International Scientific Conference „Natural Disasters in the 21st Century: Monitoring, Prevention, Mitigation“
Proceedings, ISBN 978-9941-491-52-8, Tbilisi, Georgia, December 20-22, 2021

PREDICTION OF HYDROPHYSICAL FIELDS IN THE GEORGIAN SECTOR OF THE BLACK SEA AND THE WAYS OF ITS IMPROVEMENT

[*]Kukhalashvili V., [*,]Demetrashvili D., [*,**]Surmava A.**

[*]*Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
[**] *Institute of Hydrometeorology of Georgian Technical University, Tbilisi, Georgia*
Demetr_48@yahoo.com

Summary: *Since 2010, a short-term regional marine forecasting system of hydrophysical fields – the current, temperature and salinity operates for the Georgian sector of the Black Sea and adjacent water area. This system, which is developed at M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, is one of the parts of the Black Sea basin-scale Nowcasting/Forecasting System. The forecasting system is based on the regional model of Black Sea dynamics of M. Nodia Institute of Geophysics (RM-IG), which is nested in the basin-scale model of Black Sea dynamics of Marine Hydrophysical Institute (Sevastopol). 2D and 3D impurities dispersion models are coupled with RM-IG. Further development and improvement of the regional forecasting system is associated with the development of a very high-resolution forecasting subsystem for the coastal zone of Adjara-Poti-Anaklia (with a horizontal grid step 200-250 m) with the inclusion of a model of wind-induced surface waves in the subsystem.*

Key Words: *forecasting system, numerical modeling, regional circulation, system of equations.*

Introduction. At present, under conditions of intense anthropogenic load of the world ocean (including the Black Sea), a marine forecasting system is becoming more relevant, providing forecasting of the state of the Black Sea in near operational mode.

At the beginning of the XXI century, a new phase in Black Sea oceanography began, characterized by the development of the basin-scale Black Sea Nowcasting/ Forecasting system. This System is developed under the framework of EU International scientific-technical projects ARENA, ASCABOS and ECOOP [1-3]. One of the parts of this system is the regional forecasting system developed at M. Nodia Institute of Iv. Javakhishvili Tbilisi State University, which operates for the Georgian sector of the Black Sea and adjacent water area since 2010. The forecasting system is based on the regional model of Black Sea dynamics of M. Nodia Institute of Geophysics (RM-IG), which is nested in the basin-scale model of Black Sea dynamics of Marine Hydrophysical Institute (Sevastopol). Within the framework of the Shota Rustaveli National Science Foundation Grant (2013-2015), the regional forecasting system was improved by inclusion of 2D and 3D numerical models of impurity distribution in the forecasting system. These numerical models are coupled with the RM-IG. The regional forecasting system provides 3-days forecast of hydrophysical fields – the current, temperature and salinity with 1 km spatial resolution [4-7]. In accidental situation, the regional system also makes it possible to predict pollution zones and concentrations of oil and other polluting substances. The regional forecast outputs are regularly posted at the Web-addresses: www.ig-geophysics.ge and www.oceandna.ge.

The most important part of the Georgian Black Sea sector is the Adjara-Poti-Anaklia nearshore, where human economic activity is growing significantly (if we do not take into account the 2020-2021 COVID-19 pandemic). There are the ports of Batumi and Poti in this zone, through which important port operations and sea transportation are carried out. This water area has a complex seabed topography, characterized by underwater canyons near the mouths of some rivers. Therefore, adequate modeling and forecasting of hydrophysical fields in this zone requires a higher spatial resolution of the models.

The goal of the present paper is briefly describe the method of short-term forecasting of the state of the sea with illustration of calculation of predicted fields and to discuss the ways of further improvement of the marine forecasts for the Batumi-Anaklia nearshore.

Methods. The RM-IG is received by adapting the basin-scale model of the Black Sea dynamics [8] to the easternmost part of the sea and increasing the spatial resolution from 5 km to 1 km. The RM-IG is based on a full system of ocean hydrothermodynamics equations in hydrostatic and non-compressible fluid approximation in z coordinates. Atmospheric forcing is taken into account through the upper boundary conditions by given of wind stress components, heat flux, atmospheric precipitation and evaporation from the sea surface, which is considered as a rigid surface. This model with 1 km spatial resolution is nested in the basin-scale model of the Black Sea dynamics of the Marine Hydrophysical Institute (MHI, Sevastopol) with 5 km resolution. The RM-IG covers the Georgian sector of the Black Sea and the adjacent water area having along the meridian a maximum length of 346 km and along the parallel – a maximum length of 215 km. The study area is limited from the west by the liquid boundary coinciding with the meridian 39.08^{0}E passing near the city of Tuapse (Russian Federation).

All the data needed for the calculation of short-range marine forecast are available from MHI via the Internet, providing the RM-IG with initial and boundary conditions. These data are as follows: 1. 3D initial fields of flow, temperature and salinity; 2. The flow, temperature and salinity values at the western liquid boundary; 3. Predicted meteorological fields at the sea surface – wind stress, heat fluxes, atmospheric precipitation and evaporation from the sea surface.

For modeling and forecast of oil products and other impurities in the sea environment there is considered advection-diffusion approach based on numerical solution of 2D and 3D nonstationary advection-diffusion equations.

The solution of the equations of the numerical models included in the forecasting system is based on the two-cycle splitting method with respect to physical processes and spatial coordinates. The splitting method is one of the most effective means of solving a wide range of problems in ocean and atmospheric dynamics, which is based on the representation of the main task operator as a sum of simpler operators and substantially simplifies the implementation of complex non-stationary mathematical models of geophysical hydrodynamics [9].

The modeling area is covered by a spatial grid, whose parameters are: in the RM-IG 30 calculated levels on a vertical with non-uniform vertical steps with a minimum step of 2 m at the sea surface and a maximum step of 100 m at the seabottom. The number of grid points on each horizon is 216 x 347 with the spatial horizontal resolution 1 km. The time step is 0.5 h.

Results and discussion. With the purpose of validating the RM-IG, forecast outputs were compared with the real data [5, 6]. Comparison of the computed sea surface temperature and surface flow fields with satellite observational data showed the ability of the model to really reflect the hydrophysical processes occurring in the easternmost part of the Black Sea.

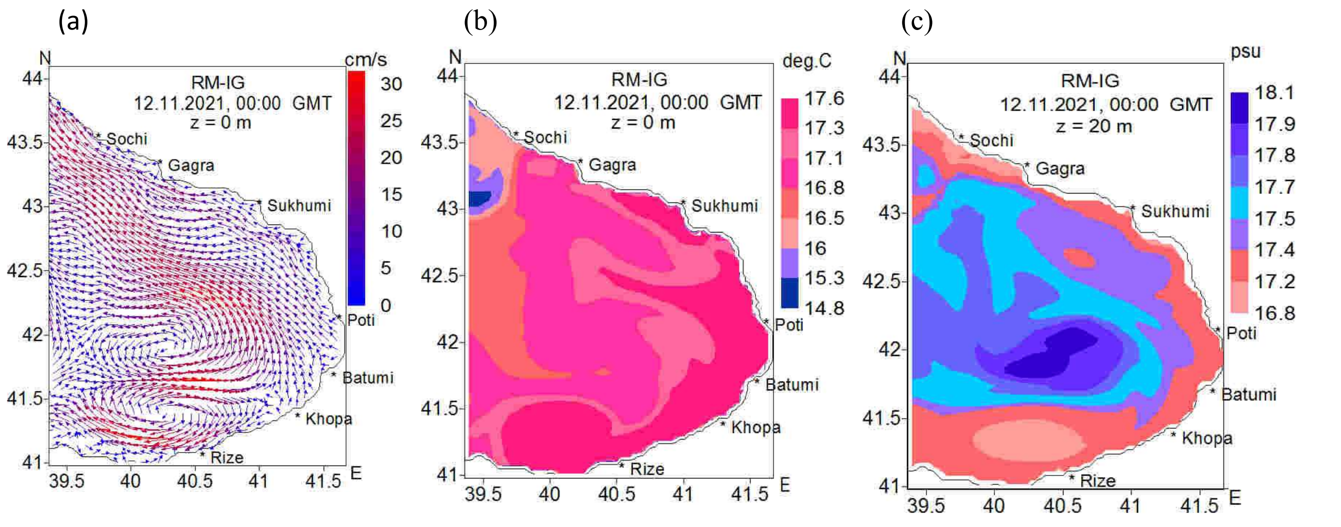

Fig.1. Predicted fields of sea surface circulation (a), sea surface temperature (b) and salinity on z = 20m (c) at t = 72 h (00:00 GMT, 12 November 2021). Forecasting interval is 9-12 November 2021.

The computations of marine forecasts, carried out regularly since 2010, have shown that the hydrophysical processes in the eastern waters of the Black Sea Basin are characterized by a significant variety and specific features of the spatial-temporal distribution of dynamic fields, accompanied by the permanent formation of mesoscale and submesoscale eddies during the year. The nonstationary atmospheric processes over the sea, having direct effect on the formation of the Black Sea hydrological structure under Earth's rotation, play an important role in the seasonal and interannual variability of sea dynamic processes, but specificity of this variability is largely determined by the sea bottom relief and the configuration of the coastline, baroclinicity, turbulent diffusion.

As an example, in Fig.1 prognostic fields of the sea surface current, the surface temperature and salinity on the depth of 20 m are shown at t = 72 h (after the start of the forecast) corresponding to 00:00 GMT, November 12, 2021. From the Fig.1a is visible, that the sea current is generally directed to the north-west in the considered regional area, but on this background, in the south-west part of the considered area formation of the dipole structure consisting of mesoscale cyclonic and anticyclonic eddies is observed. maximum flow speed of 30 cm / s is observed. The flow regime has a significant effect on the salinity field. In the area of cyclonic rotation more salinity waters with 17.9 – 18.1 psu and in the area of anticyclonic rotation less salinity waters with 16.8-17.2 psu are observed (Fig.1c). The sea surface temperature field is characterized more high temperature with 17.3-17.6 C^0 at Georgian and Turkish nearshore for the considered time moment. With distance from the coast, the waters gradually become cold (Fig.1b).

Further improvement of the existing regional forecasting system is connected to the development of a very high resolution coastal forecasting subsystem (with 200-250 m horizontal grid step) for the Adjara-Poti-Anaklia coastal zone, which will be included in the existing regional system as a subsystem. The purpose of this subsystem is to specify and make more detailed the forecast of dynamic and other fields in this nearshore water area. Operation of the subsystem will be able jointly with the existing regional forecasting system using nested modeling. At the same time the sea surface wave model will be included in the coastal subsystem. This subsystem will provide not only forecast of dynamic fields and spread of polluting substances, but also the height and direction of surface waves for the Adjara-Poti-Anaklia coastal zone. The wind surface wave model will be based on the spectral wave energy balance equation. It should be noted that the same equation is base of a well-known SWAN (Simulating Waves Nearshore) model, which quite fully describes the formation and transformation of wave motion in coastal zones and is widely used to calculate wind wave parameters in a number of coastal zones [10].

With use of the one-way nesting modeling method a joint realization of the regional model of the sea dynamics (with 1 km resolution) and very high-resolution coastal model of the sea dynamics (with 200-250 m resolution) will be carried out. The regional model outputs will be used on the liquid boundary for the high-resolution coastal model.

Thus, a new advanced version of the regional forecasting system will provide not only forecast of hydrological fields and spreading of impurities in the Georgian sector of the Black Sea with 1 km spacing, also will provide very detailed 3 days' forecast of dynamical fields and spreading of polluting substances in very important water area of the Georgian coastal zone – Adjara-Poti-Anaklia nearshore.

Conclusion. Since 2010, a short-term regional maritime forecasting system of hydrophysical fields – the current, temperature and salinity developed at M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University operates for the Georgian sector of the Black Sea and adjacent water area. This system, which is one of the parts of the Black Sea basin-scale Nowcasting/Forecasting System, consists of the RM-IG and coupled with its 2D and 3D impurities dispersion models. The regional forecasting system provides a three-day forecast of main hydrophysical fields with a spatial resolution of 1 km, and in emergency situations – a forecast of the spread of oil and other impurities in the sea.

Further development and improvement of the regional forecasting system is associated with the development of a very high-resolution forecasting subsystem for Adjara-Poti-Anaklia coastal zone (with horizontal grid step 200-250 m) and with inclusion of a model of wind-induced surface waves in the subsystem. Thus, a new improved version of the regional forecasting system will combine the forecasting system for the Georgian coastal zone with 1 km resolution and the coastal forecasting subsystem with a higher spatial resolution for the Adjara-Anaklia-Poti nearshore.

Acknowledgment "This research PHDF-21-2209 has been supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG)"

References

1. Korotaev G. K., Oguz T., Dorofeyev V. L., Demyshev S. G., Kubryakov A. I., Ratner Yu. B. Development of the Black Sea nowcasting and forecasting system. // Ocean Science, 7, 2011, pp. 629-649. DOI:10.5194/os-7-629-2011/.
2. Kubryakov A. I., Korotaev G. K., Dorofeev V. L., Ratner Y. B., Palazov A., Valchev N., Malciu V., Matescu R., Oguz T. Black Sea coastal forecasting system. // Ocean Science, 8, 2012, pp.183-196.
3. Marchuk G. I., Paton B. E., Korotaev G. K., Zalesny V. B. Data-computing technologies: a new stage in the development of operational oceanography. // Izvestiya, Atmospheric and Oceanic Physics, 49 (6) 2013, pp. 579-591.
4. Kordzadze A.,Demetrashvili D. Operational forecasting for the eastern Black Sea. // Proceed. of the 13th International MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation, MEDCOAST 2017, 30 October – 4 November, 2017, Mellieha, Malta, t.2, 2017, pp.1215-1224.
5. Kordzadze A.,Demetrashvili D. Black Sea oceanography in the past and at current stage. // I. Javakhishvili Tbilisi State University Press. 2017, 187 p.
6. 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, 2019, pp.99-107.
7. 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 See. // Proceed. of the International Conference GEOLONKS 2020, Plovdiv, Bulgaria, ISSN 2603-5472, ISBN 978-619-7495-09-6, Book 2, V.2, 2020, pp. 111-120. DOI 10.32008/GEOLINKS2020/B2/V2 .
8. Demetrashvili D., Kvaratskhelia D., Gvelesiani A. On the vortical motions in the Black Sea by the 3-D hydrothermodinamical numerical model. // Advances in Geosciences, 14, 2007, pp. 295-299, www.adv-geosci.net/14/295/2008/
9. Marchuk G. I. Numerical solution of problems of atmospheric and oceanic dynamics. // Gidrometeoizdat, Leningrad. 1974, 303 p., (in Russian).
10. Akpınar A., Gerbrant Ph.van Vledder, Komurcu M. I., Ozger M. Evaluation of the numerical wave model (SWAN) for wave simulation in the Black Sea. // Continental Shelf Research, 50–51, 2012, pp. 80–99.