Online database “See The Sea” for the Caspian Sea

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Abstract
For many years, the primary environmental problem of the Caspian Sea has been oil pollution, which is associated both with oil production and transportation, as well as changes in sea level, leading to secondary pollution, river runoff and even seismic activity, which provokes natural oil spills from the bottom of the sea. Abnormal bloom of waters every year becomes more and more long and covers more and more areas, and also occurs in areas where it was not previously observed. However, the current state of the sea, and the trends of its evolution has not been studied enough, which determines the relevance of the solution of the main task of the ongoing Russian Science Foundation Project "Assessing ecological variability of the Caspian Sea in the current century using satellite remote sensing data". Implementation of the proposed project will assess the relative contribution of each of the sources of pollution of the Caspian Sea, which varies in different periods depending on climatic factors, on the intensity of various hydrodynamic and hydrometeorological processes, on seismic activity and human economic activity. The goal of the project is to assess the changes in the ecological state of the Caspian Sea since the beginning of the current century under the impact of natural and anthropogenic factors. This calls for a detailed analysis of large banks of satellite data acquired over the Caspian Sea from 1999 to 2022 jointly with multi-year hydrometeorological and in situ data. The goal is achievable due to powerful capabilities of the “See the Sea” (STS) information portal developed by the Space Research Institute of the Russian Academy of Sciences (IKI RAS) as part of IKI - Monitoring Center for Collective Use. STS offers oceanographers new and unique tools to work with remote sensing data, enabling comprehensive analysis of data different in physical nature, spatial resolution and time of acquisition.

Key words: satellite monitoring, ecological state, oil pollution, harmful algal blooms, ice cover, anthropogenic pollution, hydrodynamic processes, climate change, the Caspian Sea, “See the Sea.”

Introduction
The informational potential of satellite data with a high degree of spatial-temporal differentiation can provide a comprehensive study of marine system characteristics, essential for the ecological assessment of water areas. A satellite monitoring is an effective way of monitoring sea surface. Environmental research technologies, based on the satellite remote sensing of the Earth, are actively developing nowadays throughout the world and are applied to the different classes of natural objects, including the marine environment. Over the last decade, a large number of studies appeared, devoted to the development of satellite methods of the sea surface oil pollution control (Gade, Alpers, 1999; Malthus, Mumby, 2003;
Klemas, 2010; Horning et al., 2010; Kostianoy, Lavrova, 2014; Nunziata et al., 2014). The primary type of contamination, which was the main focus of research in the field of sea surface satellite monitoring, is the pollution of the sea surface by oil-containing films (Lu, 2003; Topouzelis et al., 2006; Ivanov, Zatyaloga, 2007; Crocker et al., 2007; Redondo et al., 2008; Shi et al., 2008).

Unambiguous oil detection based only on SAR data is still problematic. A number of reasons complicate the interpretation of SAR images and discrimination of oil pollution: under certain hydrometeorological conditions, especially under the low wind, oil spills can be easily confused with other phenomena, the so-called “radar look-alikes”. Among look-alikes are organic films, some types of ice, land shadow zones, rain cells, upwelling zones, internal waves in the atmosphere and ocean, etc. (Gade et al., 1998; Brekke, Solberg, 2005; Migliaccio et al., 2015). One of the problems to be solved during the ongoing Russian Science Foundation Project “Assessing ecological variability of the Caspian Sea in the current century using satellite remote sensing data” is the sea surface oil pollution assessment on the base of multi-sensor approach that is on the base of combine use of various sea surface remote sensing data. This approach helps to increase the reliability of satellite remote sensing data interpretation. The methods we are going to use allow us not only to reveal main patterns of the sea surface pollution but to make some quantitative estimates.

During the warm period of the year, vast expanses of waters in various seas are enveloped in the blooming of cyanobacteria. These blooms are mainly caused by two types of cyanobacteria: _Nodularia spumigena_ and _Aphanizomenon flos-aquae_. It was shown in (Reinart, Kutser, 2006) that since clusters of cyanobacteria are located either on the surface of the water or in its immediate vicinity, this causes elevated values of the normalized brightness of the ascending radiation in these spectral ranges compared to waters free of cyanobacteria. An analysis of the temporal variability of cyanobacteria blooms intensity in the Baltic Sea based on data from optical range sensors was carried out in (Kahru et al., 2007). In this work, cumulative maps for each pixel of the blooming area of 1 x 1 km in size were compiled as well as the frequency of cyanobacteria blooms was calculated. At the beginning 2000s, the Swedish Meteorological and Hydrological Institute developed a monitoring system for cyanobacteria in the Baltic Sea – the Baltic Algae Watch System, based on AVHRR data processing (Hansson, Hakansson, 2007). As a result of studies for the period 1997-2009 maps of the number of days with cyanobacteria blooms, maps of algal bloom areas, and maps the bloom intensities were compiled (Hopkis, 2000).

The mapping of oil pollution in the Russian sector of the Black Sea is carried out by State Research Center “Planeta” and by some Russian private companies in the aquatic area of the port of Novorossiysk. None of the Caspian countries (with the exception of Russia) carry out satellite monitoring of the aquatic area of the Caspian Sea (Fig.1). This is why we can speak about the fragmentation of the information on the parameters of various types of pollution of the aquatic environment in the Caspian Sea. Therefore, the mapping of natural and anthropogenic pollution, identification of its sources and prediction of its spread is a significant problem which is extremely relevant nowadays. Thus, the proposed consolidated mapping of oil pollution, suspended matter and blooming of water, as well as the identification of natural and anthropogenic sources of these pollutants, is a task that has not yet been performed for the Caspian Sea but is extremely relevant at present. We should stress, that the great advantage of our project is that the variability of the parameters studied will be considered on a long (twenty-year) time interval. This allows us to identify the main trends of these parameters which can be used as a basis for prediction models.

The study of hydrodynamic processes in the ocean on the basis of remote sensing data has received much attention throughout the world. The rapid development of these studies in recent years has been largely stimulated by the improvement of methods of satellite remote sensing of the ocean in the infra-red (IR) and visible bands of the electromagnetic spectrum and the availability of these data (Bondur, 2004). Despite increased attention to the study of hydrodynamic processes, mesoscale processes remain the most studied and described, primarily vortices and hydrological fronts with characteristic scales of 30-100 km, since the spatial resolution of satellite sensors in the optical range is of 250-1000 m. Sub-mesoscale vortex structures, small-scale fronts, jets with characteristic scales from hundreds of meters to the first tens of kilometers are much less studied. Among the works of foreign scientists, the work of American researchers (DiGiacomo, Holt, 2001; Marmorino et al., 2010), who studied small-scale vortex structures off the coast of California, should be noted. A number of priority studies of fronts, mesoscale and sub-mesoscale eddies in the Black and Caspian Seas were conducted by Russian teams from P.P. Shirshov Institute of Oceanology and Space Research Institute (Ginzburg et al., 2000; Kostianoy et al., 2010, 2018; Lavrova et al., 2011a; 2016). The
results are reflected in numerous publications in domestic and foreign journals, as well as in the proceedings of international conferences.

Figure 1. A satellite view (true color) of the Caspian Sea on 22 August 2019 from MODIS-Terra (©NASA, 2019).

The use of satellite remote sensing data of the sea surface significantly expanded the understanding of such an important phenomenon as the internal waves in the ocean and inland seas. Remote observations of the propagation of internal waves in the oceans are devoted to hundreds of publications, while their flow does not show a tendency to decrease (Apel et al., 1975; Alpers, 1985; Hsu et al., 2000; Zeng, Alpers, 2004; Bondur, 2004; Mityagina, Lavrova, 2009; Mityagina et al., 2010; Lavrova et al., 2017). Despite the increased
attention paid to the exploration of internal waves, the internal gravitational waves in the coastal waters of the oceans and tidal seas that arise from the interaction of tidal currents with the edge of the shelf remain the most studied experimentally and theoretically described. The overwhelming part of the experimental data on internal waves of non-tidal nature was obtained using contact methods. There are a number of works devoted to field observations and numerical modeling of the processes of generation and propagation of short-period internal waves in tidal seas based on contact measurement data, while publications of the surface manifestations of internal waves in the non-tidal seas are scarce. The project team also has a priority in the study of internal waves in the Black, Baltic, and Caspian seas based on satellite radar data. In particular, they discovered a previously unknown mechanism for the generation of internal waves in the non-tidal seas by moving cold vortices (Lavrova et al., 2011b).

Until now, questions remain about the mechanisms of the emergence of small-scale hydrodynamic processes, the areas of their manifestation, duration of existence, their fine spatial structure, and their connection with mesoscale processes. The accumulation of regular satellite information obtained with high resolution in different periods and in different areas, in our opinion, will contribute to forward in the understanding of sub-mesoscale processes. Until now, the unsolved problem remains the restoration of the flow fields from satellite images. Relatively good results were achieved with the restoration of global flow fields (Chapron et al., 2005). However, the task of restoring local currents, which is extremely important for predicting the drift of oil pollution, has not yet been solved. The use of radar images of high spatial resolution and the application to them of a new algorithm for restoring currents (Seppke et al., 2010a,b) will significantly advance in this direction.

Monitoring of oil and anthropogenic pollution usually is carried out using data from synthetic aperture radars (SAR, ASAR). It requires obtaining a number of additional information about wind, wave characteristics, temperature and structure of surface mesoscale currents to describe the manifestation, transformation of oil films and their distribution. In the currently accepted world practice, when making a forecast of the spread of oil pollution on the sea surface, wind, waves and constant currents are put into the model. Our experience of multi-year satellite monitoring shows that, in addition, it is necessary to take into account the actual mesoscale circulation of water, which has a great influence on the pollution transport.

Certain aspects of the discussed issues are actively elaborated in various scientific organizations in Russia, Norway, the USA, France, and Italy. From the point of view of routine monitoring of oil pollution of the sea surface, the leading organizations are the European Space Agency, the Canadian Space Agency, and the Italian Space Agency, which own a group of satellites with SAR and ASAR radars. This gives them an advantage in the operational survey of any point of the oceans and seas (as well as land) and allows to have an extensive network of scientific and commercial dealers for the supply of raw and processed radar data (images). Among such European centers for receiving and processing satellite information are the center in Rome and the Kongsberg Satellite Services (KSAT) in Tromsø, Norway. Among the European international organizations, the European Maritime Safety Agency (EMSA), which was established in 2003 as one of the agencies of the European Union with a budget of more than 50 mln Euro, plays a leading role in the monitoring of European seas and providing coastal countries with radar information. However, in the organizations listed above, the focus is paid on solving economic and general environmental problems. Scientific issues related to monitoring of oil pollution of the sea surface are actively elaborated in Norway, in particular, at the University of Oslo (Anne H. Schistad Solberg group) and at the University of Tromsø at the Earth Observation Laboratory (Camilla Brekke). They are focused on the automatic recognition of oil pollution in radar images and the identification of oil pollution during the formation of the ice cover (Skrunes et al., 2012; Brekke et al., 2014). In the USA, in particular, the Benjamin Holt group from the Jet Propulsion Laboratory, Pasadena CA, actively cooperates with the Norwegian scientists mentioned above, and regularly conduct sub-satellite measurements of currents, during which they track the involvement of biogenic films in them (Marmorino et al., 2010). A serious scientific work was done by this group in collaboration with scientists from NOAA and the University of California Santa Barbara to study the parameters of oil film and its distribution during a catastrophic oil spill in the Gulf of Mexico in 2010 (Jones et al., 2011; Leifer et al., 2012; Minchew et al., 2012).

Among Russian scientists as world competitors should be noted research teams from the Space Research Institute (IKI) RAS (Moscow), P.P. Shirshov Institute of Oceanology (IO) RAS (Moscow), Institute of Applied Physics RAS (Nizhny Novgorod), Scientific Research Institute AEROKOSMOS (Academician V.G. Bondur) and from the Laboratory of Satellite Oceanography, established at the Russian...
State Hydrometeorological University (RSHU) and led by Bertrand Chapron (IFREMER, France) and Vladimir Kudryavtsev (RSHU).

Scientists from the Space Research Institute developed methods for processing, analyzing, and interpreting satellite radar images that were used to conduct satellite monitoring of the state and pollution of the marine environment of the Russian sector of the Black and Azov Seas, which has been held since 2003 from April to October at the Research Center "Planeta", and in which the staff of IKI RAS and IO RAS took an active part. During the monitoring, based on a joint analysis of the data obtained by satellite sensors and hydrometeorological information, 13 types of operational information products were regularly released, including maps of sea pollution with surfactant films, phytoplankton and algae distribution, chlorophyll-a concentration, sea surface temperature, etc., as well as generalized maps, diagrams of the state and pollution of the marine environment. Similar maps can be built on a regular basis for any seas (Lavrova et al., 2011a, 2016).

Scientists from the P.P. Shirshov Institute of Oceanology RAS conducts deep and comprehensive studies of the mesoscale water dynamics in the Black and Caspian Seas, its connection with the large-scale water circulation, wind effects and heterogeneities of the coastline/bottom topography. The main results were obtained by them mainly based on the analysis of available satellite images of the IR and visible spectral ranges and from data of drifter measurements (Ginzburg et al., 2008). Together with IKI team, an effective integrated (multisensory and interdisciplinary) approach to operational satellite monitoring of the ecological state of the Russian seas has been developed. For the first time, such an approach was put into practice for the Southeastern Baltic Sea region in 2004–2005. Monitoring was based on the daily reception, processing and analysis of various satellite data and included the detection of oil spills in the area of the Lukoil D-6 oil production platform on the shelf of the Kaliningrad Region (the Kravtsovskoye oil field) and throughout the southeastern part of the Baltic Sea, the detection of pollution sources, prediction of speed and direction of oil spill transfer. The integrated approach applied to monitoring favorably distinguished it from the analogous systems used by the countries of the Baltic Sea region (Finland, Sweden, Germany, Norway, etc.). In the course of the monitoring work, a weekly newsletter was compiled, in which an analysis of the hydrometeorological and ice conditions for the week was presented; a summary of all detected oil spills with their quantitative characteristics; characterization of possible sources of oil spills; oil spill map; all informative satellite maps of sea surface temperature and ocean color with the analysis of the field of currents; and a forecast of the spread of the largest oil spills (Lavrova et al., 2011a, 2016; Kostianoy, Lavrova, 2014).

The Institute of Applied Physics RAS carried out experimental studies of the mechanisms for the suppression of waves by films of different origin and the corresponding restructuring of the surface wave spectrum, as well as the dependence of the modulation of radar signals on the presence of various origins on the sea surface (Ermakov, 2012, 2013).

In the Laboratory of Satellite Oceanography at RSHU in recent years, a number of interesting results have been obtained on recognizing variations of the wind field and surface currents, distinguishing oil slicks and their similarities based on polarization differences of satellite X-ray images based on the development of a theory of scattered radar signal (Kudryavtsev et al., 2012).

For many years, the primary environmental problem of the Caspian Sea has been oil pollution, which is associated both with oil production and transportation, as well as changes in sea level, leading to secondary pollution, river runoff and even seismic activity, which provokes natural oil spills from the bottom of the sea. Abnormal bloom of waters every year becomes more and more long and covers more and more areas, and also occurs in areas where it was not previously observed. However, the current state of the sea, and the trends of its evolution has not been studied enough, which determines the relevance of the solution of the main task of the project. The goal of the Project “Assessing ecological variability of the Caspian Sea in the current century using satellite remote sensing data” is to assess the changes in the ecological state of the Caspian Sea since the beginning of the current century under the impact of natural and anthropogenic factors. This task requires a detailed analysis of large banks of satellite data acquired over the Caspian Sea from 1999 to 2022 jointly with multi-year hydrometeorological data. Implementation of the proposed project will assess the relative contribution of each of the sources of pollution of the Caspian Sea, which varies in different periods depending on climatic factors, on the intensity of various hydrodynamic and hydrometeorological processes, on seismic activity and human economic activity. In addition, the results of the project will allow to assess the transboundary transfer of oil pollution, which is especially important and relevant after the signing of the Convention on the Legal Status of the Caspian Sea in August 2018.
The goal is achievable due to powerful capabilities of the “See the Sea” (STS) information portal developed by IKI RAS as part of IKI Monitoring Center for Collective Use. STS offers oceanographers new and unique tools to work with remote sensing data, enabling comprehensive analysis of data different in physical nature, spatial resolution, and time of acquisition. A multi-factor analysis of the ecological status of the Caspian Sea will be made for the first time for the entire Caspian Sea based on multi-sensor and multiplatform remote sensing data, which determines the scientific novelty of the project. The main goal of the project will be achieved by solving a number of mutually related and complementing tasks:

(1) Assessment of the variability of the contribution of each type of pollution into the total oil pollution of the Caspian Sea in the current century. Satellite monitoring conducted by the IKI RAS research team has highlighted several ways by which oil hydrocarbons reach the surface of the sea: natural seeps from beneath the seafloor; multiple mud underwater volcanoes in the Southern Caspian that spew oil and gas; marine oil production and transportation; discharge of oily mixtures from ships; river runoff. The relative contribution of each source varies with the seasonal and climatic factors, intensity of hydrodynamic and hydrometeorological processes, seismic activity and local economic situation.

(2) Assessment of seasonal, interannual and spatial variability of phytoplankton bloom over the past 20 years. According to satellite observations, the Northern Caspian and river mouths are the main locations of intense blooming. However, cases of bloom anomalies are also known, for example, in the Southern Caspian in August-September 2005. One of the project tasks is detecting phytoplankton bloom anomalies, compiling the corresponding statistics, identifying regions and causes of the phenomena, their relationship to natural and anthropogenic factors. For example, it is still unknown what caused the above-mentioned bloom anomaly of 2005 that was the greatest ever observed, lasted two months and occupied almost half of the Southern Caspian Sea area.

(3) Assessment of seasonal and interannual variability of wind field as the main factor of water circulation and dynamic processes in the Caspian Sea. Recent works of IO RAS and international researchers suggest that the considerable rise of the role of evaporation in the seawater balance and a resulting decrease in its level is associated with changes in wind speed and direction in various parts of the Caspian Sea.

(4) Assessment of interannual variability and trends of the main hydrodynamic parameters of the Caspian Sea: sea surface temperature (SST), air temperature, atmospheric precipitation, cloud cover, sea level. These parameters directly or indirectly influence the ecological state of the Caspian. Studies of project participants from IO RAS show that over the past 15 years, in the Northern, Middle and Southern Caspian, and the Kara-Bogaz-Gol Bay, SST grew by 0.75, 1.01, 1.31 and 1.59°C, respectively, while air temperature only by 0.6°C. Such considerable difference had never been reached in the preceding 20 years and demands an explanation.

(5) Assessment of interannual variability of ice cover in the Northern Caspian: revealing trends in the timing of ice formation and melting, estimating ice cover area; estimating potential hazard of ice to oil platforms in the region. Along with the average reduction of the ice cover related to regional warming, individual years demonstrate extended ice cover, as it was in 2012 when the Turkmenbashi (Krasnovodsk) Bay in the Southern Caspian was covered by ice. It is necessary to understand the trend in these phenomena over the past decades.

(6) Assessment of changes in the character of hydrodynamic processes typical for the Caspian Sea on the basis of multi-year satellite data series: trends in current field variability, wave field and vortical activity. The project participants repeatedly demonstrated that mesoscale hydrodynamic processes have a significant impact on the transfer of pollutants in the sea.

(7) Determination of the trends in geographic propagation of pollution of different types and their relative contribution into the integral pollution of the Caspian Sea. Forecast of the trans-border transfer of pollution considering the trends in hydrometeorological parameters of the Caspian Sea, its circulation and dynamic processes revealed in the course of the project. Investigation of the interannual variability of hydrodynamic processes will help establish their role in water self-cleaning and trans-border transfer in regions of particular importance for Russia.

To solve these tasks, an integrated approach will be implemented combining the analysis of archive satellite data for 1999-2018 and operational satellite monitoring data, carried out during the project in 2019-2022. Analysis of multi-sensor and multiplatform radar, optical and infrared satellite data will be coupled with the analysis of hydrometeorological and climatic data, which will reliably establish certain cause-and-effect relationships in the interannual variability of the ecological state of the Caspian Sea. The attainability of solving the project tasks and the possibility of obtaining the planned results are supported by the use the
“See The Sea” information system, which has accumulated a unique archive of satellite data over the past 20 years. The expected results will be of great importance, because for the Caspian Sea such complex works will be performed for the first time on the basis of modern satellite systems and databases that are successfully used for other areas of the World Ocean.

Materials and methods

The principal method of solving the tasks formulated in the project is satellite remote sensing of sea regions. It relies on using digital data of satellite radars and multichannel spectroradiometers. Based on these data, one can obtain, at high spatial and temporal resolution, information on sea surface roughness, surface wave field, surface signatures of dynamic and circulation processes, films on the surface, as well as sea surface temperature field, suspended matter, chlorophyll-a concentration, other optical parameters of the sea surface, ice cover and current variability. Since assessing 20-year variability of the ecological state of the Caspian Sea requires analysis of a large archive of satellite data obtained in various electromagnetic wave ranges at different spatial resolution, the work should be highly automated and adopted for operators with different skill levels, in particular students and young participants of the project. Therefore, the project tasks will be tackled using the toolkit of the “See The Sea” (STS) information service (geportal).

STS employs technologies of automatic management of continuously renewed archives of satellite data, provides access to the data and versatile analysis tools. The toolkit includes color composition based on one or several images, brightness correction, derivation of spectral and temporal profiles. Supervised and unsupervised classification techniques enable water type mapping. Quantitative parameters are also estimated. For hyperspectral data, analysis of spectral profiles of different types of water surfaces helps select the most informative spectral ranges for further image classification. STS provides access not only to various satellite data and derived products, but also to powerful specialized analysis tools. One can perform complex joint analysis of data different in physical nature, spatial resolution, units of measurement and acquisition times (Mityagina et al., 2014). STS supports a comprehensive description of various phenomena and processes, estimation of their quantitative and qualitative characteristics, provides tools to analyze their origin and development, spatial and temporal parameters of phenomena distribution (Loupian et al., 2012; 2015; Kashnitsky et al., 2015). The tasks of the project will be implemented using the integration technique of heterogeneous sea surface satellite data developed by the participants of the project (Lavrova et al., 2011a, 2016). Satellite data types to be used for the purpose of the Project are listed below:

1. Task "Determination of individual contribution of each type of pollution into the integral oil pollution of the Caspian Sea surface" will be implemented on the basis of satellite radar data. Presence of an oil film on the surface results in a decrease of intensity of wind-wave interaction and attenuation of the resonant gravity-capillary wave component. This way smoothed areas (slicks) appear on the sea surface producing low backscatter signatures in radar images, that are hence indicative of oil films. All available data from the following satellites will be analyzed: ERS-2 SAR (1999-2011); Envisat ASAR (2002 – 2012); Sentinel-1 SAR-C (2014 - present). In addition, high resolution visible data obtained in sunglint zone will be used: Landsat-5 TM (1999 - 2012); Landsat-7 ETM+ (1999 – present); Landsat-8 OLI (2013 – present), Sentinel-2 MSI (2015 – present). Special focus will be on quasi-synchronous satellite images since they allow not only identifying pollution type most precisely and unambiguously but also estimating its propagation velocity.

2. The task "Retrieval of interannual, seasonal and spatial variability of phytoplankton bloom over the past 20 years" will be implemented using high resolution color composites of Landsat-5 TM (1999 - 2012), Landsat-7 ETM+ (1999 – present), Landsat-8 OLI/TIRS (2013 – present), Sentinel-2 MSI (2015 – present) and medium resolution spectroradiometer data of Aqua/Terra MODIS (1999 – present), Envisat MERIS (2002 – 2012); VIIRS-NPP (2011 – present); Sentinel-3 OLCI (2016 – present). These data will be used to map chlorophyll-a concentration for the purpose of assessing phytoplankton bloom variability. To investigate the causes of intense anomaly blooms, a complex analysis of data on chlorophyll-a concentration, that of suspended matter carried out by rivers, SST and wind field will be performed.

3. The task “Assessment of seasonal and interannual variability and trends in the wind field, air temperature, SST in the current Century” will be made using data of STS, DAHITI (Database for Hydrological Time Series of Inland Waters) and NASA Giovanni MERRA-2 Model M2TMNXFLX v.5.12.4.
(4). Implementation of the task "Assessment of interannual variability of ice cover" will be based both on multi-year satellite radar data and spectroradiometer data listed under points (1) and (2) of this section.

(5). Implementation of the task "Determination of the changes in the character of hydrodynamic processes typical of the Caspian Sea" will be based on multisensory technique of satellite data analysis. In radar images, many hydrodynamic processes are manifested through the slick mechanism or contrast modulation due to divergent/convergent currents. In optical images, the tracers of dynamic structures are inhomogeneities of water turbidity or chlorophyll-a concentration, less often temperature contrasts (mainly in vortical structures) are usually used. Joint analysis of various satellite data will be performed using the toolkit of STS which allows precise geo-referencing of diverse in nature and resolution satellite data and retrieving propagation velocity and direction of different hydrodynamic structures.

(6). Implementation of the task "Assessment of various changes and trends" will draw upon the results of the previous tasks that will be accumulated in the STS databases in the form of descriptions, selected testing areas and summary charts in free access for all project participants.

To achieve the goal of the project it is necessary to analyze multi-year series of various satellite data. Therefore, for the purpose of implementing tasks NN 1-6, during the first three years of project duration, both analysis of archive data of different periods (1999-2006, 2007-2013, 2014-2018) and operational (for the current year) multisensory satellite monitoring of the Caspian Sea will be conducted.

Expected Results

As a result of the project, the following main results will be obtained:

(1). As a result of the analysis of archival satellite data for 1999-2018, and operational multisensory satellite monitoring of the Caspian Sea in 2019-2022 we will reveal the areas of oil pollution of the sea surface, sources of oil pollution, areas of phytoplankton bloom, and construct ice cover maps and maps-schemes of the elements of the mesoscale circulation of the Caspian Sea waters. In addition, the characteristics of the seasonal and spatial variability of these parameters will be obtained.

(2). Analysis of satellite data for more than 20 years will reveal trends in the geographical distribution of pollution of various types and from various sources, as well as estimate the specific contribution of each of them to the integral pollution of the Caspian Sea in the current century. Such an analysis will allow for the first time to assess the links with natural and anthropogenic factors, and regional climate change.

(3). The analysis of long-term satellite data series will reveal regional peculiarities of changes in the character of hydrodynamic processes typical for the Caspian Sea: trends in the variability of currents, wave parameters, and vortex activity.

(4). A comprehensive analysis of the data will make it possible to forecast the possible transboundary pollution transfer taking into account the trends in the hydrometeorological parameters of the Caspian Sea, its circulation and dynamic processes identified during the execution of the project.

(5). At each stage of the project implementation, new tools of the “See The Sea” information system will be tested and implemented, which will make it possible to significantly modernize the Center for Collective Use “IKI Monitoring”.

(6). A summary of the results obtained during the execution of the project will be made in the form of a monograph prepared for a publication.

The scientific and social significance of the expected results is determined by their importance for solving environmental problems of the Caspian Sea, identifying “hot spots” in terms of various types of pollution of the sea surface, delimiting responsibility between neighboring countries in the event of sea pollution and developing measures to reduce anthropogenic pollution of the Caspian Sea, including modern methods of remote sensing of the Earth and satellite monitoring of marine areas. The possibility of practical use of the planned results of the project in the economy and social sphere is obvious and consists in introducing developed and tested methods of integrated satellite monitoring of the Caspian Sea into the practice of industrial environmental monitoring of state and private companies operating in the offshore oil and gas industry. In addition, the modernization of the “See The Sea” information system will allow it to be used by a wide range of specialists in the field of remote sensing in both educational and scientific fields.
Conclusions

The setting of the project objectives in their current form and the proposed ways to solve these problems were possible only due to the creation of the “See The Sea” (STS) information service at the Space Research Institute of the Russian Academy of Sciences, which is an integral part of the Center for Collective Use “IKI-Monitoring”. The need to use this service in a project can be summarized as follows:

(1) To solve the main objective of the project, a detailed analysis of large data sets of satellite sounding is required. STS allows to work with data archives, which today contain a total of more than one hundred thousand scenes of various information. This is very large, constantly replenished archives of long-term continuous satellite observations of the Caspian region, created at IKI RAS, that will form the experimental basis of the project. The archives contain data from optical, radar, hyperspectral and other sensors installed on various specialized remote sensing satellites.

(2) The tools implemented in STS in the form of specialized software allow for a comprehensive analysis of satellite data, different in their physical nature, spatial resolution, dimensionality and time of receipt, which, in turn, provides the possibility of a deeper study and a comprehensive description of phenomena and processes in the Caspian Sea, which are determined by the complex mechanisms of interaction of hydrodynamic, meteorological, anthropogenic and biological factors.

(3) It should be noted that in order to identify the causes of interannual variability and environmental trends in the Caspian Sea under the influence of natural and anthropogenic factors, it is necessary to jointly analyze remote sensing data and related meteorological information, which is also possible in the STS.

(4) Building on the basis of satellite data maps of oil pollution of the sea surface, sea surface temperature, ice cover, phytoplankton bloom, wave and vortex activity, etc., necessary to solve the task of identifying the variability of these parameters in the project, will also be ensured by the joint use of the STS tools and a mapping interface integrated in the STS.

Summarizing all of the above, we emphasize that the use of the “See The Sea” information service is critical for the successful implementation of the project, since the solution of all the tasks set in the project is based on the efficient use of large amount of satellite information. It is necessary to have a specialized information system that solves both technological problems associated with the collection, unification of data, formation of structured archives from them, and provision the research team with tools for their analysis, implemented in the form of software. It is this system that STS is. It is important to note that the technologies implemented in it provide the opportunity to study both spatial and temporal, including long-term, dynamics of phenomena and processes in the seas and oceans.

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