Slicks as indicators of vorticity in coastal zones

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Abstract – ERS-2 SAR and Envisat ASAR images of the north-east coastal zone of the Black Sea and of the south-eastern coastal zone of the Baltic Sea have always revealed high intensity of dynamic processes in the sea and atmosphere there. The analysis shows that slicks produced by surfactants of various origin and found in great quantities in the studied areas are a good means of imprinting oceanic vortex structures in radar images. Surfactants get involved into orbital motion of vortices and, in doing so, draw their signatures in radar images. Even very small vortices, 2-10 km in size, can be detected by satellite radar in the presence of slicks while neither ship nor satellite optical instruments are capable of that. Such small-sized vortices play an important role in water circulation and mixing in the regions.[1]

Keywords: remote sensing, environmental monitoring, vortices, slicks, coastal zones.

1. INTRODUCTION

Sea surface covering with visible patches and bands of short surface waves (ripples) of low intensity is called smoothing, while patches and bands themselves are called slicks. Usually, they are observed under relatively weak wind (up to 3-5 m/s) and become visible due to changes in reflection properties of sea surface caused by wind wave spectrum restructuring [Monin and Krasitskii]. Sea surface smoothing and emergence of slicks may be induced by various atmospheric and oceanic phenomena: currents (including eddies and whirlpools), internal waves, Langmuir circulations, passing vessels, surfactant and oil films, wind field inhomogeneities and others. Because of high biological activity, biogenic surface films are often present on water surface in marine coastal waters. They may form structures which are driven by local hydrodynamic processes. Since they influence backscattering of microwaves and emissivity at near-infrared (NIR) bands, they may be visible in radar and infrared imagery, thus allowing for monitoring these processes via their surface manifestation. Investigation of processes in coastal zones based on remote sensing of slicks is in the focus of international project SIMP ("Slicks as Indicators for Marine Processes: Novel Tools for Marine Remote Sensing of the Coastal Zone"). Detailed information can be found in the present Proceedings in *SIMP: Slicks as Indicators for Marine Processes* by M. Gade *et al*.
One of the tasks of the project is the investigation of vorticity in coastal zones, which is the subject of the present paper.

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Oceanic circulation is known to include global ocean circulation paths, synoptic circulations (open-ocean rings and eddies) and small-scale circulations. Coastal waters are primarily affected by synoptic and small-scale circulations. By origin, synoptic eddies may be divided into: frontal or rings developing from meanders cut off jet flows, free or open-ocean eddies emerging due to barocline instability of large-scale currents, topographic or vortices downstream bottom topography features, vortices induced by atmospheric phenomena - wind friction and atmospheric pressure sea surface tension vortex fields.
Small-scale vortices have diameters of several kilometers, while peripheral ones may be even smaller. As a rule, such vortices are spiral in shape, where from comes their name "spin-off eddies". They often emerge in bays and gulfs and in narrow straits. By vortical sign, they are divided into cyclonic and anticyclonic. In coastal zones, small-scale vortices of both types emerge.

In radar images, oceanic vortices are visualized due to numerous bands of slicks. The slicks are produced by the many surfactants of natural and artificial origin found on the surface. Surfactants alter sea surface tension smoothing ripples and thus diminishing backscatter cross-section. Surfactant films get involved in the orbital motion of vortices in such a way imprinting them in radar images.

Continuous satellite radar monitoring of north-east coastal zone of the Black Sea and south-east coastal zone of the Baltic Sea has allowed us to observe a variety of vortices of different scales through radar patterns of slicks.

2. VORTICES IN THE NORTH-EAST COASTAL ZONE OF THE BLACK SEA

The major element of Black Sea water circulation is the Cyclonic Current Ring. In Russia, it is known as the Main Black Sea Current (MBSC). It embraces the sea along its perimeter having north-west direction in the north-eastern part of Black Sea, and is characterized by hydrodynamic instability. This instability, interaction with the bottom relief and synoptic variability of wind force the Main Black Sea Current to meander. As a result, multiple vortex structures emerge, develop and break down on both sides of the Current core: cyclonic vortices in the open sea and so-called Near-Shore Anti-cyclonic Eddies (NAE) between the Current and the shore. The role of MBSC and NAE role in the hydrodynamics and ecology of the coastal zone is extremely important. Each time an NAE passes, its orbital water motion reverses the direction of the near-coast current. Thus, a bimodal current regime is maintained near the coast. Because of its convergence property, NAE accumulates polluted water and in such a way contributes to self-cleaning of the area.

Satellite observations of NAE in the eastern part of the Black Sea with the help of IR sensors accompanied by concurrent ship measurements are presented in (Ginzburg et al, 2001). In this work, the sizes of NAE are estimated and their life cycles and dynamics are described. Image resolution of NOAA data permits to register mesoscale vortex structures with diameters over 40 km in the absence of clouds.

Radar sensors can provide more detailed information on small-scale current variability at a scale not accessible by other means, and they work independent of daylight and cloud coverage. Therefore, our study of small vortices we based on data obtained by ERS-2 SAR and Envisat ASAR instruments. Since 1999, regular satellite monitoring in the region of Novorossisk-Ghelendzhik has been conducted by Space Radar Laboratory of Space Research Institute in summer-autumn seasons. The analysis of obtained data shows that vortices of kilometers to tens kilometers in size constantly emerge 20-30 km off the shore to the south or south-west of Ghelendzhik Bay and move in north-west direction at 0.5 m/s on the average. Figure 1 shows an example of such vortex. As a rule, these vortices are anticyclonic, which is conditioned by MBSC and predominating winds. In summer and autumn, east winds are the most frequent (32%) in the study region.

It has proved impossible to determine the lifetime of vortices by means of satellite data. We could not detect the same vortex in images closest in time, that is 12 hours apart for both ERS-2 and Envisat. There may be two reasons: such small vortices can have shorter lifetime or, which seams more plausible, wind gets stronger over these 12 hours and slicks become invisible in radar images.

Fig. 1.ERS-2 SAR image (fragment 25x25 km), obtained on October 16, 1998. Anti-cyclonic vortex of 13 km in diameter

Figure 2 reveals an interesting case of vortex structures so-called mushroom flows, which can form both in the ocean and atmosphere. Mushroom flows are spatial quasi symmetric structures combining a narrow jet with a pair of vortices of opposite signs at the end. In most cases, jet length is close to the size of vortex part, while jet width does not exceed 10-25% of its length. This oceanic vortices also became visible in radar images due to surfactant slicks. The image was obtained by ERS-2 SAR on August 4, 2004 at 8:17 GMT. The wind was weak, 2-4 m/s, from south-west. Meanwhile, this well-developed vortex structure is stretched from east to west, which is another argument in favor of oceanic nature of the flow formed by coastal currents.

Fig. 2. ERS-2 SAR image obtained on August 04, 2004 (fragment 50x25 km). Mushroom flow in the sea is manifested through bands of surfactant slicks

Optical imagery from the coast we performed concurrently to SAR imaging as well as contact measurements with the help of an ADCP conducted by a research group from Andreev Acoustic Institute revealed the presence of vortices of yet smaller dimensions (2-3 km). They can be both cyclonic and anti-cyclonic and have high orbital speeds.

3. VORTICES IN THE SOUTH-EAST COASTAL ZONE OF THE BALTIC SEA

Continual satellite monitoring of south-east coastal zone of the Baltic Sea has been conducted jointly by Space Radar Laboratory of Space Research Institute, P.P. Shirshov Institute of Oceanology, Geophysical Center (Moscow) and Marine Hydrophysical Institute (Sevastopol) since July 2004. Observations are based on data from synthesized aperture radars on board European satellites Envisat and ERS-2, Canadian satellite RADARSAT, as well as MODIS instrument on board AQUA and TERRA satellites. The data are received almost in real time with minimal delay from the acquisition.

In early April 2005, still weather and many natural surfactants on the sea surface gave us the opportunity to observe the complex structure of currents in this region. A large number of vortices of different sizes and vortical signs are a common feature there. Figure 3 presents a fragment of an Envisat ASAR image (60x60 km) showing a cyclonic vortex 5 km in diameter and a variety of other vortex structures.

4. VORTICES IN BAYS AND GULFS

Water circulation in more or less closed water basins such as bays and gulfs is very important for coastal studies. As a rule, local wind is weaker there, while on the sea surface, there is a large amount of surfactants, primarily of artificial origin. These conditions are favorable for the study of vortices through observation of sea surface slicks. Test regions included Tsemesskaya and Ghelendzhik Bays of the Black Sea and Gdansk Bay on the south of the Baltic Sea.

Tsemesskaya Bay (15 km long, mouth width 9 km, depth 21-27 m) is the largest Russian Black Sea port, in particular, for oil transportation industry. Many oil tankers and other vessels are always anchored near the Bay in wait for bunkerage. That is why coastal waters always contain oil products forming films on the surface. They are seen very well not only in radar images, but also in optical images taken from a helicopter. (Detailed information can be found in the present Proceedings in *DeCOP: Detection and characterisation of organic pollution in the coastal environment - a synergistic approach V.Byfield et al.*).

Ghelendzhik Bay is an almost closed area with mouth width of only 3,6 km. Along with Sochi, it is the largest Russian resort on the Black Sea. In summer and autumn, because of tourist avalanche, the coastal area of Ghelendzhik suffers from strong anthropogenic pressure. The main source of water pollution is local river Su-Aran whose main drainage area is the town. The river takes the most part of rain flows from the town territory and so water in it resembles a mixture of household and industry wastewaters by composition. A large amount of surfactants, in particular, oil products, comes from vessels always present in Gelendzhik Bay. Water replacement process in the Bay may take from 1 to 10 days depending on wind speed and direction. The main role in water circulation here is played by vortices entering the Bay with south-easterly winds. They are the main water cleaning factor as well, because they carry relatively clean water from the open sea. Under unfavorable hydrometeorological conditions (intense rain drain, weak wind and currents near the Bay), pollution substances accumulate in water and bottom sediments [Krylenko and Yesin].

Figure 4 presents a fragment of ERS-2 SAR image with a cyclonic vortex clearly visible in Ghelendzhik Bay. As a rule, such vortices, originally having diameters of 2-3 km, tend to enlarge in the Bay and occupy the whole of it. Given favorable hydrometeorological conditions, they may live there for several days. In Tsemesskaya Bay, which is much more open and where strong night breezes from shore are quite often, much less stable vortices emerge, most of them are driven away by MBSC.

Situation on the south of Gdansk Bay is similar to Ghelendzhik Bay, though not so dramatic. Several flows of the largest Poland's river Visla come into the Bay. The banks of Visla are densely populated and the Bay homes the two largest ports Gdansk and Gdynya. Certainly, the sea surface here carries large amount of artificial surfactants producing multiple slicks. In the Bay, stable vortices regularly emerge. They are visible very well both in MODIS Terra optical images (fig.5a, c) and Envisat ASAR radar images (fig.5b). According to data obtained between July 28 and August 11, initially there were two vortices – one mushroom (1), the other cyclonic (2). After a while, the former appeared to absorb the energy of the latter, incorporated it, grew in size and moved slightly westward (fig.5c).

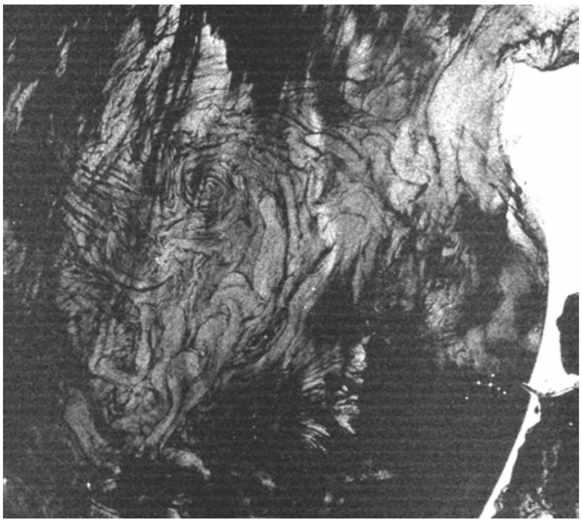

Fig. 3 Envisat ASAR image (fragment 60x60 km), obtained on April 13, 2004. Cyclonic vortex in front of Baltic channel

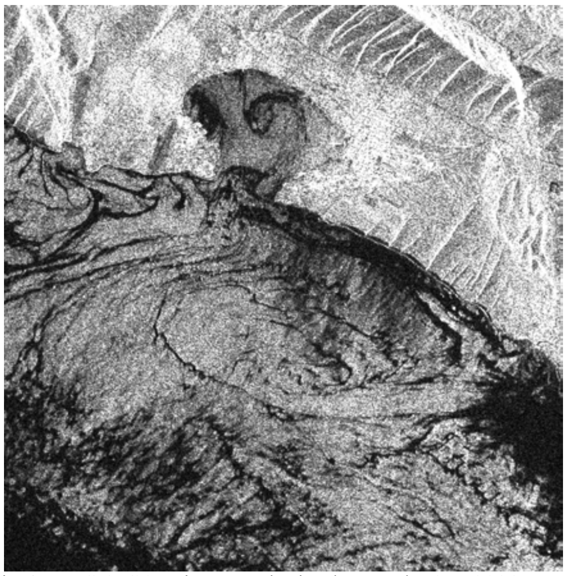

Fig.4. ERS-2 SAR image, obtained on July 27, 2001. Two vortices of opposite signs: anti-cyclonic (near the shore) and cyclonic (in the Bay of Ghelendjik)

5. CONCLUSION

The analysis of satellite SAR images of north-east coastal zone of the Black Sea and the south-eastern part of the Baltic Sea confirms that satellite radar imagery is a highly informative tool for the purpose of monitoring of dynamic processes in the sea surface – atmosphere boundary layer.Coastal waters of the regions appear to be abundant in surfactants of natural and artificial origins. Surfactant slicks imprinted in SAR images help to detect surface currents and vortex structures. In particular, we discovered an extremely intense medium- and small-sized vortical activity very close to the shoreline and in the gulfs. It plays a considerable role in water circulation and mixing but such vortices cannot be detected by any other remote sensing instrument.

6. ACKNOWLEDGMENTS

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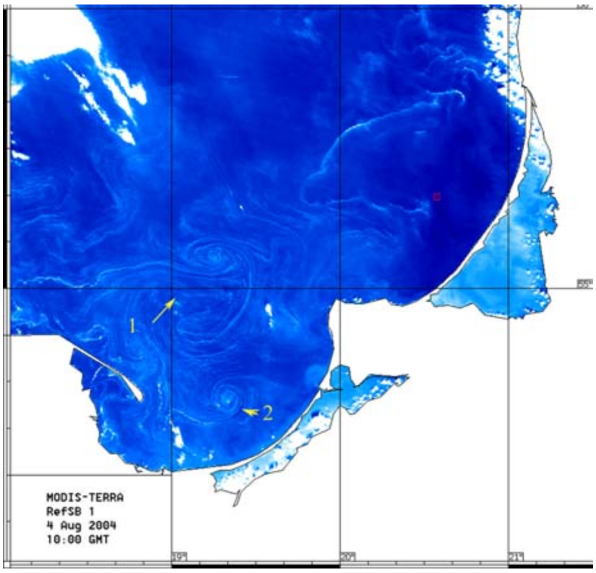
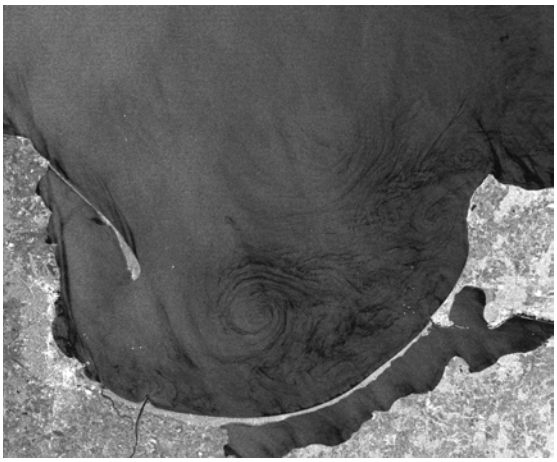
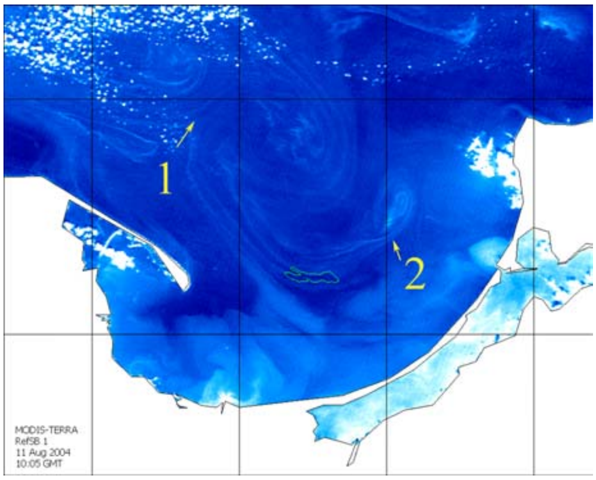


a)



b)



c)

Fig. 5. Mushroom flow (1) and cyclonic (2) vortex in the Gdansk Bay.
MODIS TERRA image obtained on August 4, 2004 (a) and on August 11, 2004 (c); Envisat ASAR image obtained on August 5. 2005 (b)

6. REFERENCES

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