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Forecast of Dynamic Fields and Impurity Dispersion in the Easternmost Part of the Black Sea

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Abstract

An advanced version of the regional short-term forecasting system for the easternmost Black Sea, is presented. The forecasting system consists of hydrodynamic and ecological blocks. The hydrodynamic block includes a high-resolution 3D regional model of the Black Sea dynamics of M. Nodia Institute of Geophysics, but the ecological block consists of 2D and 3D models of spreading of oil and other admixtures in the sea environment. The regional forecasting system, which is one of the parts of the basin-scale Black Sea nowcasting/forecasting system, is functioning in the near real time and provides 3 days' forecast of sea dynamic fields – the current, temperature and salinity with 1 km resolution, but in special situations the system will also provide to calculate impurity's concentrations and pollution areas.

***Key words*:** numerical simulation, forecasting system, pollution of Black Sea.

Introduction

Coastal and shelf zones of seas and oceans are undergoing great human pressure because of the economic and domestic activities of man, which creates a serious danger to the ecosystem of these areas. The Georgian Black Sea coastal zone is not exception. A significant increase in tourists in recent years, the construction and planning of appropriate infrastructures, hydraulic structures and ports (e. g., Anaklya port) dramatically increases the danger of contamination of Georgian coastal waters by oil and other toxic ingredients. In such conditions, development of the forecasting system of the state of the coastal waters is considerably urgent, which should become the basic component of the coastal monitoring and management system.

Development of in-situ and remote sensing methods, computing and communication tools and high-accuracy numerical modeling of sea dynamic processes in the last decade have led to the creation of the basin-scale Black Sea nowcasting/forecasting system, which allows short-range forecasts of the basic hydrophysical fields [1-3]. Such an achievement of the Black Sea operational oceanography was made possible by close cooperation of oceanographer-experts of the Black Sea riparian countries in the framework of NATO and EC international scientific projects under the coordination of the Marine Hydrophysical Institute of the National Academy of Sciences of Ukraine (MHI, Sevastopol). The regional forecasting system for the easternmost part of the Black Sea developed at the Institute of Geophysics of I.

Javakhishvili Tbilisi State University is one of the components of this basin-scale Black Sea nowcasting/forecasting system. In [4-8] description of the regional forecasting system and the results of the verification, simulation and prediction of dynamic fields are given.

In the present study, an advanced version of the Black Sea regional forecasting system extended by inclusion of 2D and 3D impurity's dispersion models is shortly described and some results of modeling and 3 days' forecast of circulation and spreading of polluting substances are also presented. This study may be consider as continuation of researches presented in [9,10], where some results of forecast of dynamic fields and distribution of contamination in the easternmost Black Sea water area are given.

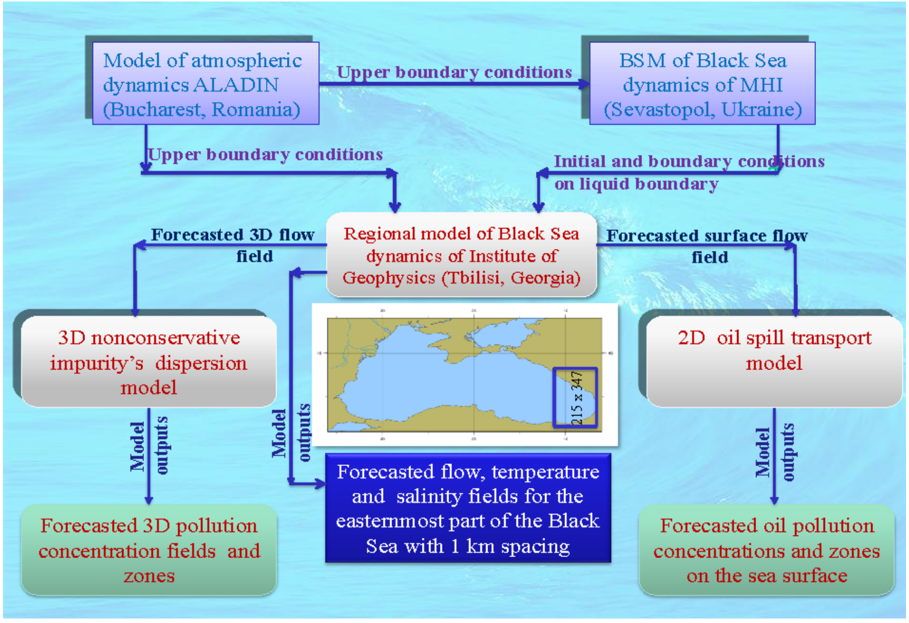

Fig.1. The forecast area, structure and scheme of functioning of the extended version of the regional forecasting system.

Advanced version of the regional forecasting system

In fig.1 the forecast area, the structure and the scheme of functioning of the regional forecasting system are shown. The regional water area is limited to the Caucasus and Turkish coastal lines and the western liquid boundary coinciding with the meridian 39.08^0 E. The new advanced version of the regional forecasting system consists of hydrodynamic and ecological blocks. The hydrodynamic block is based on the Institute of Geophysics of I. Javakhishvili Tbilisi State University's high-resolution regional model of the Black Sea dynamics (RM-IG), which is based on a primitive equation system of ocean hydro and thermodynamics in hydrostatic approximation. This model is nested in the basin-scale model (BSM) of Marine Hydrophysical Institute (MHI, Sevastopol). The input data - the initial and prognostic hydrophysical fields on the open boundary, also 2D prognostic meteorological fields at the sea surface –wind stress, heat fluxes, evaporation and precipitation rates needed for the regional forecasts of dynamic fields are provided from MHI everyday in the near-real time mode via Internet. Prognostic hydrophysical fields are results of forecast by the BSM of MHI [11] and 2D meteorological boundary fields represent the results of forecast by regional atmospheric model ALADIN [12]. All these fields are given on the grid of BSM with 5 km spacing and with one-hour time step frequency for the integrated period. During the regional model implementation these fields are transferred to the grid of the regional model at every time step with 1 km spacing by interpolation.

The ecological block is based on 2D and 3D diffusion models describing spreading of oil and other nonconservative substances in the water area and using nonstationary flow field calculated from the hydrodynamic block. The 3D diffusion model is based on the nonstationary advection-diffusion equation for nonconservative substance:

$$\frac{\partial \varphi}{\partial t}+\frac{\partial \mathrm{u} \varphi}{\partial \mathrm{x}}+\frac{\partial \mathrm{v} \varphi}{\partial \mathrm{y}}+\frac{\partial w \varphi}{\partial z}+\sigma \varphi=\frac{\partial}{\partial x} \mu \frac{\partial \varphi}{\partial x}+\frac{\partial}{\partial y} \mu \frac{\partial \varphi}{\partial y}+\frac{\partial}{\partial z} \nu \frac{\partial \varphi}{\partial \mathrm{z}}+f, \qquad (1)$$

where φ is the volume concentration of a substance; u, v, and w are the sea current velocity components along x, y and z axes, respectively; μ and ν are the coefficients of horizontal and vertical turbulent diffusion, respectively; $\sigma = ln2/T_0$ is the parameter describing changeability of concentration because of physical and biochemical factors; T_0 represents the time interval, during which the initial pollution concentrations decrease two times; in general, f describes the space-temporal distribution of a specific source power, which in case of the point source may be represented by the delta function

$$f = \mathrm{Q}\,\delta(\mathrm{x}-\mathrm{x}_0)\,\delta(y-y_0)\,\delta(z-z_0),$$

where x_0, y_0 and z_0 are coordinates of the source location. Q is power of oil emission from the point source. 2D version of the equation (1) was applied for simulation and forecast of oil spill transport. In both 2D and 3D versions Neumann boundary conditions are applied, at initial time pollution of the sea is absent.

The diffusion coefficient was variable calculated by the formula suggested in [13]

$$\mu = \gamma\, \Delta x.\Delta y \sqrt{2\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2} \quad ,$$

where Δx and Δy are horizontal grid steps along x and y axes, respectively; γ is some constant.

To solve the problems in both blocks splitting methods are used, which enable the solution of complex nonstationary problems to reduce solutions to relatively simple two-dimensional and one-dimensional problems [14,15].

The transport models of oil (2D task) and other substances (3D task) are included in the forecasting system as a separate modules and enables to calculate pollution zones and concentrations in special cases. With this purpose it is required to input in the calculated program written on the algorithmic language “Fortran” the following parameters: coordinates of source location, amount of emission, duration of emission and the parameter σ describing the change of pollution concentrations due to physical and biochemical factors depending on the type of polluting substance.

Thus, the regional forecasting system provides 3 days’ forecast of 3D dynamic fields – flow, temperature and salinity with 1 km spacing, and in case of accidental situations – the forecast of spreading the oil and other pollutants in the Georgian Black Sea coastal zone and adjoining water area.

Implementation of the regional forecasting system

All numerical models included in the regional forecasting system use a grid having 215 x 347 points with horizontal resolution 1 km. On the vertical, the nonuniform grid with 30 calculated levels on depths 2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306 to 2006 m are considered. The time step is equal to 0.5 h. the parameter of σ depends on the type of chemical ingredient. At simulation of oil spill transport we took into account that reduction of oil concentrations due to evaporation is very intensive during first day after oil flood [16]. Therefore, we accepted $\sigma = 1{,}6.10^{-5}$ if $t \leq 24$ h and $\sigma = 8{,}2.10^{-7}$ if $t > 24$ h. The first value of σ corresponds to double reduction of oil concentrations for 12 hours, and the second one - to double reduction of concentrations during 10 days.

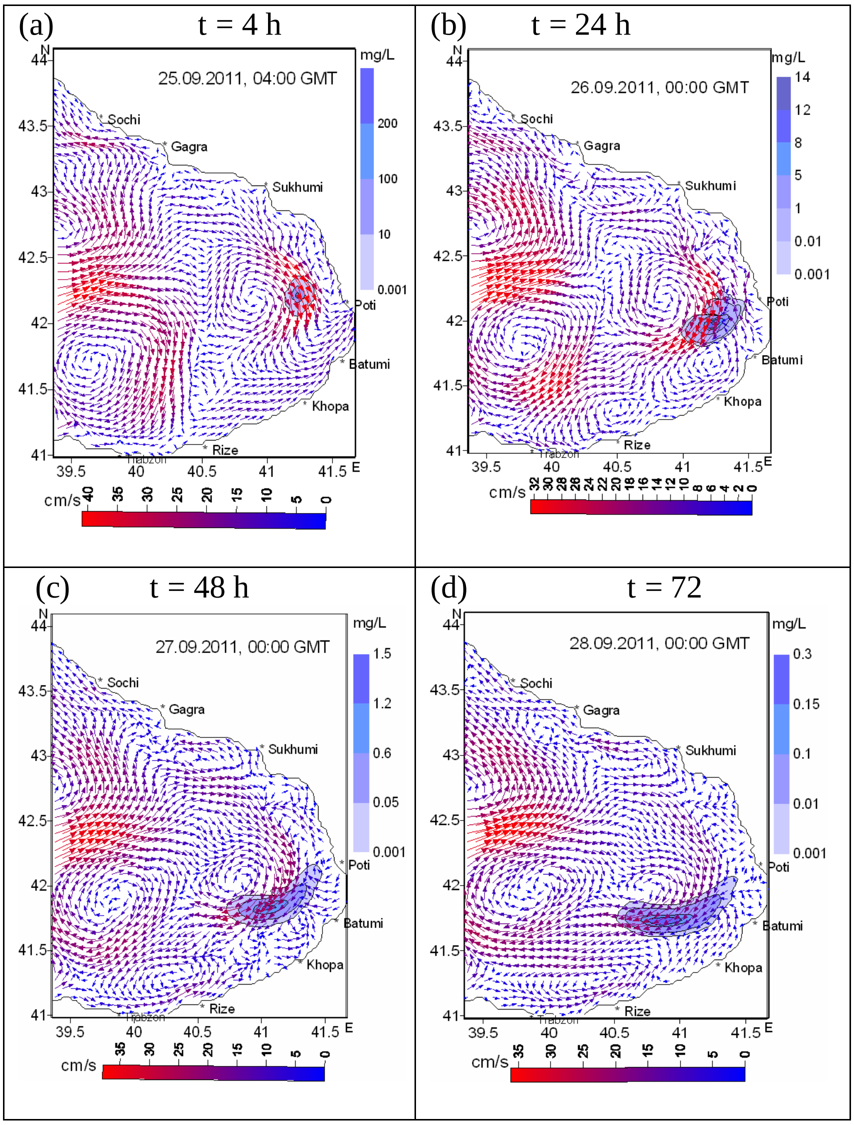

Fig.2. Simulated surface current field and oil spill transport corresponded to the following time moments after oil flood: (a) - 4h, (b) - 24 h, (c) - (48), (d) - (72). The forecasting interval is 00:00 GMT,25-28 September 2011. The source coordinates: 142Δx and 132Δy.

Regular calculations of the regional forecasts started since 2010 show that the easternmost part of the Black Sea, including the Georgian water area, is dynamically very active zone, where continuous generation, deformation, and disappearance of the mesoscale and submesoscale cyclonic and anticyclonic eddies occur throughout the year [8].

Fig. 2 illustrates forecasted regional circulation in the easternmost part of the Black Sea and drifting of oil slick in case, when 50 t was occurred on distance about 50 km from Poti shoreline in the point with coordinates 142Δx and 132Δy (the forecasting period is 00:00 GMT, 25-28 September 2011). Taking into account that the maximum allowable concentration of oil pollution is usually taken to be 0.05 mg/L in all the numerical experiments we have taken to be zero concentration of less than 0.001 mg/L.

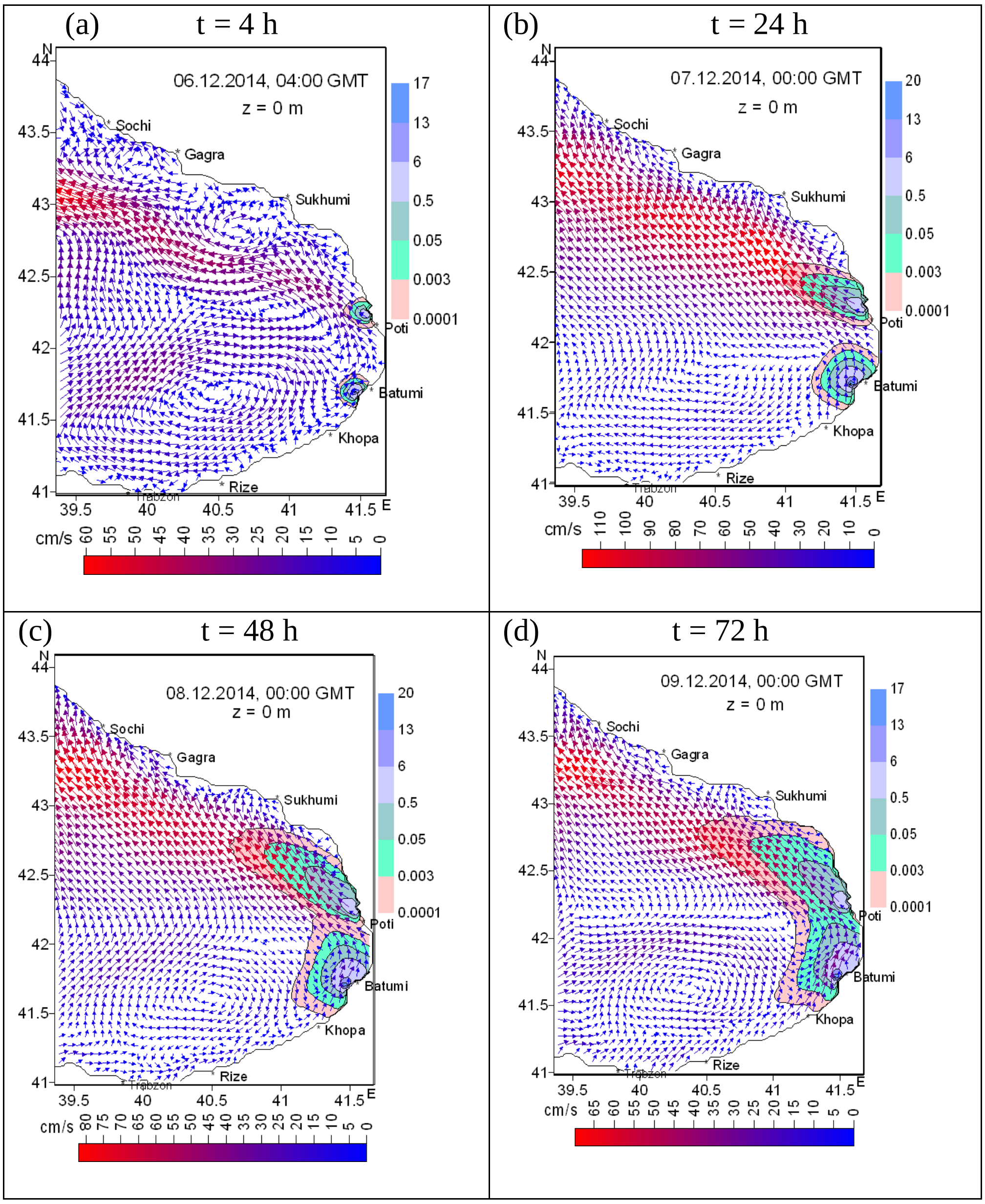

Fig. 3. Simulated surface current field and distribution of impurity at t = 4, 24, 48 and 72 h after start of getting impurity to the sea from rivers Chorokhi and Rioni. The forecasting period is 00:00 GMT, 6-9 December, 2014.

From fig. 2 is well visible that during the considered forecasting interval 25-28 September 2011 the regional circulation in the Black Sea easternmost part is characterized by significant variability with intensive mesoscale and submesoscale vortex formations. Such circulating reorganization is essentially reflected on moving of the oil spill. In the course of migration the oil slick extends gradually and deforms. Simultaneously there is a reduction of oil pollution concentrations, that is caused by diffusion expansion, evaporation and other physical and chemical factors, which are taken into account in the model indirectly.

The numerical experiments carried out in case of different location of hypothetical sources and real circulating modes show a significant role of circulating processes in formation of spatial-temporary distribution of pollution. The numerical experiments also showed that oil spill transport is significantly sensitive to the turbulent diffusion coefficient and the type of oil.

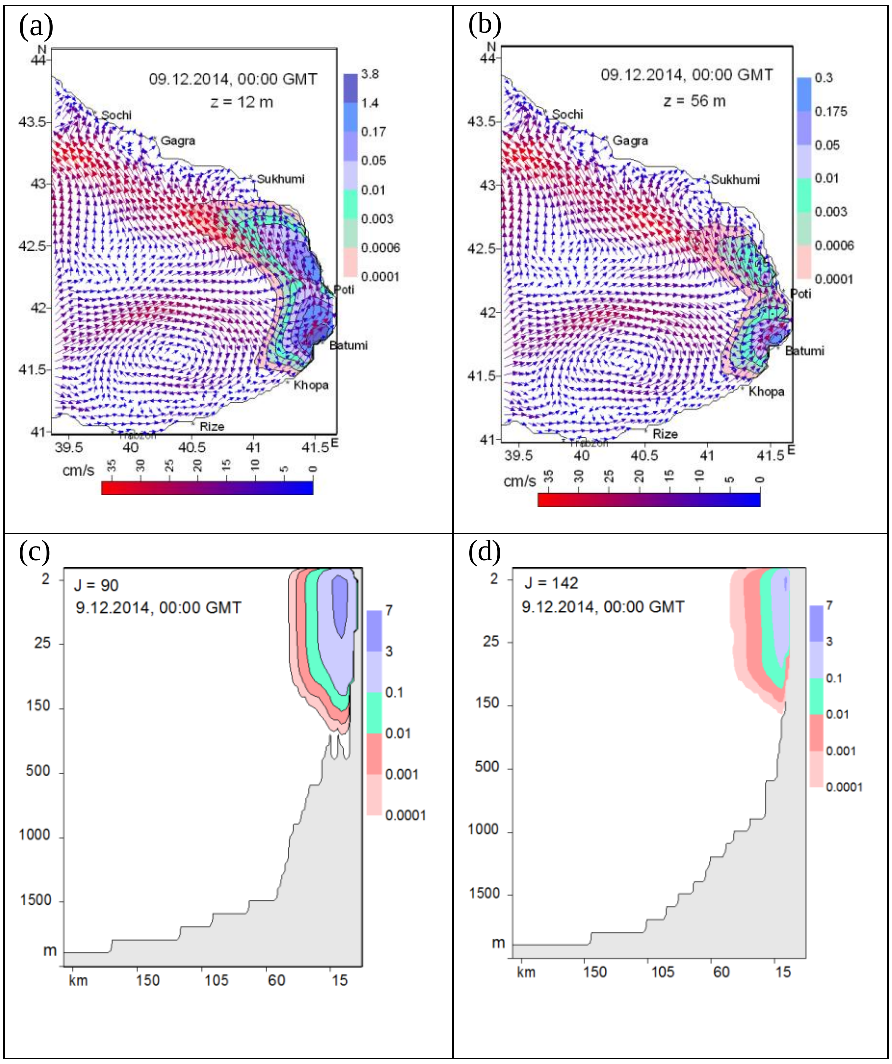

Fig. 4. Simulated surface current field and distribution of impurity on depths of 12 and 56 m (a, b) and in some vertical sections (c, d) at t = 72 h after start of getting impurity to the sea from rivers Chorokhi and Rioni. The forecasting period is 00:00 GMT, 6-9 December, 2014.

Figs. 3 and 4 illustrate results of simulation and forecast of circulation and the distribution of the nonconservative impurity which has been discharged into the sea from rivers Rioni and Chorokhi in the following amount per 1 s: from river Chorokhi - 100000 reference units, from southern and northern Rioni branches - 5000 and 10000 reference units, respectively. The time of disintegration T_0 was taken equal to 30 days. The factor of vertical turbulent diffusion was 15 cm^2/s. The forecasting period corresponded to 00:00 GMT, 6 – 9 December 2014. In Fig.3 the distribution of the impurity on the sea surface at time moments 4, 24, 48 and 72 h after start of getting the impurity to the sea from rivers is shown, but Fig.4 illustrates the distribution of the impurity on depths of 12 and 56 m (Fig.4a and 4b) and in some vertical sections (Fig.4c and 4d) at t = 72 h.

The main feature of the circulation for this forecasting period is very high speeds of sea current, which are caused by strong winds for the considered period. Strong winds and therefore strong wind stress considerably influence sea surface current and renders smoothing action weakening vortex formation in the sea upper layer [17]. From Figs. 3 and 4 it is clearly visible, that the character of circulation considerably predetermines the basic features of impurity's distribution processes. The analysis of the pollution concentration fields showed that the impurity is distributed not only in a horizontal direction, but also on a vertical due to vertical diffusion and vertical flow. pollution concentrations reached up to depth approximately 150 m during 3 days.

Conclusion

The paper presents a new version of the regional forecasting system for the easternmost Black Sea allowing to forecast with 3-days forward not only 3-D dynamical fields – the current, temperature and salinity with 1 km spacing, but also spreading of pollution zones and concentrations of the oil and other pollutants in the case of accidental situations. The regional forecasting system is a part of the basin-scale nowcasting/forecasting system and all required input data are provided from MHI (Sevastopol) in the near-real time mode via Internet. The numerical experiments carried out in different locations of hypothetical sources and real circulating modes, show a significant role of circulating processes in the formation of spatial-temporary distribution of pollution.

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დინამიკური ველებისა და მინარევის გავრცელების პროგნოზი შავი ზღვის აღმოსავლეთ ნაწილში

ა. კორძაძე, დ. დემეტრაშვილი, ვ. კუხალაშვილი

რეზიუმე

წარმოდგენილია შავი ზღვის აღმოსავლეთ ნაწილისათვის მოკლევადიანი რეგიონული პროგნოზის სისტემის გაუმჯობესებული ვერსია. პროგნოზის სისტემა შედგება ჰიდროდინამიკური და ეკოლოგიური ბლოკებისაგან. ჰიდროდინამიკური ბლოკი შეიცავს მ. ნოდიას გეოფიზიკის ინსტიტუტის მაღალი გარჩევისუნარიან სამგანზომილებიან შავი ზღვის დინამიკის რეგიონულ მოდელს, ხოლო ეკოლოგიური ბლოკი შედგება ნავთობისა და სხვა მინარევების გავრცელების ორი და სამგანზომილებიანი მოდელებისაგან. რეგიონული პროგნოზის სისტემა, რომელიც ერთ-ერთი შემადგენელი ნაწილია

მთლიანად შავი ზღვის დიაგნოზისა და პროგნოზის სისტემისა, ფუნქციონირებს რეალურთან მიახლოებულ რეჟიმში და უზრუნველყოფს შავი ზღვის დინამიკური ველების – დინების, ტემპერატურისა და მარილიანობის სამდღიან პროგნოზს 1 კმ გარჩევისუნარიანობით, ხოლო საგანგებო სიტუაციებში შესაძლებლობას იძლევა გამოვთვალოთ მინარევის კონცენტრაციებისა და დაჭუჭყიანების ზონების პროგნოზიც.

Прогноз динамических полей и распространрения примеси в восточной части Черного моря

А.А. Кордзадзе, Д.И. Деметрашвили, В.Г. Кухалашвили

Резюме

Представлена улучшенная версия региональной системы краткосрочного прогноза для восточной части Черного моря. Система прогноза состоит из гидродинамического и экологического блоков. Гидродинамический блок включает в себя высоко разрешающую пространственную региональную модель динамики моря Института геофизики им. М. Нодиа, а экологический блок состиот из двумерных и пространственных моделей распространени нефти и других примесей в морской среде. Региональная система прогноза, которая является одной из частей системы диагноза и прогноза Черного моря в масштабах всего бассейна, функционирует в режиме близком к реальному и обеспечивает прогноз на трое суток динамических полей с разрешением 1 км – течения температуры и солености, но в чрезвычайных ситуациях прогностическая ситема обеспечит также расчет прогноза концентраций примеси и зон загрязнения.