

**Annual sea surface oil pollution of the south–eastern part of the Baltic Sea by satellite data for 2006–2013*****Elena Bulycheva, Igor Kuzmenko, Vadim Sivkov***

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**Abstract** The annual average features of the spatial distribution of oil pollution at the sea surface in the south–eastern part of the Baltic Sea were determined for the first time. It was shown that the most polluted areas are the seawaters west of the Sambian Peninsula and Vistula Spit, including the coastal zone that is connected to the Baltiysk, Gdansk, and Gdynia ports. The sea surface near the oilfield Kravtsovskoye D-6 (Russia) and oil terminal Būtingė (Lithuania), as well as the coastal zone near the Curonian Spit, do not suffer from oil pollution. A lower estimation of the annual average amount of oil products at the sea surface was performed. The lack of correlation between the location of the oil slicks and main navigation routes by Automatic Identification System (AIS) was explained by the infrequent but large spillages from ships that occur outside of the main traffic lanes. A significant contribution to the oil pollution of the sea surface from nonconventional ships not equipped with AIS was discovered.

**Keywords** • oil pollution • satellite • SAR data • ship traffic

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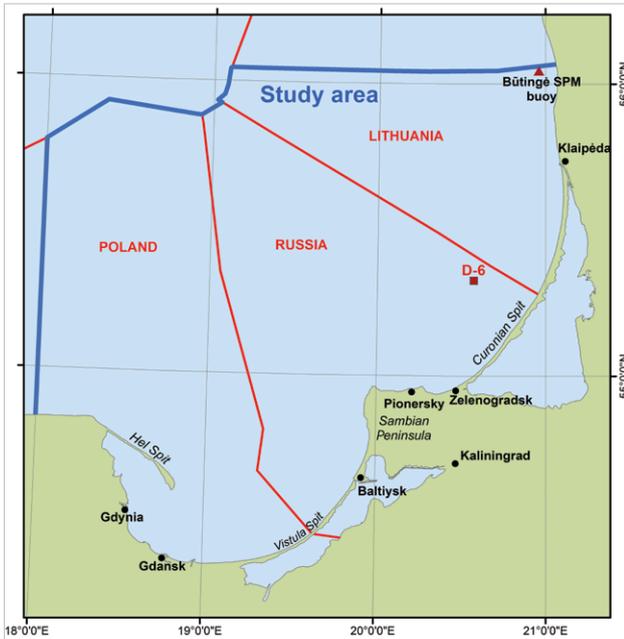
**INTRODUCTION**

Prevalent anthropogenic contributions to the concentration of oil hydrocarbons in water are one of the parameters necessary in order to analyse current and future conditions of marine ecosystems. It is necessary to estimate oil pollution to compare the anthropogenic impact and influence of climate change. The shallow semi-enclosed Baltic Sea is a basin that experiences a high frequency of shipping. According to HELCOM, shipping is the main source of oil pollution in the Baltic Sea (HELCOM 2013). During the last decade, shipping has steadily increased in the Baltic Sea, reflecting the intensification of international co-operation and economic growth. Both the quantity and size of the ships have increased; those trends are expected to continue, which inevitably leads to increased pollution of the marine environment. In addition, the dramatic increase in oil transportation significantly raises the risk of a large oil spill in the Baltic marine area.

The goal of this paper is to compile an annual average map of oil pollution at the sea surface of the south–eastern part of the Baltic Sea and compare it to ship traffic density data. Significant attention is paid to the environment close to the shore of Curonian Spit (Natural and Cultural unit of UNESCO World Heritage) due to the initiation of oil extraction in the adjacent oilfield Kravtsovskoye (D-6).

**MATERIAL AND METHODS**

Archived satellite data related to the industrial ecological monitoring of the Kravtsovskoye oilfield (D-6) carried out by LUKOIL-KMN Ltd. was used for the detection of oil spills at the sea surface (Bulycheva, Kostianoy 2011; Kostianoy *et al.* 2012; Bulycheva 2012; Kostianoy, Lavrova 2014). The study area spatially coincides with the Gdansk Basin boundary, which includes the water areas of Lithuania, Russia, and part of Poland (Fig. 1).



**Fig. 1** Study area (delineated by blue line): D-6 – oilfield Kravtsovskoye, SPM – Single Point Mooring (buoy). Compiled by E. Bulycheva, 2014.

To monitor oil pollution at the sea surface, data from several satellites were used (Table 1). These satellites are equipped with Advanced Synthetic Aperture Radar (ASAR) or Synthetic Aperture Radar (SAR), which allow for the detection of spatial variability of small-scale wind waves. These waves are always observed at the sea surface as a pattern of returned signal intensity distribution (ASAR/SAR images). The use of ASAR/SAR from satellites has proven to be an excellent tool to detect oil slicks from vessels and installations at sea and is thus an efficient tool to assist national authorities in detecting oil discharges and locating potential polluters. Decoded ASAR/SAR images were received from Kongsberg Satellite Services (KSAT, Norway).

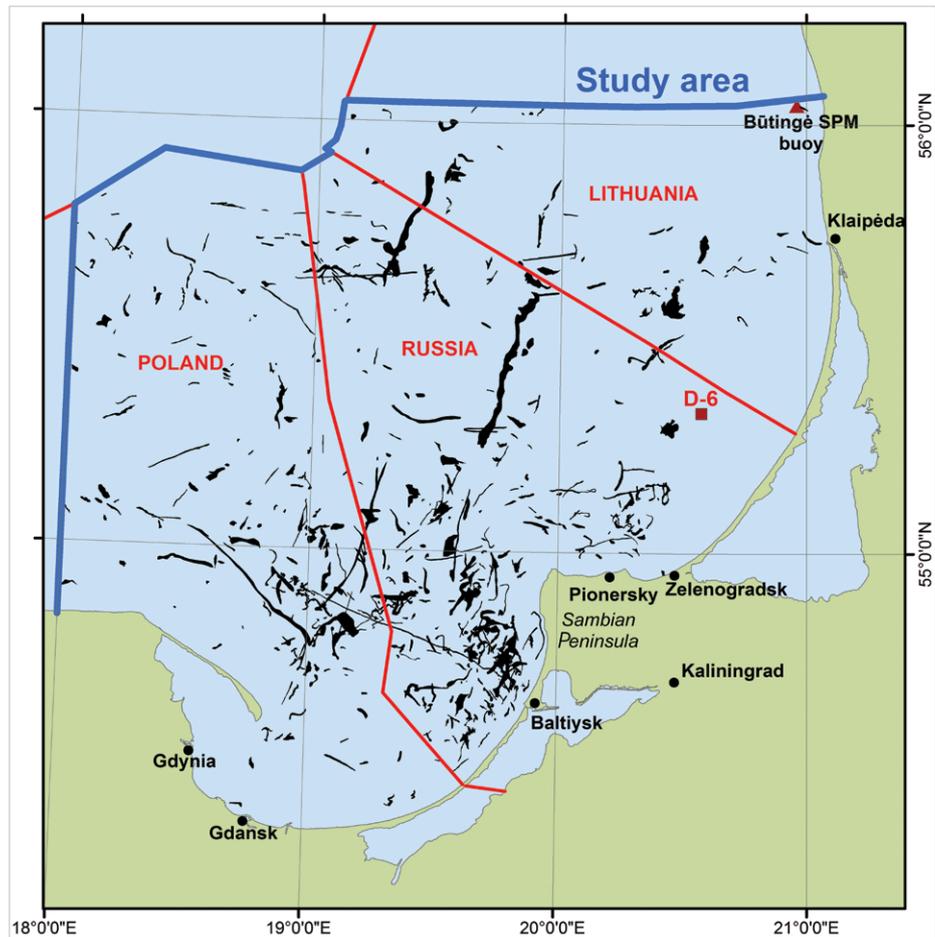
The image brightness is a reflection of the microwave backscattering properties of the surface (Brekke, Solberg 2005). Bright features indicate that a large fraction of the radar energy was reflected back to the radar, while dark features imply that very little energy was reflected. The main advantages of the method are the potential for application in

**Table 1** Main characteristics of satellite radar images.

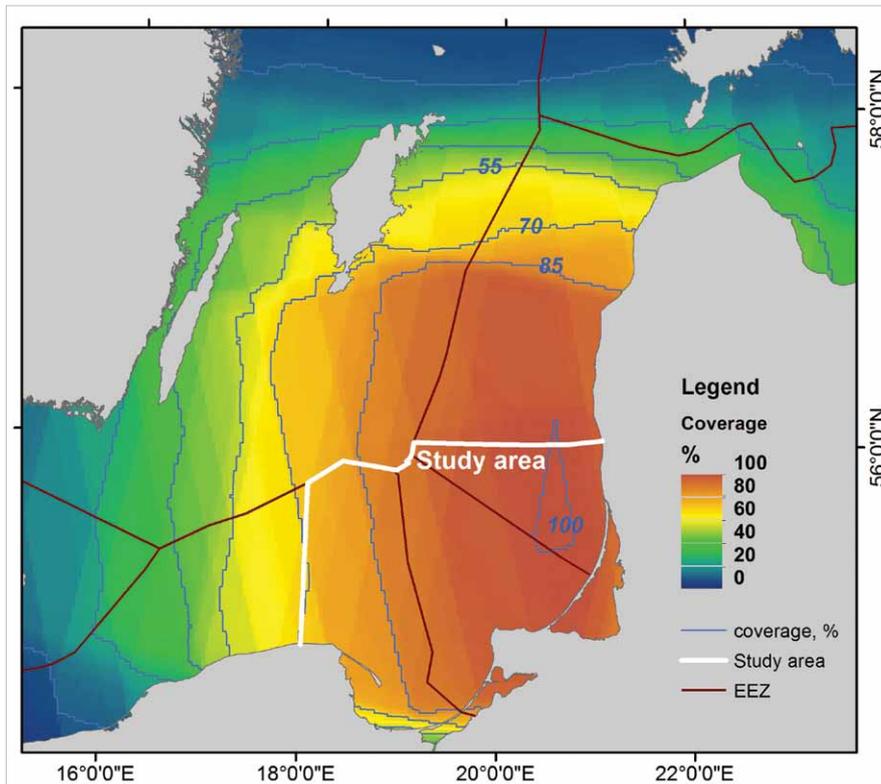
Satellite	Usage period	Scene size, km	Spatial resolution, m
ENVISAT	from 01.2006 to 04.2012	400x400	150x150
RADARSAT-1	from 01.2006 to 03.2013	300x300	50x50
RADARSAT-2	from 12.2008, to present	300x300 500x500	50x50 100x100
Cosmo-SkyMed-1, 2, 3, 4	from 04.2013, to present	200x200	100x100

all-weather conditions regardless of the time and the wide swath up to 500 km. The primary limitation of the method is the condition that the near-water wind speed should be in the range of 2 to 10 m/s.

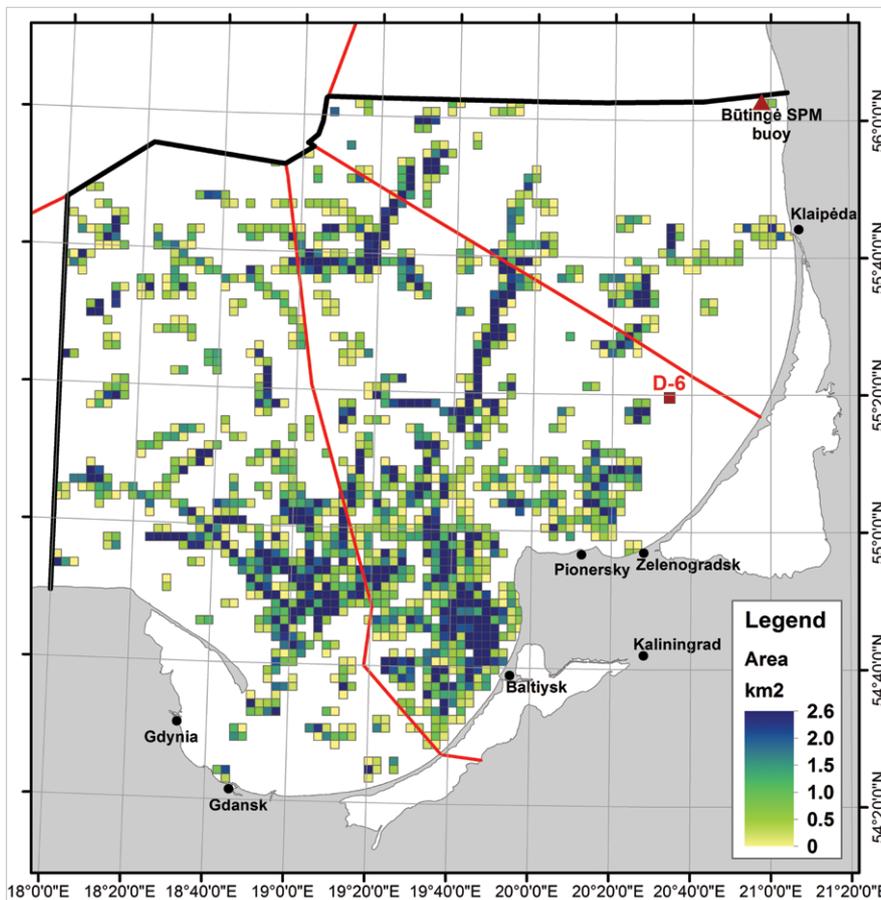
During the 2006–2013 period, a total of 1462 satellite scenes were received and analysed. More than 70 % of the received radar images are located in the study area (Fig. 2). In total, 452 oil spills were detected in the study area (Fig. 3). All of the detected oil spills were digitised using ArcGIS software, which allows for the calculation of the total area of oil spots for every cell with a size of 2.25x2.25 km throughout the eight year investigated period. As a quantitative parameter of sea surface oil pollution, an annual average value of this multiyear total area was used.



**Fig. 2** Coverage of the study area by satellite images from 2006–2013. Compiled by E. Bulycheva, 2014.



**Fig. 3** Summary map of oil spots on the sea surface detected in the study area using satellite radar images from 2006–2013. Compiled by E. Bulycheva, 2014.



**Fig. 4** Annual average oil pollution at the sea surface from 2006–2013. Compiled by E. Bulycheva, 2014.

The calculated annual average values were normalised to 100 % coverage of the study area by the satellite images (see Fig. 2). It was thought that the life time of an oil spill does not exceed one day. Assuming that the appearance frequency of oil spots remained constant during the investigated period, we extrapolated the calculated annual average values from 1462 satellite images to the number of days during the entire period.

## RESULTS

The annual average oil pollution at the sea surface in the study area from 2006–2013 is shown (Fig. 4). The most polluted zone is the water area west of the Sambian Peninsula and Vistula Spit, including the coastal zone. It includes the shipping routes of the Baltiysk Port with approaches and the area of the sea northeast of Hel Spit. It is easy to distinguish the approaches to the ports Gdansk and Klaipėda. There are noticeable large strips of oil pollution in the central part of the study area caused by occasional but large spills (see Fig. 3). At the same time, the situation near the oilfield Kravtsovskoye D-6 and oil terminal Būtingė looks better. The sea surface at the coastal zone of the Curonian Spit along its extension does not suffer from oil pollution, as it is a specially protected natural territory.

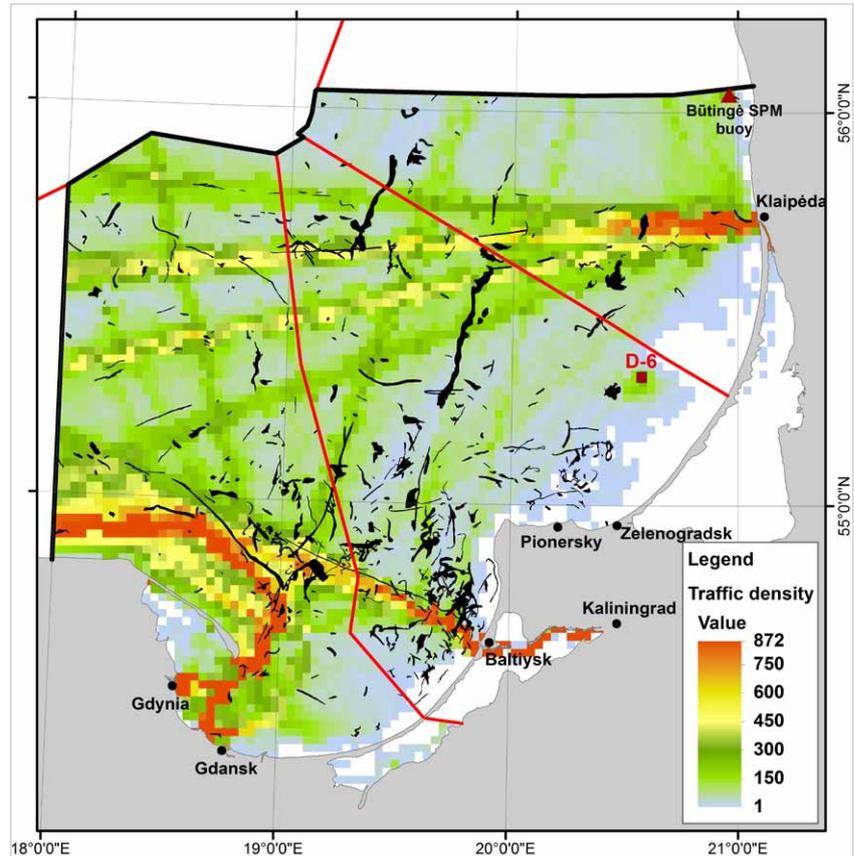
The received data allow for the evaluation of annual average amount of oil products at the sea surface. For the lower estimation, we take the oil film thickness equal to 0.0001 mm. As an oil product class, diesel fuel was selected with a density of 840–860 kg/m<sup>3</sup>. It was obtained a value of 30 tons of oil products in the study area, with 17, 3 and 10 tons from the Russian, Lithuanian and Polish zones, respectively.

## DISCUSSION

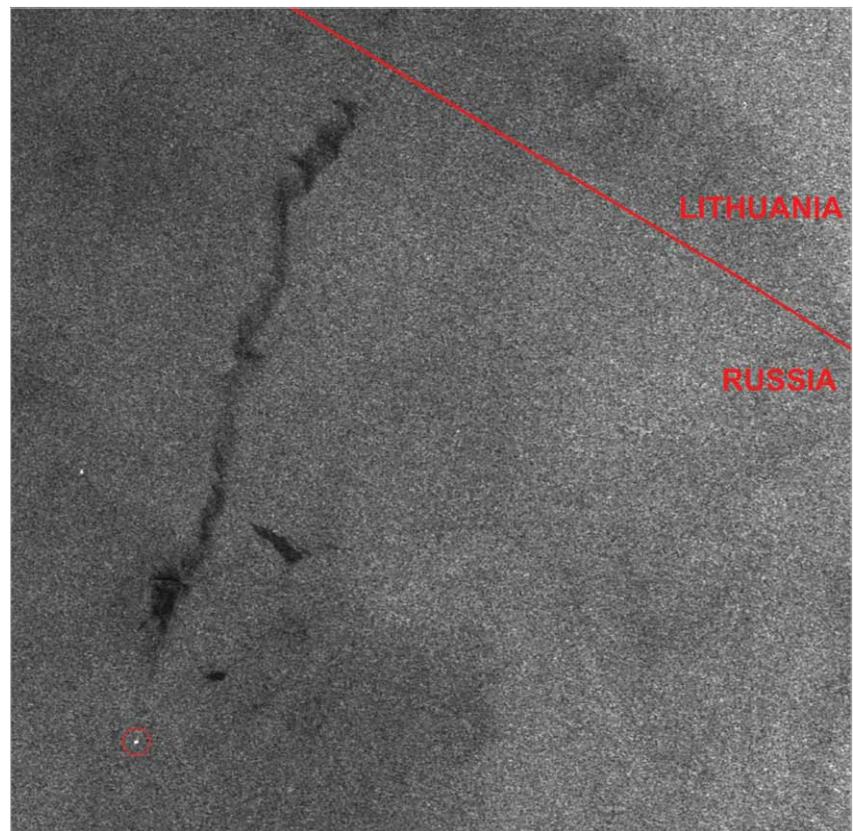
To address the prevalent opinion of the crucial contribution of shipping to oil pollution at the sea surface, it was important to compare the received data with marine traffic data. The original marine traffic data were obtained from Automatic Identification System (AIS) and covers the south-eastern part of the Baltic Sea (available at and property of HELCOM). The AIS data of ship traffic have been used to extract the recent traffic properties of ships navigating the Baltic Sea. The AIS data were reported and stored in the HELCOM AIS database hosted by the Danish Maritime Authority (DMA). The database has input values such as International Maritime Organization (IMO) and Maritime Mobile Service Identity (MMSI) numbers of the vessel, timestamps of the AIS record, geographical coordinates of the AIS record as latitude and longitude, main dimensions of the vessel, speed, course, and rate of turn. However, the only input values that were utilised were the timestamps and geographical locations of the ships.

The traffic of the ships was utilised in two definitions as both Traffic Density and Traffic Distribution (lateral distribution of the ships along the path). The traffic density was defined as the number of ships per unit area of the waterway within a desired time window (Mazaheri *et al.* 2013). On the supposition of consistency of traffic density and ship route direction, the traffic density map was created with a resolution of 2.25 km using ArcGIS software based on AIS raw data from the HELCOM AIS database for 2011. The tail-shaped form of the spills indicates their origin from moving ships. The combination of traffic density and detected oil spills is presented (Fig. 5).

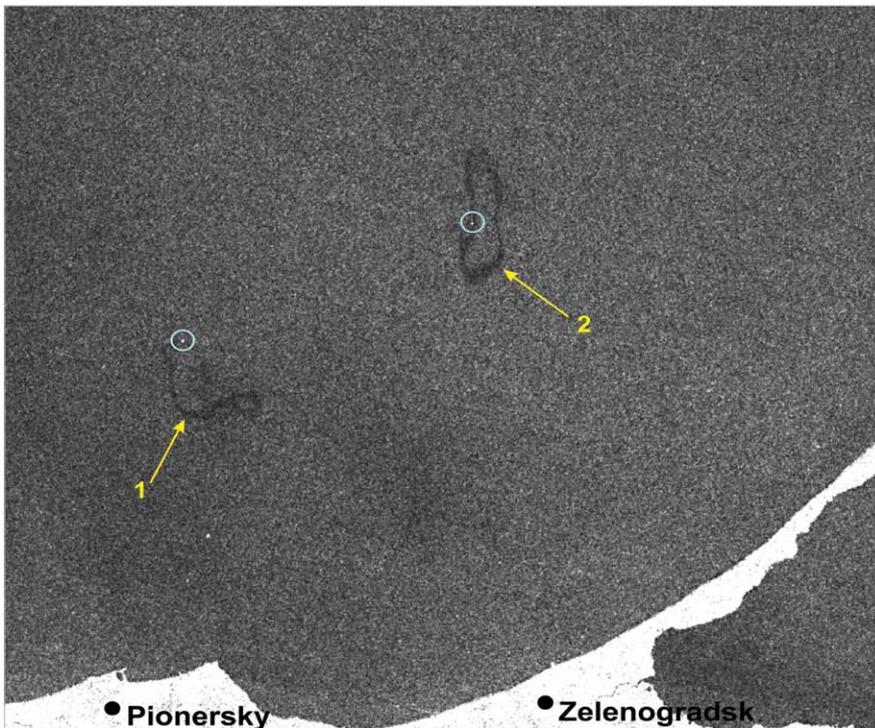
From a visual comparison of the oil spots and main shipping routes, it can be concluded that there was no noticeable relationship between these parameters. The calculated coefficient of correlation between the compared values is close to zero, which confirmed our conclusion.



**Fig. 5** Combination of average ship traffic density (from 2011) and detected oil spots from 2006–2013. Compiled by E. Bulycheva, 2014.



**Fig. 6** Oil spill detected outside of the main shipping routes (RADARSAT-2, 13.09.2013, 05:09 UTC). Compiled by E. Bulycheva, 2014.



**Fig. 7** Oil spills detected from nonconventional ships (RADARSAT-2, 29.08.2012, 04:52 UTC). Compiled by E. Bulycheva, 2014.

What are the reasons for this discrepancy regarding the leading role of shipping in oil pollution at the sea surface? First, the infrequent but large spillages from ships occur outside of the main traffic lines. For example, a huge oil spill from a moving ship was detected on 13.09.2013 (Fig. 6).

Its area was estimated to be 72 km<sup>2</sup>, which amounted to approximately 5.9 tons of oil products. It was reported that the polluter is the ship inside the red circle with coordinates 55°24'53.73"N, 19°46'58.82"E. Another reason for the absence of a correlation is the existence of oil pollution from nonconventional ships, such as small fishing ships and military vessels. For example, two tail-shaped oil spills (shown by yellow arrows 1 and 2; Fig. 7) were detected on 29.08.2012, and there were no AIS data reported from these vessels.

## CONCLUSIONS

The performed work reveals the annual average features of the spatial distribution of oil pollution at the sea surface in the south-eastern part of the Baltic Sea for the first time. It was demonstrated that the most polluted zones are the seawaters west of the Sambian Peninsula and Vistula Spit including the coastal zone of the sea, specifically the external shipping channel of the Baltiysk Port and part of the sea northeast of Hel Spit with approaches to the ports Gdansk and Gdynia. At the same time, the sea surface near the oilfield Kravtsovskoye D-6 and oil terminal Būtingė is quite clean. The sea surface at the coastal zone of the Curonian Spit does not suffer from oil pollution, as it is a specially protected natural territory.

A lower estimated amount of 30 tons of oil products is present at the sea surface of the study area, including 17, 3 and 10 tons in the Russian, Lithuanian and Polish zones, respectively. The lack of correlation between the location of the oil spills and major shipping routes (by AIS data) can be explained by the fact that infrequent but large spills from ships occur outside of main shipping routes, and oil pollution can also be caused by nonconventional ships not equipped with AIS.

## Acknowledgements

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