The goal of the project is to develop and improve the techniques for the retrieval of parameters of sea surface pollution, investigate the impact of small scale dynamic and circulation processes on pollution propagation and assess the ecological state of Russia’s seas based on a combined analysis of satellite data.

Over the past three years, new satellites have been launched that are equipped with the most advanced sensors enabling remote diagnostics of processes on the Earth’s surface. These sensors provide continuous flow of high resolution data (down to units of meters) in various wave ranges of the electromagnetic spectrum that help dramatically improve the quality of remote studies of marine processes.

In 2018, new satellite data, including data from Sentinel-1A/B, Sentinel -2A/B, Sentinel-3A, Landsat-7/8, Terra / Aqua, were received and integrated into the See the Sea geoportal (STS) created and operated by IKI RAS. A technological solution was developed for the assimilation into STS of the data from the sensors installed on the Sentinel-3B satellite launched in 2018. The possibility of obtaining specialized data processing products for analyzing the state of the water surface, including floating algae index (FAI) and sea surface temperature (SST), was implemented. Color synthesis of radar images based on the visualization of data obtained on horizontal and vertical polarizations, as well as their ratio, was implemented. All newly obtained data were analyzed and used in solving the tasks of the project.

In the course of Stage 2, the following work was performed and the main results were obtained:

Methods for reliable recognition and discrimination of various types of marine pollution were improved based on the integrated use of new types of remote sensing data obtained in different ranges of the electromagnetic spectrum: from Sentinel-2 MSI, Sentinel-3 OLCI and Sentinel-1A, -1B SAR-S sensors. The advantages and possible limitations were identified for the use of various satellite data and their combinations for detecting films of different nature on the sea surface as well as developing techniques for resolving ambiguities in interpreting radar data and refining the quantitative parameters of oil pollution of the sea surface.

A method was developed for determining the limits of the reliability of identifying the area of oil pollution from radar data, based on taking into account the dependence of the formation of radar signatures of sea surface oily films on the wave-wind and hydrometeorological conditions.

The technique was improved for distinguishing pollution in the coastal zone caused by increased concentration of suspended matter due to biogenic "pollution" in areas of intensive phytoplankton blooms based on a joint analysis of maps of total suspended matter and chlorophyll-a concentration compiled from Sentinel-2 MSI, Landsat-8 OLI and Sentinel-3 OLCI data.

From the analysis of satellite images, statistically based data were obtained on the spatial, seasonal and interannual variability of dynamic processes affecting pollution transport: meso- and submesoscale vortex structures, as well as mesoscale and submesoscale fronts (both at sea and in the near-surface layer of the atmosphere) in the southeast Baltic Sea; distribution of river water in the sea, in particular for the rivers flowing into the east Black Sea and River Rhone (Gulf of Lyon of the Mediterranean); internal waves in the northeast Black Sea.

Model simulations were carried out to identify the mechanisms of the influence of small-scale processes on the spreading of pollutants in the test areas: east and southeast Black Sea, southeast Baltic Sea, and the Gulf of Lyon in the Mediterranean Sea.

The direct and indirect contributions of dynamic processes, first of all, vortex structures and jets, to the process of pollution distribution in the marine water areas were revealed. In particular, based on the analysis of consecutive satellite images, the influence of a mesoscale anticyclonic vortex on the drift of oily patches in the northern part of the Gdansk Bay was first demonstrated and the velocity of this drift was estimated depending on where they hit the anticyclone and its associated cyclone (vortex dipole). Based on the analysis of satellite SAR images containing slicks of natural oil manifestations on the sea surface of southeast Black Sea in the area of the Turkish shelf near Rize, it was found that in 10-12% of cases, the oil film, after reaching the surface, was entrained in small-scale vortex movements, which often radically change the expected (simulated) trajectory of the slick. It was established that, depending on the size, the sign of vorticity and the trajectory of the vortex, the entrainment of a slick in vortex movements can have both a positive effect, contributing to cross-shelf transfer of pollution and purification of the coastal zone, and a negative one, contributing to pollution transport toward the coast.

On the basis of satellite monitoring data and the results of concurrent ground measurements, the distribution of pollutants, in particular highly turbid waters, was revealed to be influenced by the along-shore jet stream, which was part of the vortex dipole. The propagation velocities of the pollutants were estimated depending on their location, either within the jet stream or on the periphery of the dipole.

The work on improving the methods for predicting the propagation of various types of pollutants, taking into account more detailed information on the actual spatiotemporal structure and interaction of meso- and submesoscale processes (vortices, vortex dipoles, jets, internal waves and fronts) in regions affected by various types of pollution led to the following conclusions:

- meso - and submesoscale processes (anticyclonic and cyclonic eddies, vortex dipoles, jets and fronts) significantly affect the velocity and direction of oil patch drift;

- in the case of moderate winds and weak currents, the influence of meso- and submesoscale processes on the drift of oil patches becomes the key factor;

- in the case of a chain of oil spills, the influence of meso- and submesoscale processes on the drift of oil patches is individual, since each patch is affected by a specific part of the vorticity field, which differs in water current velocity and direction even within the same vortex. This situation is different from the effects of significantly larger and, therefore, more homogeneous (relative to the oil patch) wind fields and general currents.

The main result: the techniques of forecasting the propagation of various types of pollution, taking into account detailed information on the actual space-time structure and interaction of meso- and submesoscale processes, should assimilate high-resolution operational satellite radar and optical data (10-30 m) and the results of numerical simulation with a resolution of 100-200 m.

Based on 2017-2018 satellite data, quantitative estimates were obtained of the interannual, seasonal and spatial variability of natural and anthropogenic oil pollution of the sea surface in southeast Baltic Sea and oil pollution in southeast Black Sea, where natural oil seeps to the sea surface are observed (on the Turkish shelf near the town of Rize and in the Georgian sector of the Black Sea in the Poti-Batumi region). The total areas of oil pollution were determined and their interannual variability was studied.

The risks of oil pollution of the water area and coast for the test regions were estimated on the basis of long-term satellite data, numerical modeling and hydrometeorological information. A technique was developed for determining the zones of potential pollution of the coastline based on the results of the drifter experiments.

In 2018, two series of field measurements were carried out concurrently with satellite surveys. From April 20 to April 29, 2018, the parameters of River Mzymta (Black Sea, Sochi region) plume were measured from a small boat using the ADCP RDI WH 300 kHz and CTD instruments. Water was also sampled from the surface horizon for further laboratory analysis in order to determine the concentration of suspended matter and compare the results with those obtained from satellite data. The main purpose of the expedition work in the Sochi region was to determine the hydrological parameters in the river outflow area (temperature, salinity, turbidity) and their spatial and depth distribution. During the expedition period, 13 satellite images of high spatial resolution were obtained and analyzed. A joint analysis of satellite information and the results of concurrent field measurements was performed in order to verify satellite data interpretation.

The expedition works in the coastal zone of the Baltic Sea in the Sambia Peninsula region were carried out from July 31 to August 11, 2018. During that period, the current parameters were measured using ADCP, CTD probe, total turbidity sensor and fluorimeter. 6 hydrological sections were made and CTD probing was carried out at 66 stations. 10 Lagrangian drifters were launched in different areas under different hydrometeorological conditions. The real trajectories of the drifters were compared with the results of numerical simulation based on the POM model adapted for the southeastern part of the Baltic Sea. Replication in the model calculations of inertial loops found on the trajectories of some of the drifters occurred during a period of consistently low velocities (0.05-0.15 m/s) of current which is formed against the background of more frequent changes in the direction of moderate wind with a speed of 6 m/c. At high velocities of coastal jet current, which was observed along the northern coast of the Sambia Peninsula during the formation and propagation of a vortex dipole on August 8-10, the model particles propagated in the near-surface layer along trajectories close to the trajectories of the drifters. The trajectories of particles launched from the same points in the bottom layer had more diverse shapes, and the prevailing direction of their movement was determined by the current structure in the launch layer. For the period close to the flow periods of the real drifters, maps of suspended matter compiled from satellite data were analyzed. The directions of propagation of turbid waters and the shapes of the areas they occupied in the vicinity of Cape Taran were noted to agree with the structure of simulated surface currents in the region.

The results obtained during Stage 2 of the project were presented in 12 publications indexed by Web of Science Core Collection, SCOPUS and RSCI. 16 presentations were made at 10 international and Russian conferences.

Detailed information and materials of this project can be found at http://www.iki.rssi.ru/asp/dep_proj/proj_555.htm.