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Coastal Forecasting System for the Easternmost Part of the Black Sea

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Abstract

A coastal forecasting system for the Easternmost part of the Black Sea (including the Georgian water area), which is one of the parts of the Black Sea Nowcasting/Forecasting System, is developed. A core of the coastal forecasting system is a high-resolution baroclinic regional model of the Black Sea dynamics developed at M. Nodia Institute of Geophysics of Iv. Javakhishnili Tbilisi State University (RM-IG). The RM-IG is based on a primitive system of ocean hydro-thermodynamics equations in hydrostatic approximation. The regional area, which is limited to the Caucasian and Turkish coastal lines and the western liquid boundary coinciding with a meridian 39.36^0E, is covered with a grid having on horizons 193 x 347 points with step equal to 1 km. This model is nested in the basin-scale model (BSM) of the Black Sea dynamics of Marine Hydrophysical Institute (MHI, Sevastopol/Ukraine) with 5 km resolution. All input data with one hour time step frequency corresponding to 3 days' forecasting time period are available in operative mode from MHI via ftp site. These data provide initial and boundary conditions for the RM-IG.

With the purpose of demonstrating the functioning of the coastal forecasting system some results of marine forecasts for summer and autumn seasons are discussed. Comparison of the fields predicted from the RM-IG and the BSM of MHI shows that the usage of the model with high resolution is very important factor to real reproduction of coastal hydrophysical processes.

Keywords: Black Sea, numerical model, equation system, hydrophysical fields, circulation, wind stress.

Introduction

Approximately during last two decades the Black Sea oceanography achieved significant successes. Attraction of new technologies of observations including satellite methods of measurement and progress of computer facilities providing creation of highly resolving numerical models allowing to reproduce sea processes by sufficiently high adequacy promoted better understanding of physical and biogeochemical processes in the Black Sea (Oguz *et al*., 1992; Oguz and Besiktepe, 1999; Stanev, 2005; Korotaev and Eremeev, 2006; Salihoglu *et al*., 2011; Oguz *et al*., 2012). Especially the large scientific and technical achievement of the Black Sea operative oceanography is the development of the Black Sea Nowcasting/Forecasting System which allows to carry out continuous control over the current state of the Black Sea and its change for some days forward (Besiktepe, 2003a, 2003b; Kubryakov *et al*., 2006; Korotaev *et al*., 2006, 2011; Kordzadze and Demetrashvili, 2010). Creation of such system was promoted by the leading oceanographic centers of the Black Sea riparian countries: Institute of Oceanology (Bulgaria), Institute of Geophysics (Georgia), National Institute of Marine Research (Romania), State Oceanographic Institute (Russia), Institute of Marine Sciences-Middle East Technical University (Turkey) and Marine Hydrophysical Institute (Ukraine).

Operation of the Nowcasting/Forecasting System is very important and actual for coastal and shelf zones as these zones undergo the greatest anthropogenous loading. Here different processes are taking place-processes of dispersion and transformation of polluting substances, lithodynamical and biochemical processes, *etc*. The studying and forecast of such processes are closely connected with understanding and forecasting of dynamical processes.

One of the parts of the Black Sea Nowcasting/Forecasting System is the coastal forecasting subsystem for the Easternmost part of the

Black Sea (including the Georgian water area) allowing to forecast 3-D fields of current, temperature and salinity with high resolution.

In this study we consider the coastal forecasting subsystem for the Easternmost part of the Black Sea with demonstrating some results of marine forecast.

Materials and Methods

Method of Forecasting

The main components of the Black Sea Nowcasting/Forecasting System are: the regional atmospheric model ALADIN with 24 km grid step, the basin-scale model (BSM) of the Black Sea dynamics of Marine Hydrophysical Institute (MHI, Sevastopol, Ukraine) with 5 km grid step, some regional forecasting subsystems using high-resolution regional circulation models nested near the coasts of the riparian countries and the Black Sea observing system including the remote sensing components.

Fig. 1 schematically illustrates the functioning of the coastal forecasting subsystem for the Easternmost part of the Black Sea, which is a part of the basin-scale Nowcasting/Forecasting System. A core of the coastal subsystem is a high-resolution regional model of the Black Sea dynamics of M. Nodia Institute if Geophysics (RM-IG), which is nested in the BSM of MHI. The RM-IG is received by adaptation of the BSM of the Black Sea dynamics of the Institute of Geophysics (Kordzadze *et al.*, 2008) to the Easternmost part of the basin.

The regional area is bounded with the Caucasus and Turkish shorelines and the western liquid boundary coinciding with 39.36°E. Data needed for the forecasts-the 3-D initial and prognostic hydrophysical fields on liquid boundary, also 2-D prognostic meteorological fields at the sea surface - wind stress, heat fluxes, evaporation and precipitation rates for the regional area are available in operative mode from the MHI server via ftp site. Prognostic hydrophysical fields are results of forecast by BSM of MHI and 2-D meteorological boundary fields represent results of forecast by regional atmospheric model ALADIN.

The coastal forecasting subsystem provides to run 3 days' forecasts of 3-D fields of flow, temperature and salinity with 1 km spacing for the considered Black Sea regional area.

General Features of the Regional Model

The RM-IG is based on a primitive equation system of ocean hydrothermodynamics in hydrostatic approximation, which is written in z-coordinates for deviations of thermodynamic values from their standard vertical distributions (Kordzadze and Demetrashvili, 2010, 2011).

The regional nested model takes into account: nonstationary atmospheric wind and thermohaline forcing, quasi-realistic bottom relief, the absorption of solar radiation by the sea upper layer, space-temporal variability of turbulent viscosity and diffusion.

The two-cycle splitting method with respect to both physical processes and coordinate planes and lines is used for solving the model equation system (Marchuk, 1974). This method substantially simplifies the implementation of complex physical model and enables us to reduce solution of 3-D nonstationary problem to solution of more simple 2-D and 1-D problems.

The RM-IG uses a grid with 193 x 347 points having horizontal resolution 1 km. On a vertical the non-uniform grid with 30 calculated levels on depths:

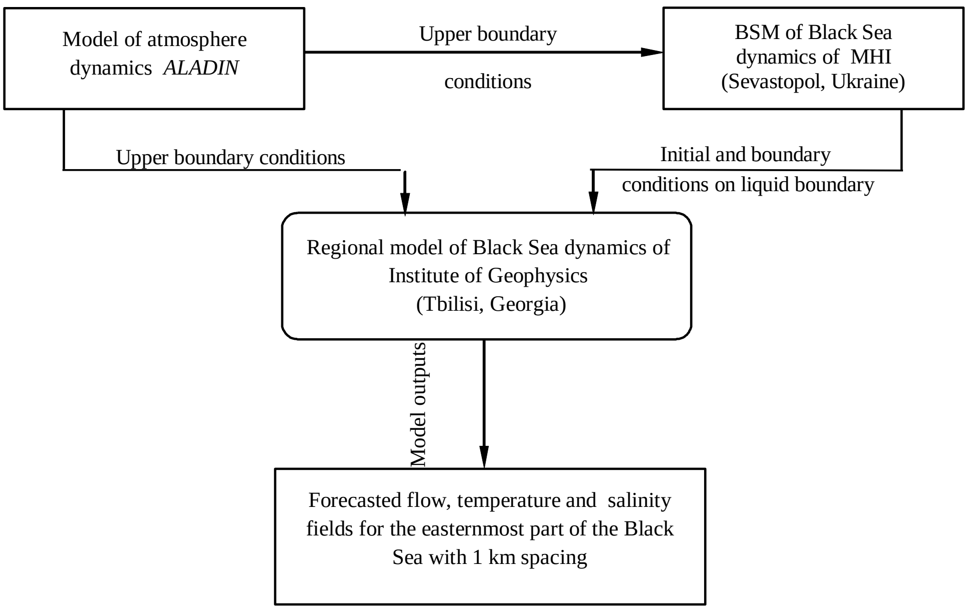

Figure 1. The scheme of functioning of the coastal forecasting subsystem.

2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306, …, 2006 m are considered. The time step is equal to 0.5 h.

Parameterization of the Turbulence

Factors of horizontal viscosity and diffusion for temperature and salt μ, $\mu_{T,S}$ where calculated by the formulas (Zilitinkevich and Monin, 1971)

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

$$\mu_T = \frac{\mu}{c_T}, \; \mu_S = \frac{\mu}{c_S},$$

where u, v are the components of the current velocity vector along the axes x, y, respectively (the axes x and y are directed eastward and northward, respectively); Δx and Δy are horizontal grid steps along x and y, respectively; c_T and c_S are some constants equal to 10.

Factors of vertical turbulent diffusion for heat and salt $\nu_{T,S}$ were calculated by using the modified Oboukhov formula presented by Marchuk *et al*., (1980) as:

$$\nu_{T,S} = (0.05h)^2 \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 - \frac{g}{\rho_0}\frac{\partial \rho}{\partial z}}.$$

Here h is the depth of the turbulent surface layer, which is defined by the first point z_m (the axis z is directed downward from the sea surface, in which following condition is satisfied:

$$(0.05z_m)^2 \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 - \frac{g}{\rho_0}\frac{\partial \rho}{\partial z}} \leq \nu^0_{T,S},$$

$$\nu^0_{T,S} = 1cm^2 s^{-1}$$

Vertical turbulent viscosity factor

$$\nu = \begin{cases} 50cm^2/s, & z \leq 55m \\ 10cm^2/s, & z > 55m \end{cases}$$

In case of unstable stratification, which might appear during integration of the equations ($\frac{\partial \rho}{\partial z} < 0$), the realization of this instability in the model is taken into account by increase of factor of turbulent diffusion $\nu_{T,S}$ 20 times in appropriate columns from the surface to the bottom.

Boundary Conditions

Atmospheric forcing is taken into account by boundary conditions on the sea surface z = 0 considered as a rigid surface, where the wind stress components are given as known functions, for temperature and salinity the Neumann conditions are used by given of heat fluxes, evaporation and atmospheric precipitations. On the sea bottom the velocity components, heat and salt fluxes are equal to zero.

On the lateral surfaces, two kinds of boundary conditions are considered: a) on the rigid boundaries, sharing the sea from the land, components of current velocity, gradients of temperature and salinity normal to the boundary surface are equal to zero; b) on the liquid boundary prognostic values of velocity components, temperature and salinity computed on the base of BSM of MHI are used.

There is applying one-way nesting which provides forcing of basin-scale processes on the coastal processes via the open boundary. Prognostic hydrophysical fields on the open boundary – the velocity components, temperature and salinity are results of forecast from BSM of MHI and are given on the course grid with 5 km spacing with one-hour time step frequency within the 4-days period (as other input data). During model implementation these fields are transferred to grid of RM-IG with 1 km spacing on each time level by interpolation. Thus, on each time step we have forecasted values of flow, temperature and salinity which are used as open boundary conditions for the RM-IG on the western liquid boundary. The analysis of numerous results of the forecast calculated from the RM-IG and their comparison with results received from BSM of MHI have shown that the liquid boundary does not play a role of the generator of fictitious eddies and does not deform simulated fields.

Validation of the Forecasting Subsystem

In July 2005 a pilot experiment on functioning of the Black Sea Nowcasting/Forecasting System in the near-real time mode has been carried out for the first time in the Black Sea region. Comparison of Calculated forecasts of the hydrophysical fields (flow, temperature and salinity) in the Georgian Black Sea coastal zone to the natural data has shown ability of the RM-IG to predict really dynamical processes in the Georgian coastal zone (Kubryakov *et al*., 2006; Kordzadze and Demetrashvili, 2008) At present we carry out comparison of simulated SST with satellite images SST derived from NOAA (http://dvs.net.ua/mp). The analysis of results of comparison show that the quantitative difference in many cases does not exceed 0.6-0.8°C (Kordzadze and Demetrashvili, 2011).

Results and Discussions

To demonstrate the operation of the coastal forecasting subsystem, there are considered two examples of the forecast corresponding to summer and autumn seasons, when circulating features in the easternmost part of the Black Sea extremely differed from each other. It is necessary to note that because of some differences between the BSM of MHI and the RM-IG and different grids used by these models, certain time interval here is required when there is a adaptation process. With this purpose we consider that the RM-IG gives forecast only for three days, though, the input data, which are given on a course grid, provide to run for 4-days. During the first day the RM-IG runs only to have better adjustment of the fine resolution to the course initial conditions provided by the BSM of MHI.

Forecast of Summer Circulation

The forecasting time period was from 00:00 h, 25 July to 00:00 h, 28 July 2011 (here and after local time is used). The surface current fields after 24 and 48 hours (time is counted from the initial moment of the forecast, 00:00 h, 25.07.2011), predicted by the RM-IG, are presented in Figure 2a and 2b, respectively and the same fields predicted by the BSM of MHI at the same time moments are shown in Figure 2c and d. From Figure 2 is well visible the anticyclonic eddy (so called the Batumi eddy) in the southern part of the considered area. The results of

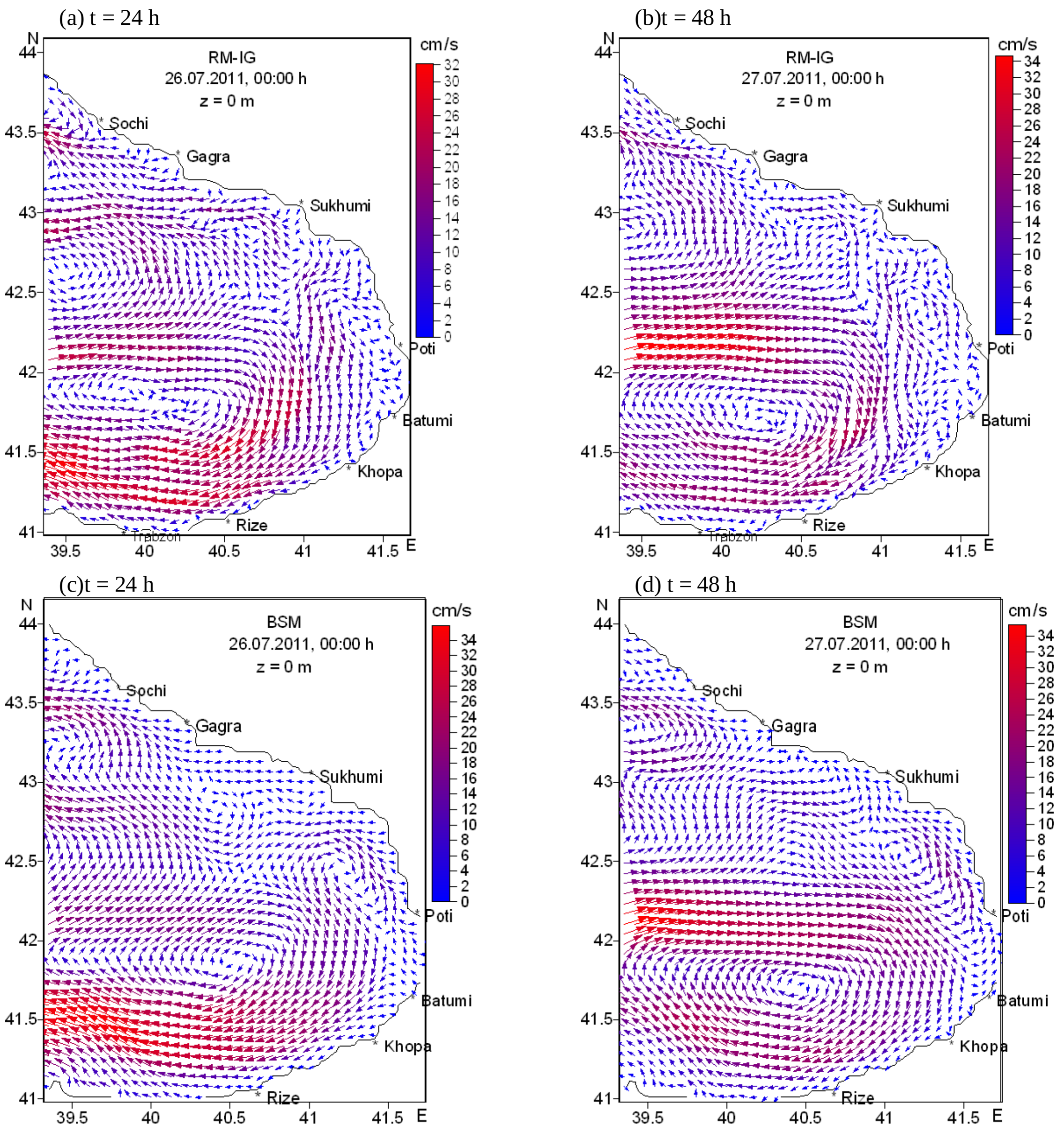

Figure 2. Surface current fields at 24 and 48 h (time is counted from the initial moment of the forecast,forecasted interval is 25-28 July 2011, 00:00 h). (a) and (b) are forecasts from RM-IG, (c) and (d) are forecasts from BSM of MHI.

other calculations show also that in most cases the Batumi eddy is the main component of the summer regional circulation in the Easternmost part of the Black Sea. This feature of the regional circulation in warm season is known from observations (Korotaev *et al.*, 2003). Comparison of circulation patterns predicted from RM-IG and BSM of MHI shows that the main differences are in the zone with width about 30-35 km along the Caucasus shoreline. By results of RM-IG coastal circulation in this zone is characterized by the clear tendency to vortex formation of small sizes and non-stationarity, whereas results of BSM specify about smoothness and practically non-stationary character in this zone. The existence of rather unstable eddies of small sizes near the Georgian shoreline is known from observations (Jaoshvili, 2006), but their identification by the mathematical models is possible by providing very high resolution, that is achieved in the RM-IG.

Some quantitative distinctions between thermohaline fields calculated from RM-IG and BSM of MHI are observed. In Figure 3 salinity fields predicted by both models after 24 and 48 hours are shown on depth of 20 m. According to both RM-IG and BSM in the central part of the Batumi eddy the zone of relatively lower salinity is observed. This low salinity zone is providing by descending currents developed in the anticyclonic eddy, which transfer relatively fresh waters from the upper layer downwards. From Figure 3 it is also well visible that waters with relatively high salinity are penetrating through the open boundary from the central part of the

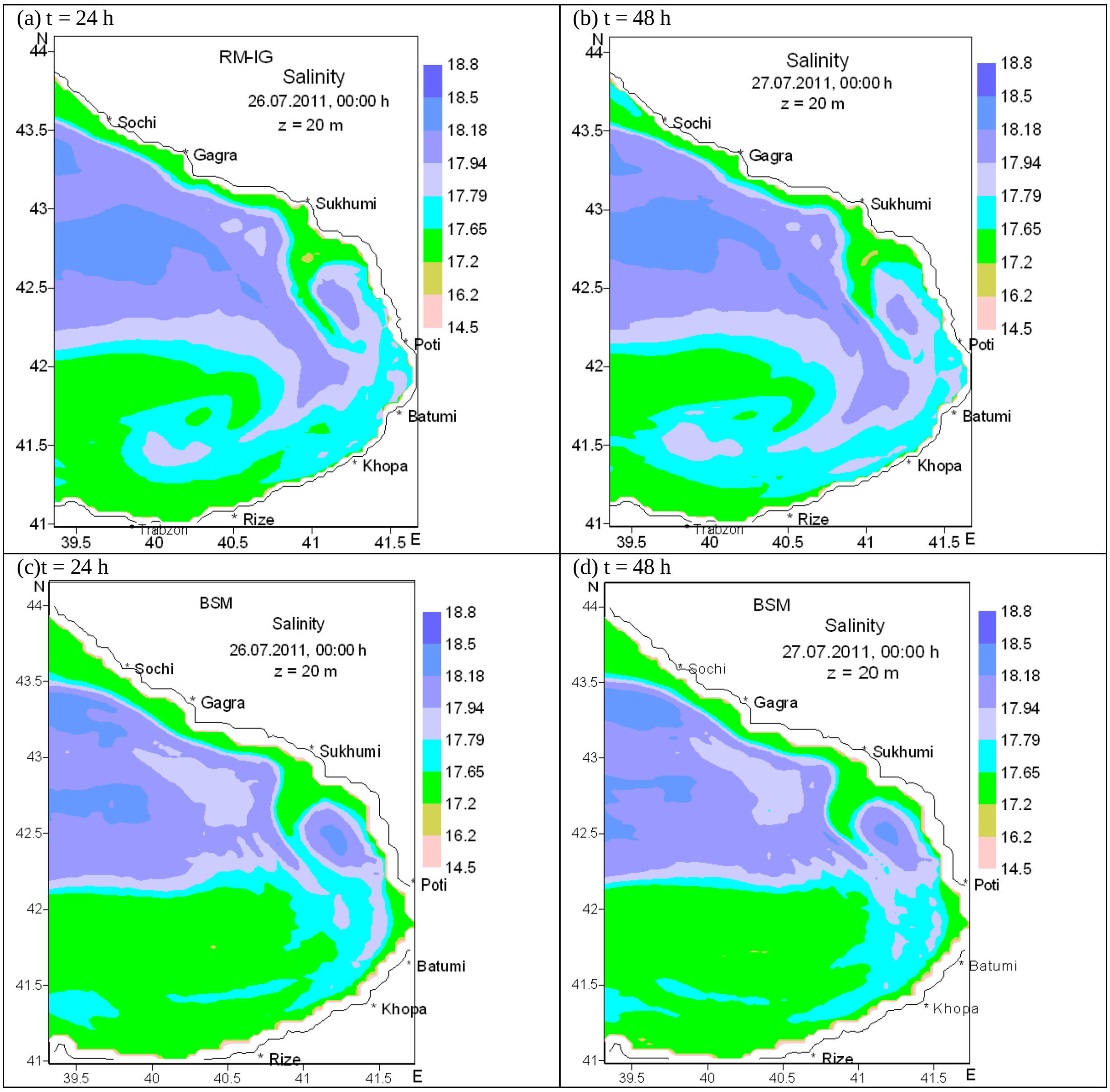

Figure 3. Salinityfields (psu) at 24 and 48 h (time is counted from the initial moment of the forecast, forecasted interval is 25-28 July 2011, 00:00 h). (a) and (b) are forecasts from RM-IG, (c) and (d) are forecasts from BSM of MHI.

Black Sea to the Georgian coastal area, but this phenomenon more evidently is expressed by results of high-resolution model.

Forecast of Autumn Circulation

At approach of a cold season the structure of the regional circulation considerably changes, the Batumi anticyclonic eddy gradually breaks up and regional circulation is characterized with formation of some vortexes of rather small sizes. Figure 4 illustrates this fact, where surface circulation patterns predicted from IG-GAS and BSM of MHI are shown in October 2010 (start of forecast was 26 October 2010, 00:00h).

Comparison of circulation patterns received from IG-GAS and BSM of MHI shows that according to results of RM-IG, during the forecasting interval the regional circulation is characterized by intensive formation, deformation and disappearance of the small eddies with diameter about 15-20 km, while these properties of the regional circulation are much less expressed by results of the BSM. This fact once again directs us to the idea, that high resolution of numerical model is a major factor for improving identification of small unstable eddies which are permanently formed in the Georgian coastal zone.

Results of the operative forecast of flow, temperature and salinity fields for the Easternmost part of the Black Sea are accessible on www.ig-geophysics.ge.

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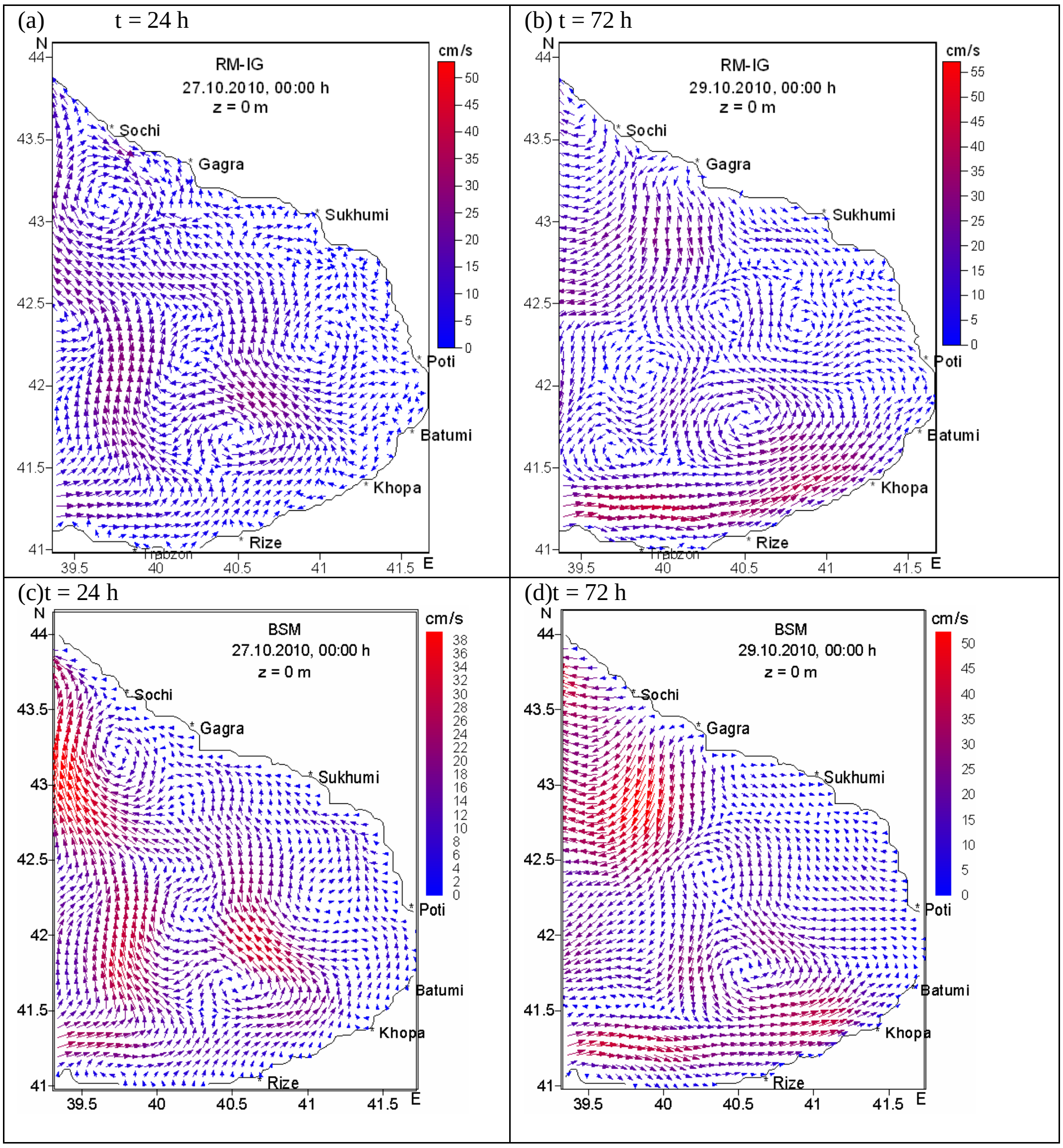

Figure 4. Surface current fields at 24 and 72 h (time is counted from the initial moment of the forecast, forecasted interval is 26-29 October 2010, 00:00 h). (a) and (b) are forecasts from RM-IG, (c) and (d) are forecasts from BSM of MHI.

References

Besiktepe, S. 2003a. Development of the regional forecasting system for the Black Sea. Proceed. of the "Second International Conference on Oceanography of Eastern Mediterranean and Black Sea: Similarities and Differences of Two Interconnected Basins, 14-18 October, Ankara, Turkey: 297-306.

Besiktepe, S. 2003b. Regional forecasting system for the physical, chemical and biological variabilities of the Black Sea. Abstracts of International Conference "Scientific and policy challenges of the Black Sea toward an effective management of the marine environment in support of regional sustainable development. Emphasis on the Black Sea and Mediterranean regions. 12-18 October, Albena Restor, Bulgaria, 333 pp.

Jaoshvili, Sh.V. 1986. The river alluvium and the beach formation of the Georgian Black Sea coast. Sabchota Sakartvelo Press, Tbilisi, 155 pp (in Russian).

Kordzadze, A.A. and Demetrashvili, D.I. 2008. Simulation and forecast of hydrophysical fields in the part of the Georgian Black Sea coastal zone. J. Georgian Geophys. Soc., 12b: 7-16.

Kordzadze, A. and Demetrashvili, D. 2010. Modeling of dynamical processes in the Black Sea. Georgian Electronic Scientific Journal (GESJ): Physics, 1(3): 25-45. http://gesj.internet-academy.org.ge/phys/

Kordzadze, A.A. and Demetrashvili, D.I. 2011. Operational forecast of hydrophysical fields in the Georgian Black Sea coastal zone within the ECOOP. Ocean Science, 7: 793-803. doi:10.5194/os-7-793-2011.

Kordzadze, A.A., Demetrashvili, D.I. and Surmava, A.A. 2008. Numerical modeling of hydro physical fields of the Black Sea under the conditions of alternation of atmospheric circulation processes. IzvestiyaRAS, Atmospheric and Oceanic Physics, 44: 213-224. doi:10.1134/S0001433808020096.

Korotaev, G.K. and Eremeev, V.N. 2006. Introduction to Operative Oceanography of the Black Sea., NPC "EKOCI-Gidrofizika", Sevastopol, Ukraine, 382 pp (in Russian).

Korotaev, G., Oguz, T., Nikiforov, A. and Koblinsky, C. 2003. Seasonal, inter annual, and Mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. J. Geophys. Res., 108: 3122-3137. doi:10.1029/2002JC001508.

Korotaev, G., Cordoneanu, E., Dorofeev, V., Fomin, V., Grigoriev, A., Kordzadze, A., Kubriakov, A., Oguz, T., Ratner, Yu., Trukhchev, D. and Slabakov, H. 2006. Near-operational Black Sea nowcasting/ forecasting system. In: European Operational Oceanography: Present and Future.4th EuroGOOS Conference, 6-9 June 2005, Brest, France: 269-275.

Korotaev, G.K., Dorofeyev, V.L., Demyshev, S.G., Kubryakov, A.I. and Ratner, Y.B. 2011. Development of Black Sea nowcasting and forecasting system. Ocean Science, 7: 629-649. doi:10.5194/os-7-629-2011.

Kubryakov, A., Grigoriev, A., Kordzadze, A., Korotaev, G., Trukhchev, D. and Fomin, V. 2006. Nowcasting/ Forecasting subsystem of the circulation in the Black Sea near shore regions. In: European Operational Oceanography: Present and Future. 4th EuroGOOS Conference, 6-9 June, Brest, France: 605-610.

Marchuk, G.I. 1974. Numerical Solution of Problems of Atmospheric and Oceanic Dynamics. Gidrometeoizdat, Leningrad, 303 pp (in Russian).

Marchuk, G.I., Kochergin, V.P., Sarkisyan, A.S., Bubnov, M.A., Zalesny, V.B., Klimok, V.I., Kordzadze, A.A., Kuznetsov, V.I., Protasov, A.B., Sukhorukov, B.A., Tsvetova, E.A. and Scherbakov, A.B. 1980. Mathematical models of ocean circulation. Nauka, Novosibirsk, 288 pp (in Russian).

Oguz, T., La Violete, P.E. and Unluata, U. 1992. The upper layer circulation of the Black Sea: Its variability as inferred from hydrographic and satellite observations. J. Geophys. Research, 97(C8): 12569-12584.

Oguz, T. and Besiktepe, S. 1999. Observations of the Rim Current structure, CIW formation and transport in the western Black Sea. Deep-See Research, 46: 1733-1753.

Oguz, T., Akoglu, E. and Salihoglu, B. 2012. Current state of overfishing and its regional differences in the Black Sea. Ocean and Coastal Management, 58: 47-56.

Salihoglu, B., Fach, B.A. and Oguz, T. 2011. Control mechanisms on the ctenophore Mnemiopsis population dynamics: A modeling study. Journal of Marine Systems, 87: 55-65.

Stanev, E. 2005. Understanding Black Sea dynamicas. An overview of recent numerical modeling. Oceanography, 18: 56-75.

Zilitinkevich, S.S. and Monin, A.S. 1971. Turbulence in Dynamic Models of the Atmosphere, Nauka, Leningrad, 41 pp (in Russian).