MODELING OF MESOSCALE CIRCULATION AND OIL POLLUTION SPREADING IN THE GEORGIAN COASTAL AREA OF THE BLACK SEA UNDER REAL ATMOSPHERIC FORCING

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Abstract. *The paper presents some results of numerical experiments on modeling mesoscale circulation and oil spill propagation in the coastal zone of Georgia and adjacent waters. Calculations of circulation and thermohaline fields are performed using a regional numerical model of the Black Sea dynamics based on solving the full system of ocean hydrothermodynamics equations using the method of splitting into physical processes, coordinate planes and lines. A 2-D advection–diffusion equation of impurity is applied to simulate and forecast oil slick transport. Numerical experiments conducted under conditions of real non-stationary atmospheric forcing with a horizontal resolution of 1km have shown that circulation in the southeastern region is characterized by the generation of cyclonic and anticyclonic eddies with diameters from about 5-8 km to 200 km. Mesoscale eddies make a significant contribution to the spread of oil pollution.*

Key words: *modeling system, Atmospheric forcing, splitting method, circulation.*

Introduction

The Black Sea, which is a nearly enclosed body of water and is connected to the World Ocean only through the narrow Bosphorus Strait, is a very vulnerable marine environment and faces increasing pressure from human activity. The coastal/shelf zone, including the coastal zone of Georgia, is under particular pressure. The Black Sea coastal zone of Georgia has been characterized in recent years by the intensification of human economic activity: the flow of tourists is increasing, coastal infrastructure is developing, the creation of a system of artificial islands and peninsulas in the waters of Batumi is planned, etc. In this regard, the threat of pollution of coastal waters with oil products and other impurities is significantly increasing. The study and forecast of hydrothermodynamic processes occurring in the coastal zone is very important, since they have a significant impact on the marine ecosystem [1] and the features of the distribution of various pollutants in the marine environment.

Currently, mathematical modeling is widely used to study and predict hydrophysical processes in various regions of the oceans and seas, including the Black Sea. Numerical models of the Black Sea dynamics are successfully used both at the basin scale and at the regional scale [2-4].

This paper presents some results of numerical experiments on modeling hydrophysical processes and transport of oil slick under real atmospheric forcing in the southeastern Black Sea, including the Georgian Black Sea coastal zone and the surrounding water area. This region is separated from the open part of the Black Sea by a liquid boundary coinciding with meridian 39.08^0E.

Materials and methods

Numerical experiments on modeling hydrophysical fields were carried out based on the regional model of hydrothermodynamics of the Black Sea developed at M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University. The model is based on a full system of equations of ocean hydrothermodynamics, written in z-coordinates, based on solving the full system of ocean hydrothermodynamics equations using the method of splitting into physical processes, coordinate planes and lines. The regional model with a spatial resolution of 1km was nested in the basin-scale model of the Marine Hydrophysical Institute (Sevastopol, Ukraine) with a spatial resolution of 5 km. The regional model and the solution algorithm based on the splitting method are described in [5-7].

The surface circulation field calculated using the regional model is used to simulate the spread of oil pollution on the sea surface using a 2-D advection-diffusion equation

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\sigma C=\frac{\partial}{\partial x}\mu_c\frac{\partial C}{\partial x}+\frac{\partial}{\partial y}\mu_c\frac{\partial C}{\partial y}+f(x,y,t) \qquad (1)$$

with the following boundary and initial conditions

$$\frac{\partial C}{\partial n}=\beta C \qquad \text{on S} \qquad (2)$$

$$\mathbf{C}=\mathbf{C^0} \qquad \text{at } t=0. \qquad (3)$$

Here C is the volume concentration of the pollutant; u and v are the components of the current velocity vector along the horizontal axes x and y, respectively. μ_c is the turbulent diffusion coefficient, n is the outer normal vector to the lateral boundary S. β is a parameter characterizing the interaction of the pollutant with the coastline. σ is a parameter taking into account the change in the pollutant concentration due to some non-hydrodynamic factors (evaporation, sedimentation, etc.). *f* describes the pollutant source, which is a function of time and coordinates.

To solve the problem (1) – (3) the two-cycle splitting method with respect to spatial coordinates is used [8].

Research results

The regional model was applied to simulate and forecast 3-D hydrophysical fields – the current, temperate and salinity with a resolution of 1 km in the southeastern part of the Black Sea, which is separated from the open part of the Black Sea by a liquid boundary coinciding with meridian 39.08^{0}E. The 3-D solution domain was covered by a grid having non-uniform vertical step from 2 m to 100 m with 30 calculated levels. The number of grid points on each horizon was 215 x 347. The time step was equal to 0.5h.

Validation of the regional model by comparing its outputs with satellite data showed that it describes hydrophysical fields with good accuracy [6, 7, 9].

Numerical experiments conducted under conditions of real non-stationary atmospheric forcing with a horizontal resolution of 1km, have shown that circulation in the southeastern region is characterized by the generation of cyclonic and anticyclonic eddies with diameters from about 5-8 km to 200 km.

(a) (b) (c) (d)

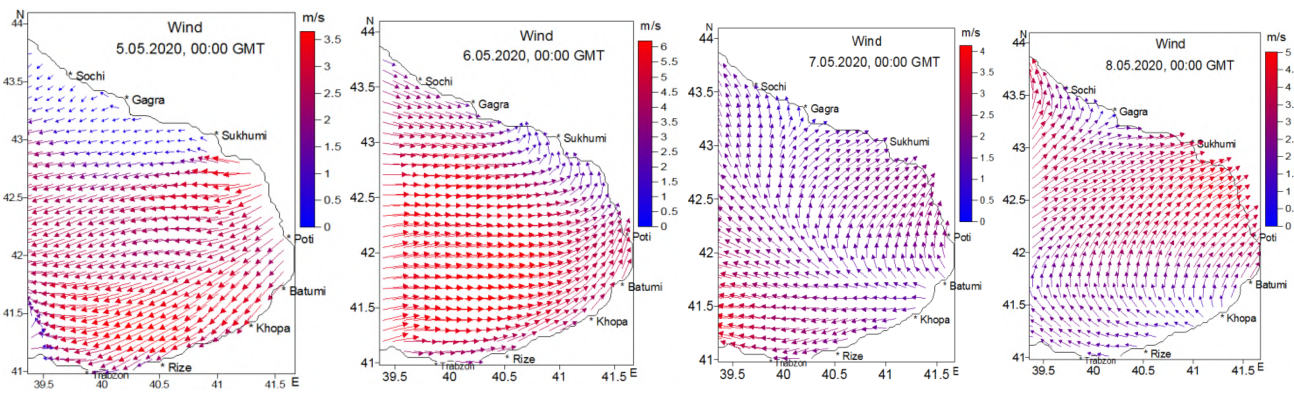

Fig. 1. Wind field over the modeling domain corresponding to 00:00 GMT, 2020:
(a) – 5 May, (b) – 6 May, (c) – 7 May, (d) – 8 May.

The present paper presents an example of forecasting hydrophysical fields corresponding to the forecast interval 00:00 GMT, 4-8 May 2020. Fig. 1 shows the wind vector field at different times over the modeling domain. The figure clearly shows that during this period of time the wind direction changed significantly, and the wind speed practically did not exceed 6 m/s. During most of the time, the average wind speed on the horizon was 2-3 m/s.

Fig. 2 shows the calculated predicted surface circulation fields after 24, 48 and 96 hours (time is counted from the initial moment of the forecast: 00:00 GMT, 4 May, 2020). The Fig.2 shows that the circulation structure as a whole changes little, even though the wind direction is highly variable during the forecast interval. The main circulation element is an elliptical anticyclonic vortex, which covers a certain area in the southern part of the considered area.

(a) **(b)** **(c)**

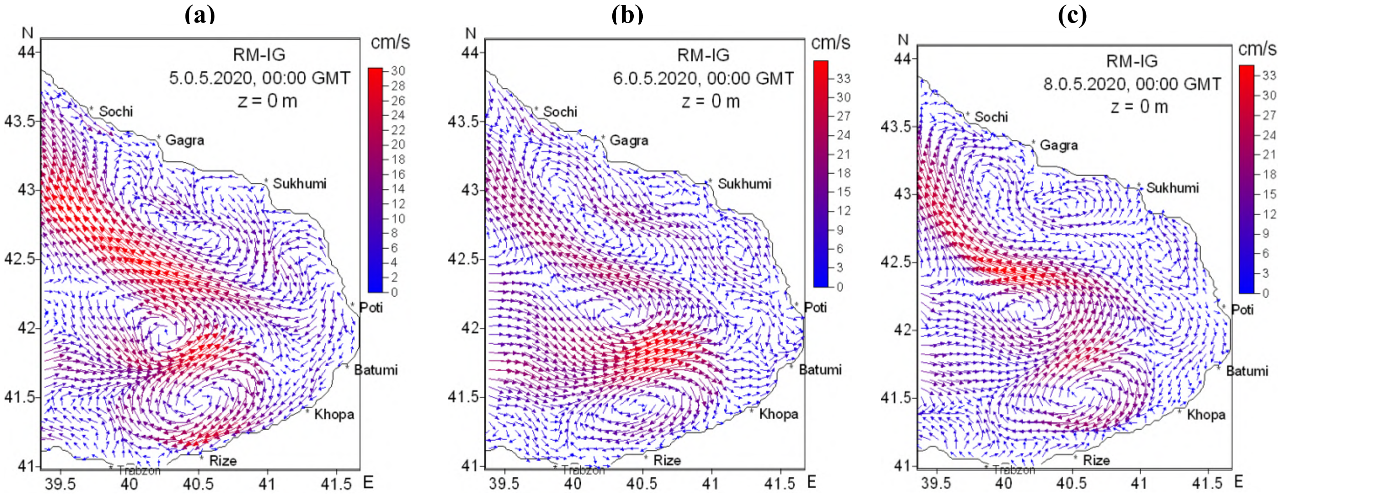

Fig. 2. The predicted surface current fields at 24 h (a), 48 h (b) and 96 h (c) (the forecasting period is 00:00 GMT, 4-8 May, 2020).

(a) **(b)**

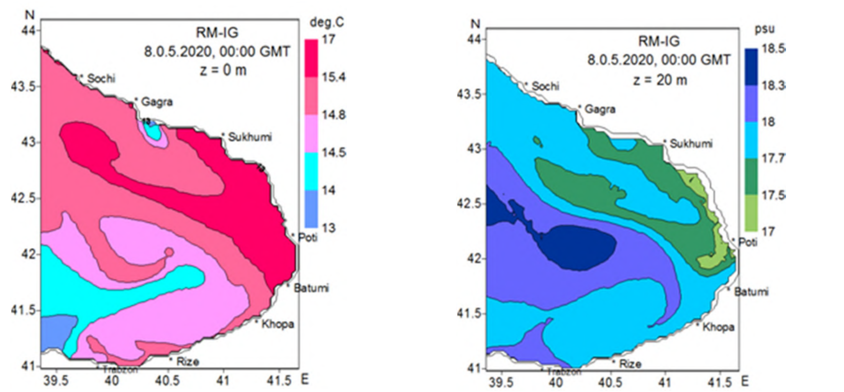

Fig. 3. Predicted sea surface temperature field (a) and salinity field at depth of 20 m corresponding to 00:00 GMT, 8 May 2020.

Fig.3 illustrates predicted sea surface temperature and salinity field at depth of 20 m corresponding to 00:00 GMT, May 8, 2020. The distribution of temperature field is typical for the coastal zone of Georgia, waters with a relatively high temperature of about 17^0C are observed near the Georgian coastline. The salinity field (Fig.3b) correlates well with the circulation. In the zones of anticyclonic movement, waters with relatively low salinity are observed and, inversely, in the zones of cyclonic movement waters with relatively high salinity are observed. This fact is in good agreement with the previous results [5-7, 9].

The circulation regime has a significant impact on the pollutants dispersion process. Numerical experiments were conducted under different real circulation modes and at different locations of the hypothetical oil spill point. The results of the calculations show that the circulation mode, characterized by various eddy structures, is one of the most important factors that essentially determines the transport of the oil slick. The turbulent diffusion factor is also important. During the spreading process of the oil slick, it changes shape, expands diffusely, and occupies more area.

Fig. 4 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 65 km from Poti shoreline. The forecasting interval was: 00:00 GMT, 1-4 March, 2014. The surface circulation is essentially changeable for this forecasting period. Such circulating reorganization is essentially reflected on moving of the oil spill. In the course of migration the oil slick extends gradually and deformed. Simultaneously there is a reduction of oil pollution concentrations that is caused by diffusion expansion, evaporation and other factors.

(a) t = 4h (b) t = 24h (c) t = 72 h

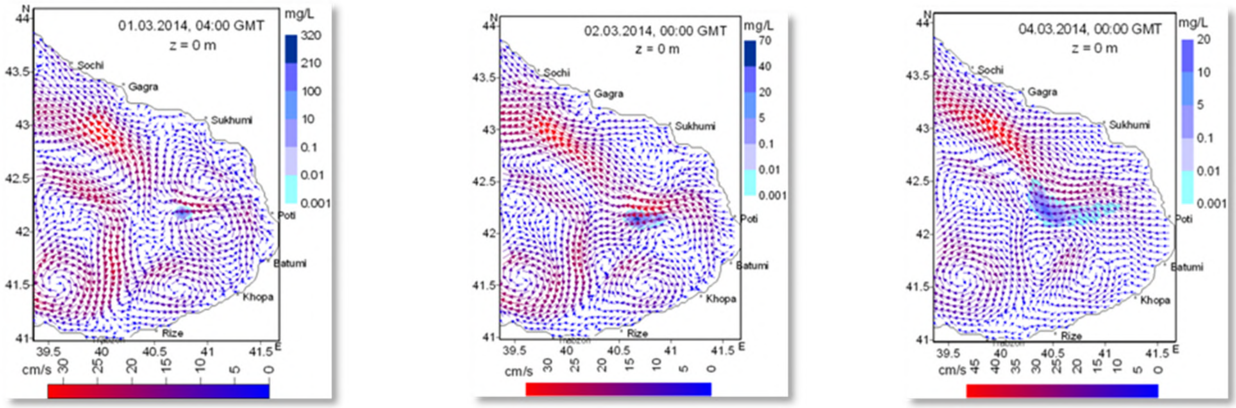

Fig. 4. Predicted surface circulation and oil slick transport at moments 4 h (a), 24 h (b), 72 h (c). (the forecasting period is 00:00 GMT, 1-4 March, 2014).

Conclusion

The regional model of the Black Sea dynamics of the M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University was used to model circulation and thermohaline fields with 1 km spatial resolution in the southeastern part of the Black Sea which covers the Georgian sector of the Black Sea and adjacent water area. The surface flow field is used to calculate oil pollution spreading. Numerical experiments are performed in conditions of real atmospheric forcing.

Further improvement of the modeling system is connected with the elaboration of very high resolution modeling subsystem (with horizontal grid step of 200 m) for Batumi-Poti-Anaklia water area, that undergo great anthropogenic impact.

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