Estimation of the Azov Sea state based on the Black Sea hydrography

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Abstract. The variability of the Azov Sea is generally determined by the weather conditions formed over the continent. Despite its very small area and depth (can be considered as the shallowest enclosed basin of the ocean), the Azov Sea is an important transport hub. Besides, the large volume of river runoff determines its high fish productivity. A large number of abnormal phenomena have been observed here recently in the context of anthropogenic pressure in the basin. The study represents the intermediate results on the implementation of the data assimilation procedure for possible improvements in the accuracy of the numerical simulation of the basin.

1. Introduction

The Azov Sea is a shallow semi-enclosed basin which is very isolated from the ocean. Therefore, the variability of its thermodynamics is generally determined by the weather conditions formed over the continent. Despite its very small area and depth (can be considered as the shallowest enclosed basin of the ocean), the Azov Sea is an important transport hub. Besides, the large volume of river runoff determines its high fish productivity.

The basin is characterized by significant spatial heterogeneity of hydrophysical parameters. Intrasecular to seasonal variability, as well as seasonal to storm surges variability are well determined in its thermohaline regime. A large number of abnormal phenomena have been observed recently under the conditions of anthropogenic pressure in the basin, described, for example, in [1].

In numerical simulations, the effect of the Black Sea waters inflow on the Azov Sea dynamics usually neglected. The joint simulation of the basins [8] with good resolution for the Kerch Strait is a more preferable approach for the analysis of long-term changes. The inflow of more saline water masses and circulation features significantly affect the salinity of the basin. At the same time, the outflow of rich in nutrients waters from the Azov Sea to the Black Sea is well pronounced, for example, in satellite observations [3]. Therefore, for forecasting of long-term variability of thermohaline and dynamical parameters, it is important to carry out such predictions for both basins jointly. This problem is very relevant for regional centers for marine forecasts, using observational data and numerical modeling to refine information on the state of the seas, for example, the Black Sea Marine Forecasting Centre (BS MFC) based at Marine Hydrophysical Institute RAS, Sevastopol (http://mis.bsmfc.net).

Note that at the moment there are no systems that provide not only visual information but also the data for the Azov Sea considering the requirement for their high resolution. The quality of the global ocean forecasting systems products (e.g., Copernicus Marine Environment Monitoring Service,
CMEMS, http://marine.copernicus.eu/) is still not enough for studying the small scale dynamics in the Azov Sea. Note that the BS MFC products of simulated hydrography and dynamics of the Black Sea, as one of the affecting factors to the Azov Sea basin, are provided with a 5 km resolution. Continuing this work, a regional configuration for the NEMO (Nucleus for European Modeling of the Ocean) modeling structure, which allows studying changes in the thermohaline regime, was proposed in [3]. Improving the accuracy of long-term hindcasts by means of numerical simulation can be achieved by the assimilation of observational data. The good data assimilation procedure demands ongoing performing of in-situ measurements which can be problematic for the Azov Sea since the observations can be carried out only from coastal meteorological stations (HMS). A fairly regular observation grid of data from hydrographic surveys and autonomous buoys in the black sea basin, however, remains incomplete for numerical simulation.

Nowadays this problem can be solved by developing techniques of the synthetical spread of available in-situ and satellite observations based on their physical relations specific to the Black Sea [4]. The study represents the intermediate results on the implementation of the proposed procedures for possible accuracy improvements of numerical simulations using observations. Section 2 describes the model and important features of its setup configuration used for reconstruction of the general circulation in the basins. The paper presents also information on the data used and the procedure of data reprocessing. Section 3 presents preliminary results of the long-term diagnostic model runs in the basin of the Azov Sea. The outlook and possible further improvements are given in the discussion section.

2. Materials and methods

2.1. Brief description of the circulation model and the setup

Simulations of the Black Sea dynamics presented in the study were performed within NEMO modeling framework [2] based on the primitive equations discretized using the so-called Arakawa’s C grid. The regional configuration used was developed earlier [3]. Its numerical domain is a regular geographical grid spanning the cascade of the Black, Azov, and Marmara basins with a resolution of 1/24° × 1/17° in the meridional and zonal directions, respectively (approximately 4.6 km) (Figure 1). The bottom topography was prepared using EMODnet bathymetry data and terrain model (https://www.emodnet-bathymetry.eu/). The configuration based on vertical partial step z-coordinate which allows for a more accurate representation of the bottom (comparing to full step). The resolution allows resolving the water exchanges between basins through the straits: explicit for the Kerch, and using an artificial approach of “partially opened” cell [2] for the Bosporus.

Figure 1. Bottom topography of the domain for shelf (left) and deep-sea (right) areas.

The subgrid-scale physics in the equations for momentum and transport – diffusion of heat and salt are parameterized as follows. Vertical turbulent fluxes are described using the differential $k$-$ε$ closure model [5]. Lateral turbulent diffusion and viscosity are represented by bilaplacian operator. The
turbulent coefficients are as follows: $5 \times 10^9$ m$^4$/s for viscosity, $4 \times 10^8$ m$^4$/s for heat/salt diffusion and are negative. For the momentum equation we use a free slip boundary condition for lateral boundaries.

When performing numerical simulation, the model is forced with the surface boundary conditions which include temperature and humidity fields obtained at the level of 2 m, the horizontal wind speed component at 10 m, the streams of descending long-wave and short-wave radiation, as well as precipitation in the liquid and solid phases obtained from ECMWF atmospheric reanalysis. To clarify the salt balance in the Azov Sea we also take into account monthly averaged river discharge values for the rivers of Don and Kuban obtained from measurements conducted by State Oceanographic Institute. In the basin of the Black Sea, the effect of runoffs is less important because the volumes of the basins differ drastically. The joint circulation of the cascade was reconstructed with the model setup for the period from August 2007 to December 2018 in a so-called free run experiment (FR) demonstrating rather adequate results (Figure 2) concerning observed salinization of the Azov Sea due to fall of the river runoffs. The full description of the steps and results while carrying out an FR experiment is given in detail in [3].

![Figure 2](image)

**Figure 2.** Simulated (orange) against observed (HMS Mariupol station) (blue) sea water salinity (example of intercomparison).

The behavior of salinity based on the results of numerical modeling qualitatively reproduces the growth of salinity in the Azov sea basin. This is confirmed by comparison with available measurements from the HMS. It is worth noting that the coastal dynamics cannot be adequately reproduced at used spatial resolution.

### 2.2. Description of the conducted numerical experiment

The proposed study is an attempt to reconstruct the joint dynamics of the basins which should be closer to available observational data. Here we use the method of the model solution correction based on the seawater temperature and salinity measurements obtained in the basin of the Black Sea (so-called assimilation of observation data). For this purpose, we use procedure based on the hypothesis of significant physical relation between the sea surface height and structure of isosurfaces of the sea water temperature and salinity. This hypothesis is based on the assumption that starting with the certain depth one can expect a slow change of uniform temperature and salinity (and hence density) of the stratification in time and space. The motion (transformation) of the salinity isosurfaces (and thus temperature) causes the transformation of the structure of the sea surface in the same way. Analysis of the relations for the Black Sea showed the ability to predict (synthesize) the full structure of the three-dimensional temperature and salinity fields between certain depths with information on the sea surface height and known major pattern of the Black Sea stratification $T(z)$ and $S(z)$ which can be obtained from the restricted number of in-situ measurements [4].

Data on temperature and salinity obtained in [4] was used in the model run with the simple data assimilation technique. The experiment was carried out with the simple nudging technique (or so-called relaxation). The idea is adding heat and salt terms in the form $-\gamma (T - T_{\text{obs}})$ for temperature and $-\gamma (S - S_{\text{obs}})$ for salinity, respectively, to the right-hand side of the discretized analogs of the transport–diffusion equations. Here $T_{\text{obs}}$ and $S_{\text{obs}}$ are the temperature and salinity fields “synthesized” from observations, $\gamma$ is the parameter of relaxation (is inverse to a relaxation time). After preliminary
tests, we empirically choose the value of $\gamma$ corresponding to 10 days. In such a way these terms will simply work as “sinks – sources” term nudging the numerical solution towards the “observed” data.

Note that nudging was implemented for the Black Sea basin because there was no evidence of described physical relation for the rest of the basins. It is obvious that such a relationship will change for the Marmora Sea, while the Azov Sea is rather shallow for the procedure. Additionally, the weighting function was used to weaken correction in the coastal area. When using the proposed nudging procedure in the Black Sea basin it is expected to correct balance for other basins and refine volume and salt transport through the straits. To analyze the differences comparing to “FR” we perform model run assimilating the data for the period of 2014-2018. For convenience, we denote here obtained results with “A”.

The reconstructed thermodynamics from both experiments are compared against each other and also with measurements from coastal HMS’s.

3. Results

Conducted experiment “A” demonstrates the growth of the salinity of the Azov Sea waters (Figure 3). We note that the use of the river runoff values based on measurements played an important role in reconstructing the salt balance of the basin. The tendency is confirmed by observations from HMS. For example, we demonstrate observed and simulated salinity values for the port of Temryuk. Here seawater salinity is mainly affected by the runoff of the Kuban River and has significant seasonal variations. This is also the case for modeling results. Nevertheless, the growth in concerned values is evident for the period.

Figure 3. Reconstructed (orange) against observed (green) seawater salinity for Temryuk HMS station. Surface salinity averaged over the area of the Azov Sea.

Analysis of the effect of data assimilation on the simulation results was made with the difference “A – FR”. As an example, differences in the salinity and sea level are presented in Figure 4. We can note that the data assimilation procedure took about the year in the model time to reach a stable level. Starting from 2014, the average level and salinity of the basin fall sharply till mid-2014. Then differences start to rise and after 2015 remained near steady. This result means the increasing the Kerch Strait outflow in experiment “A” in 2014 caused obviously by a model collapsing after nudging procedure starts. This fact was confirmed by the analysis of the volume transport difference. A possible explanation of such different behavior can be significant displacing the sea surface in the basin of the Black Sea after the correction using the nudging technique. This resulted in increasing the water exchanges between basins.

The effect of the nudging procedure with regard to the Azov Sea basin was not uniform. As can be seen during the first year of the investigated period, salinity increased in the coastal areas of the eastern and central parts (Figure 5). However, in the center of the basin and Taganrog Bay, sea surface salinity in the model run “A” is lower, especially in the Taganrog Bay. Here modeled salinity from
“A” is 0.8 ppt lesser than that in “FR”. This can be possibly explained by the enlarging of the river runoff role but this hypothesis needs more detailed analysis.

![Figure 4](image)

**Figure 4.** The difference of the sea surface salinity (blue) and height (red) between numerical experiments “A” and “FR” averaged over the Azov Sea area.

![Figure 5](image)

**Figure 5.** Yearly averaged difference of sea surface salinity between numerical experiments “A” and “FR”.

Since 2015, the large difference in the Taganrog Bay salinity is observed for all subsequent years. But it tends to decrease significantly. Furthermore in the central part of the Azov Sea salinity began to rise which is also demonstrated by the averaged surface salinity (Figure 4). Thus the year 2014 in our simulations should be considered as the period of model adjustment and should be taken into account for further investigations. For the short period from mid-2015 to 2018 statistical analysis with observational data indeed shows higher values.

4. Discussion

We represent here the results of the first attempt to reconstruct of the joint hydrodynamics in the basins of Azov and Black Seas using simple data assimilation procedure. The simulation results inter-comparison with observations in the Azov Sea has shown a more accurate reproducing of sea water salinity tendency. It was reconstructed despite the insufficient spatial resolution of the developed regional configuration of the model. The main drawback of the used nudging technique is model shock and long period necessary for adjustment of the simulated fields.
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