Main results of project RNF 14-17-00555 in 2014

The aim of the project is to develop methods to retrieve parameters of sea surface pollution, investigate the effect of dynamic and circulation processes on the spread of pollutants, and determine ecological state of Russian seas based on comprehensive analysis of satellite data. The solving of the project tasks implies complex use of data different in physical nature (active and passive microwave sensing, optical data of multi- and hyperspectral sensors), spatial resolution and units of measurement.

In the course of the first stage of the project, the variety of data accumulated by IKI RAS on satellite remote sensing of the Baltic, Black and Caspian Seas for 2004-2014 were systematized, analyzed and integrated into a geoportal developed by IKI RAS to manage satellite remote sensing data for purposes of solving fundamental problems of world ocean studies. This included:

- expert analysis of satellite data selected for incorporation into the geoportal; compiling tables featuring detailed description of each image, including detected phenomena and processes, their parameters and metocean conditions of imaging;

- compiling the list of main processes and phenomena at the sea surface and in the near-surface layer of the atmosphere intended for analysis using the geoportal tools;

- elaborating a coding pattern for phenomena introduction into the geoportal phenomena toolkit environment;

- selecting an optimal set of parameters and elaborating a format for the most complete description of each phenomena class.

At the time of preparation of the present report, the following remote sensing data of the Baltic, Black and Caspian Seas were integrated into the geoportal environment:

- over 3600 synthetic aperture radar (SAR) images;
- over 10 000 images from Landsat sensors;
- over 300 hyperspectral images from Hyperion;
- 58 hyperspectral images from HICO;
- daily Terra/Aqua MODIS data starting from 2008 until the present time.

During the first stage of the project, the specialized tools for thematical processing and complex analysis of satellite data were upgraded in order to enable determination of pollution types and scales, as well as obtaining their quantitative estimates.

In the project, a special focus is on upgrading the algorithms for recognition of marine pollution of various origins based on remote sensing data. Also, an important aspect is improving the techniques to obtain quantitative estimates and assess pollution scales.

Thematic processing of the selected satellite data was performed along with phenomenological identification of various types of anthropogenic and biogenic pollution. In SAR images, four main types of sea surface film pollution were discriminated:

- ship spills of liquids containing oil;

- outflow of sewage and river waters containing film pollutants of mixed anthropogenic and biogenic origins;

- underwater mud volcanoes and natural seeps of hydrocarbons found in the Black and Caspian Seas;

- increased bioproductivity, in particular related to life cycles of chlorophyll-a and intense algae bloom.

Mapping of sea surface oil pollution in the Baltic Sea was performed based on the analysis of SAR images for 2004-2013. Areas most affected by oil pollution were revealed. In the Southeastern Baltic Sea, the largest pollution is observed along ship routes to the ports of Klaipeda, Kaliningrad, Gdynia and Gdansk. The ship anchorage site near the mouth of the Kaliningrad channel is estimated as the most polluted area.

Areas of intense algae bloom and biogenic films were identified and mapped based on satellite SAR and optical data. For this purpose:

- The technique to discriminate between blue-green (cyanobacteria) algae and diatoms based on the analysis of satellite data and subsatellite measurement data was tested and fine-tuned for the site of the Rybinsk Reservoir. The results were proven for test sites of the Baltic Sea. The main areas of the Baltic Sea most affected by intense bloom of blue-green algae were revealed. They are the Gotland basin, Curonian and Vistula Bays, coastal waters of the Finland and Riga Gulfs, the central and southwestern regions of the sea.

- A novel indirect method to detect areas of intense algae bloom was suggested. It was established that radar patterns of long lasting wakes behind moving ships could indicate increased biogenic activity. Joint analysis of satellite SAR and optical data showed that long lasting ship wakes were observed primarily at the time of intense phytoplankton bloom. The length of the wakes provided a tentative estimate of the bloom area;

- A technique was developed to discriminate between waters with different characteristics and affected by different anthropogenic pollutants. The technique uses tools elaborated for hyperspectral data of Hyperion and HICO sensors. It was proven for test regions of the Black and Baltic Seas.

The accumulated and systematized satellite data make it possible to obtain detailed information on real spatial and temporal distribution of meso- and submesoscale processes (eddies, eddy dipoles, jets, internal waves and fronts) in various regions in near-real-time mode. Based on satellite data, an investigation was undertaken to highlight the spatial and temporal structure and dynamics of meso- and submesoscale processes influencing the transport and distribution of pollutants and facilitating cleaning of the water from pollutants in various regions of the Black and Baltic Seas. This included:

- Based on satellite data, spatial and temporal location variability of anticyclonic and cyclonic eddies in the Baltic Sea, their occurrence frequency and linear dimensions were analyzed in detail. Seasonal and summary annual maps of eddy locations in the sea were compiled.

- The results were summarized concerning the determination of different types of water circulation in the northeastern Black Sea characterized by different vorticity and effect on pollution spread.

- The main regions of surface manifestations of internal waves (SMIW) were determined in the Black and Baltic Seas. In the Black Sea, they are the Danube shelf zone, southern and southwestern coastal regions of the Crimea Peninsular and the northeastern part of the Black Sea. In the Baltic Sea, SMIW are mainly observed in the Danish Straits. Particular characteristics of SMIW SAR patterns differing between the basins were defined as well as quantitative parameters of internal wave trains.

- Meso- and submesoscale structures (eddies, jets and eddy dipoles of typical horizontal scales of 5-30 km) were shown to significantly influence the distribution of suspended matter in the sea and may carry waters with increased amount of suspended matter for over 50-100 km off the coast. For instance, such transport is an important factor of increased water turbidity in certain parts of the Gulf of Finland.

- Particular emphasis was laid on determination of the impact of hydrodynamic processes and wind conditions on the spread of turbid low-salinity waters of the Kaliningrad Bay over the coastal zone of the Baltic Sea.

The results were incorporated into the database of phenomena by study regions. This initiated the accumulation of statistics on spatial, seasonal and interannual variability of dynamical processes in coastal zones, that affects the transport of pollution.

The effect of metocean, dynamical and circulation processes on the transport of pollution was investigated via modeling the drift of oil pollution along a ship route in the Gulf of Finland using the SeatrackWeb (SMHI) model. The greatest potential oil pollution was menacing Hogland Island, less pollution was in store for some small Russian islands, islands near the Finnish coast, west of Helsinki, as well as Russia's northern and southern coast and extreme eastern part of the Gulf of Finland.

Subsatellite fieldwork was conducted in the southeastern Baltic Sea and the northeastern Black Sea.

In the course if the fieldwork in the Baltic Sea, we investigated the hydrological structure of the outflow of low-salinity turbid waters of the Kaliningrad Bay via the Baltic Channel. The effect of wind and hydrodinamical processes on the outflow spread was determined, the 3D structure of the outflow was defined. Satellite images in visible range were shown to enable rather accurate estimation of the outflow spread area. The parameters of coastal currents near the Sambian Peninsular were assessed.

Today, the task of retrieving pollution parameters as well as dynamic characteristics of water media influencing pollution spread in Russia's inner and bordering seas is crucial. These seas are severely affected by oil pollution because of wide scale oil and gas production on the shelf accompanied by construction and operation of marine stationary platforms, coastal terminals, hydrocarbon storages, underwater pipelines, seismic works and drilling, traffic increase, etc. Satellite monitoring is nowadays the only feasible and real means of operational control in these basins.

Main results of project RNF 14-17-00555 in 2015

The aim of the project is to develop methods to retrieve parameters of sea surface pollution, investigate the effect of dynamic and circulation processes on the spreading of pollutants, and determine ecological state of Russian seas based on comprehensive analysis of

satellite data. The solving of the project tasks implies complex use of data different in physical nature (active and passive microwave sensing, optical data of multi- and hyperspectral sensors), spatial resolution and units of measurement.

Stage 2 of the project saw continued progress in developing the methods to retrieve parameters of sea surface pollution, investigating the impact dynamic and circulation processes have on spreading of pollutants, and estimating ecological state of the Russian seas based on comprehensive analysis of satellite data. Processing and analysis of a large bank of satellite data were performed using the tookit of the See the Sea (STS) geoportal developed by IKI RAS.

The following work was performed during Stage 2 of the project.

Data from satellite remote sensing instruments were continually received and integrated into STS, including data from scanning radiometers Landsat-7 ETM+ and Landsat-8 OLI/TIRS, spectroradiometers Terra/Aqua MODIS, and EO-1 HYPERION hyperspectral data.

The range of satellite data for integration into STS was extended to include synthetic aperture radar (SAR) data obtained by Sentinel-1 satellite of the European Space Agency (in nominal operation since October 2014). Over the reporting period, over 7 thousand images of the Black, Baltic and Caspian Seas were integrated into STS. Geography of received and processed satellite data was extended for the northern seas of Russia, the Barents and Kara Seas, in particular. Moreover, for these seas, archive SAR data obtained by Envisat ASAR sensor in 2005 – 2012 were also integrated into STS. At the time of preparation of the present report, SAR data STS collection for the Barents and Kara Seas comprised over 8 thousand images.

Thematic processing started for satellite data from selected test regions of the Barents Sea (coastal zone of Kola Peninsula) and Kara Sea (Kara Strait, mouths of the Ob and Yenisei Rivers) aimed at phenomenological identification of different types of anthropogenic and biogenic pollution. The work to determine the main dynamic processes influencing pollution transport in these regions was initiated.

Marine pollution recognition algorithms were further upgraded to strengthen discrimination between pollution origins based on combined use of satellite data provided by various remote sensing instruments. Advantages and limitations for using particular data and data combinations were determined for application to detecting oil and biogenic films on the sea surface.

Oil pollution mapping of the Black and Caspian Seas was performed based on the results of retrospective analysis and combined satellite monitoring conducted by IKI RAS in 2009-2012. This work was implemented using STS cartography interface. The interface provides access to and management of various cartographic layers, such as bathymetry isolines, coastlines, coastal settlements and rivers, borders of states, ship traffic routes, shelf oil production sites. The maps compiled under the project helped to determine variability and regularity of oil pollution in different time and space scales. Interannual and seasonal variability of total oil pollution area was retrieved, and spatial distribution of oil pollution was estimated. Sea surface regions most frequently polluted by oil films were detected and causes of such pollution were identified: ship discharges and natural underwater seeps of hydrocarbons.

An analysis of 1845 SAR images of the Baltic Sea obtained in 2004-2014 was performed aimed at detecting oil pollution in the southeastern part of the Baltic Sea. Monthly and seasonal variability of the number of oil slicks detected in satellite data was investigated. Areas worst affected by oil pollution were determined, oil pollution mapping was performed for the whole period of monitoring.

On the basis of SeatrackWeb numerical model of the Swedish Institute of Meteorology and Hydrology (SMHI), oil spill spreading probability was calculated daily for 5 test regions of the Baltic Sea known for high risk of oil pollution: 1) ship route in the Gulf of Finland; 2) ship route toward the Kaliningrad Canal; 3) area to the west of Sambian Peninsula; 4) Lukoil marine oil platform D-6 in the southeastern Baltic Sea; 5) bottom product pipeline from D-6 to the coast. Over 1650 model calculations were made by the time of the present report.

In the case of especially extensive oil pollution of water surface in the Black, Caspian or Baltic Seas revealed in satellite data, numerical calculation of oil spill drift probability was made by FOTS model (Floating Objects Tracking System, Marine Hydrophysical Institute RAS, Sevastopol). The model calculates oil spill evolution taking into account processes influencing its dynamics and mass exchange with the environment (spreading, evaporation, etc.). Model application limitations were determined.

In the case of dramatic oil pollution in the southeastern Baltic Sea revealed in satellite data in 2015, 48 hour forecast of oil spill drift and evolution was modeled by SeatrackWeb and FOTS. Modeling results were compared, advantages and limitations of each model were demonstrated. In conditions when vortical structures existed in the region, FOTS was found to produce more realistic forecasts

Development of techniques was initiated to estimate the thickness of oil film on water surface based on Hyperion and HICO hyperspectral data and data of optical sensors of high and medium resolutions.

Satellite data were examined for manifesting water circulation elements (current meanders, temperature fronts and upwellings, vortical structures, jets, fronts and internal waves) capable to impact transfer and distribution of pollutants, as well as water cleaning in the Baltic, Black and Caspian Seas. The results were incorporated into the database of phenomena in different regions of observation. Hence statistics accumulated regarding spatial, seasonal and interannual variability of coastal dynamic processes affecting transport of pollutants.

Principal mechanisms were revealed behind the generation, formation and evolution of meso- and submesoscale eddies, eddy dipoles in the northeastern Black Sea and southeastern Baltic Sea. Mechnisms of internal wave generation were investigated for the whole of the Black Sea and southeastern Baltic Sea. Analysis of high resolution satellite data made it possible to observe generation of internal waves induced by the passage of a strong atmospheric eddy in the region of Sambian Peninsula.

The impact of meso- and submesoscale water dynamics on oil pollution transport was estimated for the following test regions: the Danube and Georgian shelves of the Black Sea, the Caspian Sea in the area of Neftyanye Kamni oil production.

The contributions of various natural factors affecting concentration and distribution of suspended matter were assessed for 5 selected test regions. On the Danube and Georgian shelves of the Black Sea and in the Gdansk Bay of the Baltic Sea, the main role is played by river inflow and wind force, while coastal wind-wave mixing is the main factor in shallow waters of the Gulf of Finland in the Baltic Sea and near Apsheron Peninsula in the Caspian Sea.

Mapping of suspended matter propagation was performed for the following test regions: the area near the Danube Delta and northeastern and eastern parts of the Black Sea, Gulf of Finland in the Baltic Sea and the area near Apsheron Peninsula in the Caspian Sea. The mapping was based on classification using a dedicated toolkit of STS geoportal. Area of each class was estimated, as well as total area of suspended matter propagation. Spatial and temporal

propagation variability of suspended matter carried out of mountain rivers to the Georgian shelf in the Black Sea was thoroughly investigated.

The correspondence between manifestations of biogenic surface films in satellite data and areas of intense algae bloom was investigated. The research was based on joint analysis of data obtained by SAR and optical sensors (multi- and hyperspectral data).

Three series of experimental measurements were conducted concurrently with satellite imaging in the southeastern Baltic Sea and in the Black Sea near the Crimea Peninsula and in the northeastern part of the sea. The aim was to measure parameters of coastal currents, identify sources of anthropogenic and biogenic pollution, investigate the impact of hydrodynamic processes on pollution propagation and verify satellite data interpretation techniques.

Solving the task of retrieving pollution parameters as well as dynamic characteristics of water media influencing pollution spreading in Russia's inner and bordering seas is crucial today. These seas are severely affected by oil pollution because of wide scale oil and gas production on the shelf accompanied by construction and operation of marine stationary platforms, coastal terminals, hydrocarbon storages, underwater pipelines, seismic works and drilling, traffic increase, etc. Satellite monitoring is nowadays the only feasible means of operational control in these basins.

The project results were published in 13 papers and 7 international and domestic conferences. Materials on the project are presented at http://www.iki.rssi.ru/asp/dep_proj/proj_555.htm.