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Simulations of Currents and Pollution Transport in the Coastal Waters of Big Sochi

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Abstract—We suggested a method for modelling the transport of pollutants over the Black Sea water basin adjacent to Big Sochi. The model is based on the application of the Institute of Numerical Mathematics Ocean Model (INMOM) over the entire basin of Big Sochi in two versions: M1 and M2. In the first version, we use uniform spatial resolution of the model with a step of ~4 km; in the M2 version, the resolution is not uniform. The step decreases to 50 m in the basin of Big Sochi. The M2 version is used only in the periods when pollution transport is simulated, for which the initial hydrothermodynamic state is specified from the M1 version. Both versions reflect a complex character of Black Sea circulation; however, the M2 version more adequately reproduces the eddy circulation in its eastern part, where the horizontal resolution of the M2 version is higher. A conclusion is made on this basis that, in order to reproduce the eddy structure of the Black Sea circulation, the resolution of the model should be on the order of 1.5 km and the main factor of the formation of the quasi-stationary Batumi anticyclonic eddy is the topographic peculiarities in this part of the sea. The pollution spreading from the Sochi, Khosta, and Mzymta rivers and from 18 pipes of deep-water sewage was simulated for the flood periods from April 1, 2007, to April 30, 2007. It was shown that mesoscale eddy formations that form a complex three-dimensional structure of pollution spreading make the greatest contribution to the spread of pollution.

Keywords: numerical model, modeling of currents, circulation, Black Sea, transport of pollutants in the marine environment

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INTRODUCTION

The assessment and forecast of the environment are especially important now in different spheres of human activity. In this work we suggest a method of modeling the Black Sea dynamics to calculate the spreading of pollutants in the coastal zone of the Adler–Sochi (Big Sochi) region. The need for this study is determined by the increasing role of the Black and Azov seas (BAS) as a multifunctional transport basin, a region of industrial shelf development, and a recreational resource. In relation with this, we especially emphasize the construction of the “Southern Flow” pipeline, the Olympic Games in Sochi, the strategic importance of the Novorossiysk port, and the Kerch Strait. It is clear that the functionality of these and other marine objects should be accompanied by hydrometeorological information with the gradual improvement of the controlling systems for the marine environment.

The industrial activity against the background of the short- and long-term natural fluctuations of the marine environment has a strong impact on the ecosystem of the Black Sea. There are data on the crucial changes in the functional characteristics of marine ecosystems and the trophical structure of biological communities caused by anthropogenic pollution [1–3]. Numerous scientific researches and monitoring data demonstrated the significant pollution of the BAS by oil products [4], which is also confirmed by satellite observations [3]. The available data provide evidence that the pollution is permanent and it has a more significant influence on the marine ecosystems than even catastrophic oil spills such as the one in the Strait of Kerch in November 2007 [2].

In this paper we suggest a method of numerically simulating pollution transport in the coastal waters of Big Sochi. It is based on the application of a σ model for sea and ocean circulation developed at the Institute of Numerical Mathematics, Russian Academy of Sciences (INM RAS), which is known in international practice as the Institute of Numerical Mathematics Ocean Model (INMOM).

1. APPLICATION OF THE INMOM FOR MODELLING OF CIRCULATION IN THE BLACK SEA

We used the INMOM σ-model for sea and ocean circulation as a hydrodynamic model for the simulation of current fields in the basin of Big Sochi [5–8]. It is based on a full system of equations, the so-called primitive equation of ocean hydrothermodynamics in spherical coordinates and hydrostatic and Boussinesq approximations. A dimensionless value σ is used as the vertical coordinate, which is specified as

$$\sigma = (z - \zeta)/(H - \zeta), \tag{1}$$

where z is a usual vertical coordinate; $\zeta = \zeta(\lambda, \varphi, t)$ is the deviation of the sea surface high (SSH) from an undisturbed surface as a function of longitude λ, latitude φ, and time t; and $H = H(\lambda, \varphi)$ is undisturbed sea depth. The prognostic variables of the model are as follows: horizontal components of the velocity vector, potential temperature T, salinity S, deviation of the SSH from the undisturbed surface, thickness and concentration of the sea ice. The equation of state specially designed for the numerical models [9] is used to calculate the water density.

The main peculiarity of the INMOM which differentiates it from other known models of the ocean, such as MOM [10], INM, and IORAS [11], which use the z-coordinate system, as well as POM [12] and ROMS [13] in the σ coordinate system and other systems, is the fact that, in the numerical realization of the INMOM, we use the splitting method with respect to the physical processes and spatial coordinates.

The splitting method allows us to effectively achieve quasi-semi-implicit integration schemes with low dissipation, which make it possible to apply time steps several times greater than in the models of the general circulation of the ocean based on explicit schemes with similar spatial resolution and coefficients of viscosity and diffusion.

In order to describe the dynamical processes more exactly, the lateral diffusion operator of the second order for heat and salt is present in a form equivalent to the horizontal diffusion in the usual z coordinate system [6]. An operator of the fourth order is used in the equations of motion to describe lateral viscosity, which effectively suppresses the two-step mode of the numerical noise.

The INMOM model considered here was used in two versions: model 1 (M1) and model 2 (M2). Uniform spatial resolution for the BAS basin with a step of ~4 km was used in M1. The M2 version was realized for the Black Sea basin but with nonuniform spatial steps, which decreased to 50 m near the coast.

The necessity of using two models is caused by the fact that version M1 allows us to rapidly calculate the circulation in the entire Black Sea by any given physical time moment because the time step of this model is long (on the order of 5 min). The second model (M2) requires significant computational resources because it has a larger dimension of the grid domain and its time step is 30 s. We suppose that M2 would be used only at the moment of simulating pollution spreading, but the initial hydrological state for the M2 version is specified from the simulations using M1 by interpolation. Since the M2 version is realized on the basin of the entire Black Sea, the problem of conditions at the liquid boundaries disappears, but it would inevitably appear if a regional model with high resolution was applied. Below we give a brief description of the peculiarities of the M1 and M2 models.

1.1. The M1 Model for Simulating the Dynamics of the Black and Azov Seas

One can find the details of the M1 model as a version of the INMOM for the BAS in [5]. The spatial resolution of the model is 3′ and 2′24″ with respect to the longitude and latitude, respectively, which is approximately ~4 km. The grid domain has 287 × 160 nodes in the horizontal plane. Forty nonuniformly distributed σ levels with respect to depth are specified by the vertical.

The GEBCO (http://www.gebco.net) data on the Earth's topography with a spatial resolution of 30″ were used to specify the depths. The initial data of high resolution were smoothed several times by the Tukey filtration and limited by a minimum depth of 1 m. This is necessary for the σ model, because we use a transformation of the vertical coordinate (1); hence function $H = H(\lambda, \varphi)$ should be nonzero and sufficiently smooth over the spatial grid because it is included in all operators of the differential differentiation [5].

We used the data of the Marine Hydrophysical Institute of the National Academy of Sciences of Ukraine (MHI NASU) [14] to construct the initial T and S conditions, which are three-dimensional monthly mean climatic fields for the Black Sea basin with a spatial resolution on the order of 25–50 km interpolated on the grid domain of the model.

Parameterizations of the large-scale horizontal turbulent diffusion of temperature and salinity were performed using a second-order operator with coefficient 50 $\mathrm{m}^2\,\mathrm{s}^{-1}$. An operator of the fourth order with coefficient 10^9 m^4/s was used as the horizontal viscosity.

The coefficients of the vertical viscosity and diffusion were selected according to the parameterization suggested by Philander–Pacanovsky [15]. The coefficient of vertical viscosity varied from 10^{-4} to 10^{-3} m^2/s and diffusion varied from 0.5×10^{-5} to 0.5×10^{-4} m^2/s for T and from 0.1×10^{-5} to 0.1×10^{-4} m^2/s for S. In the case of unstable stratification, the coefficient of vertical diffusion for the parameterization of convective mixing was specified as 2×10^{-3} m^2/s. In order to avoid possible situations for theσ models of the outcropping of vertical profiles of T, S, and velocity in the surface 2.5-m layer of the ocean, the coefficients of diffusion and viscosity were specified equal to the same value 2×10^{-3} m^2/s to provide more intense mixing. The condition of zero fluxes of T and S was specified at the lateral boundaries and bottom. The zero velocity condition is specified at the boundaries for velocity supplemented by the free-slip conditions at the lateral boundaries and squared friction at the bottom [5].

A simulation using the M1 version of the INMOM was carried out for the verification of the M1 version and a calculation of the initial state of hydrophysical fields in the BAS during the period from January 1, 2007, to December 31, 2008. The calculation of atmospheric forcing was performed using the bulk formulas (see, for example, [16]) using the surface synoptic characteristics of the atmosphere from the Era-Interim base of the European Center for Medium-Range Weather Forecast (ECMWF) (http://data-portal.ecmwf.int/data/d/interim_full_daily/) with a spatial resolution of 0.75°. The discharge of rivers was specified from the data of climatic year CORE [17] in the form of pseudoprecipitation concentrated in the basins adjacent to the river mouths.

The difference from the series of experiments in [5] carried out for 2006–2008 was in the use of so-called nagging [18] with a relaxation coefficient equal to 1/120 day^{-1} for fitting the model salinity at depths below 300 m to the climatic values. The surface salinity was fit to the climatic data by introducing a salt flux at the sea surface calculated through the flux of the fresh water and a relaxation addition, which is the difference between the model and climatic surface salinity multiplied by coefficient $\alpha_S = 10$ m/120 days. The selected value of coefficient α_S can be interpreted as the relaxation of the model salinity average over the 10-m upper layer to the climatic values with a 120-day time scale.

The need to use nagging and correction of the freshwater flux at the sea surface is stipulated by the fact that the accuracy of precipitation specification and river discharge is not sufficiently high. If we apply this method for our experiments, the model salinity does not deviate strongly from the climatic state, which is needed in experiments that last for a long time. This method also allows us to correct the salinity regime in the Bosporus region despite the fact that the mass flux through this strait was not specified.

The Black Sea Rim Current (BSRC) is distinguished well from the SSH fields and surface currents in the BAS on April 14, 2007, simulated using the M1 version of the model. This field of currents forms the so-called *Knipovich glasses* as large-scale semienclosed gyres that occupy almost all the basin of the Black Sea (Fig. 1). The eddy structure of the Black Sea circulation is easily seen in this figure. These eddies accompany the BSRC because they are formed due to its baroclinic instability under the influence of a complex of hydrometeorological processes. Anticyclonic eddy vortices with diameters up to 50–100 km regularly appear at the coastal periphery of the BSRC in many regions of the sea, which frequently have their own proper names: Batumi, Sochi, Kerch, Crimea, Bulgaria, and Synop vortices.

This pattern of currents agrees well with the charts of currents which can be found in many publications of the MHI NASU (see, for example, [19]). They also agree well with the data presented in the MyOcean site (http://www.myocean.eu). It is worth noting that the quasi-stationary Batumi anticyclonic eddy (BAE) calculated using the M1 version of the model is not clearly pronounced. It is likely that the development of the data assimilation system and, first and foremost, the satellite data on the sea surface temperature is required for a more adequate reproduction of the actual Black Sea circulation using the M1 version of the model.

The Black Sea is included in the program of diving ARGO buoys (http://www-argo.ucsd.edu) used for oceanographic measurements in the upper layer of seas and oceans on a real time basis. Figure 2 shows that the model reproduces well the profiles of T and S, in which the cold intermediate layer (CIL) is clearly seen. This layer is a characteristic peculiarity of the Black Sea.

1.2. The M2 Model for Simulating the Dynamics of the Black Sea Waters and Transport of Pollution in the Region of Big Sochi

The following grid domain was constructed for the Black Sea with the concentration in the coastal zone of Big Sochi. We used a spherical coordinate system with the location of one of the poles at a point with geographical coordinates 40.0052° E and 43.5913° N in the region of the Krasnaya Skala settlement. The nonuniformity of the grid domain was specified so that the spatial steps are on the order of 50 m in the Big Sochi basin and reach 5–9 km in the western part of the Black Sea. Twenty nonuniformly distributed σ levels are specified by the vertical. The total size of the grid domain shown in Fig. 3a is 759 × 600 points in the horizontal plane along the model longitude and latitude, respectively, which is approximately 10 times greater than in the M1 version. In view of reducing the time step, the calculation speed M2 is about 30–40 times slower than calculation speed M1. Our approach allows us to describe the circulation in the needed region with a high quality of presentation and eliminates the prob-

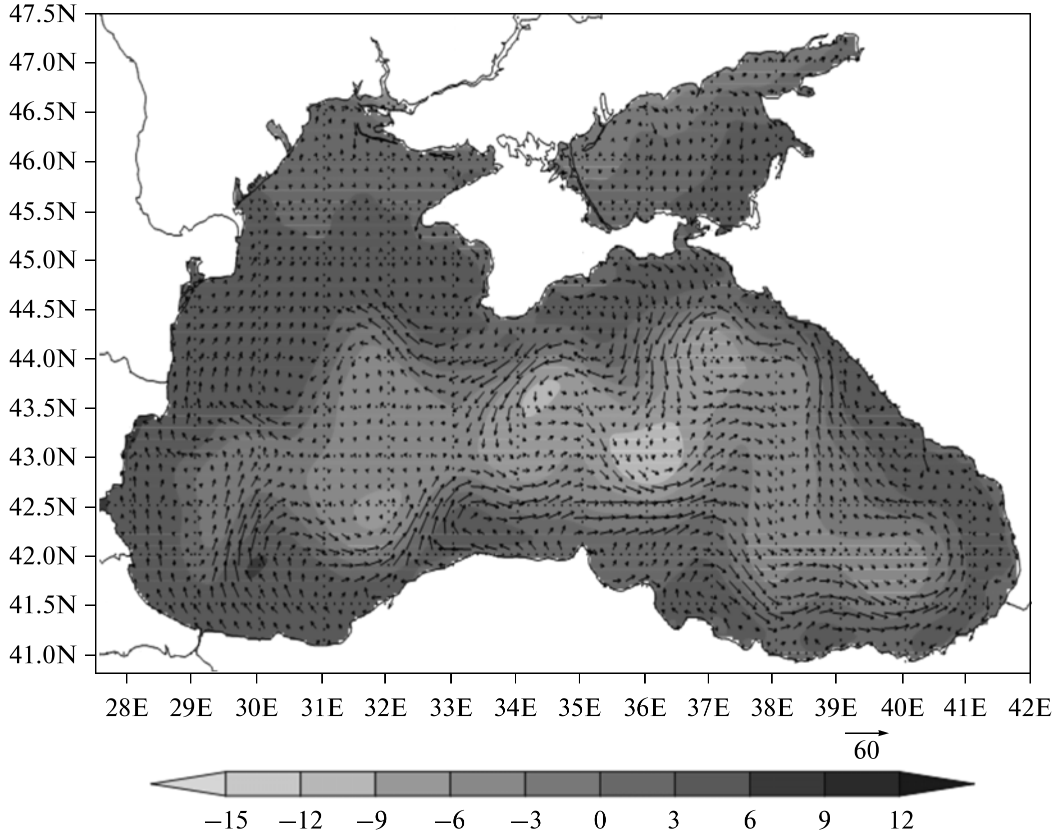

Fig. 1. Deviation fields of the SSH calculated using the M1 version (gray scale) and surface currents (velocity vectors) in the Black and Azov seas on April 14, 2007. The gray scale is in cm; the scale of arrows of velocity vectors is in cm/s. They are shown for each third point by latitude and longitude. The scales are in the bottom of the figure.

lem of specifying boundary conditions at the liquid boundaries. The simulation of circulation in the rest of the Black Sea almost does not influence the speed of calculations using the M2 version, because the main load of calculation is related to the calculation domain near Big Sochi (Fig. 3b).

The GEBCO data needed to specify the depths were transformed to the grid domain of the M2 version similarly to the M1 version. The complex character of the bathymetry is described owing to the concentration of the grid in the basin immediately adjacent to the coast of Big Sochi, which manifests itself at a high spatial resolution (Fig. 4).

The coefficients of physical parameterizations by vertical for the M2 version were selected similarly to the M1 version. The coefficient of horizontal diffusion was taken proportional to the spatial step of the grid domain, and the viscosity coefficient of the fourth order was proportional to its square. Therefore, when the steps in the M1 and M2 versions coincided, the values of coefficients also coincided.

The experiment with the M2 version was performed for the flood period from April 1, 2007, to April 30, 2007. The atmospheric forcing for the M2 version was the same as for M1. The initial conditions were obtained from the M1 model on April 1, 2007, first by means of bilinear interpolation over the M2 grid by horizontal and then by means of the linear interpolation by the vertical. The boundary conditions from the M2 version were the same as in the M1 version, excluding the discharge of the Mzymta, Sochi, and Khosta rivers. The real climatic discharges in the spring flood period were specified for these rivers [20], which were equal to 42 m^3/s for the Sochi River, 17 m^3/s for the Khosta River, and 144 m^3/s for the Mzymta River. These discharges were recalculated to the variations in the SSH at the mouths of these rivers. Such a method allows us to take into account the influence of the river discharge on salinity [12, 21, 22] and the dynamic factor of the formation of river discharges due to the gradient of the SSH.

Figure 5 shows the deviations of the SSH and surface current velocities calculated from the M2 version at the same time moment (April 14, 2007) as the values calculated using the M1 version (Fig. 1). The charts of the SSH and vectors of current velocities calculated

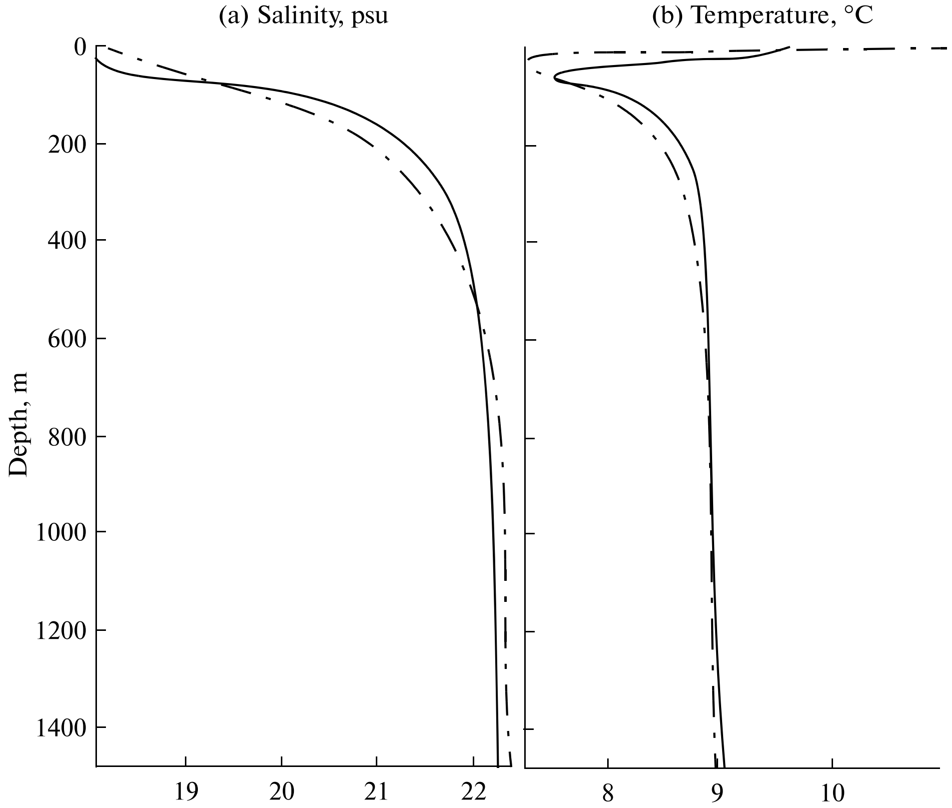

Fig. 2. Profiles of salinity (on the left) and temperature (on the right) in the Black Sea based on the results of modeling (dashed line) and ARGO buoy no. 4900489 (solid line) on April 14, 2007.

from the M2 version (Fig. 5) more adequately reflect the eddy circulation in the eastern part of the Black Sea when compared with the M1 version (Fig. 1). They show the Batumi, Caucasus, and Crimea anticyclonic eddy formations (see, for example, [23]). These eddies significantly influence the dynamics of the coastal waters; hence, they influence the spreading of pollution. The improvement is especially well pronounced in the reproduction of the quasi-stationary BAE, which is the most intense eddy formation in the eastern part of the Black Sea [24, 25]. The M1 and M2 models have completely identical programming codes and the same quite rough atmospheric forcing is used in both versions. Since the main difference between the M1 and M2 versions is in the horizontal spatial resolution of the models, we can conclude that a resolution on the order of 1.5 km is required for the adequate reproduction of the BAE; this resolution is gained in the M2 version in the southeastern part of the Black Sea. Even more, the roughness of the spatial resolution of the atmospheric forcing used in the model allows us to conclude that the topographic peculiarities in this part of the sea are the main factors of BAE formation.

2. MODELLING OF POLLUTION TRASPORT IN THE BIG SOCHI BASIN

We solve the equation of transport–diffusion of the pollution concentration as a conservative admixture to calculate the spreading of pollutants. A monotonous scheme of transport–diffusion is used in the horizontal plane in the INMOM, which is the same half-divergence scheme used for T and S, but with a coefficient of lateral diffusion equal to the product of the absolute velocity and half of the spatial grid step. In the vertical direction, we use the same scheme of transport and parameterization of turbulent diffusion as for T and S. The same method of calculating the transport of pollutants was used in the modeling of radioactive pollution spreading from the Fukushima 1 atomic power station, which gave good results [26].

It was assumed in the calculation of pollution spreading that pollutants are transported to the coastal waters of Big Sochi from the Sochi, Khosta, and Mzymta rivers and from 18 pipes of deep-water sewage discharge (Fig. 4). The locations of the ends of pipes were given to us by the Sochi Special Center on Hydrometeorology and Monitoring of the Black and

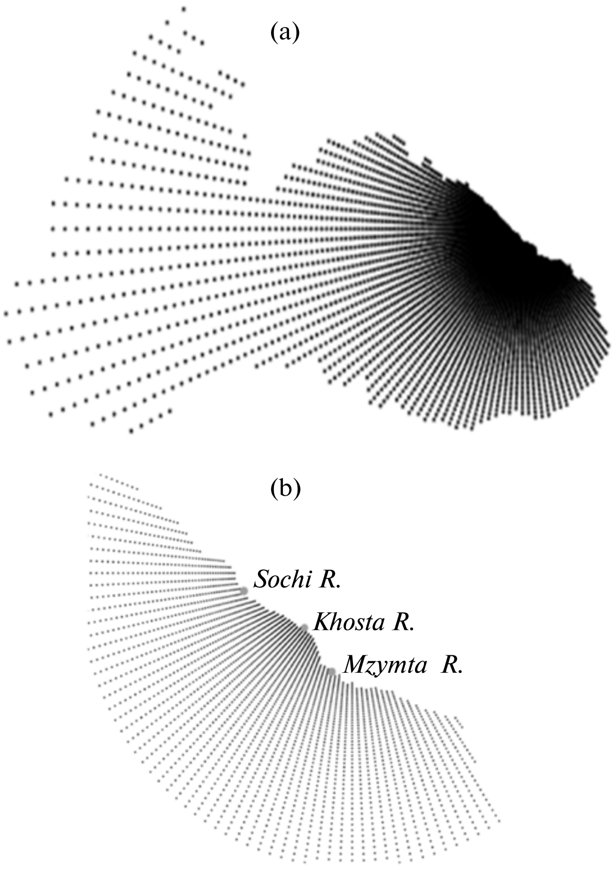

Fig. 3. Grid domain for the M1 version with the condensing grid in the region of Big Sochi. The upper pattern is related to the entire Black Sea (a); the bottom pattern shows a detailed grid for the basin at Big Sochi with the marks of the Sochi, Khosta, and Mzymta river mouths (b).

Azov Seas (SSCHM BAS). Since these discharges have different natures, we calculate them separately in the M2 version. It was taken into account in the discharge from the pipes that sewage fresh waters influence the distribution of salinity. In the simulations we assumed that the volume concentration of conventional pollutant according to the estimates of the State Oceanographic Institution in the river waters is $C_{\text{riv}} = 0.03\ \text{m}^3/\text{m}^3$, while the sewage waters from the pipes are assumed to be completely pollutant: $C_{\text{pipe}} = 1\ \text{m}^3/\text{m}^3$. The inflow of pollutants into the nearest cells at each time step of the model is calculated according to the volume concentrations of rivers and pipes multiplied by the corresponding concentration and the instantaneous dilution of pollutants over the volumes of the corresponding cells. The total transport of pollutants from all rivers was ~6 m^3/s, while the total transport of pollutants from all pipes was ~2 m^3/s.

Figure 6 presents the charts of pollution spreading at the sea surface from the pipes and rivers on April 15 and 30, 2007. These charts are plotted in the usual geographical coordinate system by the interpolation of the calculation results on the grid domain with a step of approximately 2.5 km.

The minimum considered level of dimensionless concentration of pollution was assumed equal to 10^{-7} volume parts of pollutants in the water, which is comparable with the threshold limit value (TLV) for the main pollutants in seawater. To illustrate the fact that the transport of matter by horizontal currents plays the main role in the spreading of pollutants, we plotted the vectors of the corresponding surface currents on the maps. The calculations confirmed the expected result that a greater transport of pollutants from the rivers is observed at the sea surface than from the sewage pipes, because in the scenario we use here the total transport of pollutants from the rivers is three times greater.

It is worth noting that a complex eddy structure of currents is observed at the Caucasus coast of the Black Sea, transporting pollutants both to the northwest and southeast. Such an eddy structure is reported in a number of publications both based on observations [27, 28] and on the results of numerical modeling [25, 29]. Quasi-geostrophic eddies with a radius greater than the Rossby deformation radius $R_d \approx 15$–20 km [30] and smaller scale ageostrophic eddies, which are revealed in the field observations [27, 28], are observed on the charts obtained in these experiments (Fig. 6). The mesoscale eddies transport the main amount of pollutants, forming a complex structure of the field of pollution spreading. As a result of their action, a high concentration of pollutants can manifest itself far from the local place of the discharge of river and sewage waters. The character of pollution spreading can be a good indicator of the complex eddy field of the coastal currents in the Black Sea.

It is worth noting that the formation of mesoscale quasi-geostrophic eddies occurs under the strong influence of currents and density stratification [31, 32]. Therefore, the application of a complex and physically complete model of currents with a high spatial resolution and with a prognostic calculation of temperature and salinity, even for the small coastal basin (when compared with the entire sea) of Big Sochi, is necessary and justified.

Although the alongshore transport of pollutants in the study region of Big Sochi under the influence of variable wind structure can occur in both directions, the average greater part of pollutants is transported to the northwest, according to the general direction of the BSRC. Such a character of alongshore spreading is noted also in [33].

We plotted a section of total pollution spreading from the rivers and pipes normal to the coast by the end of the calculation on April 30, 2007, to estimate

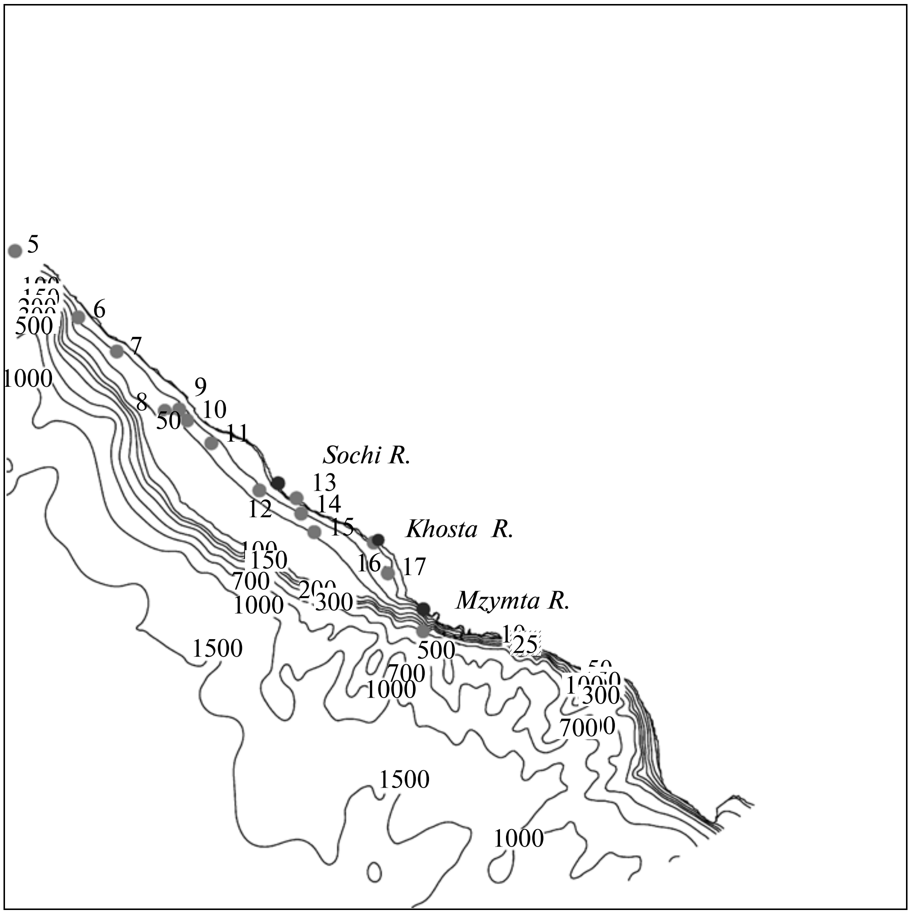

Fig. 4. Bottom topography (in meters) of the Black Sea in model 2 with condensation of the grid in the region of Big Sochi. The black circles denote the Sochi, Khosta, and Mzymta river mouths; gray circles denote the 18 locations of sewage discharge.

the peculiarities of the vertical pollution distribution (Fig. 7). Its location at pipe no. 13 is shown in Fig. 6d. The corresponding instantaneous streamlines of currents were superimposed on the chart to estimate the character of pollution transport. The results of modeling were interpolated from the σ system on the ordinary depths to plot the charts of the vertical pollution distribution. The results confirm that the propagation of pollutants by a vertical has an advective character similar to the horizontal plane (Fig. 6). The spreading of pollution to deep layers below 150 m occurs, albeit in a small concentration, due to the vertical motions generated by the complex eddy structure of the slope coastal currents in a band approximately 50 km wide. Slope currents play the greatest role in the pollution transport during the month to depths of up to 500 m, whose vertical component reaches 0.02 cm/s.

At a distance of greater than 50 km from the coast, pollution does not penetrate deeper than 100 m. It is clear that the currents here generally become quasi-geostrophic and the Black Sea salinity halocline, which is easily seen in Fig. 2, starts to play its locking role, preventing the ventilation of the deep layers.

CONCLUSIONS

In this paper we suggested a method of simulating the transport of pollutants in the coastal basin of the Black Sea adjacent to the region of Big Sochi. It is based on the application of the INMON hydrodynamic model in two versions (M1 and M2). The uniform spatial resolution of the model with a step of ~4 km over the entire basin of the Black Sea was used in the M1 version. A nonuniform spatial grid domain was used in the M2 version with increasing resolution at the coast of Big Sochi up to ~50 m. The M1 version allows us to rapidly calculate the circulation of the Black Sea at any given time moment. The time step in the M2 version is significantly smaller than in the M1 version; therefore, it requires larger computational resources. To calculate the pollution spreading in a local region, the initial hydrological state is specified from the M1 version, while the M2 version is used only

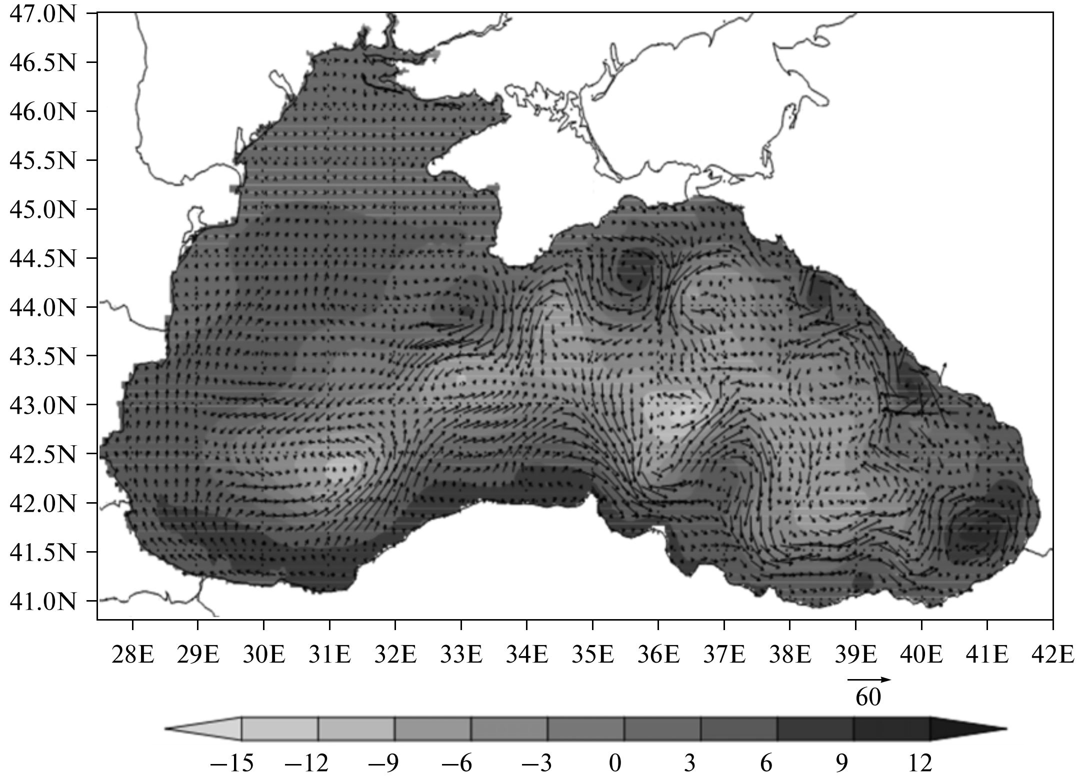

Fig. 5. Same as in Fig. 1, but the results from the M2 version are interpolated to the M1 grid.

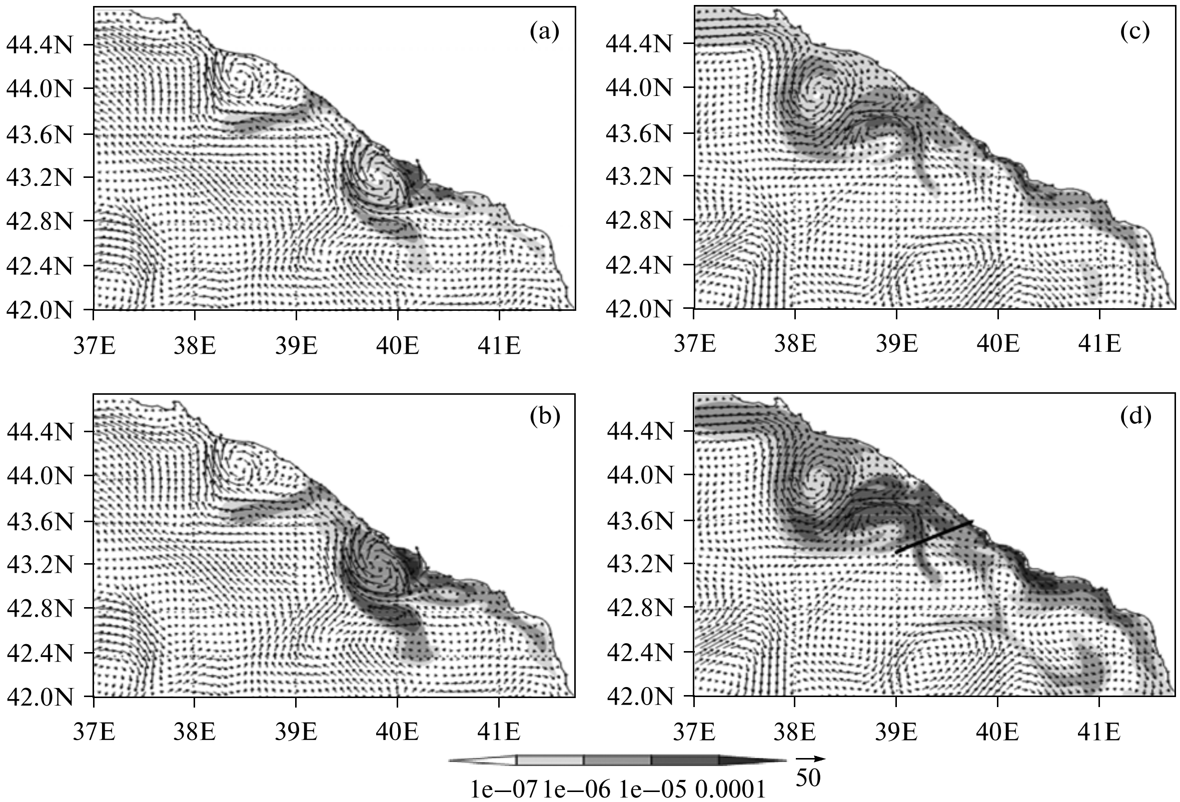

Fig. 6. Spreading of pollutants from (a, c) the pipes and (b, d) rivers for two time moments: (a, b) April 15, 2007, and (c, d) April 30, 2007. The grade scale of pollution concentration is shown in the bottom. Vectors of current velocities at the ocean surface with the scale of arrows in centimeters per second under the figures are superimposed on the charts of pollution concentration. Location of the section near pipe no. 13 is shown in Fig. 6d.

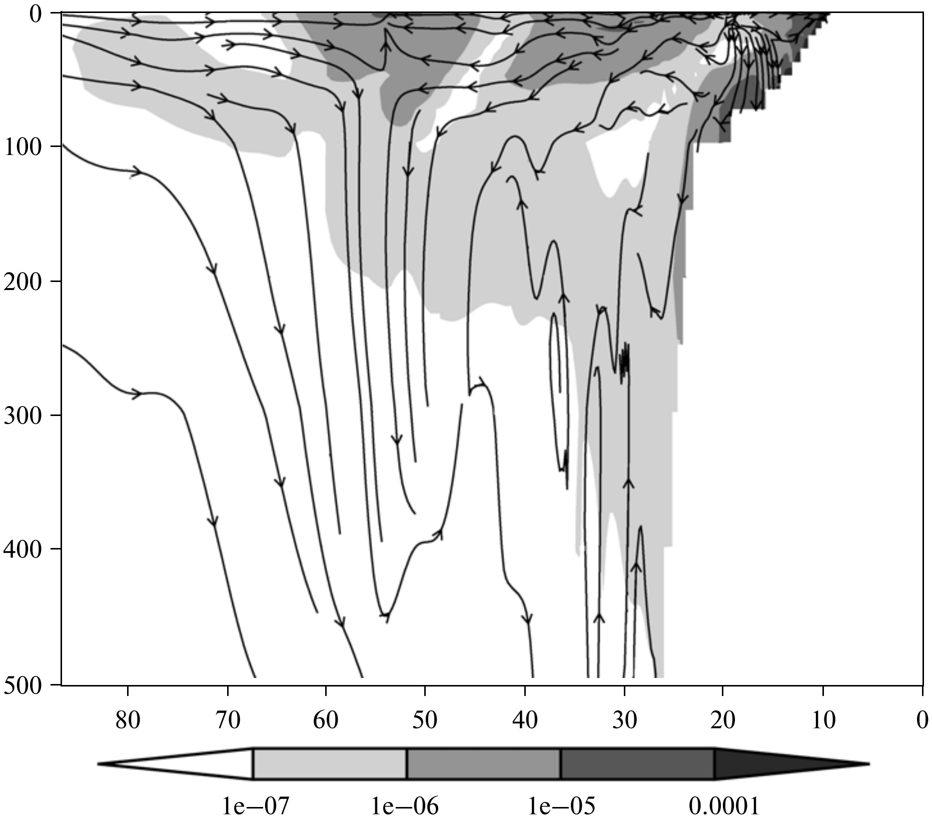

Fig. 7. Section of spreading of the total pollution concentration from rivers and pipes normal to the coast on April 30, 2007. It location is shown in Fig. 6d. The corresponding current velocity directions are shown as streamlines. The distance in kilometers is laid off as the horizontal axis; the depth in meters is laid off as the vertical axis. The grade scale of pollution concentration is shown in the bottom.

in the periods of calculation of pollution transport. Since both versions take place in the basin of the entire Black Sea, there is no problem of boundary conditions at the liquid boundaries, which would inevitably appear if we used a regional model of high resolution.

The atmospheric forcing for the M1 and M2 versions was calculated from the Era-Interim data, with a rough spatial resolution for the Black Sea equal to 0.75°. It was shown that both versions M1 and M2 adequately reproduce the circulation in the sea based on the data of observations. The M2 version with the condensation of the grid clearly reproduces the eddy circulation in the eastern part of the Black Sea with the presence of the Batumi, Caucasus, and Crimea anticyclonic eddy formations. This allows us to conclude that a spatial resolution on the order of 1.5 km is needed for reproducing the eddy structure of the circulation and the main factor of formation of the quasi-stationary BAE is the peculiarities of topography in this part of the sea basin. The vertical structure of T and S distribution is reproduced adequately to the data of ARGO buoys, which is characterized by the presence of the cold intermediate layer.

The simulation of pollution transport in the coastal basin of Big Sochi was carried out using the M2 version for the flood period from April 1, 2007, to April 30, 2007, and the monotonous transport scheme. It was assumed that pollutants are transported from the Sochi, Khosta, and Mzymta rivers and from 18 pipes of deep-water sewage. It was shown that mesoscale formations contribute strongly to the spreading of pollutants. They form a complex structure of the field of pollution spreading; hence, a high concentration of pollutants can appear far from the places of their discharge to the sea. The propagation of pollutants to the deep layers below 150 m (although in small concentrations) occurs due to the vertical motions generated by the complex eddy structure of the slope coastal currents in a band approximately 50 km wide. Pollutants are not transported below 100 m in the open sea region beyond this band. It is clear that here the currents become more geostrophic and the Black Sea salinity halocline prevents the ventilation of deep layers.

Investigations into the water dynamics in the Black Sea using a complex of M1 and M2 models allowed us to determine the character of pollution propagation in the waters of the Big Sochi region, which is generally determined by synoptic wind forcing. Since the developed method of calculating pollution spreading in the Big Sochi basin would be nested into the system of the operative calculation of the Black Sea circulation using the M1 version, the atmospheric forcing data should be adequate to the wind variability in the coastal region. The Weather Research and Forecasting Model (WRF) nonhydrostatic model of the atmospheric circulation [34], which can also be used in a forecast regime, would be applied for a better calculation of atmospheric forcing when compared with the Era-Interim. In addition, a system of data acquisition would be developed for a more adequate reproduction of the actual circulation in the BAS using the M1 version, first and foremost for the satellite data on the temperature of the sea surface.

The results obtained in this work can be introduced into the operative practice on the basis of the State Oceanographic Institution, where great experience has been accumulated in the analysis of time dynamics and spatial distribution of pollution in the Black Sea basin [2, 3, 35]. We plan to develop operative practical recommendations for providing rational and ecologically safe nature management on the shelf basin using numerical modeling and available data from monitoring.

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