

Numerical Study of some Peculiarities of Hydrological Mode for the South Eastern Part of the Black Sea (2010-2021)

**Demuri Demetrashvili^{*,**}, Vepkhia Kukhalashvili^{*},
Diana Kvaratskhelia^{*,§}**

^{*} M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

^{**} Institute of Hydrometeorology, Georgian Technical University, Tbilisi, Georgia

[§] International Black Sea University, Tbilisi, Georgia

(Presented by Academy Member Tamaz Chelidze)

The study of hydro and thermodynamic processes in the coastal and 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 numerical regional model of the Black Sea dynamics based on a full system of ocean hydro and thermodynamics equations, is used to simulate and study some peculiarities of regional hydrophysical processes occurring in 2010-2021 in the south eastern part of the Black Sea covering Georgian sector of the Black Sea and surrounding water area. Atmospheric forcing is taken into account by given at the sea surface wind stress, heat fluxes, atmospheric precipitation and evaporation using the numerical models of atmospheric dynamics ALADIN or SKIRON. The analysis of numerical experiments shows that the Georgian sector of the Black Sea and the surrounding water area is characterized by significant seasonal and interannual variability of hydrophysical fields, which is accompanied by the formation and evolution of various mesoscale cyclonic and anticyclonic eddy structures. © 2022 Bull. Georg. Natl. Acad. Sci.

numerical modeling, circulation, thermohaline fields, system of equations

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 tempe-

perature 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., [3-6]). At present, numerical models of the Black Sea hydrodynamics are 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 [7-9], 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 the Black Sea dynamics of M. Nodia Institute of Geophysics of Ivane Javakishvili Tbilisi State University (RM-IG) is used to simulate and study some peculiarities of regional hydrophysical processes developed in 2010-2021 in the south eastern 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.

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 [10, 11] 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 model takes into account [12]: 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 and SKIRON.

As envisaged by the EU projects ARENA and ECOOP, the RM-IG is nested in the basin-scale model of Marine Hydrophysical Institute (Sevastopol) and is a core of the regional marine forecasting system for the south eastern part of the Black Sea, which covers Georgian coastal zone and surrounding water area [13].

To solve the model equation system the two-cycle splitting method is used with respect to physical processes, coordinate plains and lines [14, 15].

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 [16, 17]. Numerical experiments on modeling regional dynamic

processes in the south eastern 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 [18].

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 Geostrophic currents reconstructed on the basis of satellite altimeter data [13, 19, 20]. These comparisons have shown the ability of the RM-IG to reliably predict hydrophysical fields in the south eastern 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.

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.

The Figure 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 south eastern part of the Black Sea. From Fig. (a) 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 during 2010-2021 the Batumi eddy was the most stable formation in the summer and first half of the autumn of 2010 and 2011. 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 south eastern region, but there are also other hypotheses [17]. Numerical study carried out in [21] using the basin-scale model of Black Sea dynamics [10, 11] with different climate data shows that thermohaline conditions are a very important factor in the generation of the Batumi eddy.

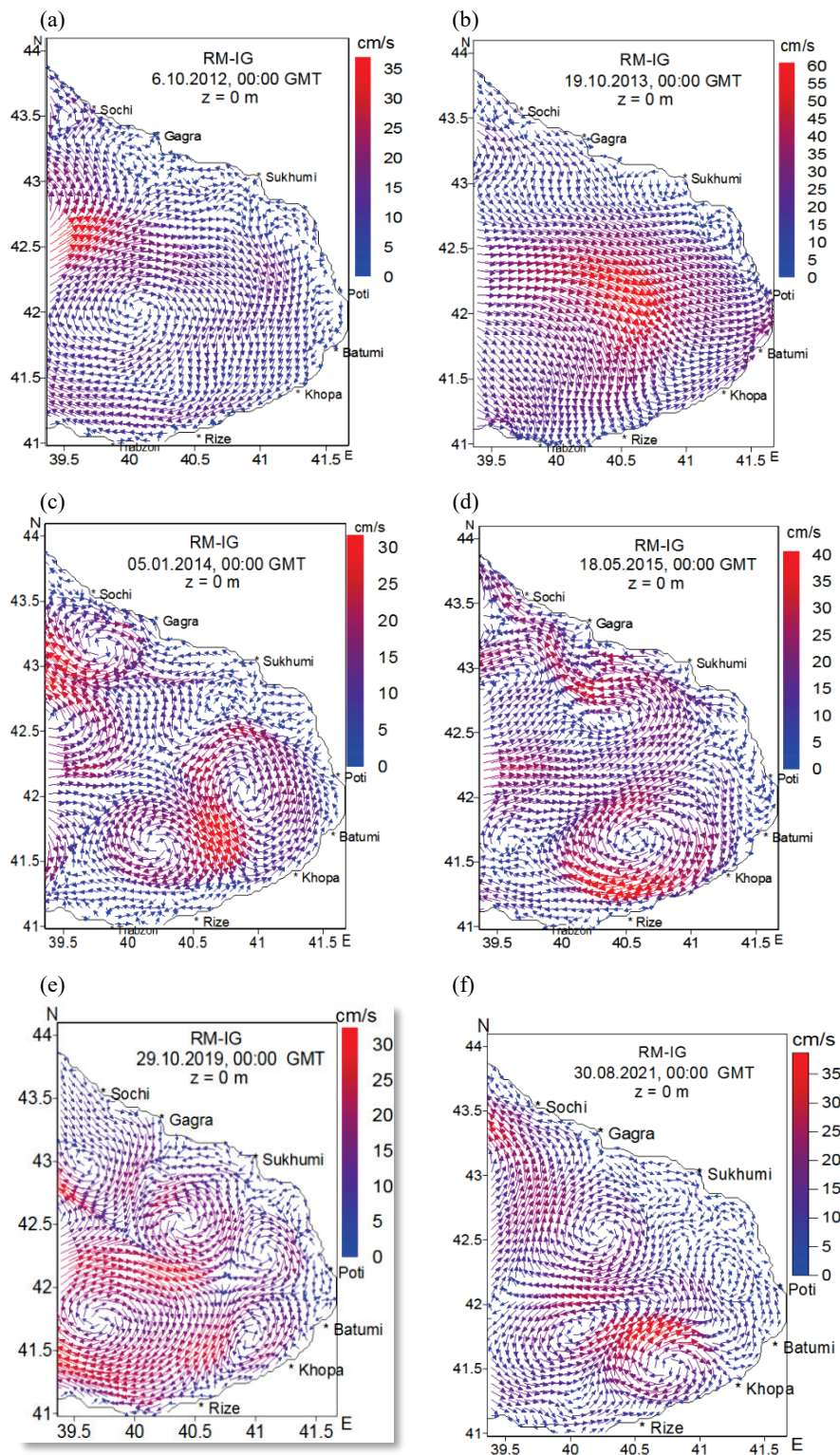


Figure. Simulated sea surface circulation for different moments of time: (a) – 6 October 2012, (b) – 19 October 2013, (c) – 5 January 2014, (d) – 18 May 2015, (e) – 29 October 2019, (f) – 30 August 2021.

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. (b) 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 the Figure is well visible, that in many cases the regional circulation in the south eastern 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. (e), (f)), which is typical for the Caucasian coast [16].

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. The anticyclonic mesoscale 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.

Sea surface temperature (SST) field is one of the main factors contributing to sea-atmosphere interaction. SST 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.

Conclusion

The regional hydrophysical processes occurring in 2010-2021 in the south eastern 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 south eastern 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.

The research PHDF-21-2209 was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG).

გეოფიზიკა

ჰიდროლოგიური რეჟიმის ზოგიერთი თავისებურების რიცხვითი შესწავლა შავი ზღვის სამხრეთ-აღმოსავლეთ ნაწილისათვის (2010-2021 წწ.)

დ. დემეტრაშვილი^{*,**}, ვ. კუხალაშვილი^{*}, დ. კვარაცხელია^{*,§}

^{*} ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, მ. ნოდის სახ. გეოფიზიკის ინსტიტუტი, თბილისი, საქართველო

^{**} საქართველოს ტექნიკური უნივერსიტეტი, ჰიდრომეტეოროლოგიის ინსტიტუტი, თბილისი, საქართველო

[§] შავი ზღვის საერთაშორისო უნივერსიტეტი, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

ზღვებისა და ოკეანეების სანაპირო და შელფურ ზონებში ჰიდრო- და თერმოდინამიკური პროცესების შესწავლა ფიზიკური ოკეანოგრაფიის ერთ-ერთი მთავარი საკითხია, რადგან ეს ზონები განიცდის ყველაზე მნიშვნელოვან ანთროპოგენურ დატვირთვას. ცირკულაციურ პროცესებს, რომლებიც მჭიდრო კავშირშია ტემპერატურისა და მარილიანობის ველებთან, მნიშვნელოვანი წვლილი შეაქვს ზღვის გარემოში სხვადასხვა მინარევეების გავრცელებაში. წინამდებარე სტატიაში, 2010-2021 წწ.-ში განვითარებული რეგიონული ჰიდროფიზიკური პროცესების ზოგიერთი თავისებურების მოდელირებისა და შესწავლის მიზნით შავი ზღვის სამხრეთ-აღმოსავლეთ ნაწილში, რომელიც მოიცავს შავი ზღვის საქართველოს სექტორსა და მიმდებარე აკვატორიას, გამოყენებულია ოკეანის ჰიდროთერმოდინამიკის განტოლებათა სრულ სისტემაზე დაფუძნებული შავი ზღვის დინამიკის რიცხვითი რეგიონული მოდელი. ატმოსფერული ზემოქმედება გათვალისწინებულია ზღვის ზედაპირზე მოცემული ქარის ხახუნის ტანგენციალური დამახულობის, სითბური ნაკადების, ატმოსფერული ნალექებითა და აორთქლებით ატმოსფეროს დინამიკის რიცხვითი მოდელების ALADIN ან SKIRON გამოყენებით. რიცხვითი ექსპერიმენტების ანალიზი აჩვენებს, რომ შავი ზღვის საქართველოს სექტორი და მიმდებარე აკვატორია ხასიათდება ჰიდროფიზიკური ველების მნიშვნელოვანი სეზონური და წლიური ცვალებადობით, რომელსაც თან ახლავს სხვადასხვა მეზომასტაბური ციკლონური და ანტიციკლონური გრიგალური სტრუქტურების ფორმირება და ევოლუცია.

REFERENCES

1. Sezgin M., Bat L., Katagan T., Ates A. S. (2010) Likely effects of global climate change on the Black Sea benthic ecosystem. *Journal of Environmental Protection and Ecology* **11**(1): 238-246.
2. Krivoguz D., Semenova A., Mal'ko S. (2021) 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 032013:1-6. DOI: 10.1088/1755-1315/937/3/032013.
3. Stanev E. V. (2005) Understanding Black Sea dynamics: overview of recent numerical modeling. *Oceanography* **18** (2): 56-75. <https://doi.org/10.5670/oceanog.2005.42>
4. Zalesny V. B., Gusev A. V., Moshonkin S. N. (2013) Numerical model of the hydrodynamics of the Black Sea and the sea of Azov with variational initialization of temperature and salinity. *Izvestiya, Atmospheric and Oceanic Physics* **49** (6): 642-658. Pleiades Publishing, USA.
5. Zalesny V. B., Gusev A. V., Agoshkov V. I. (2016) Modeling the Black Sea circulation with high resolution in the coastal zone. *Izvestiya, Atmospheric and Oceanic Physics* **52** (3): 277-293. <https://doi.org/10.1134/S0001433816030142>. Pleiades Publishing, USA.
6. Demyshev S. G., Dymova O. A. (2016) Analyzing intraannual variations in the energy characteristics of circulation in the Black Sea. *Izvestiya, Atmospheric and Oceanic Physics* **52** (4): 386-393. Pleiades Publishing, USA.
7. Kordzadze A. A., Demetrashvili D. I., Surmava A. A. (2013) Dynamical processes developed in the easternmost part of the Black Sea in warm period for 2010-2013. *Journal of the Georgian Geophysical Society*, 16b: 3-12.
8. Kordzadze A. A., Demetrashvili D. I. (2013) Short-range forecast of hydrophysical fields in the eastern part of the Black Sea. *Izvestiya, Atmospheric and Oceanic Physics* **49** (6): 674-683. Pleiades Publishing, USA.
9. Demetrashvili D., Kukhalashvili V., Surmava A., Kvaratskhelia D. (2020) 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, 2:111-120.
10. Demetrashvili D. I., Kvaratskhelia D. U., Gvelesiani A. (2008) On the vortical motions in the Black Sea by the 3D hydrothermodynamical numerical model. *Advances in Geosciences*, **14**: 295-299. www.adv-geosci.net/14/295/2008/.
11. Kordzadze A. A., Demetrashvili D. I., Surmava A. A. (2008) Numerical modeling of hydrophysical fields of the Black Sea under the conditions of alternation of atmospheric circulation processes. *Izvestiya, Atmospheric and Oceanic Physics* **44** (2): 213-224. Pleiades Publishing, USA.
12. Kordzadze A., Demetrashvili D. (2014) Development of the Black Sea regional forecasting system for its easternmost part with inclusion of oil spill transport forecast. *Bull. Georg. Natl. Acad. Sci.* **8**(3): 40-47.
13. Kordzadze A. A., Demetrashvili D. I. (2011) Operational forecast of hydrophysical fields in the Georgian Black Sea coastal zone within the ECOOP. *Ocean Science* 7: 793-803, www.ocean-sci.net/7/793/2011/.
14. Marchuk G. I. (1974) Chislennoe reshenie zadach dinamiki atmosfery i okeana, 303 s. Leningrad (in Russian).
15. Kordzadze A. A. (1989) Matematicheskoe modelirovanie dinamiki morskikh techenii (teoriia, algoritmy, chislennye experimenty), 218 s. M. (in Russian).
16. Zatsepin A. G., Baranov V. I., Kondrashov A. A., Korzh A. O., Kremenetskiy V. V., Ostrovskii A. G., Soloviev D. M. (2011) Submesoscale eddies at the Caucasus Black Sea shelf and the mechanisms of their generation. *Oceanology* **51**(4): 554-567.
17. Ivanov V. A., Belokopytov V. N. (2011) Okeanografia chernogo moria, 209 s. Sevastopol (in Russian).
18. Efimov V. V., Anisimov A. E. (2011) Klimaticheskie kharakteristiki izmenchivosti polia vetra v chernomorskom regione – chislennii reanaliz regionalnoi atmosfernoi tsirkulatsii. *Izvestiya AN Rossii, Fizika Atmosfery i Okeana* **47** (3): 380-392, M. (in Russian).
19. Kordzadze A. A., Demetrashvili D. I. (2017) Operational forecasting for the eastern Black Sea. Proc. the 13th International MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation MEDCOAST 2017, 30 October – 4 November, 2: 1215-1224. Melieha, Malta.
20. Demetrashvili D., Kukhalashvili V. (2019) High-resolving modeling and forecast of regional dynamic and transport processes in the easternmost Black Sea basin. *Proc. the International Conference on Geosciences-GEOLINKS 2019*, 26-29 March, , Book 3, vol.1: 99-107. Athens, Greece. DOI 10.32008/GEOLINKS2019/B3/V1.
21. Demetrashvili D. (2003) Modeling of hydrophysical fields in the Black Sea. *Journal of the Georgian Geophysical Society*, 8b:19-27.

Received August, 2022