methods are highly effective for a real-time and objective assessment of the ecological status of the offshore area of the strait, including the monitoring of oil pollution, water mixing, river runoff, sewer discharges, dumping of soils, and other technogenic–anthropogenic processes affecting the overall state of the marine environment (Bondur, 2010; Lavrova et al., 2011; Bondur and Zamshin, 2012; Evtushenko, 2016; Ivanov et al., 2021). Synthetic aperture radar (SAR) images from the satellites make it possible to analyze relevant information about the area of interest in the real-time (Ivanov, 2007; Ivanov et al., 2014). Besides, the full and frequent coverage of the entire Kerch Strait with satellite observations allows to conduct regular monitoring of this marine area, as well as performing a retrospective analysis of the satellite

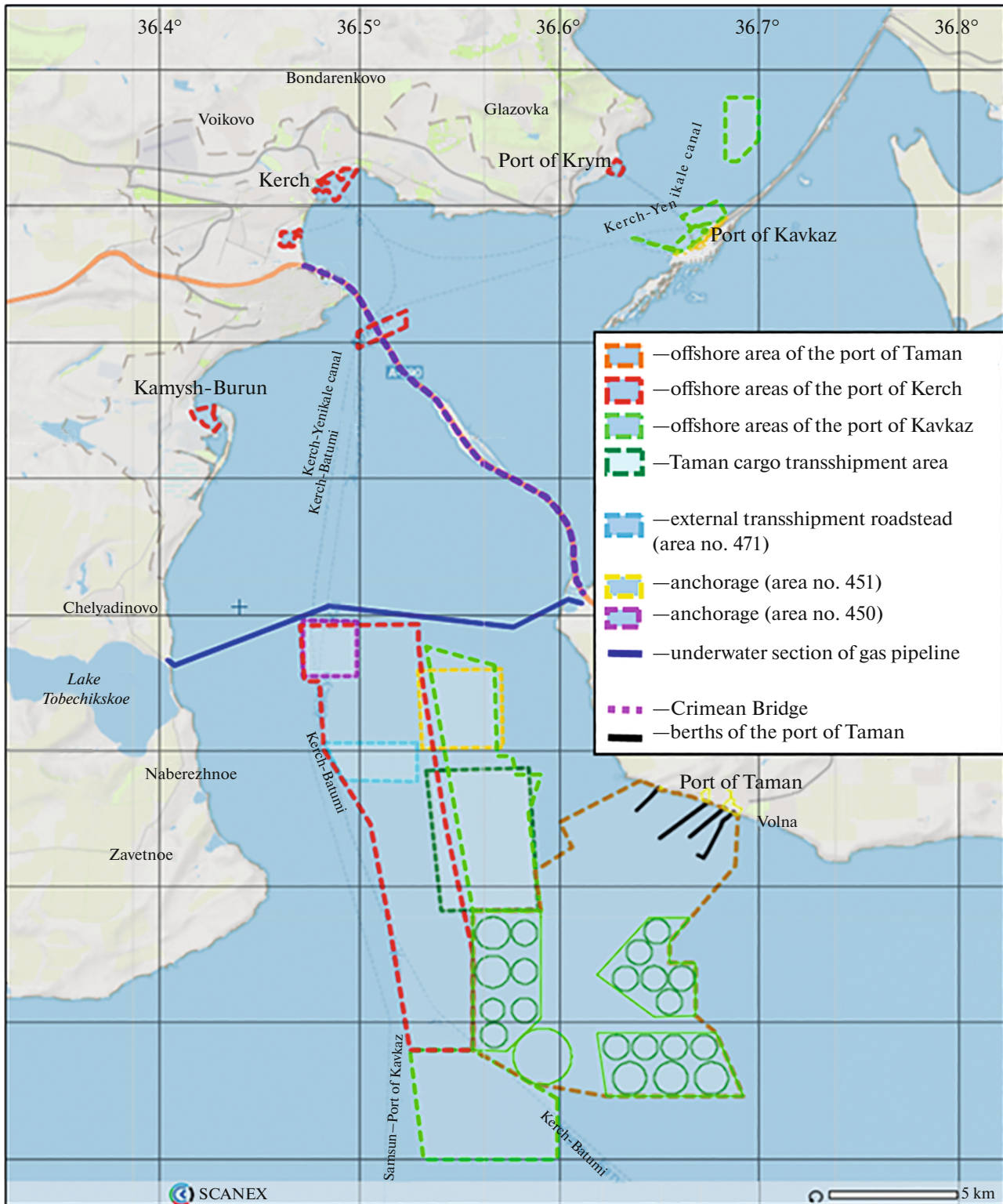


Fig. 1. Scheme of the Kerch Strait with offshore areas such as ports, prestrait anchorages, and cargo transshipment areas where oil spills are highly likely to appear.

imagery available in the databases (Ivanov et al., 2021).

It is well known that, as soon as oil or another oily substance gets onto the sea surface, oil slicks form; since they smooth small-scale wind waves, they are recognized in the SAR images (Alpers and Espedal, 2004; Ivanov, 2007). The smooth sea surface reflects the incident electromagnetic waves away from the radiation source (the radar antenna). Reflected from the smooth sea surface, radarwaves mostly do not return to the SAR; therefore, the region of an oil slick appears as a dark patch in the SAR image. This makes SAR imaging most informative for the search for oil pollution when compared to optical remote sensing. Moreover, for SAR imaging, the cloudiness or absence of sunlight is not a restriction, like for the observations in the visible bands.

Oil pollution means a set of liquid oily substances that entered the marine environment as a result of human economic activities and are capable of forming oil slicks on the sea surface (Terleeva and Ivanov, 2017). First and foremost, they are light oil and petroleum products (different kinds of fuel: fuel oil, diesel oil, kerosine oil, gasoline, lubricants, and liquid petroleum-based feedstock), as well as oily substances transported in bulk, including vegetable oils. They include liquid shipboard wastes formed as a result of ship's "life activity." In fact, they are the mixtures of petroleum products and different shipboard wastes with water, e.g., wastes (residual fuel, used fuel and lubricants), oil-contaminated (bilge) water, ballast and wash waters, onboard wastes (vessel sewage and food-unit waters), fish processing wastes, etc.; they form ship-made spills in the sea. In contrast to pollution with crude oil and heavy petroleum products, these contaminations usually form thin slicks on the water that look metallic/rainbow-colored at the origin point, and as sheen at the periphery, while their lifetime on the sea surface is several hours (Ivanov, 2007).

The construction of Crimean Bridge, the Taman port complex (PC), the active navigation, the cargo transshipment, and other technology-related processes exert a strong impact on the state of its offshore area. Therefore, during the monitoring of the Black Sea conducted by the Shirshov Institute of Oceanology, Russian Academy of Sciences (IO RAS) and SCANEX Group, the strait was given special attention; see IO RAS (2016, 2021), SCANEX (2019a, 2019b, 2019c, 2020a, 2020b). In this regard, the RS data accumulated over the five-year period (since 2017) required a careful analysis and interpretation. In addition to SAR imaging, the remote sensing monitoring of the Kerch Strait and the adjacent areas implied the gathering of all free satellite data, including images of high and average resolution from Sentinel-2, Landsat-8, Spot, WorldView satellites, etc., as well as all other information that makes it possible to identify the slicks detected in the RS data. This work presents the results of analy-

zing the data of oil spills monitoring with SAR in the Kerch Strait from January 2017 to December 2021, which allowed us to identify the main areas of concentration of oil pollution, the pollution sources, and tendencies in their dynamics.

DATA AND METHODS

For monitoring the Kerch Strait marine area and the subsequent analysis, we used the SAR images from the European Sentinel-1A and Sentinel-1B satellites. The images were accessible after being uploaded to the real-time geoportal of SCANEX Group from the Copernicus Open Access Hub database of the European Space Agency as GRD SAR products. For the monitoring, they were used in the IW (Interferometric Wide) mode with the vertical polarization of the signal and the resolution of 10 m. The area of interest was selected so that it could cover the offshore area of the strait itself and the prestraits in the Sea of Azov and the Black Sea that are related with the strait genetically in terms of the pollution.

The manual interpretation (or the extraction of valuable information from the SAR images using the human visual system) consists of an expert identifying the SAR areas corresponding to the patches of oil spills in terms of their features. Such features are determined by the formation and dynamics of the slicks of oil/petroleum products on the sea surface and, consequently, the features of their appearance in the SAR images (Ivanov, 2007; Alpers and Espedal, 2004; Ivanov, 2011; Alpers et al., 2017). They include the shape, sizes, the type of an edge, contrast, and similar information. The main features in the case of visual interpretation of signatures is the tone (brightness), the image texture, and contrast against the background of the surrounding sea surface. Not the least of the factors in recognizing oil slicks is considering the wind conditions, in particular the wind direction and speed and, if possible, the currents, as well as the context information (closeness of ships and shipping routes, prestrait anchorages, ports, oil and gas platforms, etc.).

The further interactive processing and analysis of the SAR images are usually conducted in stages using the intermediate or additional results/data for obtaining more reliable information and verification of the results of visual interpretation. Nevertheless, the manual interpretation supported by the other data and information remains a common method of analysis (Ivanov, 2007).

To detect oil slicks, we used spaceborne SAR images from the Sentinel-1 SAR satellites. The oils slicks were preliminarily detected and identified in them by the visual method with respect to the context environment. Further, the interactive analysis was performed using the GeoMixer web-GIS application (<http://geomixer.ru>), where the available georeferenced SAR images were analyzed using the additional information about the particular area. For the analysis

and identification of the oil slicks detected in the SAR images, we used a geoinformation (GIS) approach (Ivanov and Zatyagalova, 2007), which implies the use of a set of additional information, including, oceanographic, hydrometeorological, navigational, and industrial ones (in particular, the data from the nautical maps, bathymetry, oil-and-gas complex, real wind conditions), as well as the integrated information about the water basin, which characterize the location of an oil slick, and the real-time ship environment from the data of the automatic ship identification system (AIS). All this was available for analysis, since the SCANEX geoportals provide the communication with external layers and geospatial data from the international geoinformation services and databases via WMS (Web Map Service) protocol (GIS approach and the capabilities of the GeoMixer application are also described in detail at: <http://geomixer.ru>, Ivanov and Zatyagalova (2008), Ivanov (2011), Ivanov et al. (2014)).

The interactive analysis using the GIS approach included the following sequential operations in the GeoMixer web-GIS mapping application:

(1) A visual interpretation of variety of slicks, the selection of candidates for oil slicks, and their interactive analysis, including using specialized computer modules,

(2) A final expert assessment of the slick nature and determination of the position (coordinates) of the slick source,

(3) The identification and vectorization of both individual different-time slicks and their groups with the subsequent creation of vector layers suitable for import into the GIS project,

(4) The spatiotemporal analysis of all available SAR imagery,

(5) A comparison of obtained results with the available ground truth data and materials.

Figure 2 shows the typical oil slicks/spills detected in the Kerch Strait. The oil spills for each year were mapped using the GIS approach by integrating all layers with the slicks detected in each SAR image obtained throughout a year. As a result of the GIS approach, the main sources of oil pollution (Fig. 2), especially in the strait, in the summary maps of oil pollution (Fig. 3) obtained over a long time are detected almost automatically (Figs. 4a, 4b).

Besides an summary map of oil pollution constructed based on the analysis of the SAR image data over five years (Fig. 3) makes it possible to identify the regions of the largest concentration of oil slicks and provides information about pollution sources, as is shown in Fig. 4a.

POLLUTION SOURCES OF THE KERCH STRAIT

In 2017–2021, oil slicks were detected in the Kerch Strait and the adjacent prestraits on 481 SAR images.

A total of 2597 oil slicks with an area of 1120.4 km² were found.

As was repeatedly mentioned, the active navigation and cargo transshipment are among the main sources of pollution in the Kerch Strait marine area (Ivanov et al., 2021; IO RAS, 2016; SCANEX, 2019c). Oil spills can form on the sea surface as a result of the discharge of ballast, oil-contaminated bilge waters, or other liquid wastes, as well as due to leakages during the transshipment of different oily products at the prestrait anchorages and in the cargo transshipment areas.

During the analysis of the distribution maps of oil pollution in the strait, several areas were identified with the highest concentration of oil slicks that in fact, pollution sources; in descending order, they are the port complex of Taman, the cargo transshipment areas in the strait and prestrait, the Crimean Bridge, anchorages in the prestraits of the Sea of Azov and the Black Sea, the port of Kerch, etc. We consider them in detail.

The port complex of Taman. The port of Taman (and its port complex) is one of the largest ports of the Black Sea basin in regards to cargo turnover and the largest port in this offshore area, with a share of ~13–15% in the total cargo turnover of the Azov-Black Sea basin (Association of marine trade ports, 2021). It is a berthing complex consisting of four offshore berths from 1.7 to 2.4 km long that belong to OTEKO-Portservis (berth no. 1), EFKO Group of Companies (no. 2), Tamaneftgaz (no. 3), and Togliattiazot (no. 4), respectively (Taman sea port, 2021); see Fig. 1. The port complex has a total capacity of about 55 million t per year, and the transshipment of petroleum products, liquified gases, bulk food products, and other bulk cargo is conducted at its berths (Taman sea port, 2021).

The above companies and their enterprises carry out the onshore loading/transshipment of dry and liquid cargoes, including petroleum products, liquified gas, oil-raw stock, and similar substances capable of forming oil slicks on the sea surface. Works on the deepening of operational offshore areas and the approach channel to the Taman transshipment complex were completed in 2012. The construction of the Taman terminal for bulk cargoes of OTEKO-Portservis started in 2014, and it was put into operation in March 2019. The dredging operations were continued due to the development of the operational waters.

As early as 2016, it was noted that oil slicks near the port complex berths were recorded in the SAR and optical images (Evtushenko, 2016). It is quite evident that the oil pollution revealed here (Fig. 4b) is caused by transshipments and loading in bulks, as well as by leakages/discharges from ships during shipboard operations; they were observed primarily at berth no. 3; the largest oil slicks reached 3–3.5 km². The oil slicks in this area were observed quite frequently: every month, in each second or third image under favorable wind conditions, and the area of the oil slicks near the port complex varied from 0.1 to 0.6 km² on average.

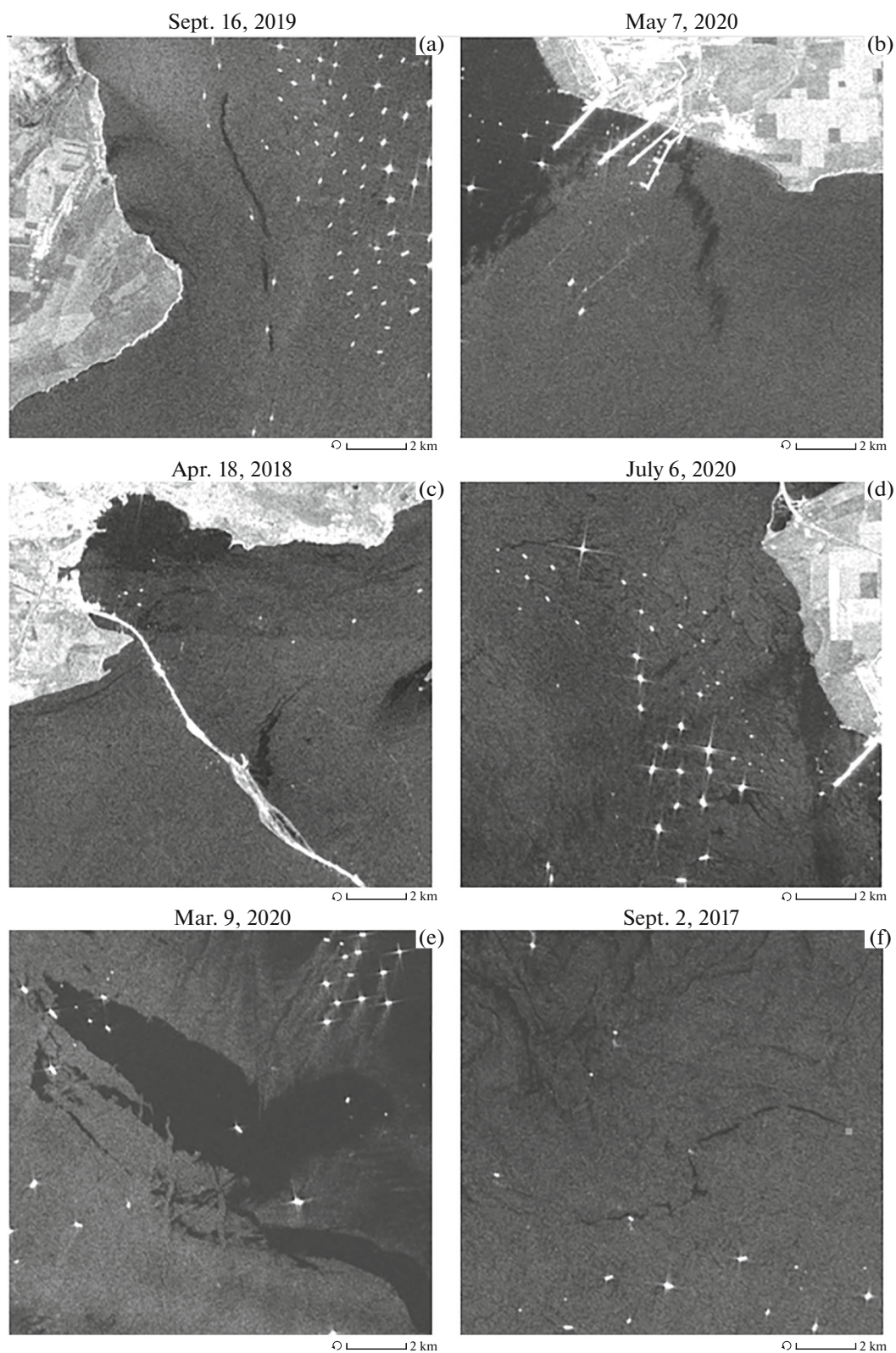


Fig. 2. Typical oil pollution of the Kerch Strait and the prestrait recorded in the SAR images: (a) ship-made spill in the main shipping lane, (b) large spill at the offshore berths of the port of Taman, (c) technogenic oil pollution near Crimean Bridge, (d) numerous ship-made spills at the cargo transshipment anchorages in the strait, (e) large ship-made spill at the prestrait anchorage in the Black Sea, and (f) natural seep manifestation (gray square is the source). ©ESA.

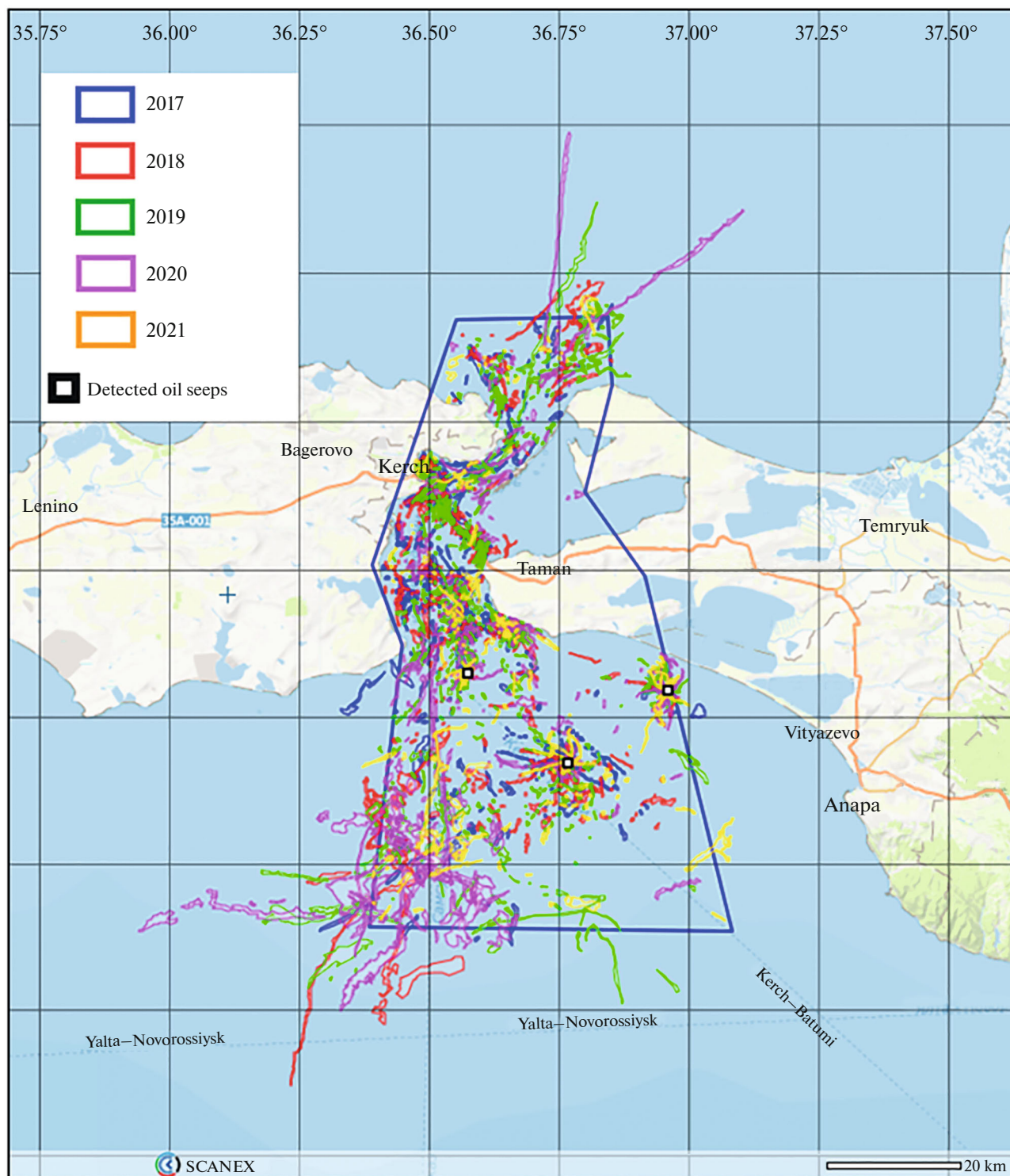


Fig. 3. Summary map of oil spills detected in the Kerch Strait and the adjacent offshore areas during the satellite monitoring in 2017–2021.

Cargo transshipment areas. The cargo transshipment areas are located in the Kerch Strait offshore area no. 451 and westward of the Taman loading complex in the Kerch prestrait (Fig. 1). In these areas, transshipments of different liquid and loose sub-

stances are conducted from the river–sea type ships into sea tankers and dry cargo carriers for further transportation (IO RAS, 2016; Ivanov et al., 2021). The petroleum product transshipments in the open sea are quite often accompanied by discharges and spills that

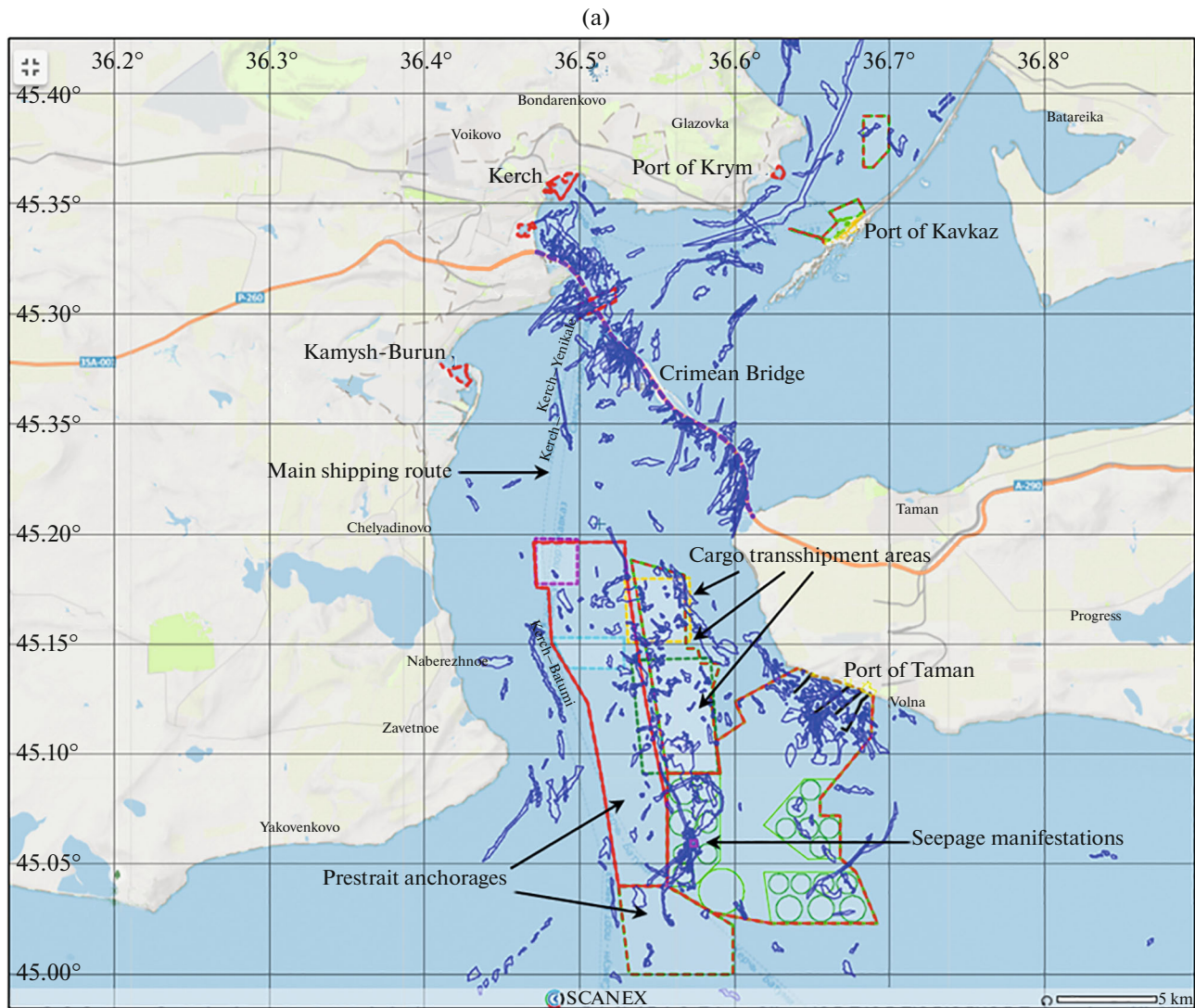


Fig. 4. (a) Example of revealing pollution sources: superposition of the summary map of oil spills for 2019 with the boundaries of the ports, roadsteads, and prestrait anchorages using the GeoMixer application. (b) Sketch-map of oil spills (contours) in the offshore area of the Taman berthing complex detected during the SAR monitoring in 2020–2021. The largest concentration of oil spills was recorded at EFKO Group' berth.

may form oil pollution and were quite often recorded in the SAR images as small round or elongated slicks. The slicks detected here were primarily small (the largest one is about 3 km^2); nevertheless, they were often seen in large quantities, which is shown in the summary map (Fig. 3) and in Fig. 4a. Moreover, it was noted that the largest concentration of oil pollution in the area of this segment is accounted for by the transshipment anchorage area of the Port of Kavkaz, where the amount of pollution is relatively stable every year and does not tend to increase. The area of oil slicks here did not largely exceed 1 km^2 .

Azov and Black Sea prestrait anchorages. These anchorages are located in the prestraits of the Sea of Azov and the Black Sea. Ships are waiting for permission to pass through the channel there. The spills dis-

covered are not large; however, sometimes, especially since the fall of 2019, they have covered significant areas (for example, the spills of 25 km^2 on the Sentinel-1B SAR image on December 15, 2019 and 26 km^2 on the Sentinel-1A SAR image on July 29, 2020) and even larger areas (e.g., a spill with an area of about 50 km^2 observed on the Sentinel-1B SAR image of March 9, 2020; Fig. 2e). It is difficult to suppose that these spills were formed by crude oil/heavy oil products; they were likely formed by shipboard wastes with oil residues, which is typical of liquid wastes (Terleeva and Ivanov, 2017) that form such large oil slicks under favorable wind conditions.

The question concerning whether these discharges are legal or not remains open. However, it is known that the discharges of waters containing petroleum

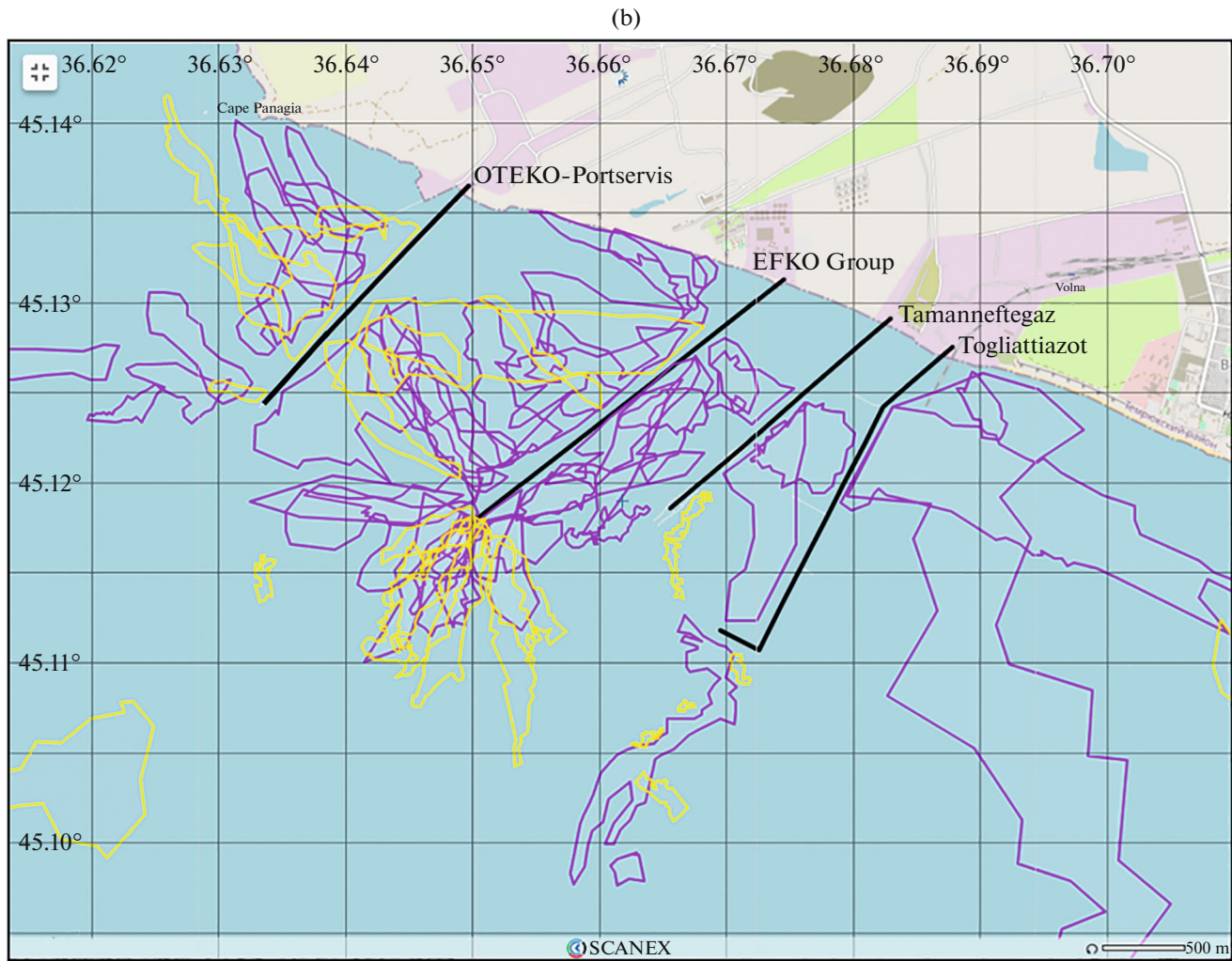


Fig. 4. (Contd.)

products in these areas should be governed by the international environmental conventions, e.g., MARPOL (MARPOL, 2008). This tendency can also be explained by the fact that the Black Sea prestrait anchorage is located outside the territorial waters of Russia, where the tight restrictions of the conventions are not applied. Therefore, the appearance of large oil slicks can be considered a breach of the convention on environment protection due to the inappropriate control of navigation by environmental protection agencies.

Crimean Bridge. The Bridge is a transport passage through the Kerch Strait connecting the Kerch and Taman Peninsulas, one of the most important socio-economic entities in Russia. When it was under construction, mainly in 2018 and 2019, numerous oil slicks were observed in its vicinity (Fig. 5). They occurred due to the release into the marine environment of fuel and lubricants residues from vehicles and machinery used during the construction; right after the construction

they ended, and appeared only those caused by storm drains from the roadway (SCANEX, 2019b).

After that the situation became stable, and the pollution volume tended to decrease significantly; after the bridge was constructed, since 2020, the number of oil slicks was recorded to sharply decrease in the offshore area adjacent to the bridge, which is confirmed by the monitoring results and, in particular, the maps in Fig. 5. Here, the typical oil pollution is small slicks (up to 1–1.5 km in length, with an area of 0.1–0.6 km²) that adjoin the bridge from the north and the south.

The Kerch Strait ports. Besides the Taman port complex, the Kerch Strait offshore area includes the ports of Kerch, Kavkaz, Krym, and Kamysh-Burun (Fig. 1). Among them, the first two ports are the largest in terms of the number of oil spills; the largest number of oil slicks was recorded in Kerch Bay, although in 2020 their number was the smallest. The areas of detected pollution in the Kerch seaport offshore area vary from 0.01 to 2 km². The genesis of pol-

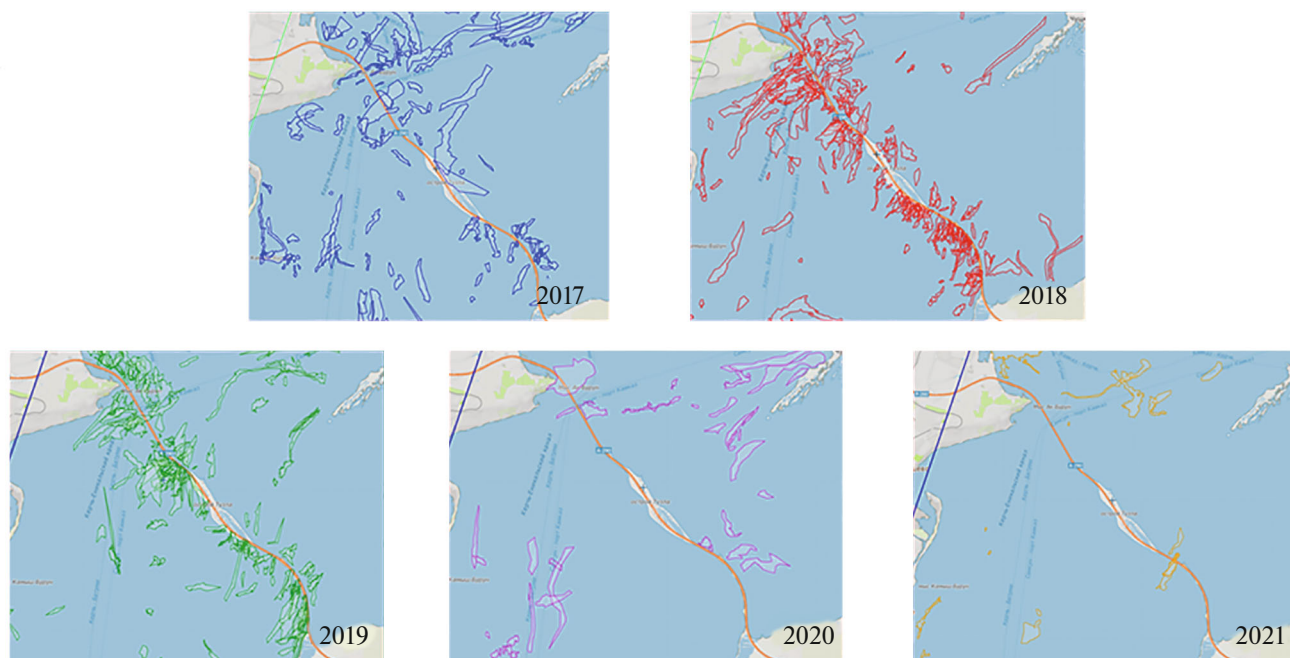


Fig. 5. Oil pollution near Crimean Bridge from January 2017 to December 2021 from the data of SAR monitoring.

lution in the bay and in the adjacent offshore areas is the most diverse: from different leaks at the port to discharges of industrial waters from the systems of large industrial enterprises in Kerch. In the offshore area adjacent to Chushka Peninsula, in the waters of Port of Kavkaz, there were far fewer oil slicks, with the maximum number recorded in 2017 and 2020; they were small in size with an area from 0.1 to 1.5 km². The port of Kamysh-Burun was the least polluted.

The main shipping lane. The major navigation route in the strait is through Kerch-Yenikale Canal, being the shipping route from the Black Sea to the Sea of Azov and back (Fig. 1). The channel is necessary because of the shallow depth of the strait; its average values are only 4 m.

Its capacity reaches 100–150 ships per day that carry, in particular, crude oil and petroleum products, which may cause oil spills along this shipping lane. Therefore, spills from the ships characterized by the elongated shape and located along the fairway were recorded here sometimes. According to monitoring data, their average length did not exceed 7–8 km. Some ship-made spills began already in the open sea, even outside the territorial waters, and ended in the strait. For example, on March 8, 2019, a spill in the Azov part of the region of interest of about 30 km long was detected. The longest ship-made spills were detected in March 2020 along the shipping lane from the Kerch Strait to the Black Sea; their length varied from 15 to 22 km. The number of ship-made oil spills in the region of the strait main shipping lane was recorded to gradually increase. We also note that, after Crimean

Bridge was constructed, this navigation route remained the only one, and since then all ships pass only through the main channel; as a result, the largest oil spills appear on the lane or nearby.

Natural seepage manifestations. Except for the ship-made oil spills, during monitoring we detected places of oil slick concentration beyond areas of human-induced load. Natural oil seepage at the sea bottom creates groups of oil slicks on the sea surface or seep manifestations that are related to the same source (usually the eruptive structures of the seafloor, such as cold seeps). Hence, the spatiotemporal grouping of oil slicks detected in the series of SAR images near one point unanimously indicates an underwater source at the bottom (Ivanov et al., 2020). If there are no sunken ships, underwater wastewater outlets, or damaged pipelines at this place, then the source is for sure natural.

The examples of seep slicks according to the RS data are presented in Fig. 6; the individual slicks were 0.3–12 km long with an area of 1–2.5 km². According to the results of the preliminary analysis of annual summary maps using the GIS approach, it was established that natural seepage manifestations can be the sources of these slicks (in Figs. 3, 7–9), since there is no information about shipwrecks or pipelines laid through this area.

The more detailed analysis allowed us to identify three clusters of oil slicks forming the fan-shaped structures (Fig. 7). In 2017–2021, these oil slicks were recorded quite frequently in the SAR imagery: every year on 40–70 SAR images. The oil slicks were grouped around the points with the coordinates of 44°56′19″ N

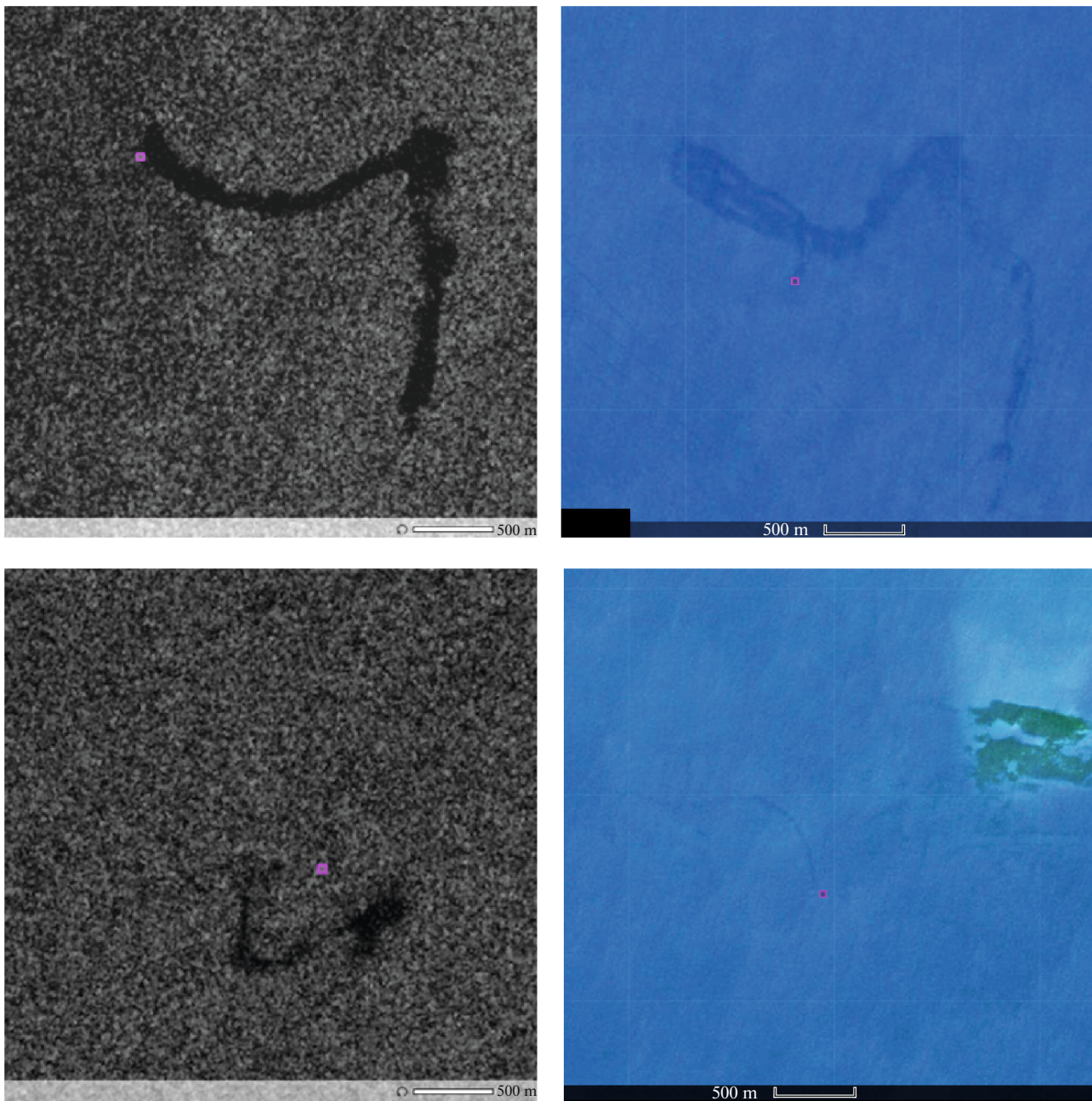


Fig. 6. Quasisynchronous images with seep manifestations no. 1 (on the top) and no. 2 (on the bottom) as of April 13, 2020: in the Sentinel-1B SAR image (03:40 UTC) and the Sentinel-2B optical image (10:33 UTC) (on the right is Maria Magdalene Bank). © ESA.

and $36^{\circ}46'03''$ E (seep no. 1), $45^{\circ}02'08''$ N and $36^{\circ}57'28''$ E (seep no. 2), and $45^{\circ}03'34''$ N and $36^{\circ}34'25''$ E (seep no. 3) and were located on the shallow shelf at depths of 32, 18, and 19 m, respectively (Fig. 8). The detected clusters of oil slicks are found in a well-known region of submarine mud volcanism and gas emissions (Shnyukov et al., 1986; Shnyukov, 2014). In addition, these seepage manifestations are located within the boundaries of the Taman oil-and-gas region, which is characterized by quite high oil and gas potential (Glumov et al., 2014). All this highly likely indicates

the occurrence of underwater sources at the bottom, which are responsible for seep manifestations observed on the sea surface.

Several oil slicks of still unknown genesis were observed sometimes between the Aksenov, Savenko, and Andreev banks (Fig. 8; the location is marked by the ellipsis). Sources of natural seep manifestations are also likely to be located here at a depth of 13–15 m; however, they release oil rather occasionally according to available data.

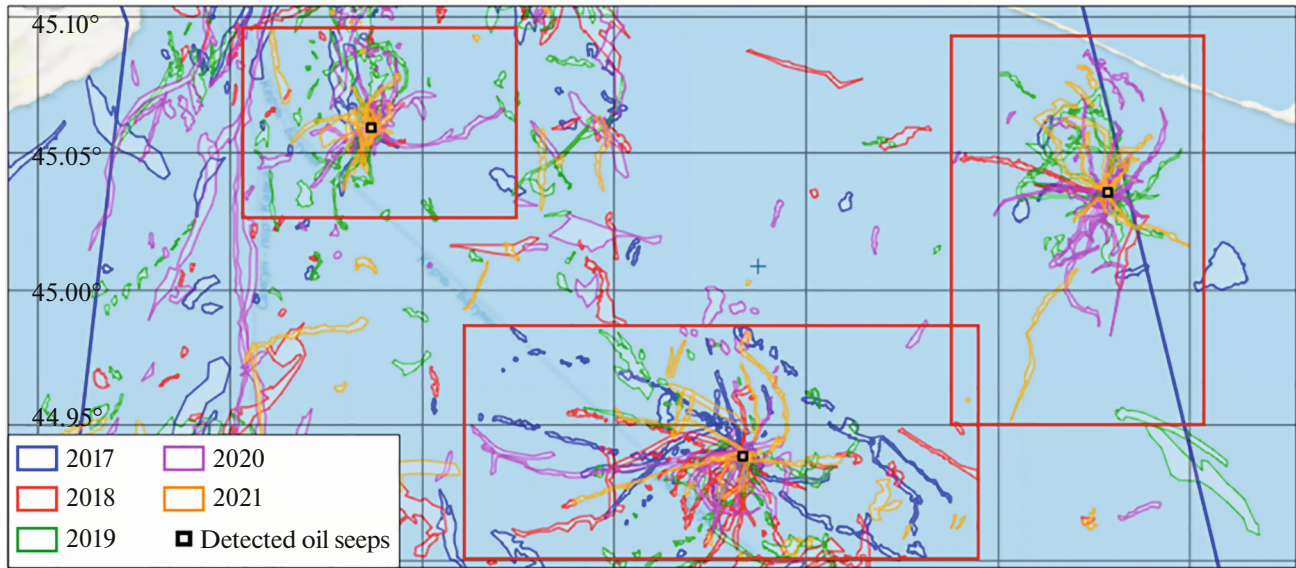


Fig. 7. Summary map of oil slicks marking natural seepage in the Black Sea prestrait based on the data of satellite monitoring in 2017–2021.

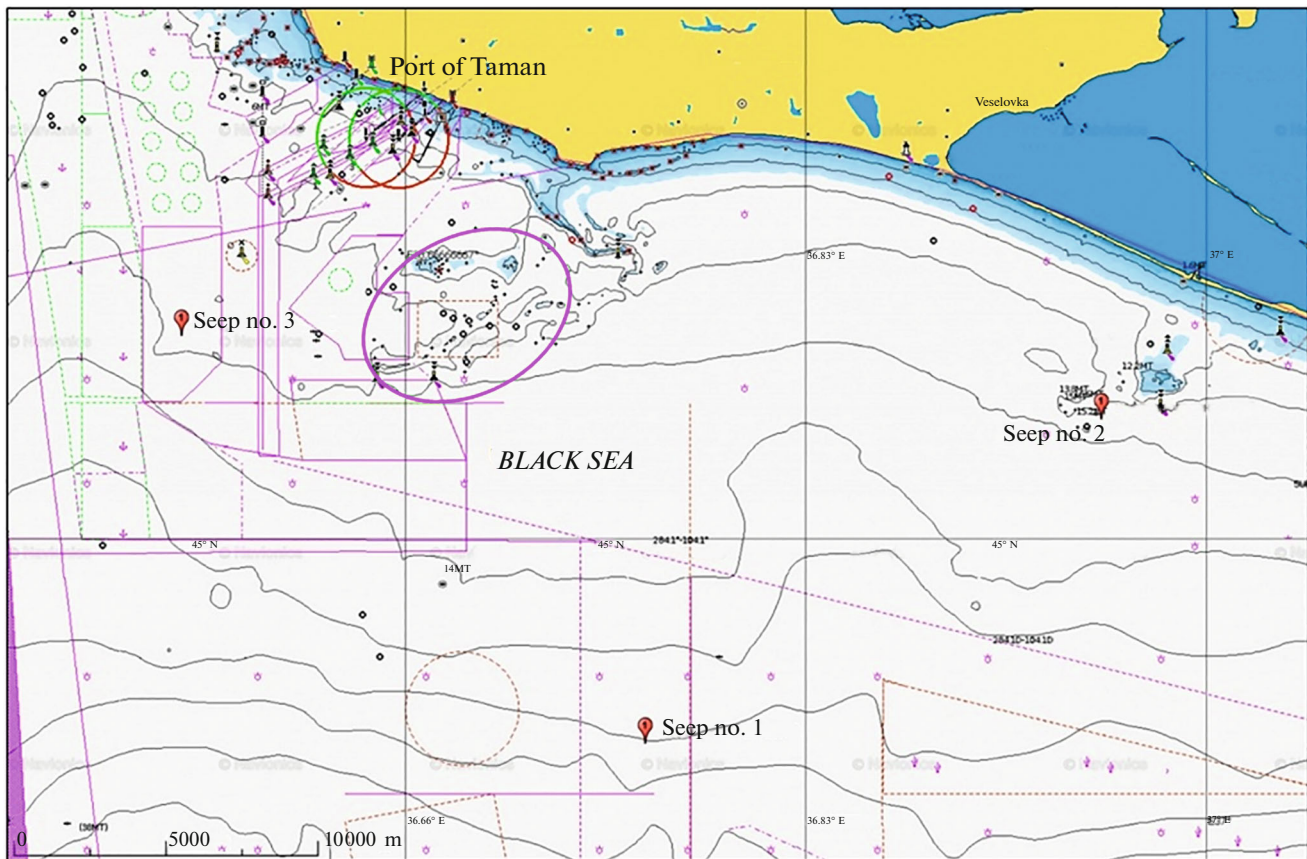


Fig. 8. Position of oil seeps detected during the monitoring on the nautical map; the ellipse designates the area where seepage is also likely to occur (Glazyrin, 2021).

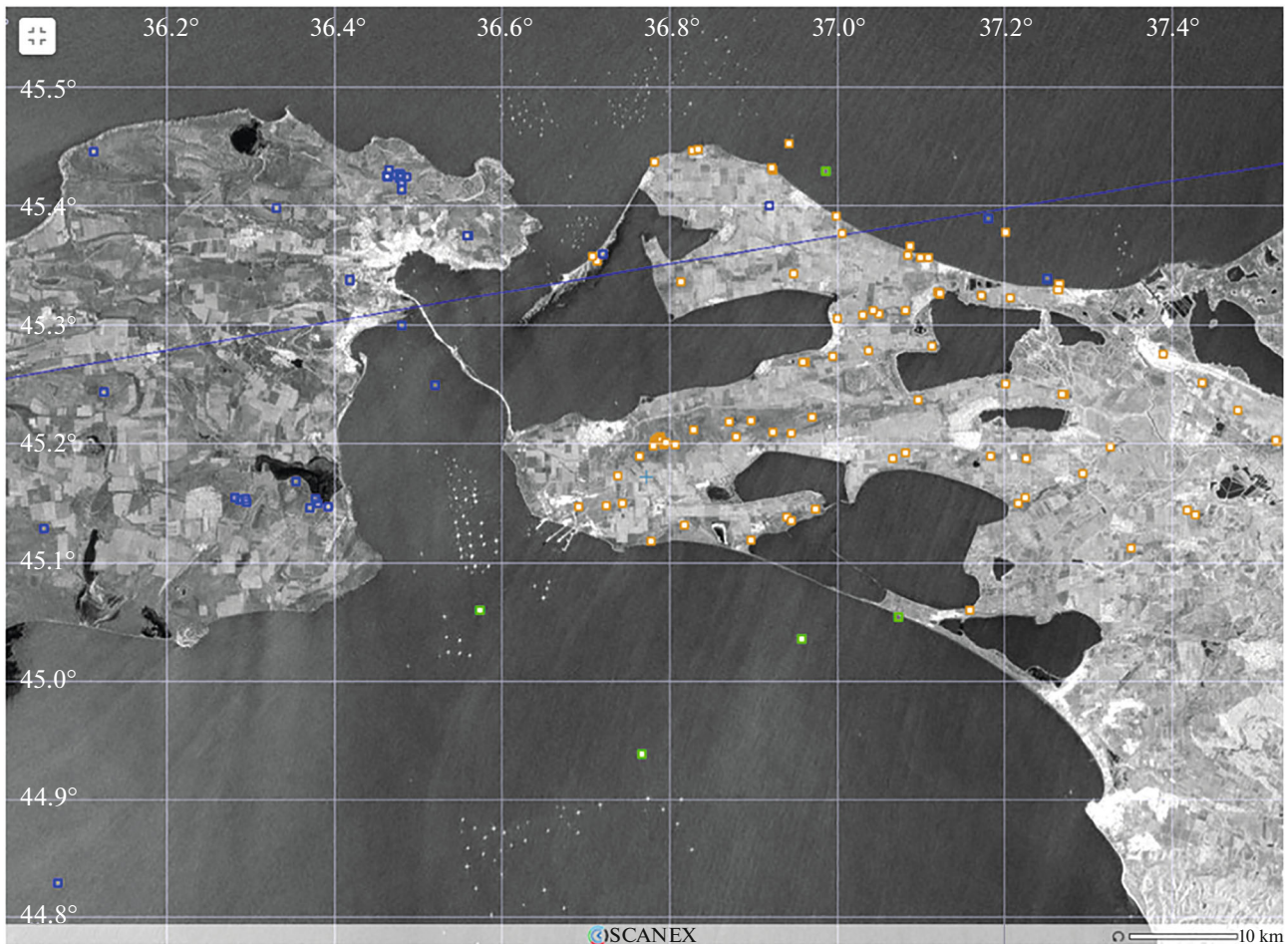


Fig. 9. Newly detected seeps (light green) in the system of the known mud volcanos of the Taman-Azov Region (blue from the data by Shnyukov (2014); light brown is from the database by Podymov (2015)).

As a result, since these seep manifestations are within the Taman oil-and-gas region and the Kerch-Taman mud-volcano region and their manifestations on the sea surface are not far from each other and they often occur simultaneously, we suggest that they belong to the same fluid dynamic system (Fig. 9). It is likely that both the seepage manifestations detected recently in the Sea of Azov and at Bugaz Spit in the Black Sea are also attributed to this system (Ivanov et al., 2020; SCANEX, 2020a, 2020b). The analysis of the available geological–geophysical material led us to conclude that these seepage manifestations may be determined by the existing oil-and-gas content and the processes of petroleum hydrocarbon migration in the sedimentary complex of the northeastern part of the Black Sea basin.

A share of natural seepage in the total number of oil slicks detected and identified during the monitoring is about 11.5% on average (Table 1). The slicks had distinctive shapes, lengths, areas, and contrast, depending on the weather conditions during the SAR imaging of the marine area.

In cold seasons, oil slicks of natural seepage were detected rarely; i.e., they did not appear on the SAR images acquired at a wind speed greater than 5–6 m/s, which is typical for fall and winter. This may indicate seeps of light fractions of crude oil, whose slicks quickly disappear from the sea surface under the action of wind and waves.

CONCLUSIONS

During the five-year SAR monitoring, 2597 oil slicks with a total area of 1120.4 km² were detected in the Kerch Strait. The main sources of oil pollution in the strait have been identified, such as cargo transshipment areas in the strait, the port of Taman with its berthing complex, and anchorages in the Azov and Black Seas prestraits. The ports in the strait and the main shipping lane are of smaller threat, although large spills appear there at times. The Crimean Bridge was one of the pollution sources before 2020, but now it has a minimal effect on the strait ecosystem.

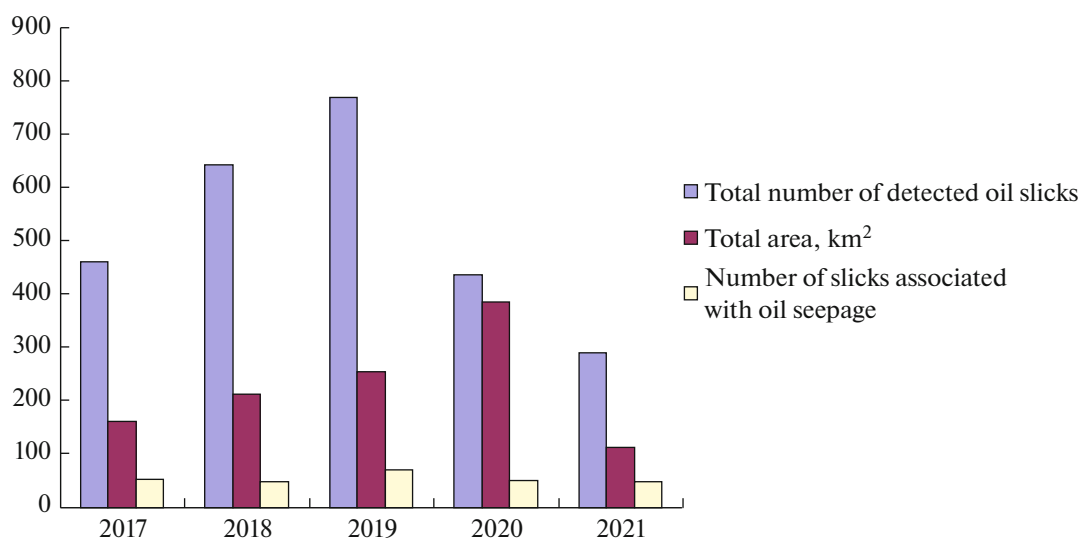


Fig. 10. Overall monitoring statistics for the Kerch Strait and adjacent offshore areas.

Figure 10 presents the five-year monitoring statistics with a tendency toward a decrease in the oil slicks number. It shows that the area of oil pollution was the largest in 2020, which can be explained by large spills from the ships that occurred at the Black Sea anchorage outside the territorial waters of the Russian Federation. Nevertheless, despite the revealed tendency to a general decrease, the problem of oil pollution in the strait has not been solved yet.

During monitoring, the tendency toward a decrease in the total number of oil slicks after 2019 may indicate the creation of a more favorable ecological environment in the strait, especially after the construction of the Crimean Bridge was completed. However, every year the total area of oil pollution gradually increases; moreover, oil slicks of a larger area (>25 km²) began to appear primarily in the Black Sea prestrait, in the anchorage area in the open sea outside the Russian territorial waters. In our opinion, the question arises about the legality of this anchorage area, where the restrictions of the MARPOL convention are not

applied and control by the Russian environmental organizations is unnoticeable or ineffective.

As for the product types that form the oil spills, it is quite evident to suppose that in the cargo-transshipment area petroleum products and oils transported in bulk are spilled into the water; at the PC Taman berths, they are both the residues of fat-and-oil products and shipboard wastes with petroleum products. On the shipping lanes and at prestrait anchorages, they are different shipboard wastes (ballast/wash/oil-contaminated (bilge) waters, waste waters, other liquid wastes containing petroleum products, oils and fats).

The sources of natural seep manifestations were detected for the first time in the Black Sea prestrait, which are natural phenomena that create a hydrocarbon background and needs to be taken into account in the general assessments along with the rest of the sources. Preliminary analysis showed that their existence does not contradict the modern geological–geophysical knowledge of the Crimea-Taman Region nature.

Table 1. Number and share of natural seep manifestations in the total number of detected oil slicks during the period of monitoring

Year	Total number of oil slicks	Number of seep manifestations	Total area, m ²	Share of natural seepage, %
2017	460	52	158.9	11.3
2018	642	46	211.9	7.2
2019	770	70	253.2	9.1
2020	435	50	385	11.5
2021	290	46	111.4	15.9
Average				11.0
Total	2597	264	1120.4	

It is quite evident that in the early 21st century the strait was again affected by extremely intense human impact, which caused a significant change in its entire ecosystem. The negative effect of the pollution on the strait waters in the form of crude oil, petroleum products, and other oily substances is also obvious. The results lead us to a general conclusion about the high degree of oil pollution in the offshore area of the Kerch Strait with a tendency to stabilize the current situation. Despite the fact that oil pollution—petroleum and oil products—remain on the sea surface from several hours to 1 day, or, e.g., until change of wind conditions, their residues do not disappear without a trace but are accumulated in the bottom sediments, water in the dissolved form, and in the sediments of coastal zone.

To sum it up the efficiency of SAR monitoring to assess the ecological status of areas with a high human-induced load such as the Kerch Strait and the adjacent marine areas has been shown again. Using SAR observations, it is possible to monitor the pollution sources in real-time mode, including shipping, prestrait anchorages, cargo transshipment areas, ports and other offshore areas), as well as compare the real-time RS data with the geospatial data from the open bases and archives. Moreover, it is quite evident that the constant SAR monitoring of the Kerch Strait is extremely necessary and should be conducted continuously, while the access to its results should be provided to all individuals and organizations concern.

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