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Geoscientific Model Development Discussions
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Interactive comment on "A Model of Black Sea Circulation with Strait Exchange (2008–2018)" *by* Murat Gunduz et al.

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Interactive comments (>> *italic black) by Anonymous* ***Referee # 1*** *(RC1).*

Authors' responses are given in blue print in each section

>>*The manuscript describes an implementation of the Black Sea circulation model (BSEA), which is based on the NEMO version 4.0 (Madec, 2008). The model domain includes the deep Black Sea basin (max depth: 2178 m) together with the shallow Azov Sea (depth 10m) in the north and the Marmara Sea in the south. In order to represent the Bosphorus exchange flows coupled to Black Sea, an artificial box representing the Marmara Sea and the Bosphorus Strait have been added to the domain. The manuscript focused mainly on the analysis of the 10-year (2009-2018) variations of*

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temperature and salinity using their monthly and sub-basin averaged values.

We thank referee # 1 for valuable comments, based on the brief reading of the paper.

>>The model could provide a good opportunity to improve the modelling ability of the Black Sea by incorporating the Bosphorus Strait into the simulations. However, I would like to express concerns that in its current form the manuscript focusing largely on the validation of a model rather than using the model to fully explore the processes responsible for the trends or capturing real dynamical features. This study does not focus adequately on new knowledge and instead focuses largely on developing and validating a model. I think the paper needs to be substantially revised in order to focus more on the new understanding of the processes that can be obtained, i.e. using the model as a tool to explore them. I recommend a major revision or possibly a resubmission.

Our main objective in the present study has been to achieve incremental new development of a model set-up for the Black Sea, satisfying inflow / outflow boundary conditions at the Bosphorus which allow to preserve approximate hydrological balance of the basin. This, however, is not a very simple task, technically not a well-posed problem to determine the natural limits of the model domain, subject to given constraints of ocean models. These limitations have been better appreciated in a series of past research articles carried out on the very systems of straits and basins that are in question (references partially provided in the present paper).*

In the present article, we aim for a realistic representation of the hydrometeorological fluxes of the Black Sea, with in and out fluxes created at the Bosphorus in response to an exterior box with specified seasonal hydrology. This approach allows addressing only one question at a time in an incremental way, identifying the Bosphorus climatological exchange as a missing element in earlier work on Black Sea modeling.

Otherwise we only know too well that the physical coupling between the basin-scale dynamics of the Black Sea and the energetic coastal-scale dynamics of the Bosphorus

Strait would lend themselves to detailed investigations much broader in context. For instance, in the present study, we have limited ourselves to the exchange fluxes through a straight channel and smooth topography not sufficiently resolved by the present model grid, simplifying the steep topography and keeping the dynamics of hydraulic controls and exit buoyant jets etc. (see references partially provided in the present paper) out of our focus and again circumventing the technicalities of where to set the artificial box domain to specify seasonal hydrography of the adjacent Marmara basin.*

While limiting our attention to Bosphorus fluxes provided by this simple coupling scheme, we also have made use of the best available re-analyses and hydro-meteorological data sets, in order to account for missing information on interannual river and overland hydrology, finally with an objective to test which of these sources of environmental controls lead to the best comparison with in-situ data, notably with the ARGO floats data set, reflecting the closest agreement with the rapid environmental change clearly observed in the Black Sea in the recent decades (Stanev et al., 2018, 2019).

While a general overview of historical development of Black Sea modelling is not in order within the present context, we only give a short review of Black Sea modeling that indirectly has accounted for Bosphorus fluxes in the previous models. To the best of authors' knowledge, modelling of the Black Sea circulation and hydrography allowing for a system of open boundary conditions applied at the Bosphorus has not been attempted in the available literature so far, although a number of stand-alone Black Sea models have attempted indirectly accounting for fluxes at the Bosphorus (Stanev et al., 2003, 2004, 2005; Miladinova et al., 2017, 2018). Our incremental model strategy, on the other hand, could be compared to the addition of an "Atlantic Box" preferred in the early phases of Mediterranean Forecasting System, MFS (Oddo et al., 2009), which only recently have been updated to involve further refinements of coupled systems (CMEMS, 2017). Recently however, there have been various efforts to couple the entire series of straits and basins of particular characteristics together, by mak-

ing use of high-resolution unstructured meshes (Ferrarin et al., 2018; Federico, 2017; CMEMS, 2017) which have yet to survive the various obstacles to properly represent coupling for each of the straits (not only Bosphorus and Black Sea but others), realistically accounting for fluxes variability between the various coastal and basin-scale elements.

In short, we do not agree with Referee #1 statement that the "paper needs to be substantially revised in order to focus more on the new understanding of the processes", although we aim to improve the manuscript based on the reviews. We provide the above summary on the development of a Black Sea model with improved Bosphorus fluxes, along with other refinements keeping abreast of the recent environmental changes in the system.

We have decided to revise the abstract and some paragraphs, which may have been interpreted by the Referee as general claims we have expressed of the present model had led us to conclude. Part of these claims was derived from other new evaluations of Black Sea climate, which are now better referenced. We would also like to state that our contribution to Geoscientific Model Development (GMD), as implied by the name, is within the scope of the international journal, serving for geoscientific model development other than the hypothesis testing expectations of the Referee.

$>>$ *Detailed comments are provided below. Main points: In my opinion, a major weakness of the manuscript is the lack of hypothesis testing. In the Abstract the authors suggested that "The present formulation with temperature and salinity relaxed to the observed seasonal climatology of the Marmara box and open boundary conditions are found to enable Bosphorus exchange with an upper, lower layer and net fluxes comparable to the observed range. This, in turn, enables to capture the trend of rapid climatic change observed in the Black Sea in the last decade." I did not find in the entire manuscript how the authors test and prove the above hypothesis that their model can capture the trend of rapid climatic change. The manuscript does not present any new aspect or particular characteristic of the Black Sea hydrodynamics. For example,* *I would like to see how the new approach, taking into account the Bosphorus Strait in simulations, helps to gain new knowledge about the disappearance of the cold intermediate layer (CIL). Comparison with other existing Black Sea models is not presented, so I cannot decide whether the proposed model better simulated the Black Sea hydrodynamics or not.*

We have edited the abstract to express better the quality of predictions based on improvements in the Bosphorus open boundary and the Black Sea, as well as the data sets used in verification. Our earlier statements in the abstract may have implied that the observed environmental changes in the Black Sea system were directly connected with the methods we used; while in fact various sets of independent observations point to the particularly rapid changes in the Black Sea. We only have gotten closer to their representation in the model, thanks to the improvements we have made.

Along the same line of our earlier comments, the main purpose of the present study has not been hypothesis testing in the most general sense, but rather to search for one of the most essential Black Sea model improvements needed to account for seasonal fluxes at the Bosphorus open boundary, being one of the essential elements of overall hydro-climatology. On the other hand, we believe closing the gaps of knowledge in predictions of the present and future states of the system in question can certainly form the basis for hypothesis testing.

We aim to produce better results, choosing the most recent version of the ocean model core, as well as the best available sets of observational data sets, evaluated in the present study.

The model has been rigorously evaluated by comparison of the results with the available observations obtained by ARGO floats. The figures shown in the comparison section of the paper were constructed by using all available ARGO floats data. To the authors knowledge, very few previous attempts have been made to compare model results with the freely available data sets supplied by ARGO floats over many years. It *is one of the main contributions of our novel Black Sea modelling effort that will have made its impact on reliable results.*

On Referee #1 comments on whether the new model improvements had any new knowledge added on Black Sea hydrodynamics, we would like to answer with particular tests we have made during this work.

Indeed, there were some significant differences in model behaviour in early runs with one grid artificial open boundary, compared with the seasonal hydrology specified in an external box. The model improvements far surpassed the short-term, seasonal and interannual variability and trends demonstrated in predictions of earlier cases which were not always in the same periods and model settings, and therefore not worthy of mention.

In-house sensitivity analyses corresponding to the model setup have been made but had to be skipped, being outside the scope of the present study. Further comparisons with most recent coupled models and observations, that in fact, we should not allow to be publicly shared, are provided to counter some claims of Referee #1. We only provide them in order to show that questions of reliability and testing have been answered outside the scope of the present paper submitted to GMD.

The following figures from a follow-up study are only privately provided for comparisons between Bosphorus temperature data predicted by using the same setting as the present study with respect to observed temperatures and those predicted in the current Black Sea CMEMS context. The continuous observations have been obtained at station K2 (described in AltÄśok and KayÄśşoÄ§lu, 2015 and Özsoy and AltÄśok, 2016a,b) next to the exit of the Bosphorus shown in Figure 1.

The predicted temperature at 60 m depth compared with observations at station K2 are given in Figure 2. The red line is the observation, the black line is what is replicated by the current model and the green line is the most recent CMEMS operational Black Sea model, which seems not to have reached proper Bosphorus dynamics. The model *improvements replicating those within the current study are clearly demonstrated in this figure. The temperature of the lower layer water of Mediterranean origin in the Bosphorus (well-known from many years of measurements in the Bosphorus, in the literature cited in the present paper) is better represented with the current model.*

The main improvements in the present study were in all time scales in question, and have been tested to produce extensive comparisons with the ARGO hydrology and sea level data, much different from the early cases, and parameter sensitivity was always tested.

The current objective of incremental model development for coupled Black Sea and Bosphorus has thus been achieved in the present study. We intend to continue scientific investigations aimed to fully understand coupled hydrodynamics of adjacent basins and straits, in addition to further investigations of climatic/environmental changes in the region with extended periods and domains.

>> *I doubt that the proposed model cannot capture the CIL adequately. Figure 7 gives the average vertical distribution of temperature for the 3 regions, namely, East, West and Rim. Even the quality of the figure is very low I can see that the CIL is almost absent. Many recent studies based on ARGO float data (Stanev et al, 2013, 2014, 2017 and2018) and numerical modelling (Miladinova et al., 2017 and 2018) clearly show the presence of CIL in the period 2009-2015. CIL is eroded but exists in winter-spring. I recommend the authors to look at the figures of Stanev et al. and try to visualize their results in a similar readable way.*

We are aware of the various references pointed out and indeed we have tried to test the effects of the modeling improvements on CIL, which equivocally shows reduced CIL over the recent years (in parallel with some recent results, e.g. Miladinova et al., 2017, 2018; Stanev et al., 2019). However, we only had to compare model results either on selected domain averages or at selected stations, producing the overall climatic trends captured in the references. We have changed the quality and legends of the figures for better visibility. Figure 7 has been constructed by sampling each ARGO profile at its particular location in the model domain. While the figure is seen as a basic plot, it is actually generated by using thousands of ARGO profiles. The shaded background is the model results and the black contours are from these observations. It is therefore clearly seen that there is no CIL in some years in the observations (black contours), which is also perfectly captured by the model. It is clear that the observations are confirmed by the model results.

>> Figure 7 shows many crossed lines of different meaning and the same colour. Please mark the isotherms 7, 8.5 and 15 °C. What is the meaning of the white gaps in Figure 7? The CIL is not visible in figs. 12 and 14,too. On the base of the proposed model, the authors stated “.

The warmer water at the upper surface is the 15 °C isotherm, which is the boundary of the thermocline in the Black Sea. In addition, we have labelled the 7°C and 8.5°C isotherms according to the Referee’s suggestion. It is most likely that the figure might have caused some confusion: since this figure is constructed by the sampling of ARGO floats, the white gaps correspond to data missed by the ARGO floats, always sampled at their individual depths.

>> The abundance of CIL in the initial conditions maintained for the first two years contrasts with the single event of cold intermediate water formation in 2012, and the weaker event in 2017”. The CIL is present during the period of ‘spin-up’ and disappears after the second year. Thus, I can conclude that the model is not able to represent the CIL adequately. Most of the figures are of poor quality. The range of variable variation is too wide to distinguish small but important variation.

As stated above, the black contour in the Figure is derived from the ARGO profiles. The disappearance of the CIL after 2014, and the weaker one in 2017 are real events clearly shown in the observations. So, the model properly represents “truth” (in parallel with recent results reviewed above), with model results in good agreement with the *available data from ARGO floats.*

$>>$ *Validation. It is not enough to present the comparisons graphically. It is necessary to give the coefficient of correlation, the absolute values of errors, and standard deviation. It is better to substitute the figures 8 and 9 with a table containing the statistics of the comparisons.*

We believe that Figures 8 and 9 contain much more information than statistics presented in tables. The seasonal and interannual variations of the temperature and salinity can easily be detected in these figures. The comparison of the model results with the numerous observations during the course of the model simulation is clearly seen in these figures. It is not clear what additional evaluation of model improvements could be provided by statistics of unevenly distributed observational data.

$>>$ *I cannot understand the following conclusion: "The reduced convection events in recent years both in the deeper central basin and near the coast stand as evidence that great changes are occurring in the Black Sea, much likely to be an amplified response to climate change in the isolated Black Sea basin severely limited in its communication with the Mediterranean Sea and eventually with the world ocean." Which their results indicate the "reduced convection" and also "great changes"? What is the meaning of the phrase "much likely to be an amplified response to climate change in the isolated Black Sea"?*

These statements reflect the introductive review of the Black Sea as a deep basin fed by excess of water, in contrast in the Mediterranean, also separated by unique controls at straits, amplifying the climate change response in the isolated domain, which are well known facts from the literature reviewed in the paper as well as elsewhere. Perhaps we need to clarify and soften our sentences in the revised manuscript in order not to be misunderstood as rather unique contributions of our study. Yet we still feel our study is entitled to emphasize these facts, which are found to be enhanced in our results.

$>>$ *I strongly recommend that the authors should: a) identify the novelty of the*

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knowledge gained; b) add the comparison with other numerical simulations; c) improve the quality and readability of the figures; d) present statistics for the model-model and model-data comparisons; e) improve the presentations of results and conclusions. Minor points: I suggest authors to use the MEDAR climatological data (http://modb.oce.ulg.ac.be/backup/medar) for initialization of temperature and salinity. MEDAR data is freely available until 2002. The thermohaline fields in 1992 are not appropriate for initialization of simulations that start in 2008. I couldn't understand this sentence "In this way the CIL, which is a product of convective mixing in the Black Sea, influences water mixed on the shelf and returned back to deeper layers of the Black Sea, also influencing Marmara Sea." How the return back of CIL waters is presented by the model?

We have so far commented on the purpose of our study limited to the incremental model development, essentially not negating the objective of "new knowledge gained", by providing up to date dynamics, seeking best observational support published within the scope of the Geoscientific Model Development (GMD). Within this context, we have not been seeking statistical and physical comparison with other numerical models which are in fact not directly comparable and not up to date in these aspects. Improvement in results are limited only by the incremental method we have used and will be followed up with future work that is already in the queue.

What is expressed by Referee #1 as a suggestion to use climatic data from data bases such as the MEDAR is something we have always suffered from in our earlier work in Black Sea modelling. We have found that such statistical averaging of seawater properties with different instruments and within different time, geography and depth windows are bound to be defective and almost always very noisy. Because we are firm believers in initialization, we have chosen the first whole-basin coverage collaborative sampling by Black Sea riparian countries, despite the fact that the initialization data are from a different decade, allowing for some initial spin-up on the order of about two years based on our experience. We believe this is a strong point that we find to be of *value in our study.*

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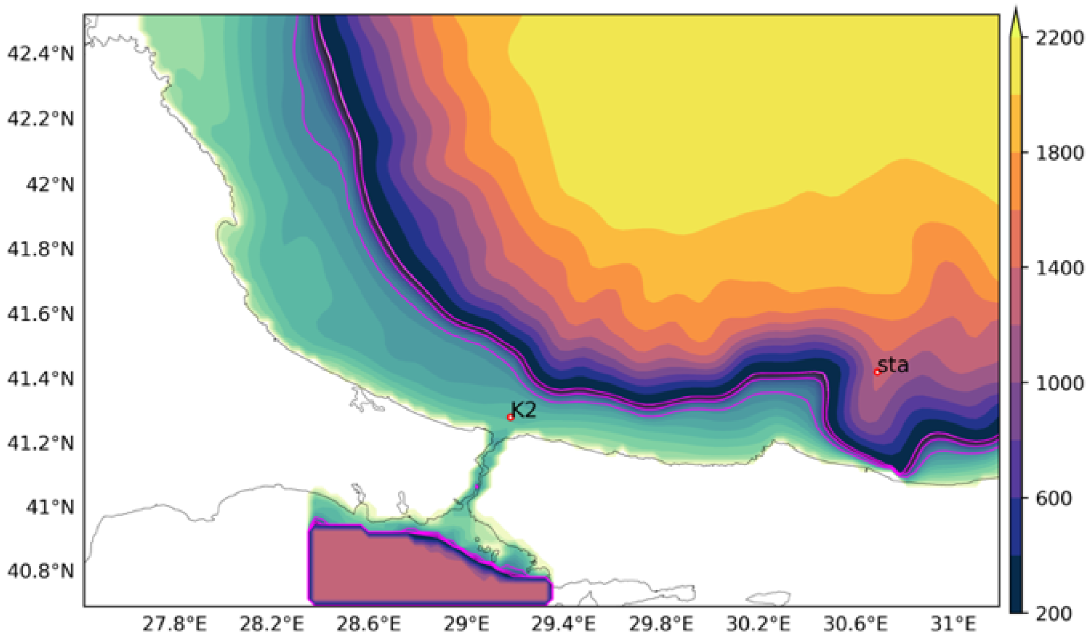

Fig. 1. Location of the observation station K2.

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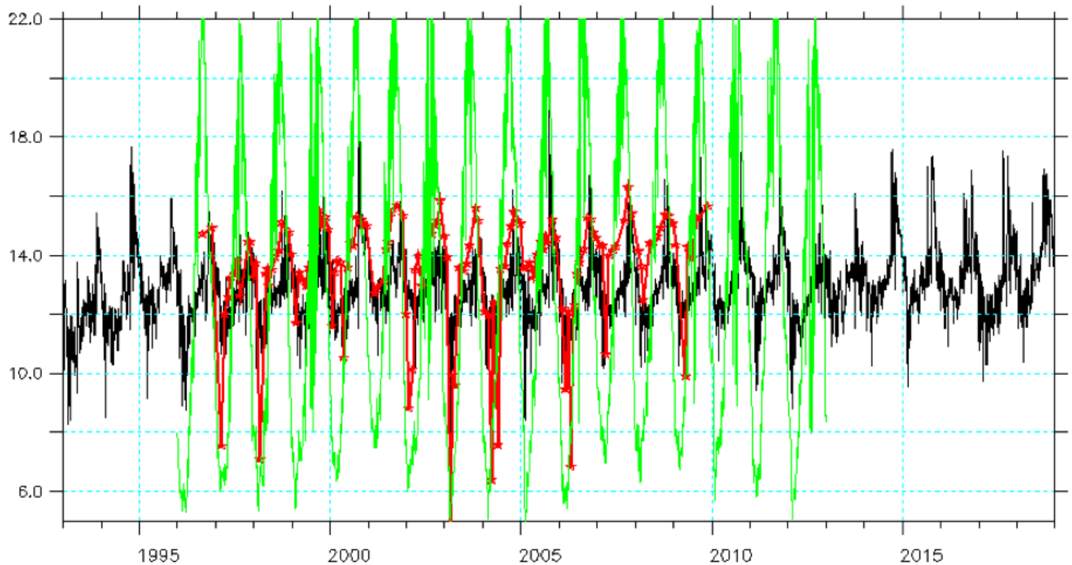

Fig. 2. Time series of temperature at 60m at station K2. Red line is observation, black line is current model and the green line is CMEMS Black Sea model.

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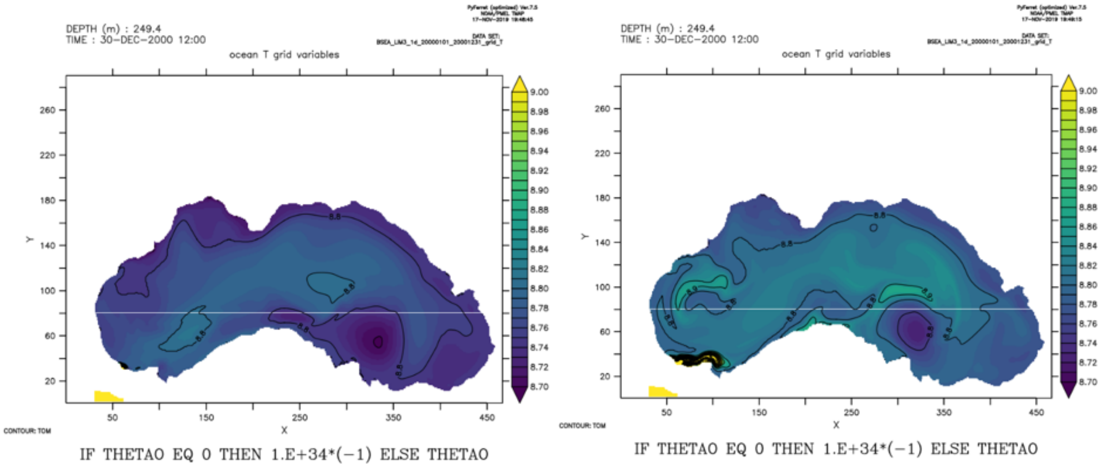

Fig. 3. Comparison of model temperature at depth level 250m, for two values of the lateral viscous velocity 0.1 and 0.15 m/s.

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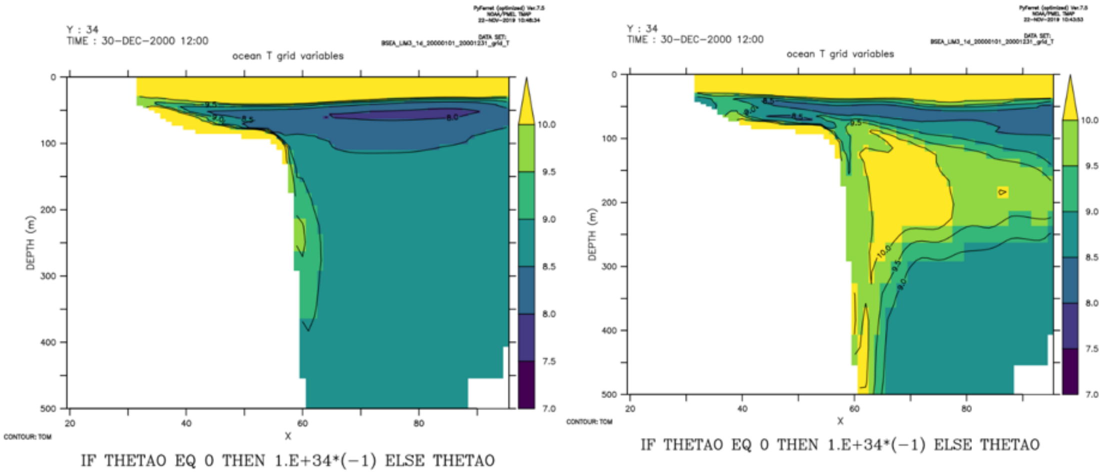

Fig. 4. Comparison of model temperature across a south to north section starting from the Bosphorus mouth and the adjacent shelf and slope regions, for two values of the lateral viscous velocity 0.1 and 0.15

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