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Research Article

Numerical Modeling of Water Dynamics of Russian Zone of the Black Sea within the Framework of Operational Oceanography Tasks

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Abstract

Modeling of the Black Sea waters dynamics (Russian zone) was conducted within the framework of the European ARENA and ECOOP projects and Russian project JISWO on the basis of Princeton Ocean Model (POM). Nowcasting and three days forecasting of the Black Sea dynamics was carried out in a daily mode with horizontal resolution of ~1 km along the Russian coast of the basin. Examples of calculations are presented and their comparison with space remote sensing and in situ (hydrological measurements) data is fulfilled, results of model validation are discussed. Model data reproduce observed real dynamic structures. Increasing a spatial permit of processes allows reproduce in calculations the detail of hydrological structure, which does not principally find displaying in large-scale models (vortexes with horizontal spatial sizes ~10 km). The conclusion that the proposed modeling technology can adequately monitor the variability of the waters of the region with the spatial and temporal resolution, unattainable using only field data, can prove important for operational oceanography.

Keywords: Black Sea; Forecasting; Modelin; Operative oceanography; Sea water structure

Introduction

Numerical modeling of the Black Sea dynamics was fulfilled in the State Oceanographic Institute of Russian Federation (SOI) within the framework of European ARENA (2003-2007 years) and, mainly, ECOOP projects (European COastal-shelf sea OPerational observing and forecasting system, 2007-2010 years) and National project JISWO (Joint Information System on World Ocean) and has continued to the present.

The purpose of the paper is a description of automated system of nowcasting and forecasting of hydrophysical parameters which built during ARENA and ECOOP and estimation of quality of modeled fields. The system output in the Russian part of the Black Sea is described. The comparison of observations and modeled fields is also presented below.

The results of modeling the dynamics and structure of waters of the Russian coastal zone of the Black Sea with high spatial resolution (~1 km) and their comparison with the data contacts and remote measurements are new. In addition, they were obtained for several years within the objectives of operational oceanography (daily nowcasting and forecasting).

Materials and Methods

A version of the Black Sea coastal forecasting system has been developed in the framework of ARENA and ECOOP projects [1], Figure 1. Regional circulation models included in the system developed by A. Kubryakov [2] using nested grid technology based on one of the versions of the widely-known models of ocean circulation of Princeton University (OzPOM) [3,4].

Necessary data on the open liquid borders of area were delivered by a basin-scale model of circulation of Marine Hydrophysical Institute (MHI), Sebastopol [5,6]. MHI model uses satellite data assimilation of altimetry and sea surface temperatures and also meteorological data (wind stress, flows of heat and mass) received from the National Meteorological Administration of Romania within the framework of the European cooperation (Figure 1).

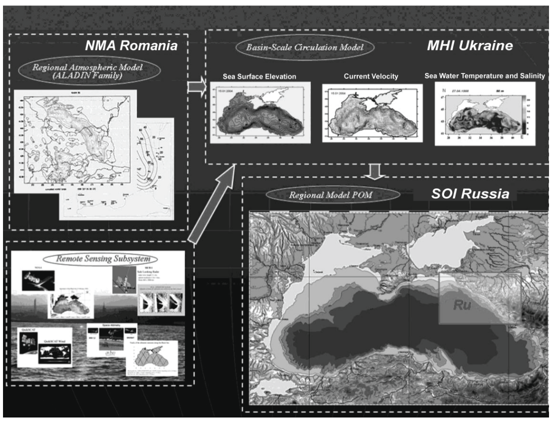

Figure 1: System of nowcasting and forecasting of Black Sea water dynamics.

The SOI receives the necessary border conditions for the regional Russian model in a daily mode from the MHI server and makes nowcasting and forecasting (for 3 days) calculations of thermohaline structures and water dynamics of the region. The initial data for the forecast is generated daily as a result of the *MHI Black Sea Forecasting Operational System work (BSFOS).*

During the ECOOP project the calculations were carried out daily for about 2 years, making it possible to obtain a large amount of simulation results. The formal parameters of the numerical regional model according to the terms of the Project in this case were the following: the grid for Russian zone of the sea had dimension 304x254 points and lay in borders of 43.0o-45.26o northern latitude and 37.25o-41.0o east longitude. Horizontal resolution of regional model is ~1 km at 18 vertical sigma-layers (Table 1).

Main features of models	Type	Vertical coordinates	Grid size	Number of grid points	Time step
Basin scale model (MHI)	MHI-model with remote sensing data assimilation	Fixed levels in the vertical z-direction	~ 4900 m	237 x 131 x 35	600 s
Northeastern Russian Coastal Zone Regional Model	POM-model	Terrain following σ-coordinates	~ 1000 m	304 x254 x 18	120 s (baroclinic mode) 3 s (barotropic mode)

Table 1: Main features of global and regional models.

Results and Discussion

Calculations for the Russian zone of the Black Sea were carried out in the test mode for debugging of technology (ARENA project). The results of the design were compared with the information of in situ (CTD) and remote (SST) observations. An example of these results is shown in Figure 2.

One of the first calculations was carried out for the period of 7 June until 14 June 2003. The result of calculations of a field of speed and corresponding in time satellite picture (NOAA) of sea surface temperature (SST) is shown. As seen in Figure 2, the model reproduces both anticyclonic vortexes located on the slope zone with a characteristic horizontal scale of ~80 km (Az1), and vortexes diagnosed according to the contact and satellite measurements eddies with a scale of ~15 km (Az2).

Resume of intercomparison between the Russian coastal zone nested model data and the data obtained during the ARENA project (R/V Akvanavt cruises and sattelite data) may be follows. Results of modeling are in general physically identical; increasing a spatial permit of processes allows reproduce in calculations the detail of hydrological structure, which does not find displaying in large-scale models. In particular, the eddies with horizontal spatial sizes ~10 km. Model calculations reproduce observed real dynamic structures. Their spatial position not wholly well complies with observed data. The main features of calculate parameters have a good correspondence with a measurements.

It is interesting to compare the results with the measured data, in situ and remote, to assess the quality of modeling of dynamics and the thermohaline structure of waters in that Black Sea region, obtained during the ECOOP project. Comparison of modeled results with in situ and remote data has been performed. Contact measurements (CTD) obtained by R/V Professor Shtokman of "Shirshov's" of Institute of Oceanology of Russian Academy of Sciences (IO RAS) for the period of 9 March until 2 April 2009 were used. In Figure 3, the regions of R/V Survey and modeling are shown.

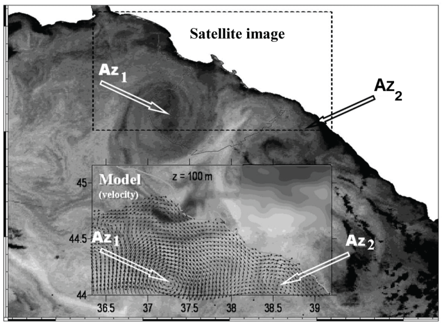

Figure 2: Comparison of the modeled results (currents) with satellite image. The dotted line allocates area of modeling.

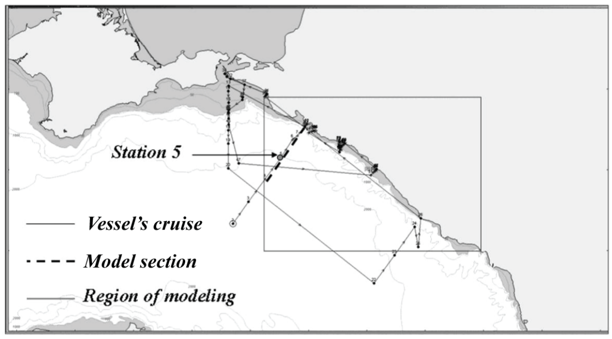

Figure 3: Region of R/V Professor Shtokman survey and modeling area.

It should be noted at the beginning that some characteristics of water in the region in March should be reflected in the measurement data and modeling [7]. The vertical structure is an upper quasi-homogeneous layer (UQHL, several tens meters), thermo- halo-pycnocline below to depths of 500 m and the underlying quasi-homogeneous layer. The main feature of the vertical structure of the waters of the Black Sea is the so-called cold intermediate layer (CIL) with the axis at depths of 50-100 m depending on the point of observation. Rim Current has extending along the continental slope, roughly along the isobath 1200 m, and produces a general cyclonic circulation in the sea. In the area of the continental slope, the eddies with spatial scales of ~ 100 km are also observed, and directly in the shelf-slope zone - anticyclonic eddies with horizontal dimensions are about 10 km (Figure 2). These dynamic characteristics are reflected in the distributions of isolines in the cross-sections. Note also that the salinity is a major contributor to the spatial distribution of the density of Black Sea water, determining its dynamics. Therefore, profiles, sections and maps are constructed from the values of salinity, the most informative in analyzing the features of water dynamics in the region.

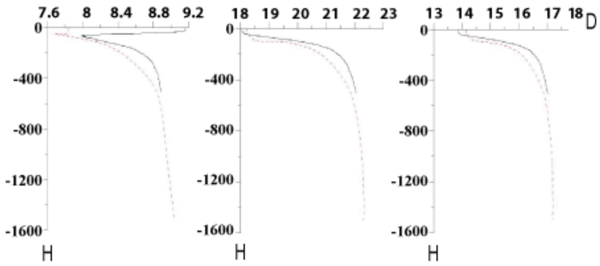

Figure 4: Vertical profiles of temperature (T), salinity (S) and density (D) for Station No. 5 from CTD data (solid) and modeling (dashed).

Vertical profiles built both from CTD and modeled data reflect the typical vertical structure of waters in the region in March (Figure 4, for hydrological Station 5), in particular, the presence of the upper quasi-homogeneous layer (UQHL) with a capacity of ~ 40 m, the cold intermediate layer (CIL) with the axis at a depth of 60 m, the main pycnocline to depths of 500 m and the underlying quasi-homogeneous layer. The vertical profiles of salinity and density are of the same type because the water density in Black Sea is mostly defined by salinity. Qualitatively, the model and the observed profiles are very similar. For the salinity difference in values of the order of ~0.1o/oo, for the temperature there is the same order in degrees oC at depth. A maximum difference in temperatures is observed on a surface – approximately 1.5°C. As the research of colleagues from MHI showed, this failing can be decreased by including the penetration of short-wave radiation [8]. But during the experiment we did not include this effect in SOI technology because do not receive the necessary information about the heat flows.

Distribution of thermohaline characteristics at a cross-section perpendicular to the coast (see Figure 5) is typical for the Black Sea, and shows a decline in the depth of isolines from coast to the center of the sea, caused by a general cyclonic circulation in a basin. The section shown in Figure 5a is built from asynchronous CTD-data made by R/V Professor Shtokman in the period 10/03/2009-13/03/2009. Figure 5b is built from model data corresponding to the points and times of ship observations. Comparing Figure 5, a and b, we can conclude that the salinity distribution in sections are similar and have similar quantitative values. As the differences can be noted, large vertical salinity gradients in halocline on the cross-section, which was built from CTD-data. But reducing the spatial discreteness of the model data in cross-section is well defined deflection contour lines in the slope (right side of Figure 5c) due to the presence of the anticyclonic vortex with the spatial size of ~ 10 km (Figure 6a). Analysis of a similar section for the temperature gives the same results. A similar distribution of isolines on the edge of the continental slope of Black Sea is fixed often from CTD data of many hydrological surveys with a small horizontal step (~1 km).

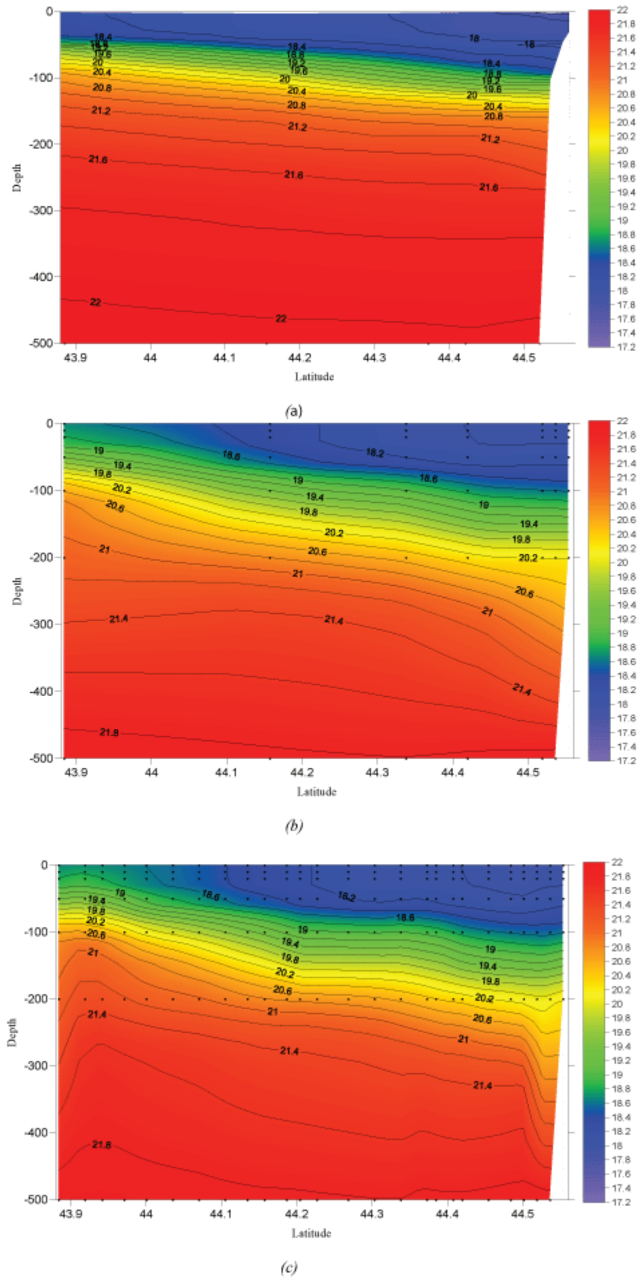

Figure 5: Distribution of salinity on a cross-section (see the Figure 5), obtained from CTD data (a) and model data (b, c).

Synoptic variability in space and time is clearly expressed in the model calculations of water dynamics in the region. As an example, the model velocity fields corresponding to the beginning and end of hydrological survey R/V Professor Shtokman is shown in

Figure 6. With regard to estimates of the degree of differences of model and measured values, then, due to high degree of asynchrony of the hydrological survey, comparison between measured (in situ) and modeled data does not make any sense. Therefore, the estimations of quality of modeling are possible using remote sensing. Examples of comparisons of modeled data with satellite observations are shown in Figures 7 and 8.

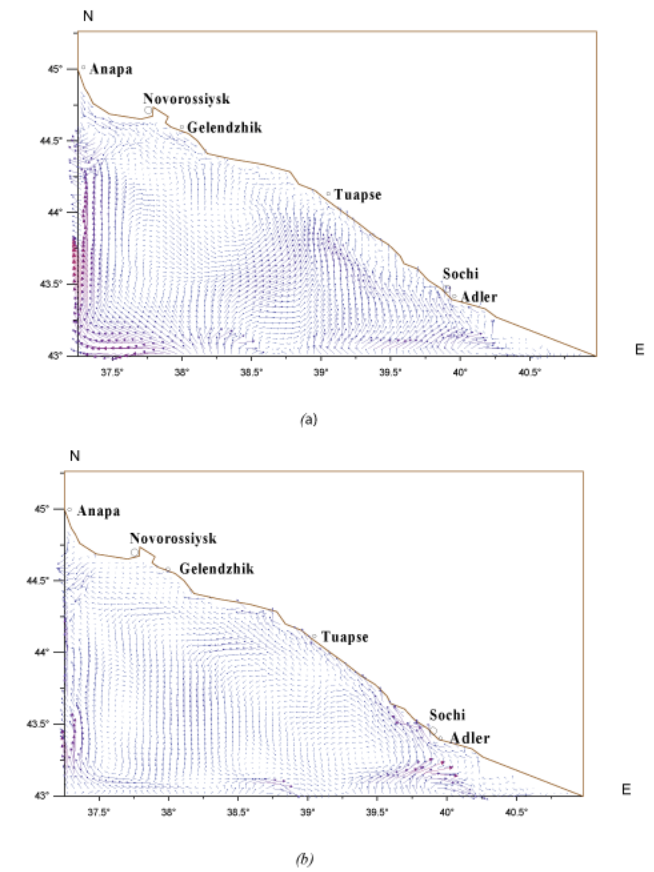

Figure 6: Model fields of sea currents at a depth of 10 m 10/03/2009 (a) and 02/04/2009 (b).

Thus, synoptic eddies, reflected in the salinity field (model) and the concentration of chlorophyll A (satellite image) show a high correspondence in the spatial size and horizontal location (Figure 7). As noted earlier, the salinity fields to better reflect the dynamics of the waters of the Black Sea in comparison with the fields of temperature. As well as images of chlorophyll are the best to fix the dynamic structures and their evolution than the SST images. Unfortunately, the analysis of conformity the salinity fields and satellite images has only qualitative character. To obtain quantitative characteristics of the spatial accuracy of model estimates makes sense to use a fields of sea surface temperature. For example, the RMS of the difference between the model and the measured SST in area of modeling for 2 July, 2009, was equal to RMS=1.1oC (Figure 8) and it is typical value. The comparison of modeled temperature field, shown in the Figure 8, with satellite data also demonstrates their qualitative agreement. But using some standard methods to assess the quality of the model output in extended period of time was not performed, because modeled and observed sea surface temperatures have a big difference. The reasons have been described above (heat flux).

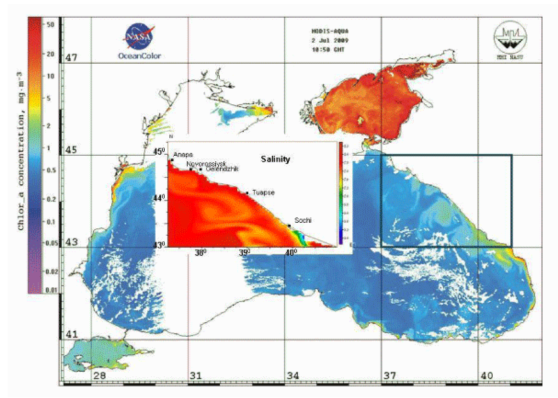

Figure 7: Satellite image (Chlorophyll concentration) and modeled sea surface salinity at 2 July, 2009.

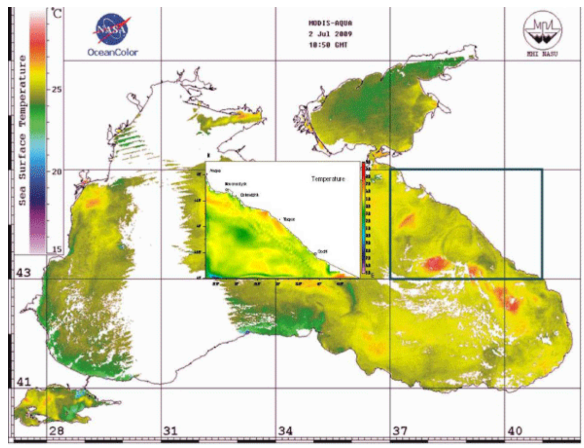

Figure 8: Satellite image (SST) and modeled sea surface temperature at 2 July, 2009.

Thus, calculations of coastal circulation of waters of Black Sea by a nested grid method have shown the reasonable consent of the received results with available representations about dynamics of waters in considered area. The received conformity of results of modeling calculations to data in situ and remote supervision gives to hope for an opportunity of satisfactory realization of monitoring of hydrophysical fields in coastal area of Black Sea on the basis of use of the described technology for the developed series of regional models.

Conclusion

The automated system of modeling the dynamics of water of the Russian zone of Black Sea was created. It allows generation of physically adequate results of calculations of thermohaline structure of water and current fields. Increasing a spatial permit of processes allows reproduce in calculations the detail of hydrological structure, which do not principally find displaying in large-scale models (vortexes with horizontal spatial sizes ~10 km). Such calculations are performed in nowcasting and forecasting (3 days) mode.

The proposed modeling technology can adequately monitor the variability of the waters of the region with the spatial and temporal resolution, unattainable using only field data, can prove important for operational oceanography.

Acknowledgment

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