Comparison of the forecasting results of Black Sea surface temperature obtained in the FSBSI MHI and Copernicus marine environment monitoring service

A L Kholod, Yu B Ratner and M V Ivanchick

Federal State Budget Scientific Institution “Marine Hydrophysical Institute of RAS”, Sevastopol, Russia

E-mail: antonholod@mail.ru

Abstract. The paper considers the matters of numerical modelling and forecast estimation accuracy of sea surface temperature in the two monitoring and forecasting centers of the Black Sea – in Federal State Budget Scientific Institution «Marine Hydrophysical Institute of RAS» (FSBSI MHI) and Copernicus marine environment monitoring service. The CTD (Conductivity Temperature Depth) profiling data of in situ measurements from research vessel “Professor Vodyanitskiy” were used to solve the problem. Spatial and temporal mismatch between the model data and in situ measurements was eliminated to form a joint sample of these two data sources. Comparison was performed for the time period from October 2017 to September 2018 and showed that the forecasting results of sea water temperature in FSBSI MHI are more reliable than in Copernicus marine service for all forecast terms.

1. Introduction
The sea surface temperature (SST) is one of the main parameters characterizing the state of the World Ocean. It allows solving the problems of weather forecasting, ocean state, climate change etc. Therefore, continuous monitoring and forecast of the marine environment state including sea surface temperature are necessary. Currently, numerical circulation models are used for these purposes in different monitoring and forecasting centers.

One of the centers is developed in Marine Hydrophysical Institute where an automatic operational system of analysis and forecasting of the Black Sea state [1] has been run since 2012. Daily calculations of the temperature, salinity, current velocities and sea level fields – from the surface to the bottom of the Black Sea – are carried out. The similar system has been created and is run operational at the Euro-Mediterranean Center on Climate Change (Lecce, Italy). It is an integral part of the Copernicus marine environment monitoring service [2].

The purpose of this work is to estimate the accuracy of numerical simulations and forecast of the Black Sea surface temperature in two different centers by their comparison with in situ measurements of CTD profiling data from research vessel “Professor Vodyanitskiy”. Several papers were published earlier [3, 4] and provided estimations of the numerical modeling accuracy of the Black Sea fields based on a comparison with in situ measurements. But it impossible correctly compare the accuracy of the Black Sea surface temperature in different centers because the accuracy of the estimations from [3,4] obtained by using different comparison methods and different comparison time periods. Validation of the Black sea temperature in the upper layer from three leading prognostic systems is carried out in the paper [5]. But this validation
is carried out when the systems run only in the now casting mode. In this article we estimate the accuracy of SST forecasts from one to five days in two centers: FSBSI MHI and Copernicus service.

2. Data used

The work of the automatic analysis and forecasting system of the Black Sea state in FSBSI MHI is based on the three-dimensional basin-scale circulation model which is elaborated by Marine Hydrophysical Institute [5]. The horizontal turbulent viscosity and diffusion are parameterized in the model by the bi-harmonic operator. The state equation includes quadratic terms. The Mellor-Yamada 2.5 model [6] is used to simulate vertical coefficients of turbulent viscosity and diffusion. The model equations are integrated numerically in the Black Sea area situated between 27.422°E and 41.895°E along the longitude and between 40.863°N and 46.685°N along the latitude on the regular horizontal grid with a step of ~ 5 km (11/180 deg lon x 8/180 deg lat). The selected horizontal grid step allows to resolve a meso-scale variability of the basin, bearing in mind that the Rossby radius is equal to 25 km. The model has 38 vertical levels non-uniformly distributed from 2.5 to 2100 meters. The finite-difference approximation of the equations is carried out on the C-grid according to the terminological of Arakawa with the second order of accuracy both in space and time in case of a uniform grid. The scheme conserves energy and enstrophy of barotropic motion [7]. The equation describing evolution of the sea level is approximated using a semi-non-explicit scheme. Approximation of the turbulent energy equations allows using the conveyer method of their solution. The data of atmosphere forcing are selected every 3 hours from the 5-day SKIRON modeling system [8] and are executed on a bulk daily mode.

The near real time system of Copernicus marine service is based on a hydrodynamic model implemented over the whole Black Sea basin. The model horizontal grid resolution is 1/36° in zonal resolution, 1/27° in meridional resolution and has 31 unevenly spaced vertical levels. The hydrodynamics are supplied by the Nucleus for European Modeling of the Ocean (NEMO, v3.4). The model solutions are corrected by the variational assimilation (based on a 3DVAR scheme), originally developed for the Mediterranean Sea and later extended for the global ocean. The observations assimilated in the Black Sea system includes in-situ profiles, along-track sea level anomalies and gridded sea surface temperature provided by Copernicus thematic assembling center. The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae using high spatial resolution (1/8°) atmospheric forcing provided by the European Centre for Medium-Range Forecast.

SST fields were validated using the observations carried out by the CTD profiling data of in situ measurements from research vessel “Professor Vodyanitskiy” in the Black Sea from October 2017 to September 2018. Geographical and temporal distributions of stations performed from research vessel “Professor Vodyanitskiy” in the Black Sea area from October 2017 to September 2018 are shown in figure 1.

![Image](image_url)

**Figure 1.** CTD measurements performed from research vessel “Professor Vodyanitskiy” in the Black Sea area from October 2017 to September 2018.
It is seen that the measurements cover central and north-eastern parts of the Black Sea. 434 CTD profiles were available during the whole study period. The temporal distribution shows that in situ measurements were made in summer and winter seasons.

3. Comparison methodology
Joint sampling of the numerical modeling results of the Black Sea surface temperature and in situ measurement of CTD profiling data was formed in order to compare them. One of the central problems in its formation was due to the fact that the location of in situ measurements and the nodes of the model grid are spaced apart in space and time. Therefore, it is necessary to combine the data in the best way in order to minimize the comparison errors due to space and time mismatch.

Taking into account the variability of the sea surface temperature, a linear interpolation method was used to form a joint sample and eliminate the space and time mismatch. Model data were interpolated in time and space on time moments and localization points of in situ measurements. Further, the vertical profile of in situ measurements was interpolated to the first vertical level of the model—2.5 meters. As a result, a joint sample of data was formed and analyzed for outliers. Outliers caused by upwelling zones, eddies and temperature fronts were excluded from further analysis. The comparison was carried out for different terms of forecasts – one, two, three, four and five days. Accordingly, five sets of statistical estimates – bias and standard deviation – were obtained for each forecasting center.

4. Results
The accuracy of the forecasting results of the Black Sea surface temperature obtained in the FSBSI MHI and Copernicus marine environment monitoring service are presented in table 1.

| Forecast term | FSBSI MHI | Copernicus |
|---------------|-----------|------------|
|               | N | µ (°C) | σ (°C) | N | µ (°C) | σ (°C) |
| 1             | 412 | 0.11 | 0.41 | 321 | 0.18 | 0.55 |
| 2             | 412 | 0.15 | 0.46 | 331 | 0.18 | 0.58 |
| 3             | 412 | 0.13 | 0.49 | 334 | 0.25 | 0.57 |
| 4             | 412 | 0.14 | 0.58 | 343 | 0.23 | 0.63 |
| 5             | 363 | 0.12 | 0.64 | 350 | 0.22 | 0.73 |

The table presents the statistical estimates of the bias (µ) and standard deviation (σ) for the five terms of forecasts. The column N contains information on the number of measurements contained in the joint sample for each forecast term. The archive of model calculations in the Copernicus marine service is sliding and is updated daily. The data of each forecast cycle is available for users during the day when this forecasting cycle is carried out. Therefore, daily downloads of the current forecast cycle were carried out interactively to form the archive. We failed to receive this information on some days for technical reasons. Therefore, the created archive has gaps in the data for some forecasting terms and therefore the total number of joint measurements (N) varies for different forecast terms.

The analysis of table 1 shows that in both centers there is a positive bias in the SST obtained by the model with respect to CTD in situ measurement. The accuracy of SST forecast in FSBSI MHI is more reliable than in the Copernicus service: the standard deviation is on average 15% less. The accuracy of forecasting decreases with an increase in the forecast term in both centers.

Figure 2 shows scatter plots between FSBSI MHI model and CTD in situ data for different forecasting terms.
Figure 2. Scatter plots between FSBSI MHI model and CTD in situ data for different forecasting terms: (a) – one day, (b) – three days, (c) – five days.

The CTD probe data are plotted along the X-axis, and the data of model calculations are along the Y-axis. Most of the joint values are concentrated near the line of equal values. They are marked by circles. Data related to outliers are located far from the line of equal values and marked by triangles. Points’ clouds are scattered relative to the line of equal values with an increase in the forecast term, which is a bright illustration of an increase in the mean-square error of forecasts with an increase in their terms.

A similar situation is observed for scatter plots in figure 3 which shows the results of calculations by the Copernicus marine service model and CTD in situ data for different forecasting terms.

Figure 3. Scatter plots between Copernicus marine service model and CTD in situ data for different forecasting terms: (a) – one day, (b) – three days, (c) – five days.

Figure 2 and figure 3 are similar because the comparison was performed on the same array of in situ measurements. However, it can be seen that the points’ clouds are more scattered and are shifted relative to the line of equal values which means that the systematic and standard deviations are greater than for the FSBSI MHI model. We can see two areas that correspond to the summer and winter seasons on each plot. The comparison in the autumn and spring seasons was not performed due to the lack of in situ measurement. The scattering of points relative to the line of equal values of temperatures in the winter season is noticeably less compared to the summer season. Systematic trends in the calculated values of the SST are not observed. There is an increase in temperature variation relative to the line of equal values with an increase in the forecast term in the summer season. This is confirmed by the values presented in Table 1.

Conclusions
The results were obtained in the summer and winter seasons, the processes of warming and cooling of the sea are not fully covered. There is a small amount of outliers in all cases of comparison results. The reason for these outliers is associated with data obtained near zones of upwelling, eddies and temperature
fronts. The results of calculations using the FSBSI MHI model are more reliable than using the Copernicus service model for all forecast terms both in cases with and without exception of outliers.

Acknowledgments
This work is supported by the Russian Science Foundation under grant 17-77-30001.

References
[1] Korotaev G K et al. 2016 Izvestiya Rossiiskoi Akademii Nauk: Fizika Atmosfery I Okeana 52 (5) 609–17
[2] Ciliberti S A et al. 2016 EGU General Assembly Conference 18
[3] Kholod A L et al. 2018 Estimation of the numerical modeling accuracy of the Black Sea thermohaline fields based on using ARGO profiling floats J. Phys.: Conf. Ser. 1128 012150
[4] Ciliberti S et al. 2019 Copernicus Marine Environment Monitoring Service 40
[5] Mizyuk A I et al. 2018 J. Phys.: Conf. Ser. 1128 012146
[6] Demyshiev S G, Korotaev G K 1992 IVM pp 163–231
[7] Mellor G L, Yamada T 1982 Reviews of Geophysics 20 (4) 851–75
[8] Arakawa A, Lamb V R 1981 Monthly Weather Review 109 (1) 18–36
[9] http://forecast.uoa.gr