

Skill assessment of a high resolution (1/72 degree) Black Sea ocean model

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Abstract: The skill of a high-resolution Black Sea circulation model (ROMS) is assessed using the available satellite and field data for Sea Surface Height Anomaly (SSHA), Sea Surface Temperature, and CTD profiles. The model is configured to simulate the 9-year period between 2012 and 2021. The model's skill is assessed using standard analytical methods for error calculation such as Root Mean Square Error (RMSE) and correlation. Additionally, the model results are assessed using several more recent methods such as the relative operating characteristic (ROC).

The results show that the model is capable of simulating daily mean SSHA with an RMSE value of 1.2 cm. When the mean monthly SSHA values are considered, the RMSE drops down to 0.7 cm. The biggest source of the error for SSHA is found to be related to the freshwater balance, as the Black Sea is a freshwater-dominated marine environment. The results for SST show that the model is able to capture both the daily and seasonal variation with high correlation values. The correlation coefficient for basin averaged SST over the entire simulation period compared to the satellite-based OISST data is calculated as 0.98, and the RMSE value is 1.6 °C. In addition to the surface comparisons obtained from SSHA and SST, the model results are compared to 2300 Argo Float CTD profiles. The RMSE is 1.1 °C for the temperature profiles and 0.7 PSU for the salinity over the entire water column. The methods used to assess the skill of the model show that the model is quite capable of simulation of oceanic conditions within the Black Sea. As one of the aims of this model's development is to simulate mesoscale-to-sub-mesoscale eddies, results on the model's capabilities show that it can simulate eddies successfully from 5 – 50 km eddies in the Black Sea.

Key words: Black Sea, regional ocean modeling system, high-resolution, model skill, assessment

1. Introduction

Oceanographic models are used increasingly in recent years. There are many reasons to use models ranging from hindcast/forecast studies for understanding large-scale phenomena to ideal cases for a better understanding of the dynamic processes of the oceans. Each of these different model studies helps improve the ecosystem around us.

Ideal cases used in modeling studies help improve the dynamics within ocean models. On the other hand, the resolution for many ocean model studies is still the limiting factor for existing known dynamics. Therefore, with the decreased cost of high-performance computing, the resolutions used for ocean models are also improving. There are many modeling studies set up for understanding the general circulation and dynamics of the Black Sea. There are relatively basic applications of models aimed at capturing the Rim Current (Staneva et al., 2001) and surface structure of salinity, temperature (Kara et al., 2005), and sea surface height (Grayek et al., 2010; Capet et

al., 2012), while other modeling studies try and capture 3D temperature and salinity along with circulation.

In previous modeling efforts, there have been little data available for model implementation (e.g., initial and boundary conditions, forcing) or verification (Stanev and Becker, 1999). Along with model quality and resolution improvement, data collection and access have increased quite rapidly in the last couple of decades. Satellite, in-situ, and autonomous systems make data collection both easier and much more accessible to researchers through different platforms such as SeaDataNet, EmodNet, and Copernicus. In recent years, the quantity of data has led to much better boundary conditions and forcing data. Therefore, simulations provide better results for oceanographic parameters and better insight into dynamics (Gunduz et al., 2020).

The Black Sea has unique dynamics, where the main Rim Current circulation is forced and modified by the local wind curl (Oguz et al., 1993; Oguz and Besiktepe, 1999).

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The salinity and temperature balances are governed mainly by the river input, evaporation/precipitation and the Bosphorus Strait flow (in/out). In the vertical direction, the water masses are stratified in a stable fashion. The vertical profile of temperature contains a Cold Intermediate Layer between depths of 50 and 100 m, differentiating between regions (Oguz et al., 1994).

Even though the quantity of data for hydrography is increasing in relation to the Black Sea, one of the most important datasets, which is the amounts of flux through the Bosphorus, has still not been accurately and continuously measured for long time periods. Ahtiok and Kayisoglu (2015) and Jarosz et al. (2011) presented a more comprehensive coverage of Bosphorus fluxes. Yet, their methods could not be fully implemented to represent the interannual variation of the Bosphorus Fluxes in a Black Sea model, since they are not long-term measurements.

In a recent attempt to remedy the aforementioned problem about the long-term fluxes of the Bosphorus Strait, a model of the Black Sea with the Bosphorus Strait open boundary including the strait and a portion of the Marmara Sea was developed by Gunduz et al. (2020). The idea was to simulate the inflow and outflow through the Bosphorus instead of using flow values that are approximated from precipitation/evaporation and river inflow as sources and sinks (Kara et al., 2008; Stanev and Becker, 1999).

The hydrodynamics and ecosystem of the Black Sea have been an interest to many researchers in detail because the environmental conditions in the Black Sea are degrading significantly over time (Capet et al., 2019). The degradation is connected to anthropogenic effects through incoming water sources (e.g., river, runoff), especially on the northwestern shelf. Regarding the need for understanding the means of degradation in combination with relatively simple and almost closed basin hydrodynamics, the Black Sea acts like a laboratory for understanding both hydrodynamics and the ecosystem.

An important characteristic of the circulation of the Black Sea that affects the transport and changes the dynamics of the ecosystem is its coastal eddies. These eddies are formed in many different ways (Korotenko et al., 2010; Staneva et al., 2001). In general, they are mainly trapped between the Rim Current and the coastline. They help mass exchange between coastal regions and offshore. Both cyclonic and anticyclonic eddies are formed, but especially two of the anticyclonic eddies, the Batumi and Sevastopol eddies, stay alive for much longer (Tutak, 2020), with much larger sizes. Considering the ecosystem dynamics and transport between the coastal zone and offshore, as well as horizontal mixing, eddies gain more importance.

Enriquez et al. (2005) studied the effects of resolution on the mesoscale circulation features of the Black Sea using 3 different model resolutions. The finest resolution

used in the study was 3.2 km for x-fine, and using this resolution did not result in an advantage over a resolution of 6.7 km. However, their study only examined the mesoscale circulation. Once the submesoscale circulation is considered, a higher resolution is a must. Korotenko (2017; 2018) studied the effects of meso-to-sub-mesoscale eddies on Black Sea transport and environmental impact using ocean models.

The primary goal of this study is to assess the quality and skill of a high-resolution (1/72 degree) ocean model of the Black Sea that will be used to study the mesoscale to submesoscale features of eddies. The assessment of the model is completed using many different model skill assessment methods to be able to obtain a comprehensive picture of the model's skills. The assessments are made for the two-dimensional surface salinity, temperature, and sea surface elevation parameters, as well as the salinity and temperature profiles along the depth at many different stations.

2. Materials and methods

2.1. Model domain

The ROMS model was set up in the Black Sea, excluding the Azov Sea. The model domain was created with a high resolution (1/72 degree) using the best available bathymetry and topography data for the region (Figure 1). The model cells that were on the coastal zone were adjusted individually to represent the coastline as best as possible, e.g., river mouths. The total model grid size was 673 and 373 in the east-west and south-north directions, respectively. This resolution gave the model cells an approximate size of 1.5 km in each direction. The model used 16 vertical layers. The vertical layers used a double-stretched sigma-coordinate system with the first 8 layers confined to the 0–200 m surface layer, where most of the mixing and eddy-related dynamics are confined to. It can be speculated that the number of vertical layers for the correct representation of the vertical structure of the eddy dynamics. However, within the scope of this study, it has been shown that the number of vertical layers was enough to capture the tracer dynamics and the dynamics of the circulation and the eddies at the surface.

The bathymetry of the model was obtained from the General Bathymetric Chart of the Oceans (GEBCO) (Becker et al., 2009). GEBCO is a 30 arc-second database for the oceans of the entire world. The data for the Black Sea were extracted and then interpolated onto the model grid. Because the resolution of the model was higher than the GEBCO bathymetry data, interpolation could create abrupt changes along the model's bathymetry. Since the nature of the sigma-coordinate used in the vertical did not go well with abrupt changes in the bathymetry, the model's bathymetry was smoothed using a Shapiro filter

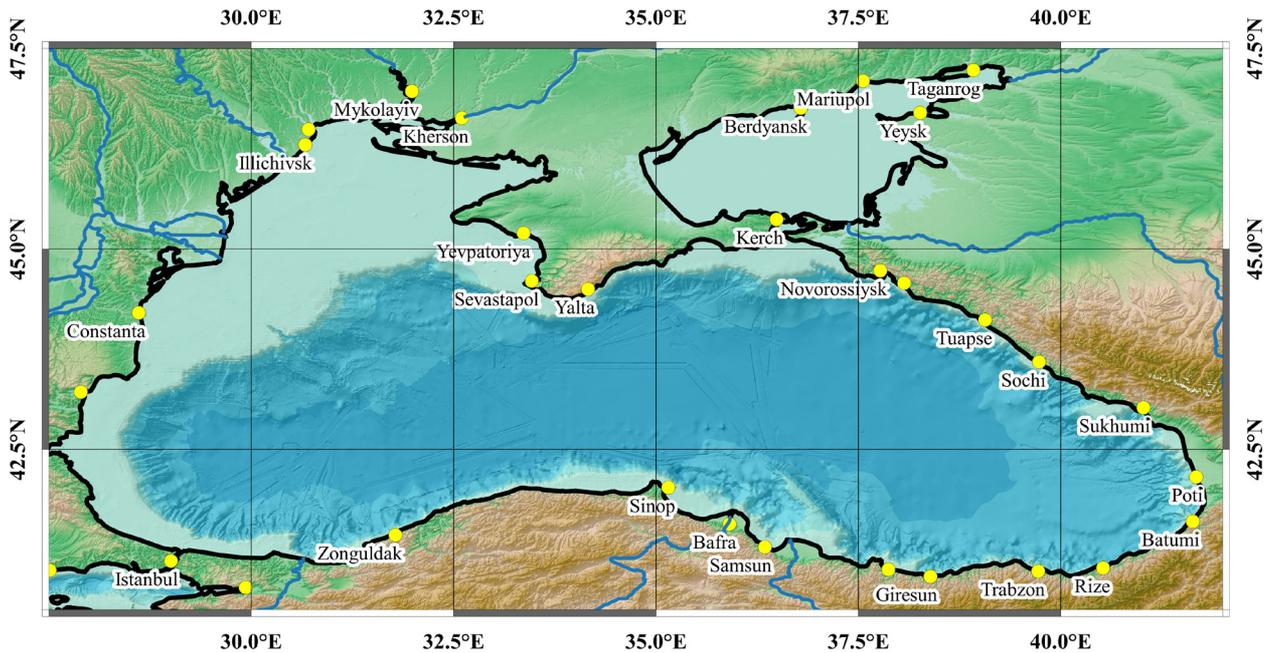


Figure 1. Black Sea region and model domain bathymetry and topography.

to clean these changes. Although the bathymetry has been smoothed, the very high resolution will compensate for the loss of Rim Current and bathymetry interaction. Staneva et al. (2001) imply several studies that resolved the continental slope with a 5 km grid cell size. Thus, the high resolution (~1.5 km) will remedy the smoothing and still capture the continental slope, as well as the interaction of Rim Current with the slope.

The topography of the model was created using E-TOPO v2 (NGDC, 2006). Nonetheless, since the model configuration in this study did not use wetting-drying (ability to change water and land cells), the topography data had no influence on the model simulations, except for the correct representation of the land cells in the model grid.

2.2. Model setup and forcing

The ocean model for the Black Sea was set up for a 9-year simulation. The simulation period started in January 2012 and ran for 9 years.

2.3. Initial Conditions

To successfully simulate the oceanic conditions, ocean models should start from a representative initial state. The initial conditions required for the Black Sea model in this study were mainly 4 different parameters as salinity, temperature, sea surface height and current velocities.

The salinity and temperature values for the entire 3D model domain were obtained from the MEDAR/MEDATLAS II platform (Fichaut et al., 2003). MEDAR data constitute

a gridded dataset, and they include the climatological values for salinity and temperature on 21 vertical levels. The values from the MEDAR platform were interpolated on the Black Sea model grid in 3 dimensions using all longitude, latitude, and depth information.

The sea surface height anomaly (SSHA) data for the model were obtained from the Copernicus Climate Change Service Climate Data Store in the form of satellite altimetry data (C3S, 2019a). The data contained 1/8-degree SSALTO/DUACS Delayed-Time Level-4 sea surface height information measured by multisatellite altimetry observations over the Black Sea. The SSHA data from this dataset were interpolated onto the model grid on the simulation start date to introduce the initial SSHA condition. Aside from these parameters, the model was initialized in a calm state in terms of barotropic or baroclinic velocities.

2.4. Boundary conditions

The Black Sea contains many river sources that bring in freshwater to the basin. Although not all these rivers have available data, the flow rates of the 7 main rivers from around the Black Sea were extracted from the RivDis database (Vorosmarty et al., 1998) as monthly mean values. A similar river configuration has been used for several different modeling efforts (Kara et al., 2008; Gunduz et al., 2020). The list of the rivers and their monthly values are shown in Table 1.

Table 1. Black Sea climatological river discharge values (m³/s).

Month	Danube	Dniestr	Southern Bug	Dniepr	Rioni	Kizilirmak	Sakarya
January	5940.7	207.1	86.8	1369.0	302.4	212.9	267.9
February	6219.3	294.6	124.5	1602.1	345.4	256.1	272.4
March	7367.1	550.6	258.6	1672.9	429.8	328.4	295.2
April	8574.0	615.1	215.2	2477.6	652.9	308.2	269.9
May	8937.9	460.1	86.3	2893.1	610.1	231.2	183.0
June	8315.7	502.8	71.0	1616.6	533.6	157.0	146.7
July	7122.5	475.5	89.6	1057.6	426.9	118.2	122.8
August	5519.1	348.8	66.5	941.9	325.4	123.8	110.8
September	4703.8	288.4	67.3	841.5	240.2	147.4	112.0
October	4446.5	247.3	88.5	979.8	293.7	167.6	123.6
November	4996	260.9	85.2	1111.5	356.6	173.4	218.4
December	5839.9	250.2	85.8	1240.9	385.1	202.6	191.8

Two of the challenges with Black Sea models are the inflow and outflow through the Bosphorus Strait. The reason for this is that there is not enough measurement data about the variability nor there is consensus about the values of the inflow and outflow. Because the model configuration was a closed basin for the entire Black Sea, the freshwater balance should be accounted for. The method used in this model configuration involved adjusting the mean monthly measured values of the lower and upper layer from Altiok and Kayisoglu (2015) according to the model freshwater input from the rivers, precipitation, and loss of water due to evaporation. Therefore, the model conserved the amount of water input/output with yearly cycles.

Atmospheric forcing was required for the model application to cover more than the Black Sea's surface area so that the ROMS model could interpolate the required forcing variables onto the ocean grid. The forcing parameters for the entire simulation period were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-5 Reanalysis data set through the Copernicus Climate Change Service Climate Data Store (C3S, 2019b). ERA-5 is an hourly dataset that has a spatial resolution of 0.25 degrees. 10 m wind velocity, short and long wave radiation, air temperature (2 m), mean sea level atmospheric pressure, relative humidity, total cloud cover, evaporation, and precipitation parameters were all obtained from the ERA-5 dataset.

One concern for atmospheric forcing is the continuity of the parameters. The model simulation in this study was set to start at a certain date and time. However, the ERA-5 dataset was continuous at the given time. Therefore, it could contain strong weather events that would make the

model simulation unstable. Smoothing was applied to the ERA-5 dataset using a hyperbolic tangent function for the first 3 days of the simulation, which prevented abrupt changes in the atmospheric parameters, especially the wind speed values.

2.5. Observed data used in assessment

During the model skill assessment process, various sources of observed data were used with different properties and availability.

One of the model skill assessments was made using the comparison of the Sea Surface Temperature (SST) satellite data. The SST for the entire Black Sea was obtained from the Optimally Interpolated Advanced Very High-Resolution Radiometer (AVHRR-OI) data (NCEI, 2016). The data were limited to the dates between 01/01/2012 and 20/07/2019.

The skill assessment of the SSHA model was achieved using the same SSHA data obtained from the Copernicus Climate Change Service Climate Data Store (C3S, 2019a). The data period for the comparison purposes was limited to the period from 01/01/2012 to 15/10/2019.

In addition to the basin-wide data, profiles from different Argo Floats were used for assessing the skill of the model. The Argo float dataset consisted of all profiles that were found in the Black Sea during the simulation period. A total of 2320 useable vertical CTD profiles were obtained from the Argo float database through the SeaDataNet services platform (SeaDataNet, 2015). Each Argo float data point was a different CTD profile that had a specific date and time associated with it. The Argo float profiles included information on the temperature, salinity, and

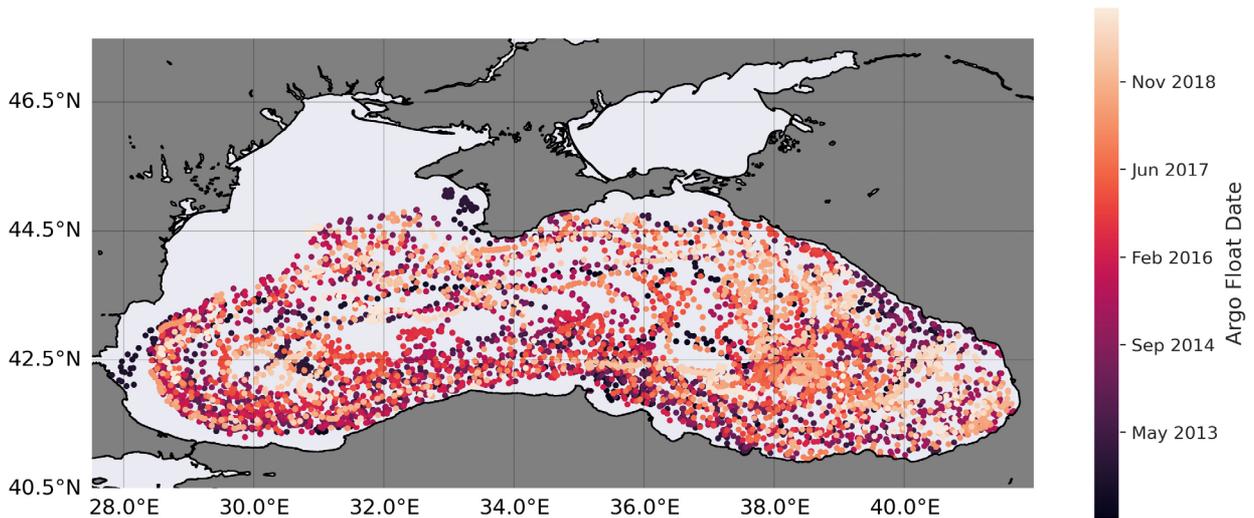


Figure 2. Argo float distribution (2012–2021) (Colors indicate date).

depth at each location. The distribution of the Argo floats data for the time period from 2012 to 2020 is shown in Figure 2.

2.6. Model stability and spin-up

The model was used for the same time period effectively twice. The first cycle took the model from the given initial conditions and ran it for 9 years (2012–2021). Then the model results from the end of the run are used as the initial condition for the second cycle of the model run, in effect making the first cycle of the simulation the spin-up cycle. However, because the model fields might be highly sensitive to the variations, all the analyses are done skipping the first year of the second cycle (2013–2021). After the second cycle of the model simulation has been completed, the model results were checked for the basin-wide total turbulent kinetic energy (TKE). When the model had reached a balance (except for seasonal variation), the model was assumed to be stable, and the preceding time period was assumed to be the spin-up time period. The TKE results showed that the model reached a stable condition after around 6 months of simulation. However, for the sake of being on the safe side and making sure that the spin-up did not alter the analysis due to seasonal variations in the second cycle, the entire first year of the simulation was assumed to be also the spin-up period. Therefore, the first-year model results were not used in the assessments of the model's skill.

3. Model skill assessment

In this section, the model skill assessment methods that were used in this study and the results of the assessments are explained in more detail.

3.1. Assessment of sea surface temperature (SST) with satellite data

Using satellite data, the model was compared in 2 different ways: 1) comparison of daily SST values, cell by cell and 2) comparison of basin averaged daily SST time series between model and data for the RMS error.

Comparing the entire surface of the Black Sea between the model and the satellite datasets required an interpolation. Since the model resolution was higher in comparison to the resolution of the satellite dataset, the model data were interpolated onto the satellite data grid to prevent superior data formation due to extrapolation. After the interpolation, the temperature values from each cell were stored for the overall RMSE comparison of the simulation. The mean RMSE for the daily SST values compared cell by cell from the model was determined as 1.68 °C.

In the comparison of the time series for the basin averaged SSTs (Figure 3), both model results and satellite data were averaged over the entire Black Sea. The model result showed strong agreement for the time variation of the daily basin averaged SST values. When compared numerically, the coefficient of the correlation between the model and the data was found to be $R = 0.98$, and the RMSE value was calculated as 1.03 °C. In comparison to the first analysis, this result indicated that there might have been high local error values, which were eliminated with the basin averaging step.

3.2. Assessment of Sea surface height anomaly (SSHA) with satellite data

The SSHA values from both the model and the satellite data were analyzed and assessed using empirical orthogonal functions (EOFs). EOF analysis provides a better method

for the analysis of SSHA since the sea surface height is much more dynamic relative to the SST variation. Therefore, even local forcing changes might create different results. With the EOF analysis method, the main trend of the model can be compared to the satellite altimetry dataset.

The cumulative variance of the model result and the satellite data was calculated, they provided a very similar trend. The model lacked some of the variances of the satellite data by up to 10%. The order of magnitude, especially where the first mode of EOF was responsible for up to 75%–80% of the variability, was in considerably good agreement between the model and the satellite data (Figure 4). Moreover, the cumulative variance of the first 10 modes accounted for up to 92% of the SSHA.

In addition to the cumulative variance, the spatial variation of the 1st mode of EOF between the satellite data and the model results is presented in Figure 5.

3.3. Assessment of temperature and salinity profiles with Argo float data

In addition to the surface comparisons of temperature and salinity, during the simulation period, 2320 CTD profiles obtained with the Argo float data were used to compare the vertical variation of temperature and salinity. Since Argo floats were moving along the Black Sea, they reported profiles for different time periods and different locations. Each model profile for the corresponding date, time and location was extracted from the model results and compared to the Argo float salinity and temperature data.

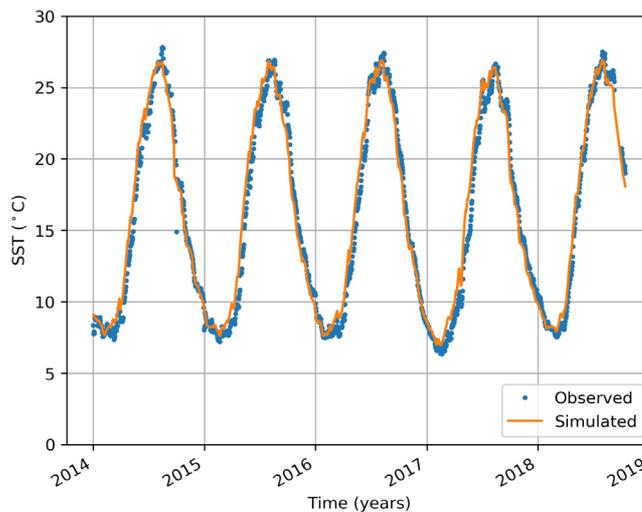


Figure 3. Daily basin averaged SST comparison between model and OISST data (2014–2020).

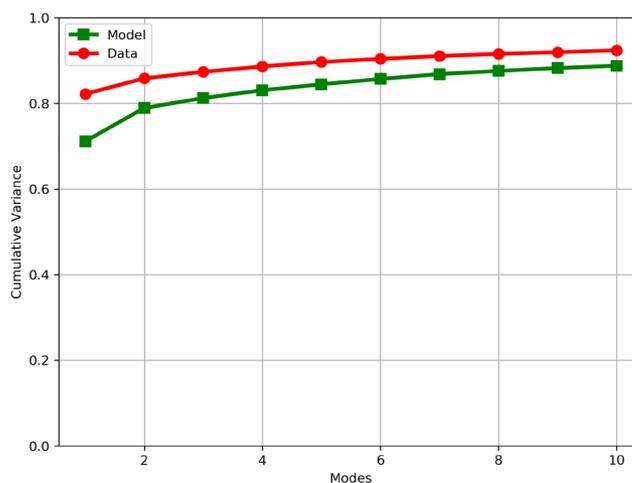


Figure 4. Cumulative variance comparison of satellite and model SSHA values (2013–2020)

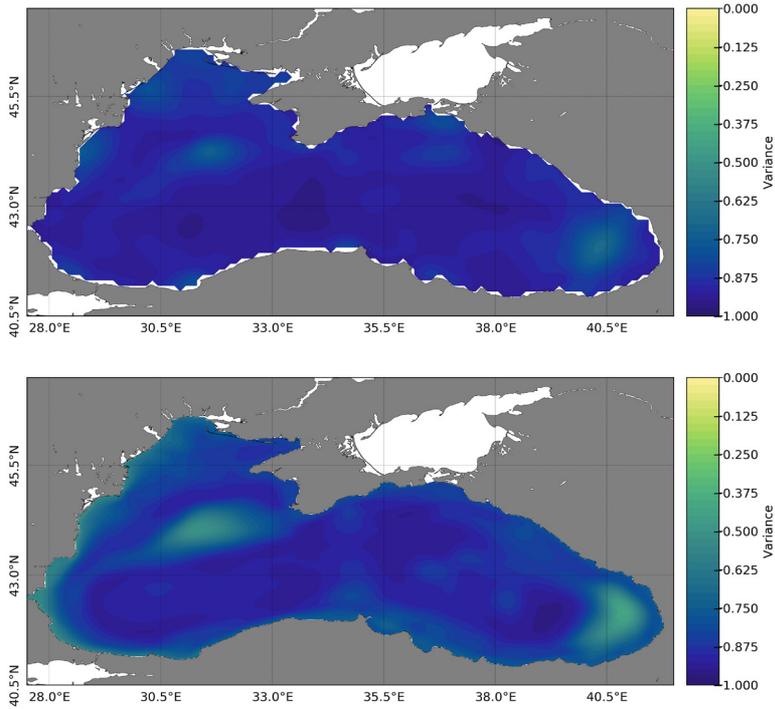


Figure 5. Comparison of spatial variation of 1st mode of EOF variation along the Black Sea between satellite SSHA (upper panel) and model data (lower panel) (2013–2020).

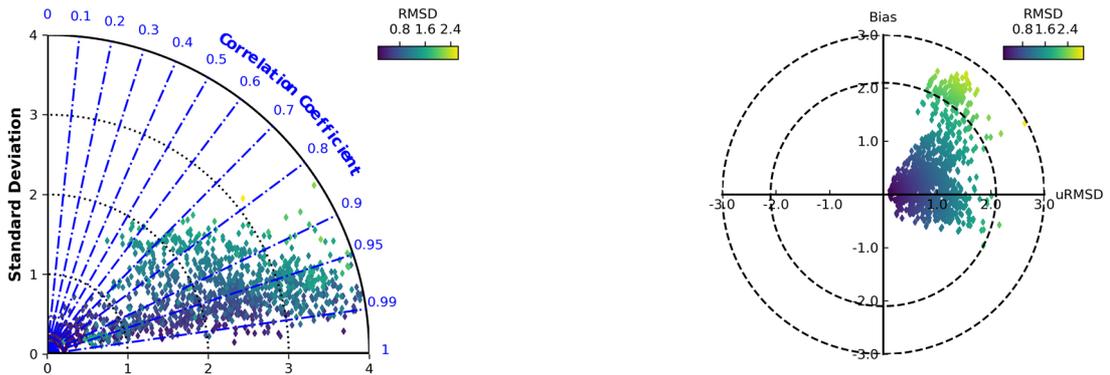


Figure 6. Taylor and Target diagrams for the temperature comparisons over the entire depth.

The RMS error for the entire water column for temperature was 1.28 °C, which mostly occurred at the top part of the water column. The Taylor and Target Diagrams including the results of all CTD profile comparisons to the model data for the temperature parameter are given in Figure 6.

The RMS error for the entire water column for salinity was 0.71 PSU. The Taylor Diagram including the results of all CTD profiles for the salinity parameter is given in Figure 7

When the profiles were divided into layers of 0–100m, 100m–300m, and 300m–800m to quantify where the error was accumulating, the error was found to mostly accumulate at the top of the profiles. This indicated a similar error distribution as in the case of the SST values. The mean RMSE values of the layered profiles are given in Table 2.

This result was consistent with the SST comparisons, where the RMSE value for the SST for the model simulation period was found to be 1.68 °C. Although there was no

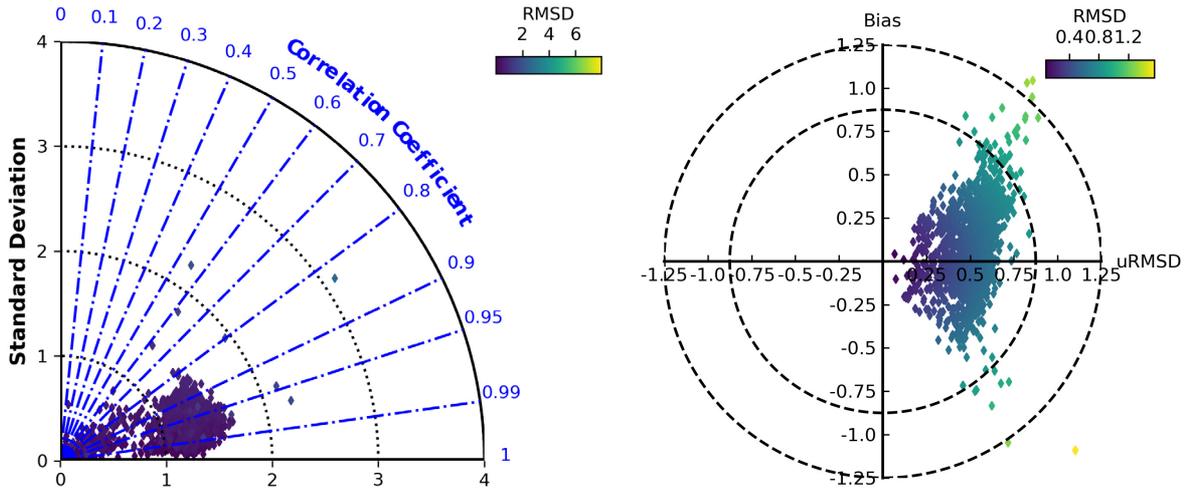


Figure 7. Taylor and Target diagrams for the temperature comparisons over the entire depth.

Table 2. RMS error values for different depth layers.

Layer Depth (m)	Temperature RMSE (°C)	Salinity RMSE (PSU)
0–100	2.02	1.17
100–300	0.72	0.39
300–800	0.03	0.13

surface salinity comparison, it was also expected to have the largest deviations from the observed data at the surface due to the top layer being the most dynamic layer of all.

In addition to the vertical profiles, comparing the T-S diagrams from both the model and CTD profiles showed a strong similarity (Figure 8). The model results successfully captured the temperature minimum at a given salinity, as well as the temperature-salinity maximum on the right-hand side of the tail. Additionally, the model successfully simulated the low-salinity tails on the left-hand side due to freshwater input and mixing.

Another means of qualitative comparison between observed and simulated data is using the Relative Operating Characteristic (ROC) curves and scores that are defined by the Area Under the Curve (AUC) (Pontius and Schneider, 2001; Sheng and Kim, 2009). ROC curves are used mostly for classification purposes and visualized as the rate of True Positives (TP) vs. the rate of False Positives (FP). A curve closer to 1 indicates better results. The results of ROC curve analyses are represented with the AUC value. It is a rational number between 0 and 1. The model is accepted to have more skill as the AUC value gets closer to 1.

The results of all vertical profile calculations in this study are represented using the ROC curves. The simulated salinity and temperature ROC curves are shown in Figure

9. The AUC value was found as 0.49 for temperature and 0.967 for salinity, which indicated a successful comparison overall.

3.4. Model capabilities for eddy simulation

One of the purposes of developing this high-resolution model was to use it as a tool for understanding the eddy dynamics in the Black Sea. In the previous sections, it is shown that the model was capable of simulating the physical properties of the Black Sea in terms of salinity, temperature, and sea surface variation. Additionally, the circulation results showed that the model was capable of simulating the complex circulation of the Black Sea, the main features of the Rim Current, prominent eddies of Batumi and Sevastopol, as well as the small-scale coastal cyclones and anticyclones (Figure 10).

In addition to these model skill assessments, the model's capacity to simulate different-sized eddies for the Black Sea is presented here. Using the daily averaged sea surface height fields from the model, the eddies were identified using the method reported by Chelton et al. (2011). This method uses the closed loop of sea surface height rings to identify the presence of local minima and maxima which implies an eddy formation. The basic distributions of the eddies that were obtained from the simulation are presented in Figure 11. The distributions indicated that the model was capable of simulating eddies as small as 5-6 km

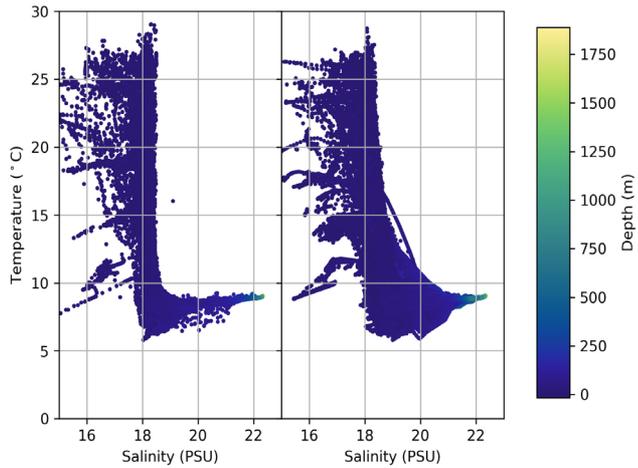


Figure 8. T-S diagram for observed CTD data (left panel) and modeled data (2013–2020) (right panel).

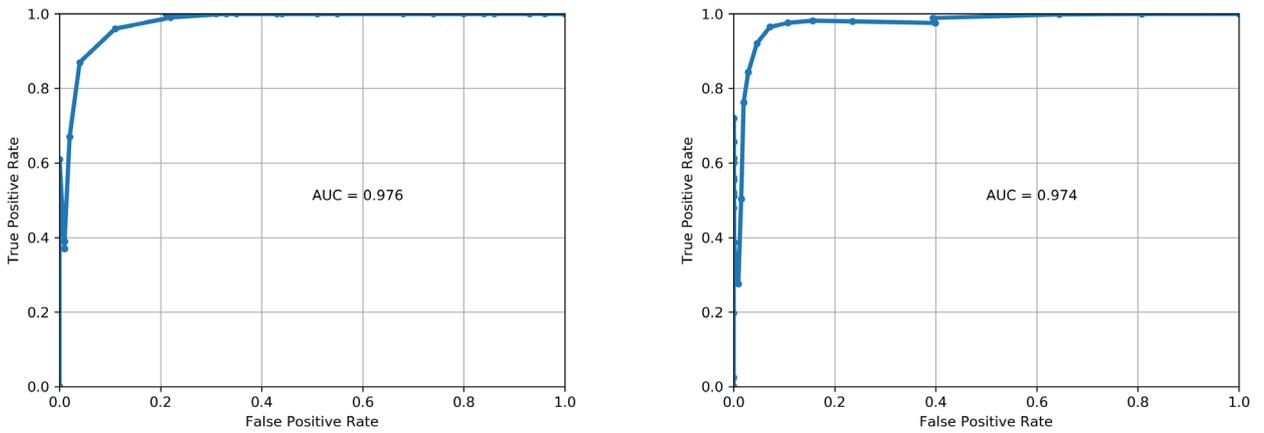


Figure 9. ROC curves and AUC values for a) salinity and b) temperature.

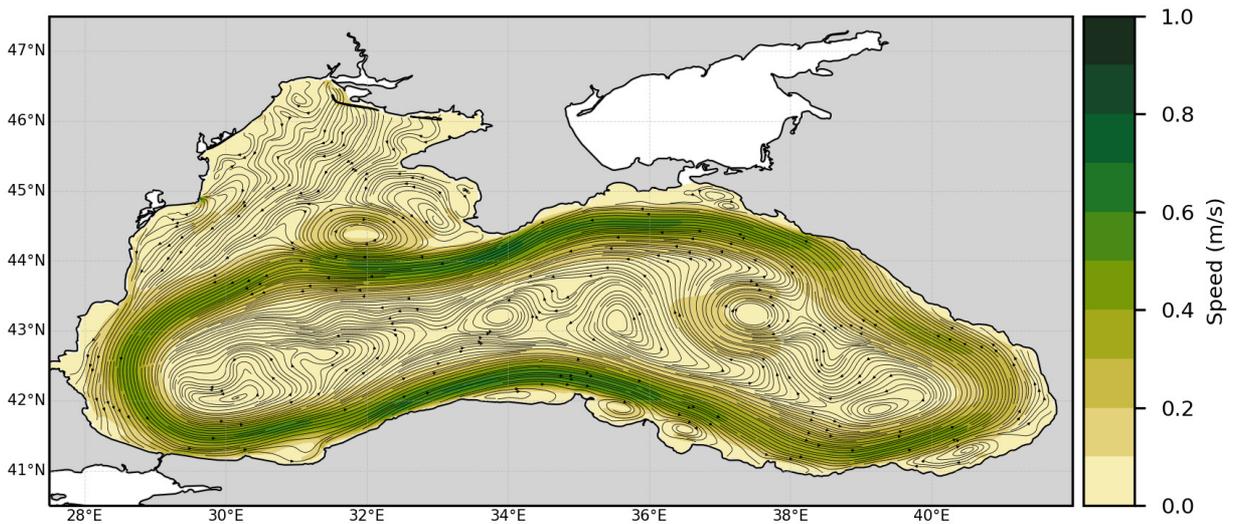


Figure 10. Yearly mean model circulation (2013–2020) result showing the rim current, prominent eddies, and small coastal eddies.

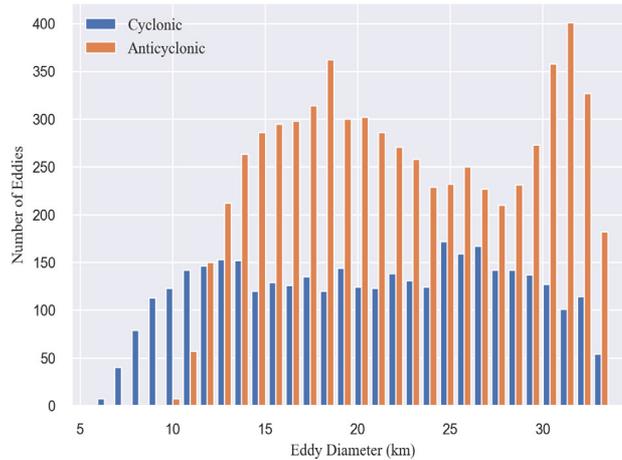


Figure 11. Distribution of eddy size and frequency for the model simulation (2013–2020).

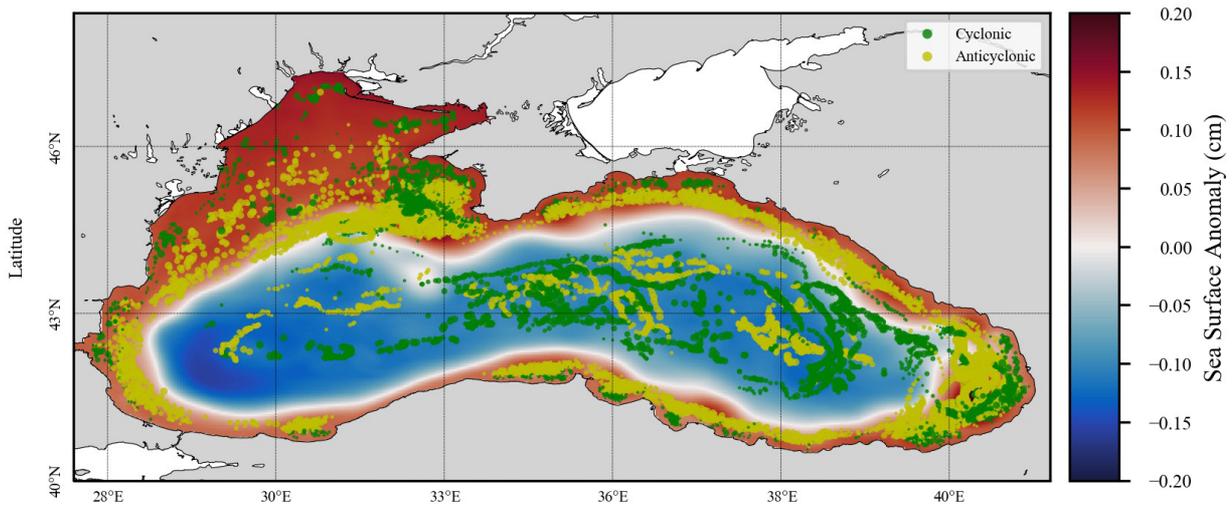


Figure 12. Spatial distribution of unique identified eddies (2013–2020).

and as large as 35–40 km in range. Although larger eddies could be identified visually within the model results, the upper scale range on the mesoscale side was limited by the identification algorithm. Thus, it was not fully represented.

Considering first Baroclinic Rossby radius to be around 20–30 km (Oguz et al. 1995, Kurkin et al., 2020) and also the 7 dx approximation for the submesoscale energy cascade (Martinez et al. 1997), the resolution for capturing the dynamics of the submesoscale structures would require at least around 3 km resolution ($\sim 1/36$ degree). Therefore, the high resolution presented in this paper should be enough for a good approximation for capturing the submesoscale eddies. The size distribution of the eddies given in Figure 11, suggests that the model is capable of capturing eddies around 5–6 km in diameter, which is within the submesoscale eddy size range. According to the spatial distribution of the eddies (Figure 12), it was clear that semi-permanent eddy structure locations for Batumi

and Sevastopol were very dynamic, as well as most of the coastal region, and both cyclonic and anticyclonic eddies were formed and identified.

In addition, satellite-derived Sea Level Anomaly (SLA) data was subjected to the same algorithm to obtain the eddies. The comparison of the model simulated and SLA-derived mesoscale eddies are presented in Figure 13.

4. Discussion

The Black Sea is one of the most researched bodies of water. It has basin-specific hydrography. The model configuration presented in this paper was an attempt to capture the dynamics of the Black Sea's physical oceanography and extend the model dynamics to the mesoscale-to-sub-mesoscale eddy dynamics.

The model had a high horizontal resolution (1/72 degree) covering the entire area. Using this configuration, the model was capable of simulating the variability of the

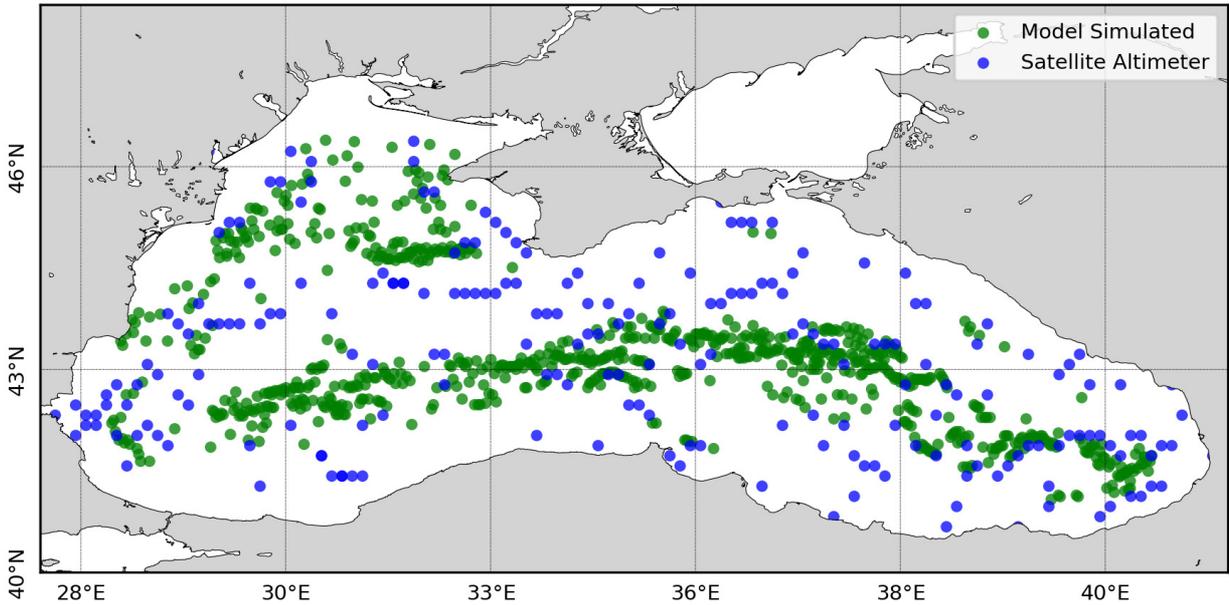


Figure 13. Distribution of mesoscale eddies obtained from the model simulation and satellite derived SLA data (2013–2019).

physical tracer parameters of salinity and temperature, as well as the currents and eddy formations.

In the results section, the verification of the model is presented using different model skill assessment techniques.

The model successfully simulated the basin averaged SST and SSHA values over the simulation period. Although the model underestimated both SST and SSHA in terms of RMSE, the variability was successfully simulated with respect to time.

The EOF comparison of the SSHA values showed that the model was capable of simulating the modes of SSH throughout the basin. The variance of EOF for different modes showed similar trends to the first 10 modes, representing 94% and 90% of the total variance for the observed and simulated datasets, respectively.

In addition to the surface value comparisons, the simulation results were compared to more than 2300 CTD profiles obtained with Argo floats. The model showed a similar capacity to the successful simulation of the profiles. Out of 2320 profiles, the mean RMSE value for temperature was 1.68 °C, and the mean RMSE value for salinity was 0.71 PSU. The model results showed higher error values towards the surface layer (0 – 100 m) for both salinity and temperature. On the other hand, as the profiles reached deeper layers (100–300 m and 300–800m), the model got

much better in simulating the oceanographic parameters. The error value was reduced to 0.03 °C for temperature and 0.13 PSU for salinity.

When circulation is considered, although there was no good source of observed circulation values, the model was quite capable of simulating the general dynamics of the circulation in the Black Sea (Oguz et al., 1994) with the prominent features of the Batumi and Sevastopol eddies.

Since the model resolution was very high (1/72 degree), it had the capacity to simulate the eddies that were as small as a range of 5–10 km in radius. This allowed the model to simulate and represent especially the coastal anticyclonic eddies that were formed on the Anatolian coasts of the Black Sea, such as the Sinop and Kızılırmak eddies. The high resolution used in this model will allow further research into mesoscale-to-sub-mesoscale eddies, their interaction with the coastal zone, including the ecosystem dynamics and exchange of matter between the coastal sea and the open sea.

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