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Modeling and Forecasting System of the Hydrological Fields in the Georgian Waters of the Black Sea and its Further Development

Demuri I. Demetrashvili

M. Nodia Institute of Geophysics of the I. Javakhishvili Tbilisi State University, Georgia,
e-mail: demetr_48@yahoo.com

ABSTRACT

This paper discusses current state and further development of the high-resolution marine regional modeling and forecasting system for the Georgian sector of the Black Sea and adjacent waters, which has been developed within the EU international scientific and technical projects ARENA (2003-2006), ECOOP (2007-2010). Its further expansion with the inclusion of impurity transport models in the system was carried out within the framework of Shota Rustaveli National Science Foundation grant (2013-2015). This system, based on a regional numerical model of the Black Sea dynamics and 2-D and 3-D transport models of the impurity, provides modeling of the main hydrological fields and the spread of oil and other impurities with a spatial resolution of 1 km. In the case of providing real input data, the system makes it possible to forecast the state of the sea for several days in advance. Further development of the existing regional modeling system is related to the development of a very high-resolution modeling subsystem for the Batumi-Poti-Anaklia nearshore water area and the inclusion of a wind wave forecast model in the subsystem. The purpose of the very high-resolution modeling subsystem is to specify and make more detailed marine forecast for the Batumi-Poti-Anaklia coastal waters (with a spatial resolution of 200 m), which are subject to the greatest anthropogenic load.

Key words: *forecasting system, mesoscale eddies, high-resolution model, system of equations, boundary conditions.*

Introduction

According to many experts, recent decades have been characterized by the intensification of human activity, which 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 litter, plastics and other pollutants is growing [1, 2]. Anthropogenic pressure on marine ecosystems increases sharply in areas of intense 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 zones, to which many marine organisms react sharply [3, 4].

For Georgia, as a Black Sea 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 Adjara (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 transport function is expected to increase since the construction of Anaklia deep-water port is on the agenda.

In conditions of intense anthropogenic load, a very high-resolution coastal modeling and forecasting system, which provides a timely and detailed forecast of the state of the Georgian nearshore waters by identifying the pollution zones, acquires significant relevance.

As a result of participation in the EU International scientific and technical projects ARENA (2003-2006) and ECOOP (2007-2010), M. Nodia Institute of Geophysics developed a regional marine forecasting system for the southeastern part of the Black Sea, which includes the Georgian sector of the Black Sea and the adjacent water area. The regional system became one of the components of the Black Sea basin-scale monitoring and forecasting system. The main core of the regional system - the regional model of the Black

Sea dynamics (RM-IG) of M. Nodia Institute of Geophysics with 1 km horizontal resolution, was nested in the basin-scale model of the Black Sea dynamics of Marine Hydrophysical Institute (Sevastopol, Ukraine) with 5 km horizontal resolution. The RM-IG is based on the solution of the complete system of the ocean hydrothermodynamic equations with appropriate initial and boundary conditions. 2-D and 3-D numerical transport models of oil and other impurities based on non-stationary advection-diffusion equations are coupled with the RM-IG.

Finite-difference methods based on the two-cycle splitting method are used to solve the equations of the models included in the modeling system [5].

We were able to receive all necessary input data every day required for forecast calculations via the Internet during 2010-2021, which was provided within the framework of the mentioned EU projects. A detailed description of the methodology for calculating marine forecasts is presented in [6-8].

In the case of real input data the regional forecasting system makes it possible to calculate a 3-day forecast of the main hydrophysical fields - current, temperature and salinity with a horizontal resolution of 1 km in the Georgian sector of the Black Sea and in emergency situations to predict zones of pollution and concentrations of oil and other impurities.

The present paper discusses the further development of a high-resolution marine regional forecasting system for the Georgian sector of the Black Sea and adjacent waters by developing a very high-resolution modeling subsystem for the Batumi-Poti-Anaklia nearshore water area. In addition, examples of short-term forecasting of the main hydrophysical fields and oil slick transport are given to illustrate the functioning of the existing forecasting system.

Results and discussions

The computer implementation of the RM-IG is carried out on a computational grid that includes 30 vertical computational levels with uneven grid steps (the minimum grid step is 2 m near the sea surface, the maximum is 100 m). The number of grid nodes on each horizon is 215x 347 with the grid step 1 km. 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 and the surrounding water area are characterized by high dynamic activity, where the formation of various mesoscale and submesoscale vortex structures continuously occurs (i. g. [9-13]).

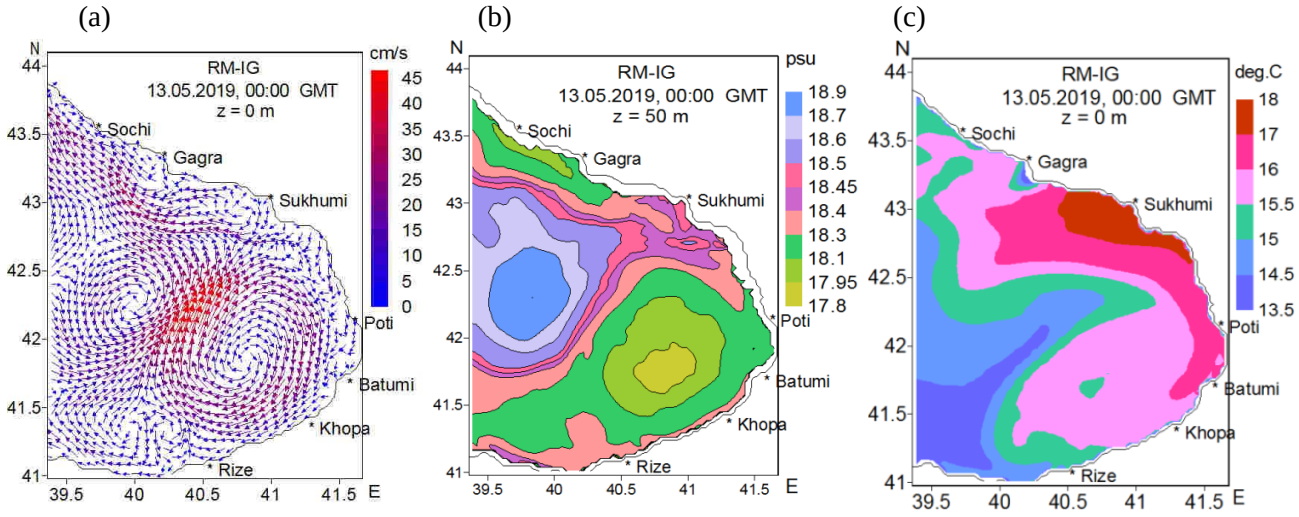

Fig.1. Predicted surface current (a), salinity (on z = 50 m) (b) and SST (c) on 13 May 2019, 00:00 GMT. The forecasting time period is 00:00 GMT, 10 – 13 May, 2019.

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.

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 (Fig1a) with the geostrophic current (Fig.2) shows good agreement with each other. Note that the geostrophic approximation cannot reproduce the submesoscale eddies identified by the model. Comparison of salinity (Fig1b) 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 cyclonic eddy the salinity is relatively high. This feature of the salinity distribution depending on the circulation regime is well known from the previous studies [6-7]. From Fig.1c is well visible that waters near the Georgian shoreline were characterized by relatively high temperature and the temperature decreases away from the shore.

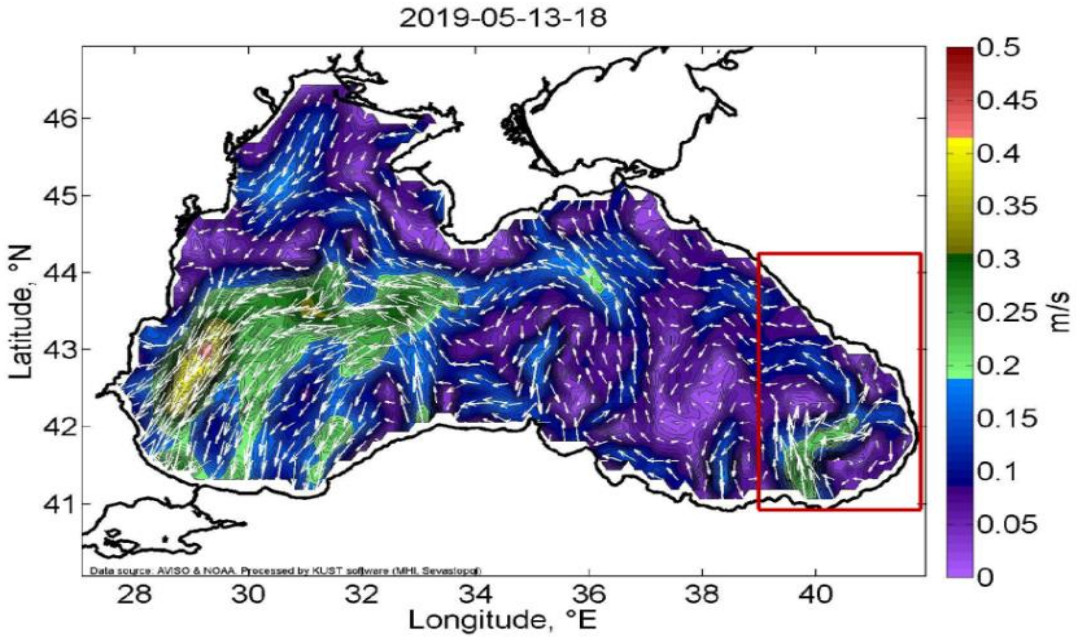

Fig.2. Geostrophic current field on 13 May 2019 reconstructed using satellite altimeter data. By rectangle the forecasting area is marked.

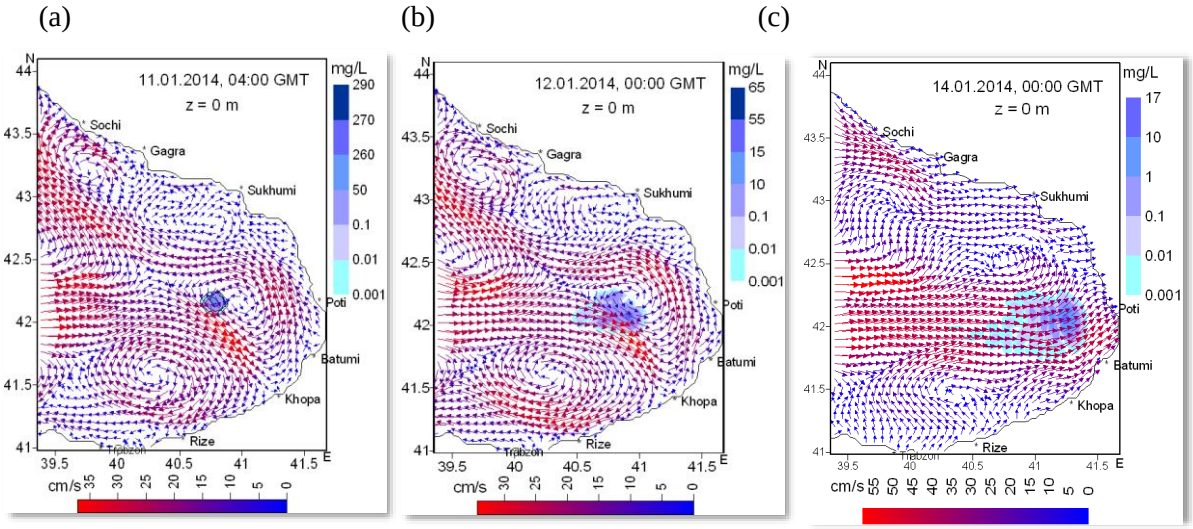

Fig.3. Predicted surface current fields and oil spill transport corresponded to the following time moments after oil flood: (a) - 4h, (b) - 24 h, (c) - (72). the forecasting period: 00:00 GMT,11-14 January 2014.

In Fig.3 predicted surface current fields and oil spill transport are shown, when the forecasting period was 00:00 GMT, 11-14 Jainuary 2014. In a numerical experiment, a hypothetical emergency oil spill into the sea occurred at a distance of about 70 km from the coast of Georgia. The oil spill occurred over four hours in the amount of 10 tons. The oil spill was considered as a point source. It is evident from the Fig.3 that the oil slick gradually expands and, under the influence of circulation, approaches the Georgian coast.

We consider further development of the regional forecasting system by developing a very high-resolution modeling subsystem (with a grid step of 200 m) for the Batumi-Poti-Anaklia nearshore area with sizes of about 54x177 km, which is subject of great anthropogenic load. The modeling subsystem will become a part of the existing regional modeling and forecasting system. 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 [14], 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.

A spectral model of the forecast of the sea surface waves will be developed, which will be included in the modeling subsystem for the Adjara-Poti-Anaklia adjacent water area.

Fig.4 shows the forecast area, where the forecast is calculated with a spatial resolution of 1 km, and the Batumi-Poti-Anaklia water area, where the forecast should be calculated with a resolution of 200 m.

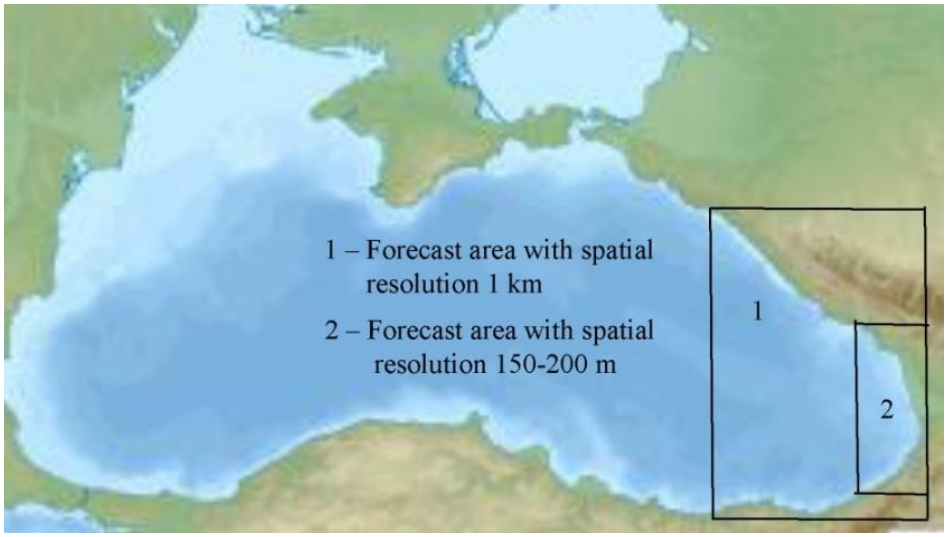

Fig.4. Regional and coastal forecast areas in the southeastern part of the Black Sea.

Fig. 5 shows the structure of the new advanced version of the marine regional forecasting system after including a very high resolution modeling subsystem into existing regional forecasting system. As shown in Fig. 5, the components of a forecasting subsystem will be the following very high-resolution models with grid step of 200 m :

- A 3-D numerical model of coastal dynamics, which will be nested in the RM-IG with 1 km resolution.
- A 2-D numerical model of oil slick transport.
- A 3-D numerical model of spreading of non-conservative impurities.
- Surface gravitational wind wave model.

The main core of the coastal forecasting subsystem will be a new very high-resolution version of the sea dynamics model, which will be obtained by adapting the RM-IG to the Adjara-Poti-Anaklia water area and increasing the spatial resolution from 1 km horizontal grid step to 200 m grid step. At the same time, the coastal forecasting subsystem will be expanded with the task of forecasting sea surface waves. It is planned that the wind wave model will be based on the spectral wave energy balance equation. It should be noted that the well known SWAN (Simulating Waves Nearshore) model in the literature is based on the same equation, which quite fully describes the formation and transformation of wave motion in coastal areas and is widely used to calculate wind waves in a number of coastal areas [15-17].

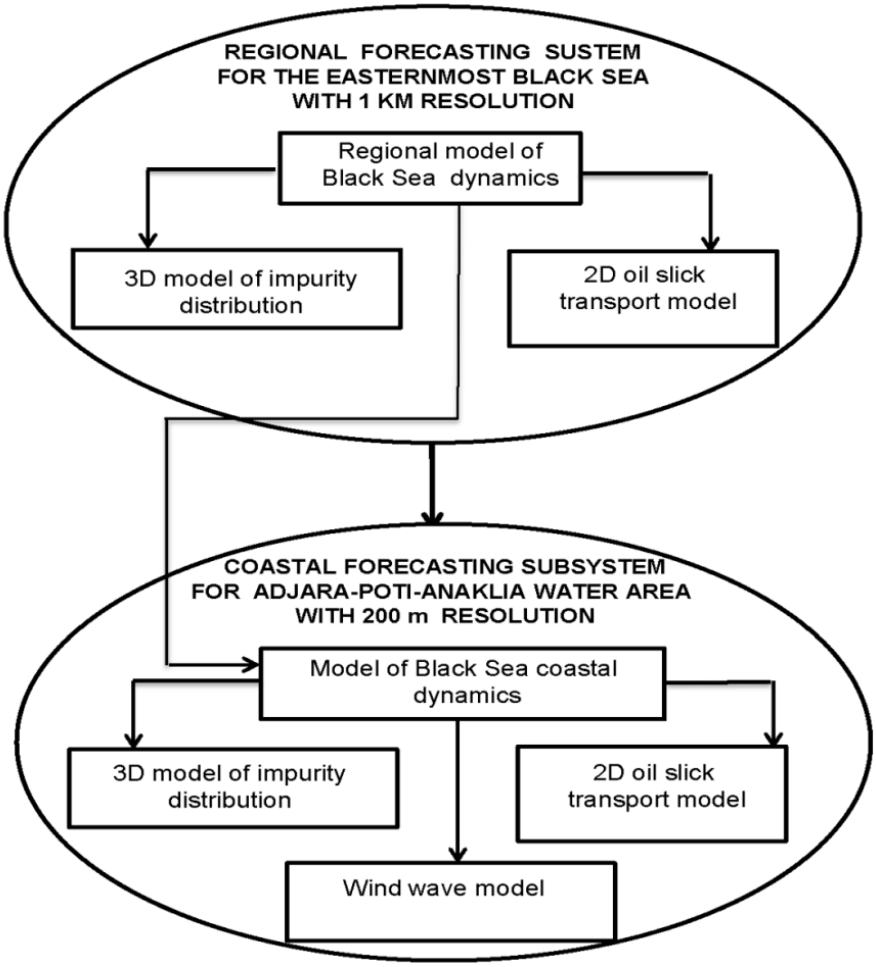

Fig. 5. The structure of the advanced version of the regional forecasting system.

The operation of the coastal forecasting subsystem will be possible together with the existing regional system using nesting modeling, which will allow us to calculate not only the forecast of dynamic fields and the spread and concentration of impurities, but also the height and direction of surface waves with a resolution of 200 m in Adjara-Poti-Anaklia nearshore zone.

the atmospheric forcing will be specified by the Meteo France regional atmospheric model **ALADIN** acting in Romanian Meteorological Organization or by the **SKIRON** forecasting system (University of Athens, http://forecast.uoa.gr/).

Conclusion

The paper presents the current state of the regional marine forecasting system for the Georgian sector of the Black Sea and adjacent water area, which will be developed by creation of a very high-resolution modeling subsystem for Batumi-Poti-Anaklia water area spatial resolution of 200 m. Modeling of hydrological processes in the Adjara-Poti-Anaklia coastal area with a very high resolution is an essential factor for high-precision reproduction of coastal processes.

Thus, a complex regional forecasting system will be created, which will combine the existing regional forecasting system with a resolution of 1 km and very high-resolution forecasting subsystem with a resolution of 200 m for the Batumi-Poti-Anaklia coastal zone. The development of this improved regional forecasting system is of great importance from the point of view of its practical use, since the operation of such a system will make it possible to provide with marine forecasts such economic sectors, for the full functioning whose operational information on the state of the Black Sea is required.

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შავი ზღვის საქართველოს წყლებში ჰიდროლოგიური ველების მოდელირებისა და პროგნოზირების სისტემა და მისი შემდგომი განვითარება

დ. დემეტრაშვილი

რეზიუმე

ნაშრომში განხილულია შავი ზღვის საქართველოს სექტორისა და მიმდებარე წყლებისთვის მაღალი გარჩევადობის საზღვაო რეგიონული მოდელირებისა და პროგნოზირების სისტემის ამჟამინდელი მდგომარეობა და შემდგომი განვითარება, რომელიც შემუშავდა ევროკავშირის საერთაშორისო სამეცნიერო-ტექნიკური პროექტების ARENA (2003-2006) და ECOOP (2007-2010) ფარგლებში. მისი შემდგომი გაფართოება პროგნოზირების სისტემაში მინარევების გადატანის მოდელების ჩართვით განხორციელდა შოთა რუსთველის ეროვნული სამეცნიერო ფონდის გრანტის ფარგლებში (2013-2015). ეს სისტემა, რომელიც დაფუძნებულია შავი ზღვის დინამიკის რეგიონულ რიცხვით მოდელსა და მინარევების 2-D და 3-D გადატანის მოდელებზე, უზრუნველყოფს ძირითადი ჰიდროლოგიური ველების და ნავთობისა და სხვა მინარევების გავრცელების მოდელირებას 1 კმ სივრცითი გარჩევადობით. რეალური შემავალი მონაცემებით უზრუნველყოფის შემთხვევაში, სისტემა შესაძლებელს ხდის ზღვის მდგომარეობის პროგნოზირებას რამოდენიმე დღის წინსწრებით. არსებული რეგიონული პროგნოზირების სისტემის შემდგომი განვითარება დაკავშირებულია ბათუმი-ფოთი-ანაკლიის სანაპირო წყლებისთვის ძალიან მაღალი გარჩევადობის მოდელირების ქვესისტემის შემუშავებასთან და ქვესისტემაში ქარისმიერი ტალღების პროგნოზირების მოდელის ჩართვასთან. ძალიან მაღალი გარჩევადობის მოდელირების ქვესისტემის მიზანია უფრო დეტალური საზღვაო პროგნოზის განხორციელება (200 მ სივრცითი გარჩევადობით) ბათუმი-ფოთი-ანაკლიის სანაპირო წყლებისთვის, რომლებიც ყველაზე დიდ ანთროპოგენურ დატვირთვას განიცდიან.

საკვანძო სიტყვები: პროგნოზის სისტემა, მეზომასშტაბური გრიგალები, მაღალი გარჩევისუნარიანი მოდელი, განტოლებათა სისტემა, სასაზღვრო პირობები.

Система моделирования и прогнозирования гидрологических полей в грузинских водах Черного моря и ее дальнейшее развитие

Д. Деметрашвили

Резюме

В данной работе рассматривается современное состояние и дальнейшее развитие системы морского регионального моделирования и прогнозирования с высоким разрешением для грузинского сектора Черного моря и прилегающих вод, разработанной в рамках международных научно-технических проектов ЕС ARENA (2003-2006), ECOOP (2007-2010). Дальнейшее ее расширение с включением в систему прогнозирования моделей переноса примесей было осуществлено в рамках гранта Национального научного фонда имени Шота Руставели (2013-2015). Данная система на основе региональной численной модели динамики Черного моря и 2-D и 3-D моделей переноса примесей

обеспечивает моделирование основных гидрологических полей и распространения нефти и других примесей с пространственным разрешением 1 км. В случае предоставления реальных входных данных, система позволяет прогнозировать состояние моря на несколько суток вперед. Дальнейшее развитие существующей региональной системы прогнозирования связано с разработкой подсистемы моделирования сверхвысоко разрешения для прибрежной акватории Батуми-Поти-Анаклия и включением в подсистему модели прогноза волнового режима. Целью подсистемы моделирования со сверхвысоким разрешением является уточнение и более детальное осуществление морского прогноза для прибрежных вод Батуми-Поти-Анаклия (с пространственным разрешением 200 м), которые подвержены наибольшей антропогенной нагрузке.

Ключевые слова: система прогнозирования, мезомасштабные вихри, модель высокого разрешения, система уравнений, граничные условия.