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Numerical Study of Variability of Hydrological Regime for the Southeastern Part of the Black Sea (2010-2021)

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ABSTRACT

The study and forecast of mesoscale dynamic processes in the coastal/shelf zones of seas and oceans is one of the main issues of physical oceanography, because these zones experience the most significant anthropogenic load. Circulation processes, which are closely related to temperature and salinity fields, make a significant contribution to the distribution of various impurities of anthropogenic and natural origin in the marine environment. In the present paper, a high-resolution numerical regional model of the Black Sea dynamics of M. Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University (RM-IG) is used to simulate and study some peculiarities of regional hydrophysical processes occurring in 2010-2021 in the southeastern part of the Black Sea covering Georgian sector of the Black Sea and surrounding water area. The RM-IG is based on a primitive system of ocean hydro and thermodynamics equations in hydrostatic approximation written in the Cartesian coordinate system and is implemented with a spatial resolution of 1 km under real atmospheric forcing.

Key words: *circulation, pollution, modeling system, system of equations, boundary conditions.*

1. Introduction

The study of formation and variability of main hydrological characteristics - currents, temperature, salinity of the seas and oceans is of particular scientific and practical interest for coastal and shelf zones, which experience the most significant anthropogenic load. Modeling and forecasting of coastal circulation and thermohaline fields plays an important role in solving problems related to navigation and construction of coastal structures, in the spatial-temporal distribution different impurities of anthropogenic and natural origin, in assessing the state of the marine ecosystem. Many marine organisms are known to be very sensitive to thermohaline conditions [1, 2]. Sea water temperature and water salinity play an important role in forming of normal environment for marine living organisms and have a significant affect on species biodiversity. Additionally, the important role of dynamic processes in the upper layer of the sea in the interaction between the sea and the atmosphere should be noted.

In recent decades, the progress of computer technology has largely contributed to the widespread use of numerical modeling methods in oceanology and, in particular, in the study of the Black Sea dynamics (e. g., [3-12]). At present, numerical models of the Black Sea hydrodynamics are mainly based on a full system of ocean hydro thermodynamics equations using different coordinate systems, methods of parameterization of some physical factors and numerical algorithms.

In our previous works [13-15], some features of regional circulation processes in 2010-2013 and 2017-2019 were numerically studied for the Georgian sector of the Black Sea.

In the present paper a numerical regional model of Black Sea dynamics of M. Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University (RM-IG) is used to simulate and study some peculiarities of regional hydrophysical processes developed in 2010-2021 in the southeastern part of the Black Sea covering Georgian Sector of the Black Sea and surrounding water area. Our Participation in EU scientific and technical projects ARENA (2003-2006) and ECOOP (2007-2010) provided us to calculate

hydrophysical fields using real input data. We were able to receive all input data, corresponding to the above time period, via Internet regularly. All these data provided the setting of the necessary initial and boundary conditions on the sea surface and on the liquid boundary of the calculation area.

2. Description of the RM-IG

A high-resolution RM-IG is developed on the basis of the basin-scale model of the Black Sea dynamics [16, 17], adapted to the southeastern part of the Black Sea, and is based on a full system of ocean hydrothermodynamics equations written in Cartesian coordinate system for deviations of temperature, salinity, pressure and density from corresponding standard vertical distributions. The RM-IG takes into account: 1. The sea bottom relief and shoreline configuration; 2. Atmospheric forcing; 3. The absorption of total solar radiation by the sea upper layer; 4. the spatial-temporal variability of factors of horizontal and vertical turbulent viscosity and diffusion; 5. discharge of some rivers entering the eastern coast of the Black Sea. Atmospheric forcing is taken into account by given at the sea surface wind stress, heat fluxes, atmospheric precipitation and evaporation. Corresponding meteorological fields at the sea surface were provided from models of atmospheric dynamics ALADIN or SKIRON.

As envisaged by the EU projects ARENA and ECOOP the RM-IG was nested in the basin-scale model of Marine Hydrophysical Institute (Sevastopol) and is a core of the regional marine forecasting system for the southeastern part of the Black Sea, which covers Georgian coastal zone and surrounding water area [18, 19].

To solve the model equation system the two-cycle splitting method is used with respect to physical processes, coordinate plains and lines [20, 21].

3. Results and discussion

At present, as a result of numerous experimental and theoretical studies, the basin-scale circulation pattern of the Black Sea is well known. In general, the Black Sea circulation is cyclonic and consists: of the Rim Current, which, in the form of a cyclonic jet stream, passes along the periphery of the sea basin; internal cyclonic eddies; coastal anticyclonic eddies formed in the area between the Rim Current and shoreline. Numerous comprehensive studies show that against the background of this general circulation picture, the coastal and shelf zones of the Black Sea are characterized by a large variability of dynamic processes [22, 23]. Numerical experiments on modeling regional dynamic processes in the southeastern part of the Black Sea, carried out by us using RM-IG, confirm these conclusions. Circulation processes in the Georgian water area of the Black Sea are characterized by great diversity and variability with permanent generation and dissipation of mesoscale and submesoscale eddies, which significantly affects the distribution of various impurities, temperature and salinity fields. The main factor providing seasonal and interannual variability of hydrophysical processes is atmospheric forcing. Atmospheric processes over the Black Sea are characterized by high variability, which significantly affects the circulation of the Black Sea and the distribution of thermohaline fields in the upper layer [24].

With the purpose of model computer realization, the solution domain, which is limited by Caucasus and Turkish shorelines and by western liquid boundary passing along the meridian 39.08E, was covered with a grid 215x347 having horizontal resolution 1 km. On a vertical the non-uniform grid with 30 calculated levels on depths: 2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306,…, 2006 m was considered. The time step was equal to 0.5 h.

The model results were compared with available observational data – satellite SST (sea surface temperature) derived from NOAA satellites (http://dvs.net.ru/mp/data/201806bs_sst.shtml) and the Geostrophyc currents reconstructed on the basis of satellite altimeter data [19, 25, 26]. These comparisons have shown the ability of the RM-IG to reliably predict hydrophysical fields in the southeastern coastal zone of the Black Sea.

The structure of the surface regional circulation is characterized by significant seasonal changes and often differs in the warm (April-October) and cold (November-March) periods of the year. In the warm season, the main element of regional circulation is often the Batumi anticyclonic eddy, although it can also form in the cold period. In October-November, the Batumi eddy often gradually weakens and it gradually transforms into smaller eddy formations.

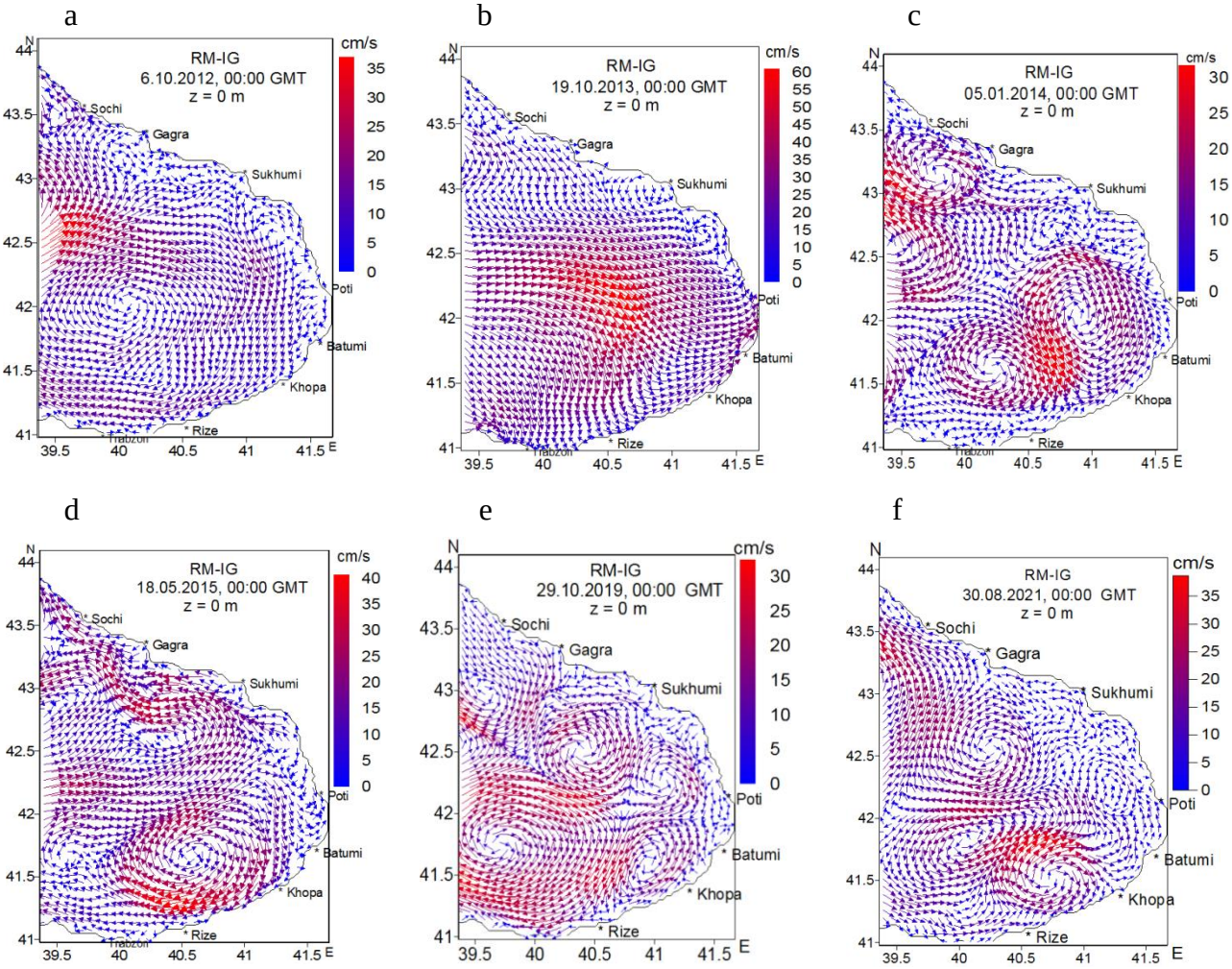

Fig. 1. Simulated sea surface circulation for different moments of time: (a) – 6 October 2012, (b) – 19 October 2013, (c) – 5 January 2014, (d) – 18 May 2015, (e) – 29 October 2019, (f) – 30 August 2021.

Often the winter circulation is dominated by cyclonic motion; in some cases the winter circulation is characterized by the formation of relatively small cyclonic and anticyclonic eddy formations with a diameter of about 40-60 km.

Fig.1 shows the simulated sea surface flow corresponding to different years and seasons. The Figure well illustrates the significant diversity of the circulation mode in the southeastern part of the Black Sea. From Fig.1a is well visible, that on October 6, 2012, the sea circulation was characterized by the formation of a stable Batumi anticyclonic eddy with a diameter of about 200 km. This circulation mode was maintained almost throughout October. It should be noted that the Batumi eddy appears with different intensity in different years. Our calculations showed that the Batumi eddy was the most stable formation in the summer and first half of the autumn of 2010 and 2011during 2010-2021. It covered the largest area of the considered modelling area and its structure remained practically unchanged vertically for several hundred meters**.** Calculations show that in some warm seasons the Batumi eddy may be practically absent. For example, the Batumi eddy was practically not observed during the summer 2018 and circulation was characterized with formation of different eddies with relatively small sizes. In our opinion, the question of the Batumi eddy

generation mechanism has not yet been finally established. There is a hypothesis of the direct impact of the wind associated with negative wind vorticity over the southeastern region, but there are also other hypotheses [23]. Numerical study carried out in [27] using the basin-scale model of Black Sea dynamics [16, 17] with different climate data shows that thermohaline conditions are a very important factor in the generation of the Batumi eddy.

An analysis of computational experiments shows that strong winds acting over the Black Sea basin prevent the development of eddy-forming processes and have a smoothing effect on the surface current. At this time, the flow velocities increase significantly and can exceed 100 cm/s. The circulation presented in Fig. 1b corresponds to October 19, 2013, when strong winds prevailed over the eastern part of the Black Sea. It can be seen from this Figure that the wind had a smoothing effect on the circulation, and the flow was practically irrotational. The maximum current velocity in this case reached 60 cm/s, and in a large part of the water area the current was directed from the west towards the coast of Georgia.

In Fig.1 is well visible, that in many cases the regional circulation in the southeastern part of the Black Sea is characterized by intense mesoscale cyclonic and anticyclonic vortex formations during all seasons in a wide range of scale sizes. In a narrow zone along the Georgian coastline, the formation of small unstable submesoscale eddies is observed (Fig.1e,1f), which is typical for the Caucasian coast [22].

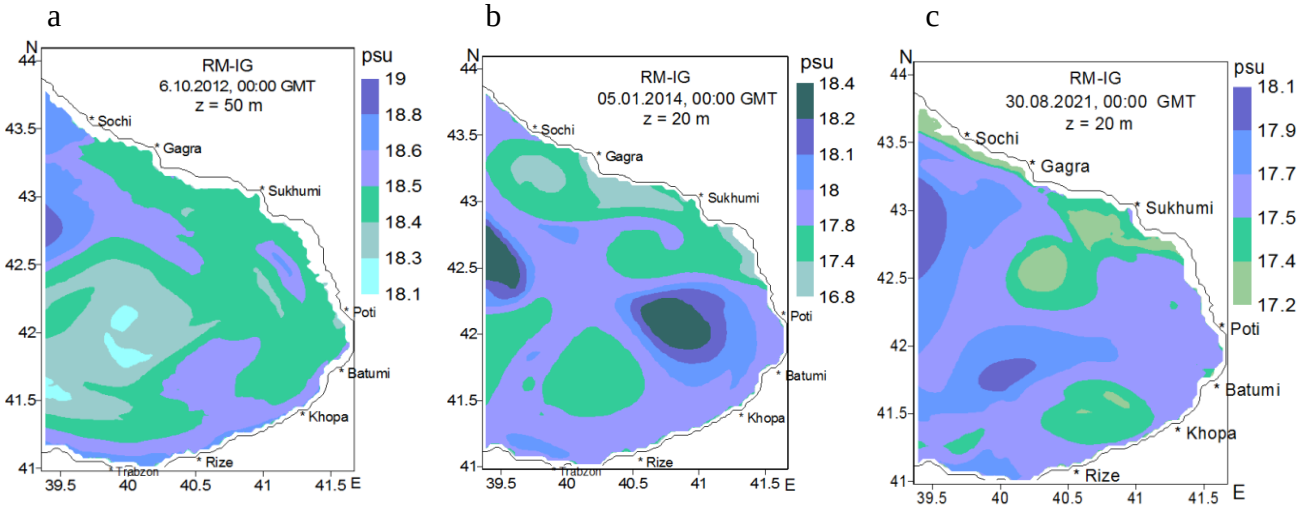

Fig.2. simulated salinity fields at following time moments: (a) – 6 October 2012, z = 50 m; (b) – 5 January 2014, z = 20 m; (c) – 30 August, 2021, z= 20 m.

Eddy formations make significant contribution to the formation of salinity and temperature fields having feedback with the flow field. The influence of mesoscale eddies on the distribution of various pollutants is also of great importance.

Data analysis 2010-2021 shows that the distribution of the salinity field in the considered regional area has undergone certain changes and correlates well with the current field. To illustrate this fact, Fig.2 shows the calculated salinity fields at the depths of 20 and 50 m in different years and seasons. Comparison of salinity fields illustrated in Fig.2 with corresponding circulation fields (Fig. 1a, 1c, 1f) shows that anticyclonic eddies contribute to the formation of low salinity waters in its central part, while in the central part of cyclonic eddies waters with high salinity are observed. The ascending current in the center of the cyclone contribute to the transfer of more saline waters from the deep layers to the upper ones, but the downward current in the central part of the anticyclonic eddy carries less saline water from the surface layers to the lower ones.

In Fig. 3 simulated sea surface temperature (SST) fields are shown at the same time moments as in Fig.2. SST is one of the main factors contributing to sea-atmosphere interaction. The sea surface temperature field is formed by the influence of several factors - the thermal interaction between the sea and the atmosphere, the absorption of solar radiation, advection-diffusion factors. It is a regularity that waters at

the Georgian nearshore are characterized by a relatively high temperature, which is apparently due to meteorological conditions.

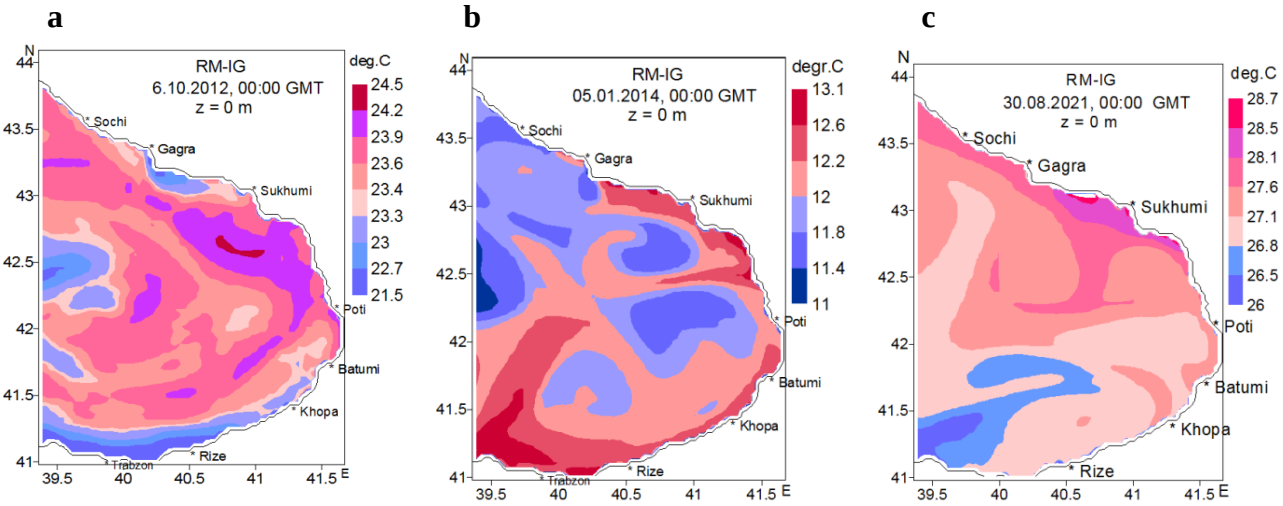

Fig.3. simulated sea surface temperature at the same time moments as in Fig.2.

Conclusion

The regional hydrophysical processes occurring in 2010-2021 in the southeastern part of the Black Sea, which covers the Georgian sector of the Black Sea and surrounding water area, are numerically investigated. The basis for these studies was the numerical baroclinic regional model of the Black Sea dynamics, developed at M. Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University (RM-IG). The RM-IG is based on a full system of ocean hydrothermodynamics equations and provides to calculate main hydrophysical fields – the current, temperature and salinity with 1 km spacing. All real input data required for initial and boundary conditions of model equation system were providing via Internet. Calculations showed some specific features of the regional circulation for the southeastern part of the sea basin, which is characterized by generation and transformation of different mesoscale eddies. Such eddies make a certain contribution to formation of thermohaline fields. Anticyclonic eddies promote formation of waters with low salinity in the central part of the eddy, but cyclonic eddies - formation waters with relatively high salinity in the central part. For the distribution of the SST field, it is characteristic that the waters close to the coastline of Georgia are often characterized by relatively high temperatures.

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References

[1] Sezgin M., Bat L., Katagan T., Ates A. S. Likely effects of global climate change on the Black Sea benthic ecosystem. J. Environ. Prot. Ecol., 11(1), 2010, pp. 238-246.
[2] Krivoguz D., Semenova A., Mal'ko S. Spatial analysis of seasonal patterns in sea surface temperature and salinity distribution in the Black Sea (1992-2017). IOP Conf. Series: Earth and Environmental Science 937 032013, 2021, pp.1-6. DOI: 10.1088/1755-1315/937/3/032013.
[3] Oguz T., Malalnote-Rizzoli P., Aubrey D. Wind and thermohaline circulation of the Black Sea by yearly mean climatological forcing. J. Geophys Rsearch 100, C4, 1995, pp. 6845-6863. https://doi.org/10.1029/95JC00022 .
[4] Oguz T., Malalnote-Rizzoli P. Seasonal variability of wind and thermohaline –driven circulation in the Black Sea: Modeling studies. J Geophys. Research. 101(C7), 1996, pp. 16551-16569. DOI:10.1029/96JC01093
[5] Staneva J. V., Dietrich D. E., Stanev E. V., Bouman M. J. Mesoscale circulation in the Black Sea: New results from DiaCast model simulation. J. Mar. Sys, 31, 2001, pp. 137-157.
[6] Kara A. B., Wallcraft A. J., Hurlburt H. E. Sea surface temperature sensitivity to water turbidity from simulations of the turbid Black Sea using HYCOM. J. Physic. Oceanography 35(1), 2005,pp. 33-54. .https://doi.org/10.1175/JPO-2656.1 .

[7] Kara A. B, Wallcraft A.J., Hurlburt H. E. A new solar radiation penetration scheme for use in ocean mixed layer studies: An application to the Black Sea a fine resolution Hybrid Coordinate Ocean Model (HYCOM). J. Phys. Oceanography 35(1), 2005, pp.13-22. https://doi.org/10.1175/JPO2677.1
[8] Stanev E. V. Understanding Black Sea dynamics: overview of recent numerical modeling. Oceanography, 18 (2), 2005, pp. 56-75. https://doi.org/10.5670/oceanog.2005.42
[9] Zalesny V. B., Gusev A. V., Moshonkin S. N. Numerical model of the hydrodynamics of the Black Sea and the sea of Azov with variational initialization of temperature and salinity. Izvestia, Atmospheric and Oceanic Physics, 49 (6), 2013, pp. 642-658.
[10] Zalesny V. B., Gusev A. V., Agoshkova V. I. Modeling Black Sea circulation with high resolution in the coastal zone. Izvestia AN, Fizika Atmosfery i Okeana, *52* (3), 2016, pp. 316-333. DOI:10.7868/S0002351516030147 (in Russian).
[11] Demyshev S. G., Dymova O. A. Analyzing interannual variations in the energy characteristics of circulation in the Black Sea. Izvestia, Atmospheric and Oceanic Physics, *52* (4), 2016, pp. 386-393.
[12] Dymova O. (2017) High-resolving simulation of the Black Sea circulation. In: Ozhan E(ed) Proceedings of the 13th International MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation, 31 Oct-04 Nov 2017, Melliecha, Malta. vol.2,2017, pp. 1203-1213. https://www.medcoast.net/modul/index/menu/Proceedings/36
[13] Kordzadze A. A., Demetrashvili D. I., Surmava A. A. Dynamical processes developed in the easternmost part of the Black Sea in warm period for 2010-2013. J. Georgian Geophys. Soc., 16b, 2013, pp. 3-12.
[14] Kordzadze A. A., Demetrashvili D. I. Short-range forecast of hydrophysical fields in the eastern part of the Black Sea. Izvestya RAN, Fizika Atmosfery i Okeana, 49 (6), 2013, pp. 733-745 (in Russian).
[15] Demetrashvili D., Kukhalashvili V., Surmava A., Kvaratskhelia D. Modeling of variability of the regional dynamic processes developed during 2017-2019 in the easternmost part of the Black Sea. Proceedings of the International Conference GEOLINKS 2020. Book 2, Vol. 2. 2020, pp. 111-120.
[16] Demetrashvili D. I., Kvaratskhelia D. U., Gvelesiani A. On the vortical motions in the Black Sea by the 3D hydrothermodynamical numerical model. Advances in Geosciences, 2008, 14, pp. 295-299. www.adv-geosci.net/14/295/2008/.
[17] Kordzadze D. I., Demetrashvili D. I., Surmava A. A. Numerical modeling of hydrophysical fields of the Black Sea under the conditions of alternation of atmospheric circulation processes. Izvestya AN, Fizika Atmosfery i Okeana 44 (2), 2008, pp. 227-238 (in Russian).
[18] Kordzadze A., Demetrashvili D. Development of the Black Sea regional forecasting system for its easternmost part with inclusion of oil spill transport forecast. Bulletin of the Georgian National Academy of Sciences 8(3), 2014, pp. 40-47.
[19] Kordzadze A. A., Demetrashvili D. I. Operational forecast of hydrophysical fields in the Georgian Black Sea coastal zone within the ECOOP. Ocean Science 7, 2011, pp.793-803, www.ocean-sci.net/7/793/2011/ .
[20] Marchuk G. I. Numerical solution of problems of atmospheric and oceanic dynamics. Gidrometeoizdat, Leningrad, 1974, 303 p. (in Russian).
[21] Kordzadze A. A. Mathematical modeling of the sea current dynamics (the theory, the algorithms, the numerical experiments), Moscow, 1989, 218 p (in Russian).
[22] Zatsepin A. G., Baranov V. I., Kondrashov A. A., Korzh A. O., Kremenetskiy V. V., Ostrovskii A. G., Soloviev D. M. Submesoscale eddies at the Caucasus Black Sea shelf and the mechanisms of their generation. Oceanology, 51(4), 2011, pp. 554-567.
[23] Ivanov V. A., Belokopytov V. N. Oceanography of the Black Sea. Sevastopol, 2011, 209 p (in Russian).
[24] Efimov V. V., Anisimov A. E. Climatic parameters of wind-field variability in the Black Sea region: numerical reanalysis of regional atmospheric circulation. Izvestya AN, Fizika Atmosfery i Okeana, 47 (3), 2011, pp. 380-392 (in Russian).
[25] Kordzadze A. A., Demetrashvili D. I. Operational forecasting for the eastern Black Sea. Proceed.of the 13thInternational MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation MEDCOAST 2017, 30 October – 4 November, 2017, Melieha, Malta, t.2, pp.1215-1224.
[26] Demetrashvili D., Kukhalashvili V. High-resolving modeling and forecast of regional dynamic and transport processes in the easternmost Black Sea basin. Proceed. of the International Conference on Geosciences (GEOLINKS 2019), 26-29 March 2019, Athens, Greece, Book 3, vol.1, pp.99-107.
[27] Demetrashvili D. Modeling of hydrophysical fields in the Black Sea. J. Georgian Geophys Soc., 8b, 2003. pp. 19-27.

შავი ზღვის სამხრეთ-აღმოსავლეთ ნაწილის ჰიდროლოგიური რეჟიმის ცვალებადობის რიცხვითი გამოკვლევა (2010-2021)

დ. დემეტრაშვილი, ვ. კუხალაშვილი, დ. კვარაცხელია

რეზიუმე

მეზომასშტაბური დინამიკური პროცესების შესწავლა და პროგნოზირება ზღვების და ოკეანეების სანაპირო/შელფურ ზონებში ფიზიკური ოკეანოგრაფიის ერთ-ერთი მთავარი საკითხია, რადგან ეს ზონები განიცდიან ყველაზე მნიშვნელოვან ანთროპოგენურ დატვირთვას. ცირკულაციურ პროცესებს, რომლებიც მჭიდრო კავშირშია ტემპერატურისა და მარილიანობის ველებთან, მნიშვნელოვანი წვლილი შეაქვს ზღვის გარემოში ანთროპოგენური და ბუნებრივი წარმოშობის სხვადასხვა მინარევების გავრცელებაში. წინამდებარე ნაშრომში, ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტის შავი ზღვის დინამიკის მაღალი გარჩევისუნარიანი რეგიონული რიცხვითი მოდელის (RM-IG) გამოყენებით მოდელირებულია და გამოკვლეულია 2010-2021 წწ.-ში მიმდინარე რეგიონული ჰიდროფიზიკური პროცესების ზოგიერთი თავისებურები შავი ზღვის სამხრეთ-აღმოსავლეთ ნაწილში, რომელიც მოიცავს შავი ზღვის საქართველოს სექტორსა და მიმდებარე აკვატორიას. RM-IG ეფუძნება ოკეანის ჰიდროთერმოდინამიკის განტოლებათა სრულ სისტემას ჰიდროსტატიკურ მიახლოებაში, ჩაწერილს დეკარტის კოორდინატთა სისტემაში და რეალიზებულია 1 კმ სივრცითი გარჩევისუნარიანობით რეალური ატმოსფერული ზემოქმედების პირობებში.

საკვანძო სიტყვები: მიმოქცევა, დაბინძურება, მოდელირების სისტემა, განტოლების სისტემა, სასაზღვრო პირობები.

Численное исследование изменчивости гидрологического режима юго-восточной части Черного моря (2010-2021 гг.)

Д. И. Деметрашвили, В. Г. Кухалашвили, Д.У. Кварацхелиа

Резюме

Изучение и прогноз мезомасштабных динамических процессов в прибрежно-шельфовых зонах морей и океанов является одним из основных вопросов физической океанографии, так как эти зоны испытывают наиболее значительную антропогенную нагрузку. Циркуляционные процессы, которые тесно связанны с полями температуры и солености, вносят значительный вклад в распространение различных примесей антропогенного и природного происхождения в морской среде. В настоящей работе, с использованием высокоразрешающей региональной, численной модели динамики Черного моря института геофизики им. М. Нодиа (RM-IG) Тбилисского государственного университета им. Ив. Джавахишвили моделируются и исследуются некоторые особенности региональных гидрофизических процессов, происходящих в 2010-2021 гг. в юго-восточной части Черного моря, которая включает в себя грузинский сектор Черного моря и прилегающую акваторию. RM-IG основана на примитивной системе уравнений гидротермодинамики океана в гидростатическом приближении, записанной в декартовой системе координат, и реализована с пространственным разрешением 1 км при реальном атмосферном воздействии.

Ключевые слова: циркуляция, загрязнение, система моделирования, система уравнений, граничные условия.