

# **Radar Monitoring of Anthropogenic Pollution of the Caspian Sea with Petroleum Products**

## **Introduction**

Environmental issues of the Caspian Sea are related to water pollution as a result of oil and gas production and transportation on the continental shelf, the ingress of pollutants from the Volga and other rivers flowing into the Caspian Sea, and the daily activities of a number of cities, such as Makhachkala, Kaspiysk, Derbent, etc.

A significant part of pollution, including containing oil and oil products, forms quite strong film-type buildups on the sea surface. Longevity of such film-type pollution depends on its composition and hydrometeorological conditions (wind, wave disturbance, currents).

## **Remote Monitoring Methods**

In order to detect film-type pollution on the sea surface, modern instruments of broad-band Earth remote sensing (ERS) are used (UV, visible, near- and far-infrared, and microwave). However, when using satellite instruments of ERS, the most efficient are radar techniques, as they are of the all-weather category. This means that the quality of the information in radar images (RIs) does not depend on the level of illumination and cloud coverage.

Capability to detect film-type pollution on the sea surface from space in the active microwave range is determined by the draping effect that films have on the high-frequency content of the sea disturbance. Presence of films on the disturbed sea surface results in reduction of radar scattering compared to clean water, and in sharp decrease of brightness in radar images.

At the same time, smoothing of the sea surface can result not only from oil-containing films, but also from various processes occurring in the surface layer of the sea and the near-water atmospheric layer. Calm areas, rain cells, floating aquatic plants, organic films of biogenous origin, and other objects can create similar surface phenomena in RIs, which can be easily confused with oil spillage patterns.

For that reason, during detection and decoding, the sections that differ in brightness from the background sea surface are highlighted in the RIs. Then, the procedure includes interactive analysis, identification and classification of the detected spots-slicks followed by highlighting film-type and oil pollutions, based on analysis of the form, size, texture, contrast, etc. Other factors and additional information, such as geographical, hydrometeorological, navigation and ship, and satellite data are also considered.

For this work, we use the CLASS.PRO analytics platform (<https://class-cloud.ru/products/class>). Its interface is shown in Fig. 1.

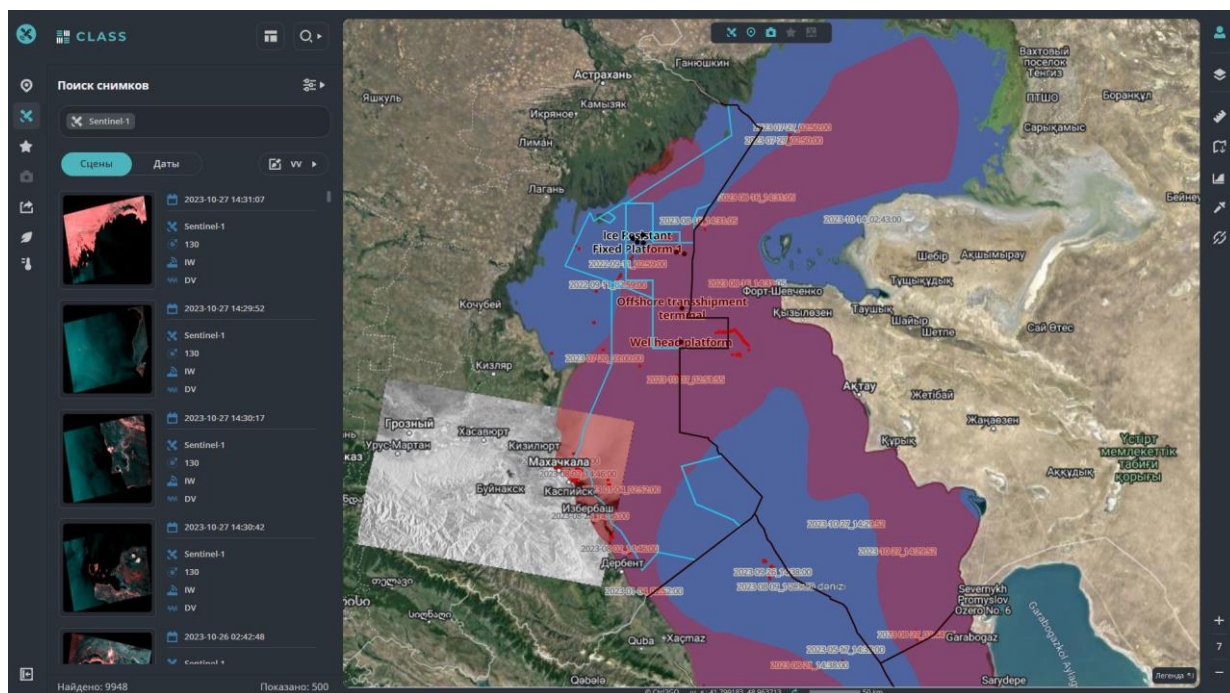


Fig. 1. Interface of the CLASS.PRO web-GIS portal

## Performed Operations

The region covered by the monitoring for oil pollution includes the northern part of the Caspian Sea area. The main data used are RIs obtained by the Sentinel-1 radar satellite. Operations started in the latter half of July 2023. From 20.07. to 30.11.2023, 260 RIs were obtained, processed, and analyzed in total; 71 spots/groups of spots were detected and highlighted in them (Fig. 2, Table 1).

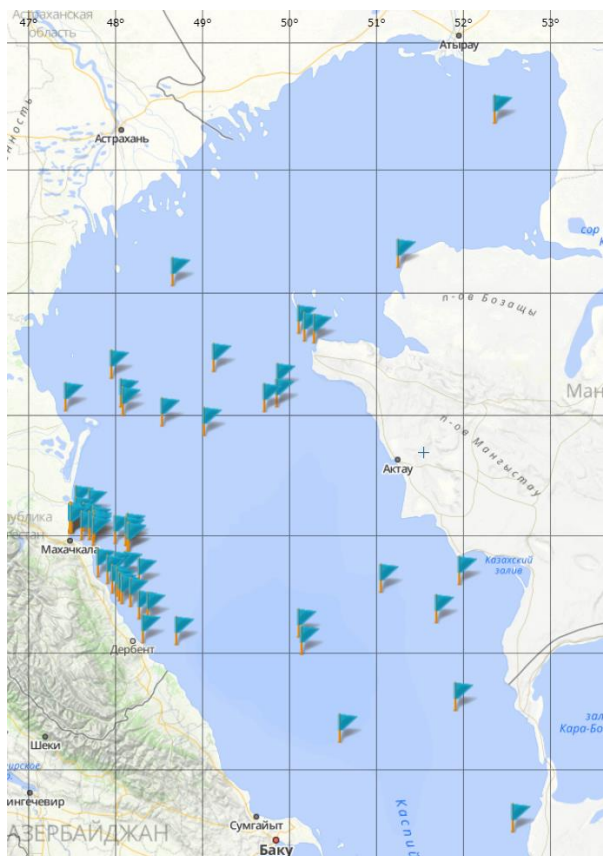


Fig. 2. Integral map of oil-containing film-type pollutions detected during monitoring from 20.07.2023 to 30.11.2023.

Table 1. Identified oil-containing film-type pollutions detected during monitoring from 20.07.2023 to 31.10.2023.

Item	Date	Time (UTC)	Territorial waters	Area (sq.km)	Coordinates of the center (wgs 84)	Source of pollution
1	20.07.2023	3:00:00	Russian Federation	2.18	43°58'58"N, 48°4'24"E	Ship Discharges
2	20.07.2023	3:00:00	Russian Federation	0.55	44°3'14"N, 48°3'27"E	Ship Discharges
3	20.07.2023	3:00:00	Russian Federation	0.63	43°1'22"N, 47°29'7"E	Onshore facility
4	20.07.2023	3:00:00	Russian Federation	0.10	43°0'35"N, 47°28'24"E	Onshore facility
5	20.07.2023	3:00:00	Russian Federation	0.18	43°0'3"N, 47°29'2"E	Onshore facility
6	21.07.2023	14:46:00	Russian Federation	3.35	43°4'19"N, 47°32'33"E	Not determined
7	27.07.2023	2:51:00	Kazakhstan	0.08	44°20'57"N, 49°7'25"E	Not determined
8	02.08.2023	14:46:00	Russian Federation	12.37	42°16'38"N, 48°16'2"E	Ship Discharges
9	02.08.2023	14:46:00	Russian Federation	1.38	42°59'33"N, 47°44'1"E	Ship Discharges
10	02.08.2023	14:46:00	Russian Federation	0.15	42°55'56"N, 47°45'1"E	Ship Discharges
11	02.08.2023	14:46:00	Russian Federation	0.80	42°57'21"N, 47°44'57"E	Ship Discharges
12	02.08.2023	14:46:00	Russian Federation	0.22	42°57'1"N, 47°44'19"E	Ship Discharges

13	02.08.2023	14:46:00	Russian Federation	2.31	42°54'2"N, 47°43'50"E	Ship Discharges
14	02.08.2023	14:46:00	Russian Federation	0.37	43°1'9"N, 47°37'31"E	Ship Discharges
15	09.08.2023	14:37:00	Azerbaijan	2.80	41°58'40"N, 50°8'7"E	Ship Discharges
16	10.08.2023	2:36:00	Turkmenistan	2.86	40°26'23"N, 52°33'31"E	Ship Discharges
17	13.08.2023	3:00:00	Russian Federation	12.35	42°57'8"N, 47°36'11"E	Not determined
18	20.08.2023	2:51:53	Russian Federation	0.10	43°0'39"N, 47°28'21"E	Onshore facility
19	20.08.2023	2:51:53	Russian Federation	0.22	43°0'6"N, 47°28'53"E	Onshore facility
20	21.08.2023	14:38:00	Russian Federation	0.15	42°29'37"N, 47°57'32"E	Not determined
21	21.08.2023	14:38:00	Azerbaijan	2.22	41°12'59"N, 50°34'29"E	Ship Discharges
22	21.08.2023	14:38:00	Kazakhstan	0.13	44°3'18"N, 49°50'51"E	Not determined
23	21.08.2023	14:38:00	Kazakhstan	0.11	44°10'56"N, 49°51'19"E	Not determined
24	25.08.2023	3:00:19	Russian Federation	0.19	43°0'4"N, 47°28'57"E	Onshore facility
25	25.08.2023	3:00:19	Russian Federation	0.39	43°1'42"N, 47°28'35"E	Onshore facility
26	25.08.2023	3:00:19	Russian Federation	0.04	43°0'35"N, 47°28'22"E	Onshore facility
27	26.08.2023	14:47:00	Russian Federation	1.85	44°17'43"N, 47°56'48"E	Not determined
28	26.08.2023	14:46:00	Russian Federation	0.06	43°0'17"N, 47°28'27"E	Not determined
29	26.08.2023	14:46:00	Russian Federation	0.48	42°34'30"N, 47°53'47"E	Not determined
30	27.08.2023	2:44:06	Kazakhstan	4.08	41°29'18"N, 51°53'51"E	Ship Discharges
31	01.09.2023	2:51:54	Russian Federation	1.11	43°7'59"N, 47°41'41"E	Ship Discharges
32	06.09.2023	2:59:00	Russian Federation	0.15	45°2'56"N, 48°38'40"E	Ship Discharges
33	06.09.2023	3:00:00	Russian Federation	0.44	43°0'57"N, 47°29'54"E	Ship Discharges
34	06.09.2023	3:00:00	Russian Federation	0.27	43°0'9"N, 47°28'44"E	Onshore facility
35	06.09.2023	3:00:00	Russian Federation	0.03	43°0'37"N, 47°28'9"E	Onshore facility
36	06.09.2023	3:00:00	Russian Federation	0.20	43°1'8"N, 47°28'2"E	Onshore facility
37	07.09.2023	14:46:36	Russian Federation	0.05	43°9'53"N, 47°32'16"E	Ship Discharges
38	14.09.2023	14:38:01	Russian Federation	0.65	42°3'28"N, 48°41'36"E	Ship Discharges
39	19.09.2023	14:46:00	Russian Federation	0.81	42°57'2"N, 47°41'17"E	Ship Discharges
40	21.09.2023	14:30:42	Kazakhstan	0.39	44°34'53"N, 50°16'20"E	Not determined
41	21.09.2023	14:30:43	Kazakhstan	0.17	44°39'39"N, 50°5'49"E	Ship Discharges
42	25.09.2023	2:52:20	Russian Federation	1.45	42°15'35"N, 48°21'47"E	Ship Discharges
43	26.09.2023	14:38:00	Azerbaijan	14.60	42°7'24"N, 50°6'4"E	Ship Discharges
44	26.09.2023	14:38:00	Russian Federation	0.88	43°53'53"N, 48°31'35"E	Ship Discharges
45	02.10.2023	2:42:48	Kazakhstan	0.02	46°21'13"N, 52°21'17"E	Ship Discharges
46	03.10.2023	14:30:00	Kazakhstan	3.50	44°0'58"N, 49°42'4"E	Not determined

47	07.10.2023	2:51:55	Russia– Kazakhstan border	1.98	43°49'20"N, 49°0'33"E	Ship Discharges
48	08.10.2023	14:38:00	Russian Federation	2.44	42°22'52"N, 48°10'5"E	Ship Discharges
49	13.10.2023	14:47:01	Russian Federation	0.58	44°1'36"N, 47°24'42"E	Not determined
50	14.10.2023	2:43:00	Kazakhstan	0.11	45°11'56"N, 51°14'37"E	Onshore facility
51	15.10.2023	14:30:42	Kazakhstan	0.15	44°35'55"N, 50°9'55"E	Ship Discharges
52	24.10.2023	3:00:00	Russian Federation	0.49	42°24'35"N, 48°4'4"E	Ship Discharges
53	24.10.2023	3:00:00	Russian Federation	0.10	43°0'36"N, 47°28'18"E	Onshore facility
54	24.10.2023	3:00:00	Russian Federation	0.02	43°0'22"N, 47°28'27"E	Onshore facility
55	24.10.2023	3:00:00	Russian Federation	0.31	43°0'7"N, 47°28'44"E	Onshore facility
56	25.10.2023	14:46:00	Russian Federation	0.82	42°51'21"N, 48°7'57"E	Ship Discharges
57	25.10.2023	14:46:00	Russian Federation	0.75	42°55'44"N, 48°7'53"E	Ship Discharges
58	25.10.2023	14:46:00	Russian Federation	0.42	42°54'0"N, 48°7'6"E	Ship Discharges
59	25.10.2023	14:46:00	Russian Federation	0.40	42°54'54"N, 47°59'20"E	Ship Discharges
60	27.10.2023	14:29:52	Kazakhstan	0.20	42°30'13"N, 51°2'21"E	Ship Discharges
61	27.10.2023	14:29:52	Kazakhstan	1.44	42°14'54"N, 51°40'45"E	Ship Discharges
62	01.11.2023	14:38:00	Russian Federation	0,64	42°32'58"N, 48°15'37"E	Ship Discharges
63	05.11.2023	3:00:00	Russian Federation	3,28	42°54'1"N, 48°6'44"E	Ship Discharges
64	06.11.2023	14:46:35	Russian Federation	0,22	42°26'0"N, 48°2'2"E	Fishing waste
65	06.11.2023	14:46:35	Russian Federation	0,06	42°28'22"N, 48°0'21" E	Fishing waste
66	06.11.2023	14:46:36	Russian Federation	0,36	42°36'42"N, 47°59'26" E	Ship Discharges
67	06.11.2023	14:46:36	Russian Federation	5,05	42°51'3"N, 48°8'39"E	Ship Discharges
68	08.11.2023	14:30:00	Kazakhstan	0,88	42°33'58"N, 51°56'20" E	Ship Discharges
69	13.11.2023	14:38:00	Russian Federation	0,20	42°4'18"N, 48°18'18" E	Not determined
70	25.11.2023	14:38:00	Russian Federation	0,44	42°36'39"N, 48°5'41" E	Ship Discharges
71	30.11.2023	14:46:00	Russian Federation	0,68	42°37'48"N, 47°47'43"E	Not determined

The highest frequency of film-type pollution occurrence during the specified period was observed within the Makhachkala agglomeration area (25 facilities) (Fig. 3). Onshore sources of pollution can be identified extremely accurately; however, in most cases the detected ship discharges could not be attributed to any particular vessel.



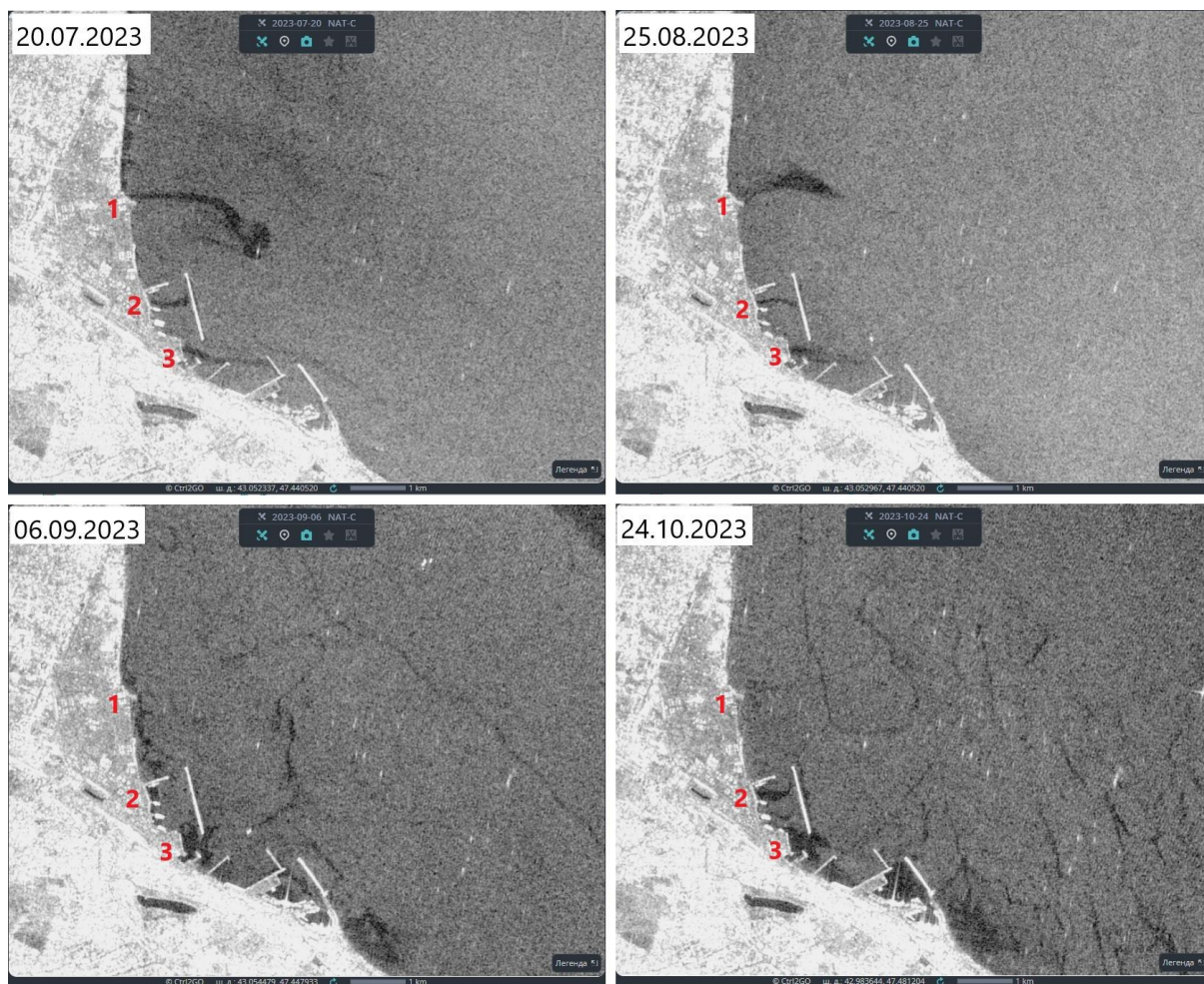


Fig. 3. Obtained by the Sentinel-1 satellite radar image segments of the Makhachkala agglomeration with the most characteristic pollution spots. Main sources of pollution: an oil depot (1), oil harbour (2), and a ship-repairing yard (3).

During the monitoring period, new and old ship spills have been most frequently observed in Russian territorial waters (49 events), then in Kazakhstan (13), Azerbaijan (3), and Turkmenistan (1 event) (Fig. 4).



Fig. 4. Examples of ship spills identified in radar images.

Such asymmetry in the occurrence of the detected spots in the territorial waters of different states can be explained, among other factors, by closer attention (and, consequently, increased monitoring) to the Russian territorial waters.

As a result, we can confirm that ship discharges and pollution from onshore facilities are fairly common events. If the onshore sources of oil and oil products can be identified to a high degree of accuracy, we have not succeeded in matching a ship discharge event with a particular vessel during the specified monitoring period. To increase the accuracy of identification of ships which are sources of pollution, we need to engage additional sources of space images and RIs to increase the shooting frequency and data from the Automatic Identification System (AIS).