Concurrent Field Experiments and Satellite Surveys for Assessing Environmental Risk in the Coastal Zone of Southeast Baltic

OLGA Yu. LAVROVA, KSENIA R. NAZIROVA, EVGENY V. KRAYUSHKIN & ALEXEY Ya. STROCHKOV

Space Research Institute of the Russian Academy of Sciences, Russian Federation

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Abstract
The results of field experiments concurrent to satellite surveys conducted in the summer periods of 2014-2019 in the southeastern part of the Baltic Sea off Sambian Peninsula are presented. The main goal was to study coastal currents in a highly variable wind field and its impact on the transport of potential marine pollution. Southeast Baltic is, on the one hand, an area of active navigation, fishing, off-shore oil production, and, on the other hand, a rapidly developing recreation area. It is also an area of frequent massive blooming of harmful algae. Considering these facts, studying coastal currents and their impact on anthropogenic and biogenic pollution propagation in the area is highly important. Our main research instrument was drifting Lagrangian buoys (mini-drifters) that are quite often used in oceanography today, Acoustic Doppler Current Profiler (ADCP) and CTD probe measuring temperature, conductivity (salinity) and pressure (depth) and in-situ turbidity and CHL-a. In addition, we used satellite remote sensing data publicly available from European and American databases. Mainly, these were data obtained from Sentinel-2 (MSI), Landsat-8 (OLI/TIRS), Sentinel-3 (OLCI) and MODIS (Aqua/Terra) satellites. The experimental data allowed us to describe in detail the alongshore current structure and identify the areas most affected by marine pollution, among which are the most popular places of the region: the beaches of the Yantarniy settlement and Curonian Spit, a national nature reserve and a UNESCO World Heritage Site.

Key words: satellite monitoring, in-situ measurements, ecological risks, Lagrangian drifter, southeast Baltic Sea.

Introduction
The southeastern part of the Baltic Sea (Fig. 1) can be regarded as a zone of ecological risk (Lavrova et al., 2016b). The main reasons are as follows. First, it is an area of active navigation, there are shipping routes connecting the ports of Poland (Gdansk, Gdynia), Russia (Baltiysk, Kaliningrad), Lithuania (Klaipeda) with numerous ports in the Baltic and the North Seas (Fig. 2). Second, there are marine oil platforms, the largest one, D-6, is situated at a distance of only 22.5 km from the Curonian Spit natural reserve and has a subsea pipeline to the Sambian Peninsula (Kulikovo). In January 2019, a liquefied natural gas regasification terminal, 5 km off the coast was commissioned, during its construction period water turbidity in this area had sharply increased. Third, in the southeast Baltic, especially in the Curonian and Vistula Lagoons, intense bloom of harmful algae (cyanobacteria) is observed every year. The lagoon waters flow into the sea,
increasing biogenic pollution along the coast. At the same time, this region is popular among tourists for its picturesque sandy beaches, and Curonian Spit, as mentioned above, is a nature reserve and a UNESCO World Heritage Site. Southeast Baltic is characterized by complex coastal currents that can abruptly change direction with changing hydrometeorological conditions (Golenko M., Golenko N., 2012; Lavrova et al., 2011; 2016b; Kostianoy, Bulycheva, 2014; Zhurbas et al., 2006; 2019). Any anthropogenic and harmful biogenic pollution entering the waters of southeast Baltic, can be carried over long distances and damage the fragile ecosystem of the sandy coasts. Therefore, regular environmental monitoring in this region is most important.

**Figure 1.** Map of the South-Eastern part of the Baltic Sea. Red square marks a location of the fragment of MODIS Terra image of 20.07.2019.

Detection of anthropogenic contaminants, primarily oil, is based on satellite data and was initiated by the Lukoil oil company, which owns D-6 and the Kravtsovskoye oil field. Scientists from the Institute of Oceanology RAS (and its branch in Kaliningrad) and the Space Research Institute RAS actively participate in conducting satellite monitoring of pollution in this region. The results of many years of the work are discussed in multiple Russian and international publications (Kostianoy et al., 2006; Kostianoy, Lavrova, 2014; Lavrova et al., 2011; 2014 2016b; Bulycheva, Kostianoy, 2014; Bulycheva et al., 2016a, b). Pollution detection is only part of the problem. It is equally important to predict its drift and evolution under different meteorological conditions. The forecast of pollution distribution for the whole Baltic Sea is based on the Seatrack Web SMHI model (Kostianoy et al., 2014; Kostianoy, Bulycheva, 2014). This is the best interactive numerical model developed specially for the Baltic Sea, but it does not always provide correct forecasts of oil pollution drift. This is because the model does not take into account submesoscale eddies that can play a critical role in the distribution of pollutants (Ginzburg et al., 2015a, b; 2017; 2019). And the Gdańsk Bay, that occupies the most part of southeast Baltic, is known for regular formation of eddy structures (Ginzburg et al., 2015a, b; 2017; 2019; Lavrova et al., 2018; Zhurbas et al., 2019). Another important scientific and practical problem that must be addressed in the framework of environmental monitoring is the determination of the areas of ecological risk, i.e. areas of the coastline that, under certain hydrometeorological conditions, will be most likely affected by pollution. To solve this very difficult problem, we conduct, concurrently with satellite survey, field measurements of coastal currents as well as parameters of the state and pollution of coastal waters.
Figure 2. 2015 traffic density map of southeast Baltic (© Marine Traffic).

Instruments and methods

Our field works in the southeastern part of the Baltic Sea have been carried out every July - August since 2014. They are both scientific and educational in nature. Alongside with scientists from Space Research Institute RAS, students and graduate students of Lomonosov Moscow State University take part in the expeditions. The main objectives of our expeditions are: verification of the results of the studies of hydrodynamic processes based on satellite images of high spatial resolution using the results of field measurements; determination of the three-dimensional structure of lagoon waters in the sea; measurement of coastal current parameters (velocity, direction) using Acoustic Doppler Current Profiler (ADCP) from a small research boat; identification of areas of increased acoustic scattering, frontal zones, vortex structures, and internal waves; determination of the parameters of coastal currents at different depths using Lagrangian drifters; obtaining contact measurement data for the parameters of the near-surface atmospheric layer (temperature, wind speed and direction) and the sea (water temperature and salinity, turbidity, chlorophyll-a (CHL-a) concentration); conducting express analysis of water samples for the total content of suspended matter.

The obtained characteristics make it possible to restore the three-dimensional structure of the waters and determine the distribution parameters of various pollutants not only in the upper layer of the sea, but also in depth. The results obtained during field measurements are compared with the results of concurrent satellite observations.

Field measurements were carried out from a small boat using the following oceanographic equipment. In order to track the currents in the region of expedition, an ADCP survey was carried out accompanied by CTD casting. Teledyne RD Instruments WorkHorse Monitor 300 kHz ADCP was firmly fixed on board of the boat providing real-time current velocity and direction data as well as GPS georeferencing. Considering the acoustic blank distance, each current profile started at 4 m depth and cell size was 2 m. ADCP measured current ensembles at 0.5 Hz interval, which, given the boat speed of ~ 2 m/s, resulted in overall spatial resolution of ~ 4 m. With this technique, averaged standard deviation was 6.94
cm/s. Such deviation is unacceptable for coastal oceanographic investigations, so further on all current ensembles were averaged within corresponding cell level with an interval of 240 ensembles. Finally, standard deviation of 0.63 cm/s was calculated at ensembles spatial resolution of 1 km. ADCP accuracy was 0.5% of a sum of boat and water speeds, the latter being 1-2 cm/s.

CTD casts were done using RBR Concerto CTD probe measuring temperature, conductivity (salinity) and pressure (depth) and additionally in-situ turbidity and CHL-a concentration at a frequency of 6 Hz. CHL-a concentration and turbidity values were derived from external optical sensors installed on the CTD probe. Each cast was further filtered with low pass filter and several statistical filters to exclude erroneous data and, finally, vertically averaged with a predetermined vertical depth bin. In 2019, the instrument base was expanded with a portable seawater turbidity meter, which is capable of operating in several value ranges, from insignificant to extreme (up to 1000 NTU), and to provide measurement results in a thin surface layer, which is difficult to do with a hydrological probe.

Meteorological parameters were obtained with the use of onboard station Airmar 150WX providing real-time values of wind speed and direction as well as air temperature and atmospheric pressure during the cruise. All the data were further time-averaged into 30-minute time scale.

Interesting results were obtained using Lagrangian mini drifters (Krayushkin et al., 2019). Lagrangian drifter is a passive floating object with underwater sail and minimized surface part equipped with a location identification and transmission unit. The most important feature and the main purpose of a drifter is operational transmission of the data. At the end of the working cycle, the drifter can be found and collected for further use, but by that time its memory data is of no value any more. There is always a possibility of losing it as a result of damage or malicious acts and, in this case, the collected information will be lost.

To transfer the coordinates of a drifter operating in the ocean or open sea, satellite communication channels are used. The main instrument is GPS/GSM tracker that determines the current coordinates of the drifter and transmits them at specific time intervals over the mobile network (GSM, 3G or 4G) to the receiving device, a mobile phone in our case, in the form of short messages (SMS).

The tracker with an external battery is placed in a waterproof plastic box fixed on the float to which a string is attached that goes down to the depth where the movement of water is to be measured and ends with a sail and a weight. The drifter must meet certain requirements in order to be suitable for measurements of sea water dynamics. First, the impact of the near-surface wind, often having direction opposite to current, should be minimized. Therefore, the surface part should be as small as possible. Also, underwater sail should be large enough so that wind forcing may be neglected against that of current.

Next, it is necessary to control drifter roll and tumbling due to surface waves. When the drifter is tumbled upside down, the transmitted signal is lost due to attenuation in the water. The device must maintain its position relative to the water surface. For this purpose, a load is fixed fast to the float below the water level acting as a weebly wobble to correct the position of the drifter tilted by waves.

Also, the drifter should provide the ability to track the movement of water masses not only in the surface layer, but at a certain depth. In the underlying layers, current velocity and direction are unlikely the same as on the surface. So, it is necessary to set the sail at the depth of interest. More information on the drifters that we use can be found in our publications (Krayushkin et al., 2019).

Measurements are performed every year along the standard sections in order to have the opportunity to explore interannual variability. The regions of the measurement are selected on the basis of the following considerations. In the vicinity of Cape Taran (northwestern tip of Sambian Peninsula) the coastline bends at an almost right angle, which facilitates formation of a complex system of currents depending on hydrometeorological conditions, the wind field in the first place (Gurova, Chubarenko, 2012; Krayushkin et al., 2018; Lavrova et al., 2018). In case anthropogenic and biogenic pollutants appear in this region, they can spread both east, along the northern coast of the Sambia Peninsula, and south, along its western coast. In some cases, quite rare, and certain wind rose, pollutants can be driven into the open sea. Given the complexity of nonlinear hydrophysical processes in the region of Cape Taran, regular formation of eddies and jet streams contributing to the spread of pollution, measurements in the region are made along 3 sections: Taran-Nord, Taran-Nord-West and Taran-West (Fig. 3). This region is also the main launch location of the drifters.
Another main section is done near the Yantarny settlement. We regularly observe there high water turbidity. The sharp increase in suspended matter in water can be caused by operation of one of the local enterprises, such as JSC Kaliningrad Amber Plant. From open sources it is known that the technology of amber production at the plant allows periodic discharges of industrial effluents to the Baltic Sea. In the course of production, fresh and sea water (at 1:3 volume ratio) carrying rock waste is collected in the tailings ponds. Suspended particles are supposed to settle down in the ponds. In irregular situations, e.g. in difficult weather conditions, large amount of wastewater may be discharged, containing, in particular, suspended sand and clay particles that do not settle and spread over long distances.

Finally, one of the main sites of field work concurrent to satellite survey was the Baltiysk Canal and the adjacent sea. The purpose of this study was to investigate the characteristics of fresh water outflow from the Vistula Lagoon to the Baltic Sea and verify them with satellite data (Lavrova et al., 2016a). The main environmental problem of the Vistula Lagoon is strong eutrophication. Three phytoplankton species dominate: cyanobacteria, green algae and diatoms, with cyanobacteria comprising over 80% of the total population. Usually, Vistula Lagoon outflows into the sea carry large amount of cyanobacteria that are distributed along the coastline over great distances. In the area of Baltiysk, measurements of all possible water parameters were conducted at more than 20 stations.

**Satellite data**

All field work is carried out concurrently with satellite survey. For satellite monitoring of southeastern Baltic, we use both radar data from SAR-C radars of Sentinel-1A, -1B satellites, and optical data. The latter are high spatial resolution data from Sentinel-2A, -2B MSI; Landsat-8 OLI; and medium resolution from
Sentinel-3A, -3B, OLCI; Landsat-8 TIRS, Terra/Aqua MODIS, Suomi NPP VIIRS sensors. Waters turbidity and intense algae bloom zones are detected and assessed using true color (RGB) images and products derived from satellite data: Total Suspended Matter (TSM); Water Leaving Radiance (WLR) at 551 nm and CHL-a concentration.

In visible true color images, zones of increased bloom are clearly manifested as bright green or greenish-brown areas. The signal registered by the sensors in the visible range is determined by scattering by the hydrosols, phytoplankton and suspended mineral particles. Hydrosols can also be considered as passive tracers of surface currents. The frontal zones that they form, as a rule, correspond to streamlines (Fig. 1). The suspended matter is manifested as areas of light tones. The lighter the area the greater is the concentration of suspended matter (Fig. 4). Figure 4 shows a fragment of a true color Sentinel-2A MSI image of 16 August 2016 featuring high water turbidity near the coast caused by the installation works of an offshore gas receiving terminal.

Areas with high levels of suspended matter caused by natural shallow water turbulence are distributed mainly along the coast and have rather intricate shapes due to mesoscale dynamic processes. They are capable of spreading the suspended matter over southeast Baltic and even as far as the central part of the sea.

Results

In the course of field experiments concurrent to satellite imaging many new and interesting results were obtained. In part they are described in our previous papers (Lavrova et al., 2016a; 2018; Krayuskin et al., 2018; Golenko, Lavrova 2019). In this work we present more new results relating to the identification of possible directions of pollution distribution in southeast Baltic.

Figure 4. Example of high water turbidity manifestation in a true color image. Fragment of Sentinel-2A MSI of 16.08.2018 in the area of underwater pipeline construction. Arrow indicates the offshore gas receiving terminal.
Results of drifter experiments

In total, 28 mini-drifters were launched during the works in 2015-2019. Since the main restriction on the distance of operation was imposed by the necessity to have stable mobile communication, which was available within 20-25 km from the coast, most drifters were launched at distances of 15-20 km. The drifters started operation on the standard sections shown in Figure 3. On the sections near Baltiysk, the drifters were launched at a distance of only 2 km to determine the parameters of the flow associated with propagation of Vistula Lagoon waters in the sea. Each drifter carried in its transparent box a written note asking to call the contact number in case someone collects it. Only 4 drifters unexpectedly ceased communication during work and their fate remains unknown. Most likely, they were carried into the open sea. Analysis of the trajectories of the other 24 drifters showed that almost all land on the coasts of southeast Baltic. We can distinguish two main landing areas: the beach near the Yantarny settlement and the Curonian Spit approximately at the border of Russia and Lithuania (some were found on the Lithuanian, some on the Russian coasts). Three drifters landed on the Vistula Spit (one of them on the territory of Poland), and another three in the area of the Svetlogorsk resort. Figure 5 (left) shows a map with the landing areas, Figure 5 (right) drifter distribution among them (percents).

Typically, a drifter lands ashore in 2 - 3 days after launch. The maximum period of operation was 8 days (28.07 - 05.08, 2016). That case is described in detail by Krayushkin et al. (2019).

Figure 5. Landing areas of the drifters (left) and their percentage distribution (right).

Even more interesting case was observed in August 2018. A drifter with sail at a depth of 1 m was launched 08.08.2018 at the exit from the Baltiysk Canal. Under southeast wind it should have drifted to the sea, but in previous days a northward coastal current had formed in that area. The drifter was not cast ashore near Yantarny, as one would expect given the heterogeneity of the coastline. It safely reached Cape Taran, where made an inertial loop and then got entrained by the jet of an eddy dipole downstream Cape Taran (Krayushkin et al., 2018). The dipole is manifested in satellite images of 7-9 August 2018. A day and a half later the drifter landed at Curonian Spit, having made a distance over 100 km. This example clearly demonstrates that pollution from the area of Baltiysk (where oil spills are frequent) can quite soon reach Curonian Spit. Another important result was obtained in August 2018 when drifters with sails at the same depth of 5 m were launched approximately in the same area (Taran – Nord section) but at different distances from the coast. They reached Curonian Spit within time periods more than three times different: those entrained along the coast by a stream associated with a drifter drifted 2 days, others that avoided the dipole or got into its cyclonic part drifted more than 6 days. This suggests that eddies and eddy dipoles have a significant impact on propagation of floating objects, in particular on spreading of pollution. It should be noted that while the results of numerical simulations carried out for August 2018 data (Golenko, Lavrova, 2019) reflected adequately the situation of passive admixture (proxy drifter) flow along the western coast of the Sambia Peninsula from the Baltiysk Canal exit to Cape Taran, we could not simulate the movement of the tracer under the influence of the dipole along the northern coast of the Sambian Peninsula and its landing
on the coast of Curonian Spit. This proves that experiments with mini-drifters provide valuable information that is almost impossible to obtain otherwise.

**Spreading of turbid waters from the Vistula Lagoon to the Baltic Sea**

As noted above, the Vistula Lagoon, like the Curonian Lagoon, is subject to intense summer bloom of cyanobacteria. It is connected to the sea by the Baltiysk Canal, through which, under certain conditions, the water of the bay is carried to the sea (Chubarenko, Margonski, 2008). Since it differs significantly in optical characteristics from more transparent sea water, its plume is as a rule well manifested in satellite imagery of visible range. Lagoon outflow monitoring is very important from environmental point of view. It is necessary to understand under what hydrometeorological conditions it intensifies, how far and in what direction lagoon waters containing harmful biogenic pollutants can spread, either to Vistula Spit, relatively deserted in the north, or to the tourist beaches of Sambian Peninsula. In addition, two important problems arise that we aim to address in our field experiments supported by satellite survey. The first one is the accuracy of estimating spatial characteristics of lagoon outflows from satellite data. The second is the depth of lagoon water penetration. These problems cannot be solved using satellite data alone.

Measurements of the parameters of lagoon water outflows to the sea carried out in July and early August 2014 under different wind conditions revealed the main role that wind plays in the formation and spreading of the lagoon plume (Lavrova et al., 2016a). During upwelling, wind-driven coastal currents carried the plume southwest along the Vistula Spit for 5 to 6 days (July 22–27). When the coastal upwelling weakened and changed to downwelling (July 28–30), the distant end of the plume moved to the north. During strong coastal downwelling, the lagoon outflow propagated to the north along the Sambian Peninsula, eventually forming an eddy near Cape Taran. The lagoon waters did not propagate to depths below 5 m (Lavrova et al., 2016a).

In 2019, we focused on in-situ measurement of turbidity and CHL-a concentration in the plume area. On August 01, measurements at 22 CTD stations were made near the outflow source from board of a research boat (Fig. 6, right). Using an RBR Concerto CTD probe equipped with external optical sensors to measure CHL-a concentration and turbidity, measurements were taken to determine temperature, salinity, backscatter (turbidity) and CHL-a distribution. Also, we measured turbidity in the upper layer using a portable seawater turbidity meter and current using ADCP and Lagrangian drifters.

**Figure 6.** Manifestation of Vistula Lagoon outflow via the Baltiysk Canal in a true color composite image of Terra MODIS of July 31, 2019 (left); CTD-station locations during field work on August 01, 2019 (right).
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Figure 7. Turbidity in the upper layer (left) and CHL-a concentration surface distribution (right) in the area of the Vistula Lagoon outflow on August 01, 2019.

Unfortunately, during in situ measurements on August 01, the sky was completely covered with clouds. The surface manifestation of Vistula Lagoon outflow through Baltiysk Canal could only be observed in a MODIS image of July 31, the day before the experiment (Fig. 6 left). Despite low spatial resolution of MODIS data (250 m), it is clearly seen that the plume is asymmetric with the main axis extending southwest.

The results of upper layer turbidity and CHL-a concentration measurements at 22 stations are presented in Figure 7. Absolute values of backscatter turbidity in the surface waters in the area of the outflow are quite small, ranging 0 - 5 NTU (Fig. 7 left). The area of maximum turbidity corresponds to the area of low salinity, which proves that the outflow propagates southwest from its source and which is in agreement with satellite data (Fig. 6, left). Low content of suspended matter indicates that the lagoon waters, unlike river waters, do not carry to the sea a lot of suspended materials. The difference in the optical properties of the lagoon plume and the seawater, visible in satellite images, is determined by the presence of cyanobacteria. Figure 7 (right) shows surface distribution of CHL-a concentration. Maximum CHL-a concentrations (up to 15 mg/l) are measured in the western part of the study area which additionally confirms that the outflow water full of algae propagates west in agreement with satellite image of July 31.

Joint analysis of the satellite data and concurrent in-situ measurements demonstrates that satellite optical data allow accurate assessing of Vistula Lagoon outflow spreading.

Conclusions

Multi-year annual field measurements concurrent to satellite surveys that have been conducted in southeast Baltic since 2014 reveal coastline areas worst affected by seawater anthropogenic and biogenic pollution. Lagrangian mini-drifters with underwater sails installed at different depths were used as passive tracers. Such simple design allows tracing the propagation direction and velocity of various kinds of pollution under the impact of coastal currents and other mesoscale and submesoscale dynamic processes. As shown by our experiments, no matter where the drifter is launched and what is its sail depth, it will land either on the beach of the Yantarny settlement or at the central part of Curonian Spit. Meanwhile, the beach of Yantarny was the first in Russia to receive the Blue Flag certification confirming compliance with high international standards of quality and safety. First of all, these are ecologically clean sea and coast. And it is this particular beach with white fine sand that most likely will be contaminated, for example, in case of illegal discharges of polluted wastewater from ships. Also, our bold hypothesis is that it is because of the nature of local sea currents, this area is famous for the greatest quantity of amber thrown ashore by the sea.

The second area where our drifters landed is Curonian Spit, which is a natural reserve and UNESCO World Heritage Site. 2018 works demonstrated how a drifter launched in the area of Baltiysk, a large Russian port, got entrained by the jet of an eddy dipole and in a short period reached the beach of Curonian Spit. It would be impossible to obtain such information either from satellite data or numerical simulations.
Considering abundance of harmful algal cyanobacteria in the Vistula Lagoon and frequent outflow of its waters to sea via the Baltiysk Canal, it is important to conduct regular satellite monitoring of the plume and estimate its main parameters: water turbidity, CHL-a concentration, salinity and temperature. Also, satellite data allow determining spatial characteristics of the plume, while its propagation direction can be derived from a series of satellite images. However, the results of satellite observations still require verification against concurrent in situ measurements.

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References
Bulycheva, E.V., Kostianoy, A.G. (2014) Results of satellite monitoring of the sea surface oil pollution in the Southeastern Baltic Sea in 2004-2013. Sovremennye problemy distantzionnogo zondirovaniya Zemli iz kosmosa, 11 (4), 111-126. (In Russian).
Bulycheva, E.V., Krek, A.V., Kostianoy, A.G. (2016a) Peculiarities of distribution of oil pollution in the Southeastern Baltic Sea by satellite data and in situ measurements. Oceanology, 56 (1), 75-83. https://doi.org/10.1134/S000143701601001X.
Bulycheva, E.V., Krek, A.V., Kostianoy, A.G., Semenov, A.V., Joksimovich, A. (2016b) Oil pollution in the Southeastern Baltic Sea by satellite remote sensing data in 2004-2015. Transport and Telecommunication, 17 (2), 155-163. DOI: https://doi.org/10.1515/ttj-2016-0015.
Chubarenko, B., Margonski, P. (2008) The Vistula Lagoon. Ecology of Baltic Coastal Waters. Ecological Studies. Schiewer (Ed.). Springer-Verlag, 167-195.
Ginzburg, A.I., Bulycheva, E.V., Kostianoy, A.G., Solovyev, D.M. (2015a) On the role of vortices in the transport of oil pollution in the Southeastern Baltic Sea (according to satellite monitoring). Sovremennye problemy distantzionnogo zondirovaniya Zemli iz kosmosa, 12 (3), 149-157. (In Russian).
Ginzburg, A.I., Bulycheva, E.V., Kostianoy, A.G., Solovyov, D.M. (2015b) Vortex dynamics in the Southeastern Baltic Sea from satellite radar data. Oceanology, 55 (6), 805–813.
Ginzburg, A.I., Krek, E.V., Kostianoy, A.G., Soloviev, D.M. (2017) Evolution of mesoscale anticyclonic vortex and vortex dipoles/multipoles on its base in the South-Eastern Baltic (satellite information: May–July 2015). Journal of Oceanological Research, 45 (1), 10-22.
Ginzburg, A.I., Krek, E.V., Kostianoy, A.G., Soloviev, D.M. (2019) Oil spill transport under the influence of mesoscale vortex movement in the Southeastern Baltic (satellite information: June 2015). Journal of Oceanological Research, 47 (3). (In Russian).
Golenko, M.N., Golenko, N.N. (2012) Structure of dynamic fields in the Southeastern Baltic during wind forcings that cause upwelling and downwelling. Oceanology, 52, 604-616. DOI:10.1134/S0001437012050086.
Golenko, M.N., Lavrova, O.Yu (2019) Investigation of the dynamics of stream currents along the coast of the Sambian Peninsula (South-Eastern Baltic) based on numerical modeling and analysis of ocean color satellite images. Sovremennye problemy distantzionnogo zondirovaniya Zemli iz kosmosa, 16 (4), 175-191. DOI: 10.21046/2070-7401-2019-16-4-175-191. (In Russian).
Gurova, E., Chubarenko, B. (2012) Remote-sensing observations of coastal sub-mesoscale eddies in the south-eastern Baltic. Oceanologica, 54 (4), 631–654. DOI: 10.5697/oc.54-4.631.
Kostianoy, A.G., Ambjörn, C., Solovyov, D.M. (2014) Seatrack Web – a Numerical Tool for Environmental Risk Assessment in the Baltic Sea. Oil Pollution in the Baltic Sea, (Eds.) A.G. Kostianoy and O.Yu. Lavrova, Springer-Verlag, Berlin, Heidelberg, New York, 27, 185-220.
Kostianoy, A.G., Bulycheva, E.V. (2014) Numerical simulation of risks of oil pollution in the Southeastern Baltic Sea and in the Gulf of Finland. Sovremennye problemy distantzionnogo zondirovaniya Zemli iz kosmosa, 11 (4), 56-75. (In Russian).
Kostianoy, A.G., Lavrova, O.Yu. (2014) *Oil pollution in the Baltic Sea*. Springer-Verlag, Berlin, Heidelberg, New York, 27, 268 pp.

Kostianoy, A., Litovchenko, K., Lavrova, O., Mityagina, M., Bocharova, T., Lebedev, S., Stanichny, S., Soloviev, D., Sirota, A., Pichuzhkina, O. (2006) Operational Satellite Monitoring of Oil Spill Pollution in the Southeastern Baltic Sea: 18 Months Experience. *International Journal of Environmental Research*, 43, 70-77.

Kostianoy, A.G., Ginzburg, A.I., Lavrova, O.Y., Mityagina, M.I. (2018) Satellite Remote Sensing of Submesoscale Eddies in the Russian Seas. *The Ocean in Motion: Circulation, Waves, Polar Oceanography*, Eds. Velarde M., Tarakanov R., Marchenko A. Springer, Cham, Switzerland., 397–413. URL: https://doi.org/10.1007/978-3-319-71934-4_24.

Krayushkin, E.V., Lavrova, O.Yu., Nazirova, K.R., Alferyeva, Ya.O., Soloviev, D.M. (2018) Formation and propagation of an eddy dipole at Cape Taran in the southeast Baltic Sea. *Sovremennye problemy zondirovaniya Zemli iz kosmosa*, 15(4), 214-221. DOI: 10.21046/2070-7401-2018-15-4-214-221. (In Russian).

Krayushkin E., Lavrova O., Strochkov A. (2019) Application of GPS/GSM Lagrangian mini-drifters for coastal ocean dynamics analysis. *Russian J. Earth Science*, 19, ES1001. DOI: 10.2205/2018ES000642.

Lavrova, O.Yu., Kostianoy, A.G., Lebedev, S.A., Mityagina, M.I., Ginzburg, A.I., Sheremet, N.A. (2011) *Complex satellite monitoring of the Russian Seas*. Moscow: IKI RAN. 470 p. (In Russian).

Lavrova, O., Krayushkin, E., Golenko, M., Golenko, N. (2016a) Effect of wind and hydrographic conditions on the transport of Vistula Lagoon waters into the Baltic Sea: Results of a combined experiment. *IEEE J. Selected Topics in Applied Earth Observations and Remote Sensing*. 9 (9). 5193–5201. DOI:10.1109/jstars.2016.2580602.

Lavrova, O.Yu., Mityagina, M.I., Kostianoy, A.G. (2016b) *Satellite methods of detection and monitoring of marine zones of ecological risks*. Moscow: IKI RAN, 2016, 336 p. (In Russian).

Lavrova, O.Yu., Kostianoy, A.G., Semenov, A.V. (2014) Oil pollution in the southeastern Baltic Sea in 2009-2011. *Transport and Telecommunication*, 15 (4), 322-331.

Lavrova, O.Yu., Mityagina, M.I., Uvarov, I.A., Loupian, E.A. (2019a) Current capabilities and experience of using the See the Sea information system for studying and monitoring phenomena and processes on the sea surface. *Sovremennye problemy zondirovaniya Zemli iz kosmosa*, 16 (3), 266-287. DOI:10.21046/2070-7401-2019-16-3-266-287. (In Russian).

Lavrova, O.Yu., Mityagina, M.I., Kostianoy, A.G. (2019b) Online database “See The Sea” for the Caspian Sea. *Ecologica Montenegrina*, 25, 79-90.

Zhurbas, V., Oh, I.S., Park, T. (2006) Formation and decay of a longshore baroclinic jet associated with transient coastal upwelling and downwelling: A numerical study with applications to the Baltic Sea. *J. Geophysical Research*. 111. C04014. DOI: 10.1029/2005JC003079.

Zhurbas, V, Välib, G., Kostianoy, A., Lavrova, O. (2019) Hindcast of mesoscale eddy field in the southeastern Baltic Sea: Model data vs satellite imagery. *Russian Journal of Earth Sciences*, 19. DOI:10.2205/2019ES000672.