MARINE FORECAST FOR THE EASTERNMOST PART OF THE BLACK SEA

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ABSTRACT

Modelling and forecasting of dynamic processes and distribution of various substances of anthropogenic and natural origin in coastal and shelf zones of the seas and oceans are of great interest due to the high anthropogenic load of these zones. The aim of this paper is to present some examples of modelling and short-term forecasting of dynamic fields – the current, temperature and salinity in the easternmost Black Sea covering Georgian sector of the Black Sea and adjacent water area using a high-resolution regional model of the Black Sea dynamics. The z-level regional model is based on a full system of ocean hydro-thermodynamics equations and is nested in the basin-scale model of the Black Sea dynamics of Marine Hydrophysical Institute (Sevastopol). To solve the model equation system, a numerical algorithm based on the splitting method is used. Calculations show that circulation processes in the easternmost water area of the Black Sea are characterized by a permanent alternation of different circulation modes with the formation of mesoscale and submesoscale eddies throughout the year, which significantly affect the formation of thermohaline fields; atmospheric wind forcing substantially determines not only the peculiarities of the sea surface horizontal circulation, also the vertical structure of the current field.

Keywords: *numerical modelling, hydro-thermodynamic processes, thermohaline fields, system of equations, boundary conditions*

INTRODUCTION

Modelling and forecasting hydro and thermodynamic processes in the upper layer of the Black Sea is one of the main issues of the Black Sea oceanography and is of great theoretical and practical importance. One of the main factors determining the importance of studying dynamic processes, occurring in the upper layer of the sea, is a significant contribution of the Black Sea to the formation of the regional weather and climate. The Black Sea and the atmosphere are the main objects of the unified hydrodynamic system, between which the processes of energy and substance exchange take place continuously. The features of these exchange processes are significantly influenced by the dynamic processes occurring in the upper layer of the sea, and vice versa, the formation of the spatial-temporal distribution of hydrophysical fields in the upper layer is significantly determined by the interaction between the sea and the atmosphere.

There are especially important studying and forecasting circulation processes in the coastal areas that are subject to the greatest anthropogenic impact. The importance of studying coastal circulation processes is due to their significant role in the spatial and temporal distribution of thermohaline fields and various substances of natural and anthropogenic origin strongly affecting the marine ecosystem. Sea currents are the main mean of transporting pollutants in the coastal zone and make a significant contribution to the formation of features of temperature and salinity fields having feedback on the circulation through the density field. From this point of view, the easternmost water area covering Georgian sector of the Black Sea and surrounding water area is of considerable interest, which is a dynamically very active region with formation and evolution of various mesoscale and submesoscale eddies.

Over the last two decades researches on the Black Sea dynamics have been widely developed. The attraction of new observation technologies, including satellite measurement methods, creation of highly resolving mathematical models allowing to reproduce basin-scale and coastal dynamic processes by sufficiently high adequacy, raised the Black Sea oceanography to a higher level (e. g., [1-5]). The development of effective data-computing systems has led to the creation of the Black Sea nowcasting/forecasting system [4], [6]. [7], [8]. Such an achievement of the Black Sea operative oceanography became possible as a result of close cooperation of oceanologists from the Black Sea countries in the framework of the EU projects ARENA, ASCABOS, ECOOP. One of the components of this system is a high-resolution regional forecasting system for the easternmost part of the Black Sea based on the regional model of the Black Sea dynamics of M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University (RM-IG) [9], [10], [11].

In the present paper, some results of 3-days forecast of main hydrophysical fields – the current, temperature and salinity using the RM-IG are analyzed illustrating variability of regional hydrophysical processes in the easternmost part of the Black Sea limited from the open part of the basin by the liquid boundary passing along the meridian 39.08^0E.

MATERIALS AND METHODS

The high-resolution RM-IG is obtained by adaptation of the basin-scale model [12] to the easternmost regional area with increasing of spatial resolution to 1 km. The RM-IG is a z-level hydrostatic model based on a solution of a full system of ocean hydro and thermodynamics equations, which is nested in the basin-scale model of Black Sea dynamics with 5 km spatial resolution of Marine Hydrophysical Institute (MHI, Sevastopol) using one-way nesting technology. All input data used for the initial and boundary conditions of the model equation system are available from MHI via ftp site. The RM-IG provides a 3-days forecast of 3D flow, temperature, salinity and density fields in the easternmost water area of the Black Sea. To solve the equation system with corresponding initial and boundary conditions splitting method is used [13]. The 3D solution domain is covered with a grid consisting of 30 horizons with non-uniform vertical steps – minimal equal to 2 m near the sea surface and maximal equal to 100 m from depth 206 m to the bottom. The number of grid points on each horizon is 215x347 with a spatial horizontal resolution 1 km. The time step is 0.5 h. The simulated and predicted sea surface temperature (SST) and currents were compared with available observational data – satellite SST derived from NOAA satellites and Geostrophyc currents reconstructed on the basis of satellite altimeter data. The comparison showed sufficient reliability of the model results [9], [10], [11].

RESULTS AND DISCUSSION

The computations of the marine forecast, carried out by us regularly last decade, have shown that the hydrophysical processes in the easternmost water area of the Black Sea are characterized by a significant variety and specific features of the spatial-temporal distribution of dynamic fields, accompanied by the permanent generation and evolution of mesoscale and submesoscale eddies with cyclonic and anticyclonic rotation. The nonstationary atmospheric processes over the sea basin, having a 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 the specificity of this variability is largely determined by the sea bottom relief and the configuration of the coastline, baroclinicity, turbulent diffusion.

One of the general patterns characteristic for the processes taking place in the easternmost water area is that the hydrological modes are significantly different for the warm (April-October) and cold periods (November-March). In winter, the regional circulation as a hole is often cyclonic, against the background of which cyclonic and anticyclonic eddies with a diameter of about 20-40 km are often formed.

(a) (b) (c)

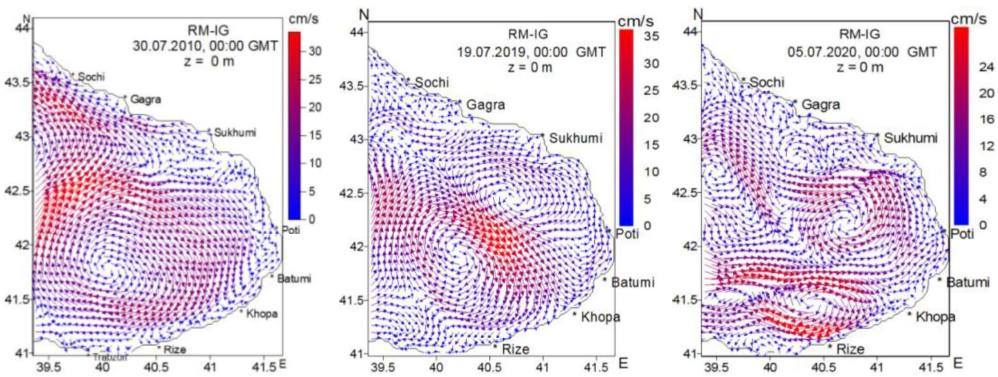

Fig.1. *Predicted surface current fields at 00:00 GMT for the following days and years: (a) - 30 July 2010 (start of forecast 27.07.2010, 00:00 GMT); (b) – 19 July 2019 (start of forecast 17.07.2019, 00:00 GMT); (c) - 5 July 2020,(start of forecast 3.07.2020, 00:00 GMT).*

In summer and early autumn, anticyclonic movement predominates in the easternmost waters, although the formation of cyclonic structures can also be observed against this background. In many cases, the formation of an intense anticyclonic vortex, known as the Batumi eddy, is observed in the warm periods. The Batumi eddy, which vertically covers a layer of about 300-400 m, is found with different intensities in different years.

Fig.1 illustrates prognostic sea surface circulation patterns corresponding to July 2010, 2019, and 2020, which clearly show that in the same seasons of different years the sea surface circulation modes can differ significantly from each other.

Fig.1a and the analysis of other calculations carried out by us shows that the regional circulation in the summer and September 2010 in the easternmost water area was characterized by the formation of an intense Batumi eddy, which was characterized by great stability.

The circulation in July 2019 was characterized by the formation of dipole structure “cyclone-anticyclone” (Fig.1b). The Batumi eddy together with cyclonic eddy created the dipole structure, which underwent minor changes during summer of 2019. Fig.1c shows the typical circulation for July 2020, where the Batumi eddy is not clearly dominated and the surface circulation is characterized by the formation of mesoscale and submesoscale eddies with cyclonic and anticyclonic rotations.

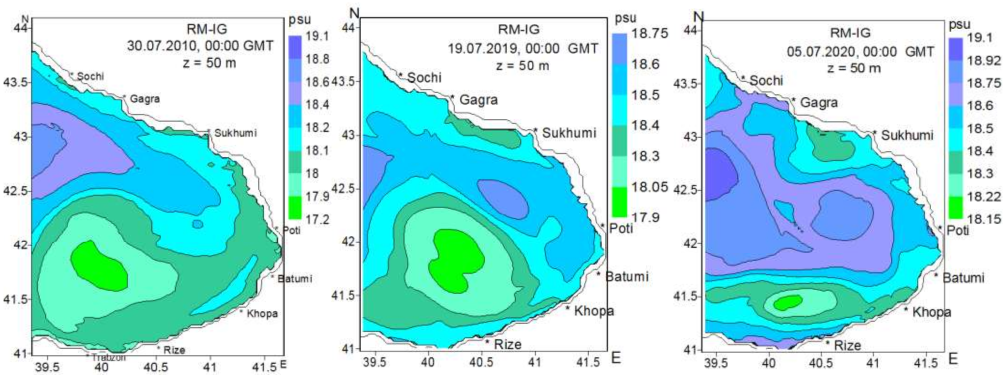

Fig. 2. *Predicted salinity fields on depths of 50 m at the same time moments as in Fig.1.*

The structure of the circulation is largely reflected in the distribution of salinity field, which is clearly illustrated in Fig. 2. The salinity fields are shown at the horizon z= 50 m on the same days and years as in Fig.1. From a comparison of Figs.1 and 2 it is clearly seen that the areas of relatively low salinity waters coincide with an allocation of the centres of anticyclonic eddies, and the areas of relatively high salinity coincide with the cyclonic movement. The anticyclonic vortex structure forms a downward flow that transfers waters with relatively low salinity from the upper layers downwards, while the upward flows formed at the centres of the cyclonic vortices raise salt water from the lower to the upper layers. Marine living organisms are highly sensitive to water salinity and thus the sea circulation regime can have a significant impact on the marine ecosystem.

Fig. 3 shows the sea surface temperature (SST) on the same moments of time as in the previous Figures. Peculiarities of SST fields are significantly influenced by heat fluxes on the sea surface. Summer of 2010 was characterized by abnormally high air temperatures, which were also reflected in the distribution of SST fields. That is why the maximum SST 29^{0}C on July 30, 2010 (Fig.3a) was higher than it was on July 19, 2019 (Fig.3b) and July 5 2020 (Fig.3c).

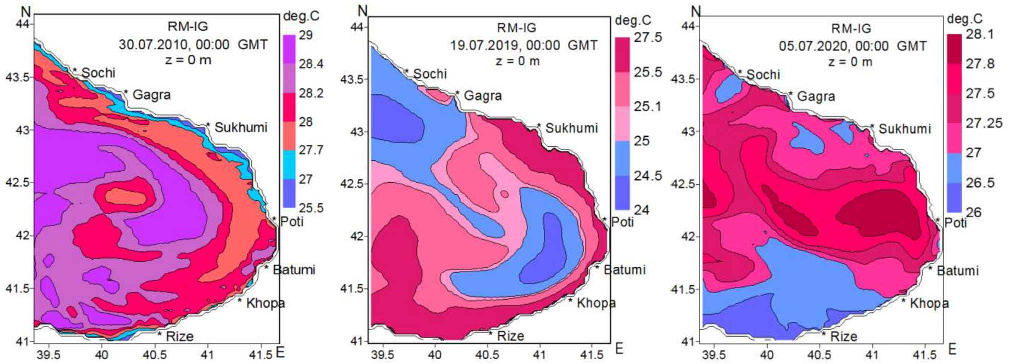

Fig. 3. *Predicted SST at the same time moments as in previous Figures.*

Considerable interest is the question of the vertical structure of the flow field under different atmospheric wind forcing. Our calculations show that the atmospheric wind field above the sea surface substantially determines not only the peculiarities of the sea surface circulation horizontally, but also the vertical structure of the current field.

For the purpose of illustration, Fig. 4 shows the circulation field on the sea surface and at a depth of 20 meters under two atmospheric forcing: in cases of strong (Fig. 4a and b) and relatively weak wind stresses (Fig. 4c and d). From Fig.4a is visible, that the intense atmospheric circulation operated above the easternmost Black Sea on December 25, 2018, caused high speed of drift currents on the sea surface with a maximum speed of 70 cm/s and provided practically vortex-free flow. Strong wind stress on the sea surface acts as an external smoothing factor and prevents the formation of vortex structures.

On June 9, 2020, relatively weak winds developed over the sea, which contributed to the formation of vortex structures on the sea surface (Fig.4c). A large difference in the vertical variability of the flow field in cases of strong and weak atmospheric wind forcing is clearly visible from a comparison of Figs.4b and 4d.

Under strong atmospheric conditions, the circulation pattern undergoes sharp qualitative and quantitative changes with depth, while in the absence of strong winds, the circulation pattern changes slightly. In the first case, the maximum speed decreased from 70 cm/s on the sea surface to 30 cm/s at a depth of 20 m, but in the second one - from 28 cm/s to 24 cm/s. By the depth, the effect of the wind stress weakens and the role of such internal factors as the configuration of the seashores, baroclinicity, etc. becomes the main one.

(a) (b)

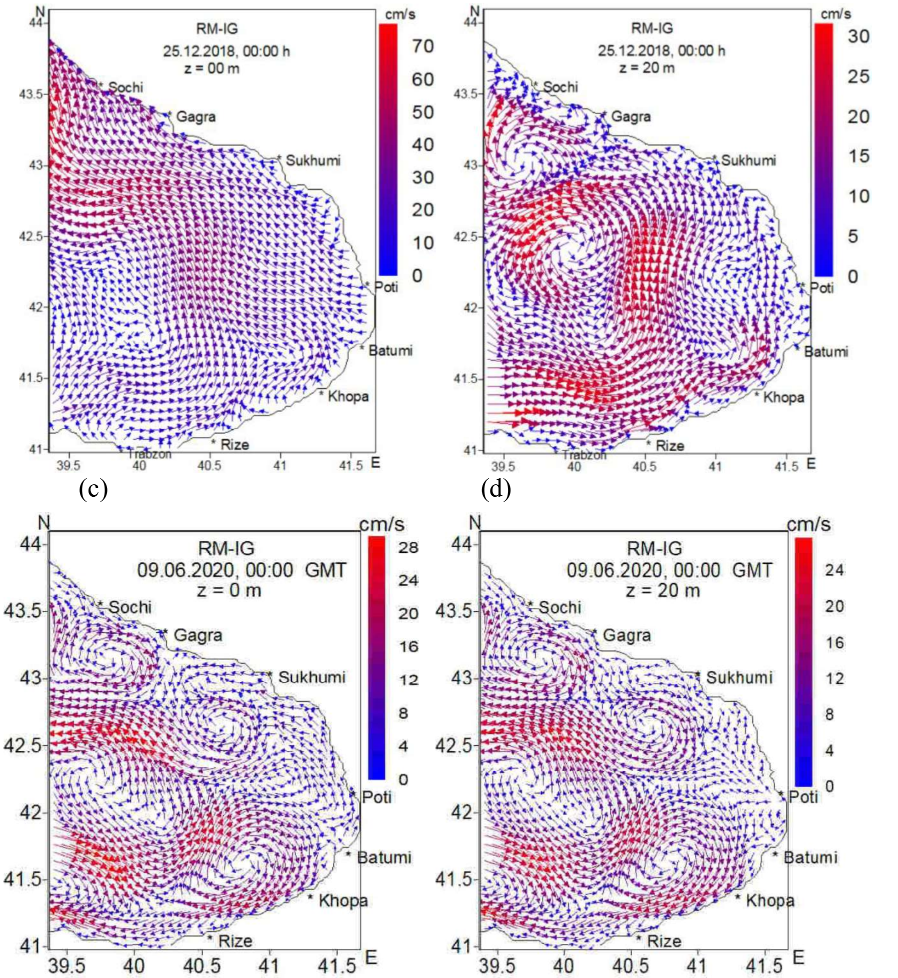

Fig. 4. *Forecasted sea current fields on horizons of 0 m and 20 m: (a), (b) - in conditions of strong atmospheric forcing, corresponding to December, 25 2018; (c), (d) – in conditions of weak atmospheric forcing, corresponding to June 9, 2020.*

CONCLUSION

Marine forecasting for the easternmost part of the Black Sea is based on a z-level, hydrostatic RM-IG with 1 km resolution, which is nested in the basin-scale model of MHI with 5 km resolution using one-way nesting technology. The RM-IG is based on a full system of ocean hydrothermodynamics equations and provides a 3-days forecast of main 3D dynamic fields – flow, temperature, salinity and density with 1 km spacing.

Numerous calculations show that the Georgian sector of the Black Sea and adjacent area are characterized by the diversity of the hydrological regime, where the continuous development and evolution of various vortex structures takes place throughout the year.

Analysis of the prognostic fields shows a significant difference in the vertical hydrological structure of the upper layer of the Black Sea under different atmospheric forcing. Strong winds cause “abrasion” of vortex formations on the sea surface. With depth, due to the weakening role of the wind stress and the increasing role of internal factors, the system of sea currents in the upper layer undergoes sharp changes with eddy formations.

The Batumi eddy, which very often is the main element of the regional circulation in the easternmost water area of the Black Sea during the warm season, is characterized by different intensities and stability in different years. The circulation regime has a strong influence on the distribution of the salinity field, which is a very important factor for marine living organisms.

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