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SPATIAL DISTRIBUTION OF OIL SPILLS AT THE SEA SURFACE IN THE SOUTHEASTERN BALTIC SEA ACCORDING TO SATELLITE SAR DATA

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Statistical analysis of the spatial distribution of oil spills detected using Synthetic Aperture Radars (SAR) in 2004-2015 at the sea surface in the Southeastern Baltic Sea was conducted. Number, area, and shape of oil pollution division between Exclusive Economic Zones (EEZ) of Poland, Russia, and Lithuania were estimated for the first time. The most polluted area of the Southeastern Baltic Sea is Russian EEZ, where 55% of the total amount of detected oil spills, and 52% of the total area of oil pollution were located. The average area of an oil spill detected within Territorial Sea (TS) and EEZ was estimated. Tail-shaped spills associated with oil discharge from the moving vessels are prevailed, and their amount and area within TS and EEZ were estimated.

Keywords: Oil spills, synthetic aperture radar (SAR), Southeastern Baltic, tail-shaped spill, Territorial Sea (TS), Exclusive Economic Zone (EEZ)

1. Introduction

Since historic times the Baltic Sea has been an important route for maritime trade. Today, according to the Automatic Identification System (AIS), an average of 2,000 ships are at sea every day, including 200 tankers carrying oil or other potentially harmful products (Fig. 1a). Increasing of ship traffic in the Baltic Sea during the last decades has led to deterioration of its ecological state (http://helcom.fi/action-areas/shipping). The amount of oil shipped in the Baltic Sea would grow by 64% by 2030, from about 180 million tonnes to almost 300 million tonnes (HELCOM, 2018).

Besides, the Baltic Sea area has been designated as a special area in accordance with the International Convention for the Prevention of Pollution from Ships (MARPOL). Any discharge of oil or oily mixtures into the Baltic Sea area is prohibited based on MARPOL as well as the 1992 Helsinki Convention in the entire Baltic Sea area (both in Territorial Seas (TS) and Exclusive Economic Zones (EEZ)) (HELCOM, 2018).

Despite of the restrictions mentioned above, the illegal oil discharges are observed during aerial surveillances conducted by HELCOM Contracting Parties. Oil spills detected in 1998-2015 are presented in Figure 1b. The reason of "clean sea" in Russian, and Lithuanian EEZs is a lack or absence of air surveillance system. The only source of information about oil pollution of the sea surface in the Russian EEZ of the Southeastern Baltic Sea is satellite monitoring of oilfield Kravtsovskoye (D-6) initiated by LUKOIL-KMN Ltd. with the beginning of oil extraction in 2004 (Bulycheva *et al*., 2014, 2015, 2016a, 2016b, 2016c; Lavrova *et al*., 2014). The spatial distribution of oil pollution (number, area, and shape of oil spills) divided between the parts of Polish, Russian, and Lithuanian EEZs was analysed for the first time. Oil pollution detected within the TSs of the mentioned states was estimated.

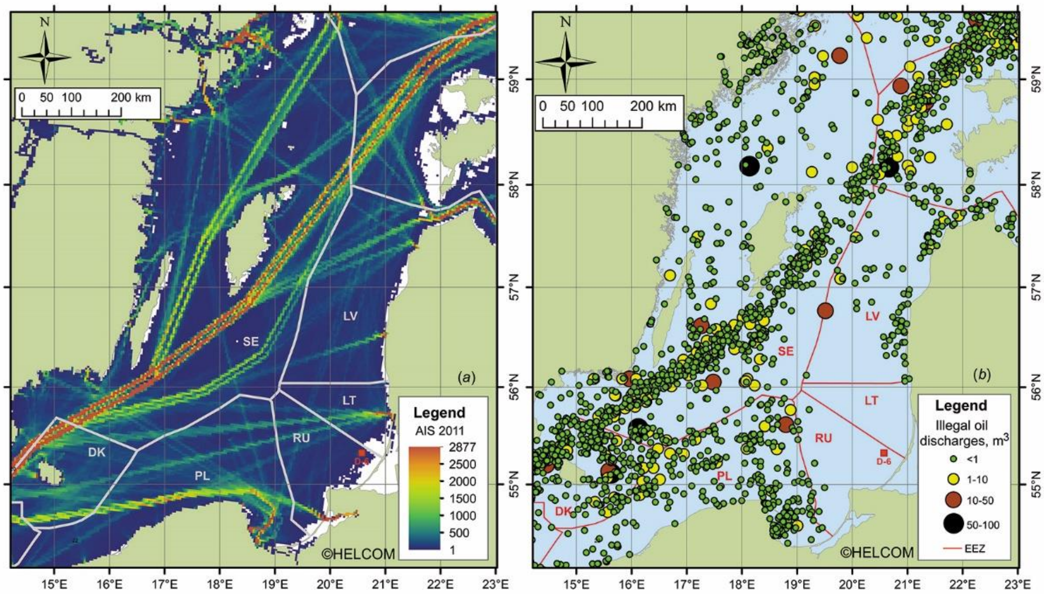

Figure 1. The average monthly density of ships in the Baltic Sea by HELCOM AIS for 2011 (a), and confirmed oil spills in the Baltic Sea detected during aerial surveillance in 1998-2015 (©HELCOM) (b)

2. Material and methods

Data on oil pollution of the Southeastern Baltic Sea surface were obtained during operational satellite monitoring of the Kravtsovskoye oilfield (D-6) from June 2004 to December 2015. The monitoring was based on the analysis of satellite images from satellites equipped with SAR/ASAR tools: ENVISAT (European Space Agency, ESA), RADARSAT-1 (Canadian Space Agency, CSA, Canada), RADARSAT-2 (McDonald, Dettwiler & Associates, MDA, Canada), TerraSAR-X (German Aerospace Center, DLR, Germany), and Cosmo-SkyMED (Italian Space Agency, ASI, Italy). Kongsberg Satellite Services AS (KSAT, Norway) delivered processed SAR images. In total 1946 SAR images of the Southeastern Baltic were received and analysed.

SAR has proven to be an excellent tool for detection of slicks at the sea surface due to its wide area coverage and day and night all-weather capabilities (Brekke and Solberg 2005). SAR allows detection of spatial variability of gravity-capillary waves, presented at the sea surface. Films of different origin locally modify the roughness of the sea surface what is detected by satellite radars. Limitation of the method for oil spill detection is its applicability in the certain wind speed range of 2-10 m/s.

3. Results

3.1. Oil spills number

To analyse the spatial distribution of oil spills the Study area was divided into six subareas, namely: EEZs of Poland, Russia, and Lithuania, and TSs of the mentioned states. If a spill intersected TS or EEZ then each fragment of this spill was accounted to each subarea as an oil spill, and area of its' fragments was divided between subareas. Due to this procedure, an artificial increase in the number of spills occurred, but the total area of oil pollution remaining the same.

As a result of SAR images analysis, in total 1232 oil spills were detected during 2004-2015, including 638 oil spills (or 671 spills including fragments assigned to certain subareas) within the Study area (Fig. 2), that includes Russian, Lithuanian, and part of Polish waters limited by 18°E from the west.

The most polluted area of the Southeastern Baltic Sea is Russian sector, where 55 % (369) of the total amount of detected oil spills and its' fragments were detected. 33 % (223) of total oil spills and fragments were detected in Polish sector, and 12 % (79) in Lithuanian sector. The most polluted area of the Russian sector is TS, where 59 % (219) of oil spills detected in Russian sector were located, and 33 % of the total amount of oil spills were concentrated within the TS of Russia. 23 % (51) of the total amount of spills detected in Polish sector were located within the TS of Poland. 24 % (19) of oil spills detected in the Lithuanian sector were found within its TS (Fig. 3).

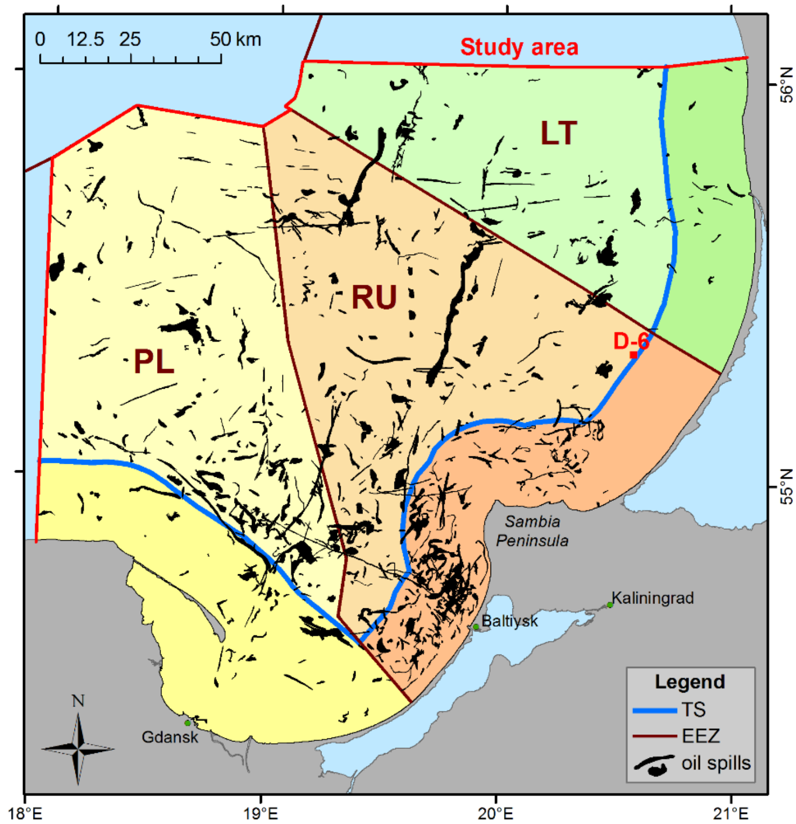

Figure 2. Oil spills detected in Study area in 2004-2015

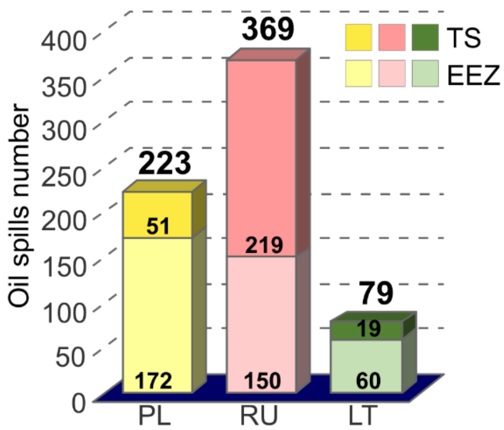

Figure 3. Distribution of oil spills number in the subareas

3.2. Area of oil pollution

The total area of oil pollution for 2004-2015 is 1862 km^2, i.e. in average about 160 km^2 per year. In the Russian EEZ, 52 % (982.1 km^2) from the total oil pollution area was located, and 22 % (406.7 km^2) from the total area of oil pollution was detected within the TS of Russia (Fig. 4). The total area of detected oil spills within the TSs of the Study area is 563 km^2, which is 30 % of the total area of oil spills. At the same time, the area of the TSs is 32 % of the total area of the Study area (Fig. 5). The average spill area is 2.2-2.3 km^2. In the TSs of Russia and Lithuania, spills were smaller and their average areas were 1.7 and 0.9 km^2, respectively (Fig. 6). It was estimated that, in average, for every 100 km^2 of the Russian, Polish and Lithuanian EEZ four (10 km^2), two (6 km^2), and one oil spill (3 km^2) were detected during 11.5 years of satellite monitoring, respectively.

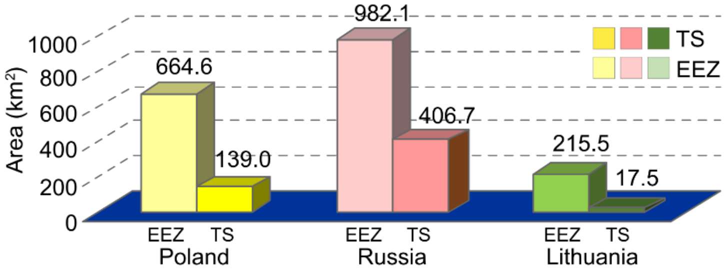

Figure 4. Area of oil spills in the subareas

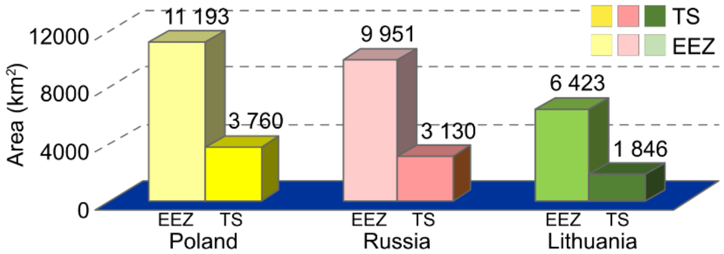

Figure 5. Area of the subareas

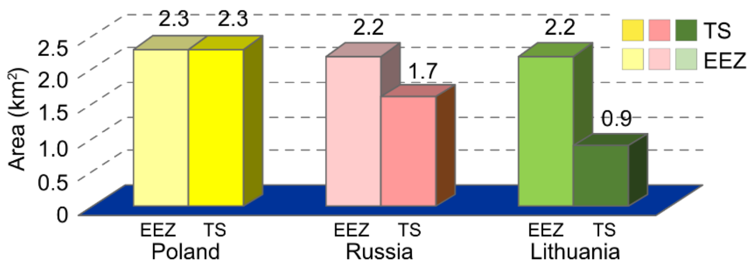

Figure 6. Average spill area in the subareas

3.3. Shape of oil spills

Tail-shaped slicks are wittingly associated with oil discharge from the moving ship (Espedal, 1999; Indregard *et al*., 2004). Authors compared the number of tail-shaped oil spills to other shapes of slicks also determined as oil pollution.

Most of the oil spills were tail-shaped, what is typical for releases from a moving source, i.e. a ship (Espedal, 1999; Bulycheva *et al*., 2016c). It was noticed that illegal discharge of oil begins immediately after leaving TS. For example, a tail-shaped oil spill from the vessel was detected by Radarsat-1 on 24 July 2008 (Fig. 7). Another large oil pollution from the ship was observed on 13 September 2013 from Radarsat-2. Ship-polluter was identified using www.marinetraffic.com. After crossing the Lithuanian-Russian EEZ, a discharge from the vessel began on the distance of 1.5 nautical miles (nmi) from Lithuanian EEZ in the Russian sector (Fig. 8). No AIS data was transmitted during leakage. Data transmission resumed after the oil discharge before entering TS of Russia (see Fig. 8). An unprecedented case is also described in (Kostianoy *et al*., 2016) when the ship deliberately went to the sea outside the TS of Poland to make a discharge into the sea, and then returned to the port of Gdynia. Ship-polluter was also identified. However, the source is not always possible to establish unambiguously. The reason is either few tracks of ships passing through the area of oil pollution or the lack of the AIS data (Bulycheva *et al*., 2014).

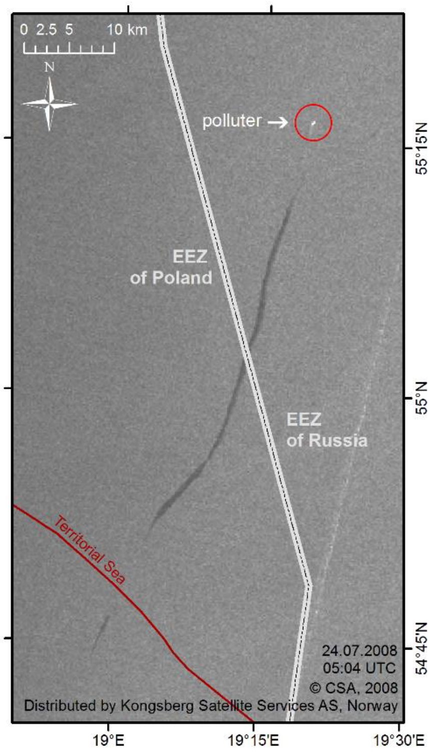

Figure 7. Oil spill detected from Radarsat-1 on 24 July 2008 (05:04 UTC)

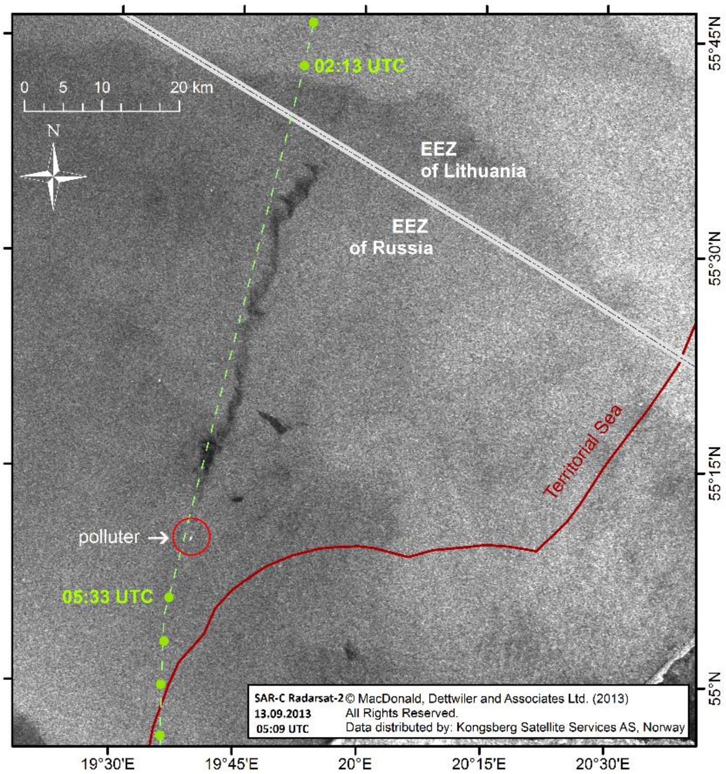

Figure 8. Oil spill detected from Radarsat-2 on 13 September 2013 (05:09 UTC). Track of ship “Zamoskvorechye” by www.marinetraffic.com is shown as a green dashed line. Green points are indicated AIS signals with a time interval of 15 min; specified time marks are AIS signals before and after the oil discharge according to www.marinetraffic.com

These examples show that large discharges from moving vessels mainly occur outside the territorial seas. 59 % (399) from the total amount of oil spills are tail-shaped. At the same time, 59 % (289) from the oil spills located within TS are tail-shaped (Fig. 9). The tail-shaped slicks accounted for 63 % (824.7 km^2) of the total area of oil spills (1299 km^2) outside TS, and 72 % of the total area of all tail-shaped slicks (1147 km^2) is located outside TS. Area of tail-shaped spills within TS accounted for 57 % (323 km^2) of the total area of all spills (564 km^2) detected within TS (Fig. 10).

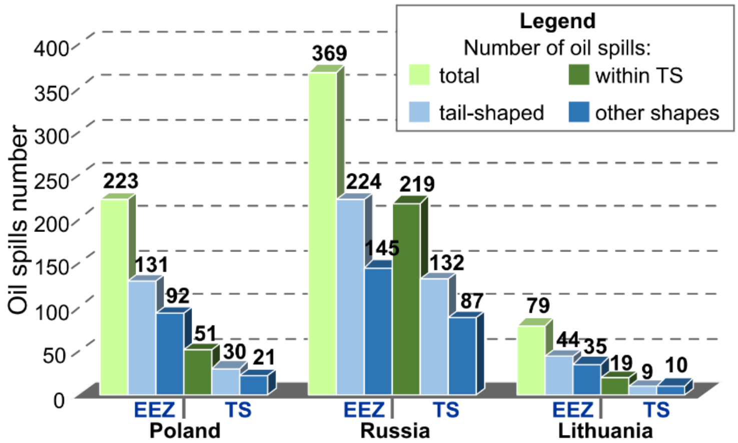

Figure 9. Shape of oil spills detected from 12 June 2004 to 31 December 2015

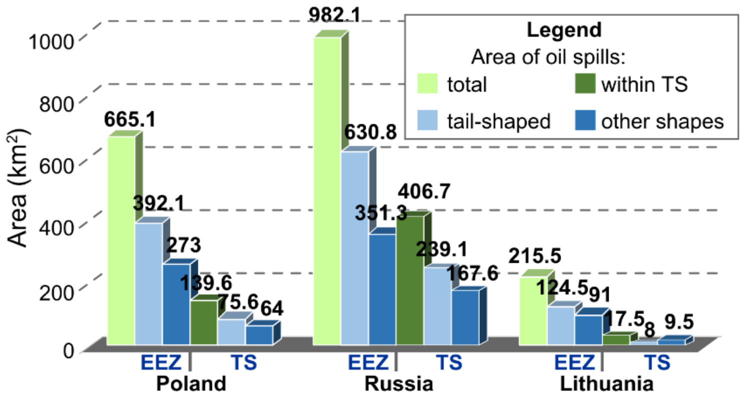

Figure 10. Area of oil spills detected from 12 June 2004 to 31 December 2015

4. Conclusions

The most polluted area of the Southeastern Baltic Sea is Russian sector, where 55 % of the total amount of detected oil spills and its' fragments were detected. 33 % of total oil spills and fragments were detected in Polish sector, and 12 % in Lithuanian sector. The most polluted area of the Russian sector is TS, where 59 % of oil spills detected in Russian sector were located. 23 % of the total amount of spills detected in Polish sector were located within the TS of Poland. 24 % of oil spills detected in the Lithuanian sector were found within its TS.

In average about 160 km^2 of oil pollution area was detected every year. The average spill area is 2.2-2.3 km^2. It was estimated that, in average, for every 100 km^2 of the Russian, Polish and Lithuanian EEZ four (10 km^2), two (6 km^2), and one oil spill (3 km^2) were detected during 11.5 years of satellite monitoring, respectively.

It was noticed, that illegal discharge of oil begins immediately after leaving TS or finished before entering TS. 59 % from the total amount of oil spills are tail-shaped, what is typical for discharges from the moving vessel. At the same time, 59 % from the oil spills located within TS are tail-shaped. The tail-shaped slicks accounted for 63 % of the total area of oil spills outside TS, and 72 % of the total area of all tail-shaped slicks is located outside TS. Area of tail-shaped spills within TS accounted for 57 % of the total area of all spills detected within TS.

Acknowledgements

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