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Ecology

Clarification of Hydrological Regime and Ecological Parameters in the Georgian Black Sea Coastal Zone Using Mathematical Modeling and Experimental Methods

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The expected intensification of human economic activity in the Black Sea coastal zone of Georgia in the coming years makes scientific research and forecast of ecological state and dynamics of coastal waters very relevant. The aim of the present work is to study some features of local circulation and thermohaline fields in the coastal waters of Georgia based on mathematical modeling and quantitative assessment of the main ecological parameters through experimental research. Mathematical modeling is based on the regional baroclinic model of the Black Sea dynamics, which provides the calculation of 3D hydrophysical fields – the current, temperature and salinity with a spatial resolution of 1 km in the Georgian sector of the Black Sea. The assessment of ecological parameters is carried out on the basis of field-scientific studies conducted in the Georgian water area and laboratory analysis. Quantitative indicators of seawater acidity and salinity were determined at 35 sensitive points along the 110-km coastline of the Black Sea, including the estuaries of major rivers, seaports, and oil terminals. Also, quantitative indicators of heavy metal pollution were determined in laboratory conditions, the values of which were found to be less than the permissible concentration.

mesoscale eddies, numerical model, ecological parameters, acidity, salinity

According to many experts, in recent decades, the intensification of human economic activity has led to a deterioration in the ecological state of the natural environment, including the hydrosphere. In this regard, the Black Sea is no exception. According to numerous studies the level of pollution of the Black Sea with oil products, marine debris, plastics and other pollutants is growing [1,2]. The anthropogenic load on marine ecosystems increases sharply in areas of intensive technogenic activity. Intensive use of the coastal and shelf zones of the Black Sea leads to an increase in anthropogenic load and deterioration of the ecological situation in these areas, to which many marine organisms react sharply [3, 4].

For Georgia, as a Black Sea riparian country, the ecological safety of the coastal zone is especially important, since the contribution of the

Black Sea in terms of the socio-economic situation of the country is very relevant. The most important part of the Georgian Black Sea sector is the Batumi-Poti-Anaklia nearshore water area, where economic activity is growing significantly: the flow of tourists is growing every year, the coastal infrastructure is developing intensively. In the coming years, the Black Sea recreational and transport function is expected to increase since the construction of Anaklia deep-water port, the reconstruction of the Poti port and the construction of a system of artificial islands and peninsulas in Batumi water area are on the agenda.

In conditions of increasing anthropogenic impact, the study and forecasting of sea circulation processes, thermohaline fields and main ecological parameters acquires significant relevance.

In the present paper, some features of mesoscale circulation and thermohaline fields in the Black Sea coastal waters of Georgia based on mathematical modeling and quantitative assessment of the main ecological parameters by experimental measurements are discussed.

Numerical Study

Numerical study of hydro and thermodynamic processes in the Georgian water area of the Black Sea is carried out using the regional numerical model of the Black Sea dynamics developed at M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University [5-7]. The regional model is based on a full system of ocean hydro and thermodynamics equations written in z coordinates, which is solved in the area with complex geometry with appropriate initial and boundary conditions using two-cycle splitting method with respect to physical processes, vertical coordinate planes and lines [8, 9]. Atmospheric forcing, which is the main factor affecting the hydrodynamic processes, is taken into account by boundary condition on the sea surface which is considered as a rigid surface. Within the EU projects AREAN and ECOOP the regional model was nested in the basin-scale model of Marine Hydrophysical Institute (Sevastopol, Ukraine). Since 2010 we were able to receive all necessary input data to calculate 3-day marine forecasts of hydrophysical fields via the Internet during 12 years. These data, which was provided within the framework of the mentioned EU projects. Are as follows: 3D initial fields of the current, temperature and salinity; 2D prognostic meteorological fields at the sea surface – wind stress, heat fluxes, evaporation and precipitation rates, derived from the model of atmospheric dynamics SCIRON; 2D prognostic hydrophysical fields of velocity components, temperature and salinity on the liquid boundary derived from the basin-scale model of the Black Sea dynamics of MHI.

The regional model takes into account the main physical factors, in particular: nonstationary atmospheric forcing, the topography of the seabed and the configuration of the coastline, the inflow of main rivers of Georgia, atmospheric precipitation and evaporation from the sea surface, absorption of solar radiation by the upper payer of the sea, spatial-temporal variation of turbulent viscosity and diffusion coefficients, influence of basin-scale processes on regional processes through the liquid boundary.

The regional model is implemented for the Georgian sector of the Black Sea and adjacent water area with dimensions of approximately 215 x 340 km with a horizontal grid step of 1 km. 30 calculated horizons were used with a minimum grid step of 2 m near the sea surface and a maximum of 100 m below a depth of 200 m. The time step is equal to 0.5 hours.

Numerous numerical studies conducted on the basis of the RM-IG under the conditions of real atmospheric forcing showed that the Georgian sector of the Black Sea is characterized by high dynamic activity, where the formation of various mesoscale and submesoscale vortex structures continuously occurs [10-14]. These vortex structures, in turn, make a significant contribution to the formation of thermohaline fields, to which marine

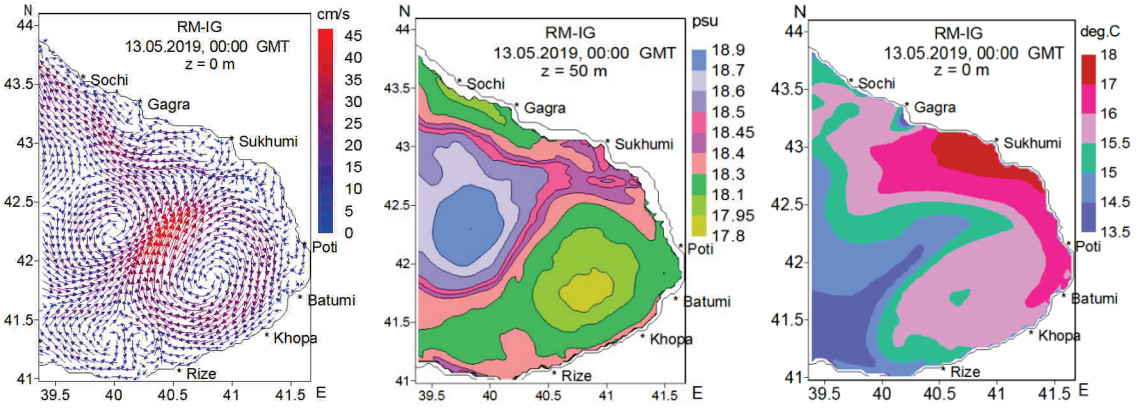

Fig. 1. Predicted surface current (a), salinity (on z = 50 m) (b) and SST (c) at 13 May 2019, 00:00 GMT. The forecasting time period is 00:00 GMT, 10 – 13 May, 2019.

living organisms are very sensitive. The role of circulation processes in the spatial-temporal distribution of oil products and other impurities that accidentally enter the the sea is also great. Numerical experiments showed that atmospheric wind forcing is one of the most important factor affecting the circulation processes in the upper layer of the Black Sea with depth about 15-20 m [15]. Our calculations also show that cyclonic circulation dominates in the winter period, while anticyclonic circulation mainly develops in the summer season. Among the anticyclonic eddies, the Batumi anticyclonic eddy should be noted, which often forms in the southeastern part of the sea, especially in the warm season.

As an example, in Fig. 1 predicted sea surface current, salinity (on the depth of 50 m) and sea surface temperature (SST) fields are shown at t = 72 hours (time is accounted from the initial moment of the forecast) corresponding to 00:00 GMT, 13 May 2019. The forecasting time period was 00:00 GMT, 10.05.-13.05 May 2019. In Fig. 1a is clearly shown that the circulation on May 13, 2019 was characterized by the formation of two main structural elements - an anticyclonic eddy in the southeastern part of the considered area and a cyclonic eddy located in the northwest direction from the cyclonic eddy. The formation of some submesoscale eddies is also observed here.

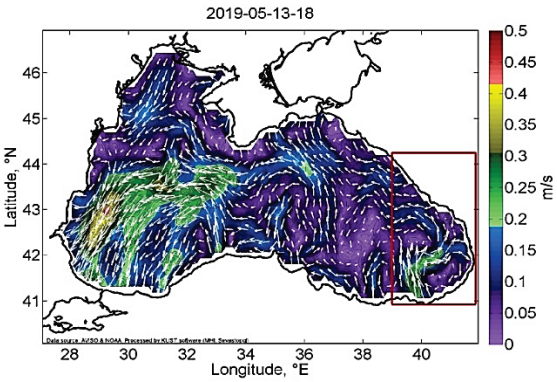

Fig. 2. Geostrophic current field at 13 May 2019 reconstructed using satellite altimeter data. By rectangle the forecasting area is marked.

In Fig. 2 geostrophic current field reconstructed using satellite altimeter data is shown for the same time moment (http://dvs.net.ru/mp/data/main.shtml). Comparison of the predicted circulation field (Fig. 1a) with the geostrophic current (Fig. 2) shows good agreement with each other. Fig. 2 clearly shows the formation of mesoscale cyclonic and anticyclonic eddies in the southeastern water area. Note that the geostrophic approximation cannot reproduce the submesoscale eddies identified by the model. Comparison of salinity (Fig. 1b) and circulation fields (Fig. 1a) shows a significant contribution of the flow field to the formation of the distribution of salinity: waters of the central part of the anticyclonic eddy are characterized with relatively low salinity, while in the central part of cyc-

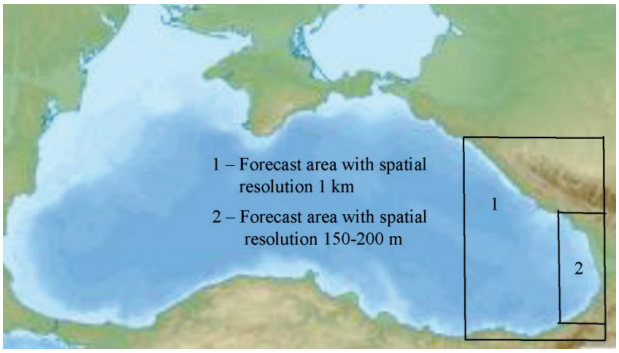

Fig. 3. Regional and coastal forecast areas in the southeastern part of the Black Sea.

lonic eddy the salinity is relatively high. This feature of the salinity distribution depending on the circulation regime is well known from the previous studies [5-7]. From Fig. 1c is well visible that waters near the Georgian shoreline were characterized by relatively high temperature (16°-18°C) and the temperature decreases away from the shore.

We consider further development of the modeling system by developing a very high-resolution numerical model with a grid step of 150-200 m for the Batumi-Poti-Anaklia nearshore area with sizes of about 50 x 180 km, which is subject of great anthropogenic load. The very high-resolution model will be developed on the bases of the existing numerical model with 1 km resolution. The model with 150-200 m resolution will be nested in the regional model with 1 km resolution using one-way nesting technology. Increasing the resolution of the numerical model is a very important factor for identifying unstable coastal submesoscale eddies that often form in this water area. It should be noted that the seabed topography in this area is characterized by the presence of underwater canyons [16], which are practically impossible to take into account in a model with a resolution of 1 km. In addition, a very high resolution of the model will allow us to more adequately reflect the contribution of rivers to coastal processes.

Fig. 3 shows the modeling and forecast area, where hydrophysical fields are calculated with a spatial resolution of 1 km, and the Batumi-Poti-Anaklia water area, where the fields should be calculated with a very high resolution.

Experimental Study

Field-scientific research was carried out in 2015-2017 within the water area of Georgia [17]. Quantitative indicators of seawater acidity and salinity were determined at 35 sensitive points along the 110 km coastline of the Black Sea, including the estuaries of major rivers, seaports, and oil terminals. Quantitative indicators of pollution of the Black Sea water with heavy metals including Zinc (Zn^{2+}), Ferrum (Fe), Cadmium (Cd), Copper (Cu), Plumbum (Pb) were determined under laboratory conditions, the indicators of which according to the established standards of EU and Georgia are less than permitted level of concentration provided by the documents mentioned above.

In the estuaries of major rivers and seaports, seawater analyzes were taken and the quantitative parameters of seawater acidity and salinity were determined in laboratory conditions. The Table 1 shows the results of the field research conducted in the spring of 2015 in the main river estuaries. It can be seen from the table that the minimum acidity was observed in the Chorokhi River estuary equal to 7.14 (Ph), and the maximum – 7.84 (Ph) in the south branch of Rioni river.

In order to determine the ecological parameters of the Black Sea in the seaports of Georgia, oil pipeline terminals and their surrounding areas, in April, May and June 2016 field-scientific studies were carried out, which included taking the analysis of the Black Sea water and its laboratory exami-

Table 1. Results of field research in river estuaries (Spring 2015)

№	Name of rivers	GPS –Coordinates X, Y	Acidity of marine water (Ph)	Salinity (TDS)
1	Chorokhi (left bank)	41596952; 41569943	7.14	9.70
2	Chorokhi (right bank)	41600395; 41571039	7.14	9.78
3	Kintrishi	41811607; 41771416	7.15	5.23
4	Natanebi	41913572; 41767241	7.45	4.34
5	Supsa	42016078; 41753594	7.13	9.67
6	Rioni (south branch)	42134187; 41659283	7.84	6.37
7	Rioni (right branch)	42177666; 41641295	7.82	7.80
8	Khobistskali	42259918; 41637102	7.71	6.76
9	Enguri	42389302; 41560674	7.73	7.67

Table 2. Data of field research surveys of April 27, 2016 in seaports and oil pipeline terminals of Georgia

№	Name of the place	GPS –Coordinates X, Y	Acidity of marine water (Ph)	Salinity (TDS)
1	Chorokhi river	41600395; 41548731	8.33	12.8
2	Batumi port	41662161; 41678955	8.08	6.97
3	Supsa river	42016078; 41753594	8.30	11.2
4	Baku-Tbilisi-Sufsa oil pipeline terminal	42038751; 41735281	8.38	12.3
5	Rioni river	42132201; 41660636	8.37	13.1
6	Poti port	42147724; 41655297	8.22	6.25
7	Kulevi oil terminal	42276524; 41631693	8.38	12.3
8	Khobistskali river	42259918; 41637102	8.33	13.5
9	Anaklia port under construction	42382543; 41577101	8.29	10.4
10	Enguri river	42389302; 41560674	8.32	9.29

nation. The Table 2 shows the quantitative indicators of water acidity and salinity in the waters of Georgian seaports (Batumi, Poti, Anaklia) and oil pipeline terminals (Baku-Tbilisi-Sufsa, Kulevi), obtained as a result of field studies conducted on April, 2016.

As a result of the conducted experimental studies and laboratory analysis of water samples, it was determined that in the spring-summer period of 2016, the value of salinity (TDS) of the Black Sea water varied between 5.84-15.12, and the acidity (pH) – between 7.71-8.65.

Conclusion

The paper presents investigation of hydro and thermodynamic processes in the Georgian sector of the Black Sea on the basis of mathematical modeling using the high-resolution numerical regional model of the Black Sea dynamics and quantitative assessment of such important ecological parameters as acidity of marine water and salinity in the sensitive points of Georgian shoreline – the estuaries of major rivers, seaports, oil pipeline terminals and their surrounding areas.

Numerical experiments carried out under real atmospheric forcing show that regional circulation in the Georgian Black Sea coastal zone is very often accompanying with formation of mesoscale and submesoscale vortexes which make significant contribution to the distribution of thermohaline fields, especially to the salinity field. In the perspective very high-resolution modeling system will be developed which will combine the regional model of the Black Sea dynamics with 1 km spatial resolution and very high-resolution model with 200 m spatial resolution for the Batumi-Poti-Anklia nearshore area, which is of great importance for

high-precision reproduction of coastal dynamic and ecological processes.

In the estuaries of the main rivers, in seaports and in the vicinity of oil terminals, seawater analyzes were taken and the quantitative parameters of seawater acidity and salinity were determined in laboratory conditions. Also, quantitative indicators of a number of heavy metals (zinc, lead, copper, etc.) in sea water were determined in laboratory conditions, and it was determined that their concentrations are less than the permissible concentrations.

It should be noted that within the framework of the NATO Science for Peace and Security Program project it is planned to establish a Black Sea observatory in the city of Poti, which will make a significant contribution to the scientific study of the ecological problems in the Georgian part of the Black Sea for the purpose of safety and forecasting the state of the sea.

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ეკოლოგია

საქართველოს შავი ზღვის სანაპირო ზონაში ჰიდროლოგიური რეჟიმისა და ეკოლოგიური პარამეტრების დაზუსტება მათემატიკური მოდელირებისა და ექსპერიმენტული მეთოდების გამოყენებით

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დღეისათვის საქართველოს შავი ზღვის სანაპირო ზონაში ადამიანის ეკონომიკური აქტივობის მოსალოდნელი გააქტიურება ძალზედ აქტუალურს ხდის სანაპირო წყლების ეკოლოგიური მდგომარეობისა და დინამიკის მეცნიერულ კვლევას და პროგნოზს. ნაშრომის მიზანია საქართველოს სანაპირო წყლებში ლოკალური ცირკულაციისა და თერმოჰალიური ველების ზოგიერთი თავისებურების შესწავლა მათემატიკური მოდელირების საფუძველზე და ძირითადი ეკოლოგიური პარამეტრების რაოდენობრივი შეფასება ექსპერიმენტული კვლევის გზით. მათემატიკური მოდელირება ეფუძნება შავი ზღვის დინამიკის რეგიონულ ბაროკლინიკურ მოდელს, რომელიც უზრუნველყოფს 3D ჰიდროფიზიკური ველების – დინების, ტემპერატურისა და მარილიანობის გამოთვლას 1 კმ სივრცითი გარჩევისუნარიანობით შავი ზღვის საქართველოს სექტორში. ეკოლოგიური პარამეტრების შეფასება განხორციელებულია საქართველოს აკვატორიაში ჩატარებული საველე-სამეცნიერო კვლევებისა და ლაბორატორიული ანალიზის საფუძველზე. ზღვის წყლის მჟავიანობისა და მარილიანობის რაოდენობრივი მაჩვენებლები განისაზღვრა შავი ზღვის 110 კმ სიგრძის სანაპირო ზოლის 35 სენსიტიურ წერტილში, მათ შორის, მთავარი მდინარეების შესართავებში, საზღვაო პორტებში და ნავთობის ტერმინალების სიახლოვეს. ასევე, ლაბორატორიულ პირობებში დადგინდა მძიმე ლითონებით დაბინძურების რაოდენობრივი მაჩვენებლები, რომელთა მნიშვნელობები დასაშვებ კონცენტრაციაზე ნაკლები აღმოჩნდა.

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