Reviewer 1

The authors investigated the potential role of Data Assimilation in improving the accuracy of barotropic processes induced variant scale/mode sea level anomaly in the Mediterranean Sea. The study is based on the state-of-the-art simulation kernel in SHYFEM. The authors comprehensively investigated the improvement of the astronomical tide, surge and seiches implemented by DA, and promoted the adaptability of SHYFEM with inclusion of EnKF. The manuscript is well written and organized with a sensible logic. However, given I still have these several following major concerns, I cannot recommend an acceptance at its present form.

We thank the Reviewer for the helpful comments, which will improve the quality of the paper. We answer the individual points below.

- *Although it is still a nowadays great challenge to DA to treat/improve the hindcast and forecast of sea level anomaly in the region where the SLA oscillation is significant, I'm still wondering why the authors conduct this simulation in a two-dimensional or barotropic configuration? Will the inclusion of, e.g. dynamic height associated with the baroclinic processes be really negligible in the region? If it is not, why the heat fluxes, evaporation and precipitation, as well as riverine discharges are excluded? The larger scale circulation, at least those in the synoptic scale, is another issue related to this concern. Could the authors include some discussion related to the unimportance of these processes? Or, the authors may want to state that they are treating those larger-scaled motions as reference levels already, although I don't think that is a straightforward statement.*

  This comment has points in common with the second Reviewer's fourth comment, so please read that explanation as well.

  Actually, this point is not sufficiently clarified in the paper; therefore, a detailed explanation will be added in the Introduction. Sea level is one of the most complex oceanographic variables to model, due to the innumerable components it can have. For this reason, we explicitly wrote in the title that we analyse the "barotropic" sea level, not the baroclinic component, thus using the model in the barotropic version. With the term "barotropic sea level" we refer to the barotropic tide, the storm surge and the total level made up of these two components (and the oscillations of the barotropic modes - seiches - triggered by the storm surge). Indeed, the storm-surge definition is sometimes not unique. In this study and following Pugh (1996), we consider the storm surge as the sea level induced by the effect of the wind stress and the Inverse Barometric Effect

  There are, however, several other factors influencing the sea. The contribution of the river run-off may not be negligible in some specific coastal areas, such as deltas and estuaries (e.g., Mississippi river, Bangladesh coast). However, in the Mediterranean Sea, the conditions are very far from those present in these places.

  As for the baroclinic processes related to vertical and horizontal temperature and salinity gradients, forced by (sensible, latent) heat fluxes, rain, freshwater inputs from rivers, and the associated SLA, they are not investigated in this paper, as stated in the title. However, these processes follow much larger timescales of variation and, to our knowledge, are never considered in storm surge or tidal models in European seas (see the papers cited below).

The effectiveness of barotropic models to reproduce storm surges and tides is also proved by the corrections usually applied to SLA altimeter data. The storm surge part is removed using the (2D barotropic) Mog2D model with this motivation: "The high-frequency oceanic signal (pressure and wind meteorological forcing) is badly sampled by altimeter measurements" - https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/dynamic-atmospheric-correction/description-atmospheric-corrections.html). The astronomical tide is instead subtracted through another barotropic 2D model, the FES2014.

As regards the effects of the synoptic circulation on the sea level, the synoptic ocean signal is filtered into the Mediterranean through the Strait of Gibraltar. It consists of low-frequency oscillations (Bajo et al., 2019) and it is included in the boundary conditions. As regards the synoptic atmospheric circulation, this is present in the wind and pressure forcings. We will add in the paper a further explanation of the boundary conditions.

The above-mentioned arguments justify the use of the 2D approach in simulating and forecasting storm surges and tides. In the Adriatic Sea, the most extreme events that occurred in 1966, 2018 and 2019, were successfully modelled using SHYFEM in a configuration analogous to the one used in this paper (Roland et al., 2009; Cavaleri et al., 2019; Ferrarin et al., 2021). Furthermore, the model, always in barotropic configuration, has been used for over ten years at the centre for forecasting and warning of high tides in Venice (Bajo et al., 2007). SHYFEM in 2D barotropic version has been effectively used for the reproduction of the seiche oscillations (Bajo et al., 2019) and for the study of the astronomical tide (Ferrarin et al., 2018). A similar 2D barotropic approach was successfully used by Fernández-Montblanc et al. (2019) with the SCHISM model to reproduce storm surge, tide and the total level (barotropic) in several European seas. In Xavier et al., (2014) SELFE in 2D barotropic version is used to reproduce the storm Xynthia, one of the most extreme ever recorded in Europe. Similar models are also used elsewhere, still in Europe, by several storm surge and tide researchers (e.g., Flowerdew et al., 2010, Horsburgh et al., 2021). Regarding the astronomical tide, as mentioned before the various versions of FES use a 2D barotropic model.

To conclude, in the next version of the paper, the focus of the article will be better explained in the introduction (the barotropic component, as written in the title) and a part will be added in the introduction to better analyse the various contributions of the sea level and adding the citations presented here.

- *I still have concerns about how did the simulation treat the open boundary condition, although the manuscript did clarify that the authors treated the boundary condition with great effort. If sea level is kind of prescribed at the western boundary, how could the circulation (including their impacts in SLA and currents) be connected with that to the further west of the open boundary, which I think is provided by, for example, the CMEMS reanalyses. I may also suggest the authors include a paragraph to elaborate the way the open boundary condition is implemented or explicitly show the algorithm of the open boundary condition.*

The boundary conditions are described in section 2.1. Actually, they are described shortly. As suggested we will extend the description, evaluating whether to introduce a subsection for boundary conditions and, perhaps, for surface forcings. In the paper we made two mistakes in describing the boundary condition:

- we said we applied the conditions to Gibraltar, but the model grid ends at -7.2W, in the Atlantic Ocean. This allows for a fairly distant boundary from the Mediterranean Sea.

- The link specified in the paper refers to the reanalysis of the CMEMS model, while we have used the analysis/forecast product (https://doi.org/10.25423/CMCC/MEDSEA_ANALYSISFORECAST_PHY_006_013_EAS7).

- *Why the satellite altimetry data is not used as observed data in this research? Are they at least usable for the astronomical tide correction and forecast? If gridded data is problematic, how about the along-track data? There are dataset of harmonic constants extracted from the along-track data by using this operation, and the authors mainly used much higher resolution records at the surrounding tidal gauge. I mean, there are more observations with much higher spatial coverage may help further improved the DA.*

This comment has similarities with the second Reviewer's fifth comment, so please read that explanation as well. This is a good suggestion, we thank the Reviewer for pointing it out to us. Indeed we can validate the model not only in the validation stations but also where the altimeter harmonic constants are available. We will therefore add a validation part of the astronomical tide based on altimetric data if these will have good quality in the Mediterranean Sea.

- *In the perturbation runs, why the drag coefficient Cd in the quadratic formulation is not perturbed? Dissipation of energy with the scales smaller than tides through the bottom friction could also be an important process that determines the characteristics of tidal currents, and in this sense, although the authors stated that the current research is focusing on SLA variations, in the current configuration, accuracy in flows will also be an important aspect.*

We thank the Reviewer for noting this. Actually, the Cd was perturbed, but we forgot to write it. In addition to the Cd, we also perturbed a calibration factor for the calculation of the loading tide (called ltidec in SHYFEM) in the simulations using the tidal potential (tide and total level). For both parameters, in each simulation, the 80 perturbations belonging to a Gaussian distribution are calculated, centred at 0.0025 (Cd) and 6.e-05 (ltidec), with a standard deviation of 0.0005 (Cd) and 1.e-05 (ltidec). As commented by the Reviewer, Cd has great importance in the dissipation of energy and therefore also in the correct reproduction of the levels. Also, since tide-only simulations do not have atmospheric forcing, in this case, Cd and ltidec are even more important to create an ensemble with a wide enough spread. We will add new paragraphs to section 2.3 describing what is reported here.

Did the authors analyze whether the current design could also improve flows or not?

We noted a change in water transports compared to the simulation without DA but we did not compare them to any measures. However, if the cross-correlation between levels and currents is correct (the size of the ensemble - 81 members - should be sufficient), then currents should improve as well. On a smaller scale, we had seen improvements in the current by assimilating sea-level data in the inlets of the Lagoon of Venice (Ferrarin et al., 2021).

- *In my opinion, it is still important to rely on DA to improve the parameterization in the simulation, since it is not that feasible for operational users to generate a large number of perturbation runs to have that short-term forecast improved.*

The parameter estimation technique with the DA is very interesting and we had taken it into consideration. Although we haven't currently developed the necessary code, it shouldn't be very complicated to do in the future, and we could use it to estimate Cd or the loading-tide coefficient with spatial variability. We will discuss this future development in the conclusions.

Regarding the operational use of an ensemble, there are already several examples of operational systems with ensemble DA much more computationally heavy than the system presented here. For example, the CMEMS model for the Arctic (Topaz, https://doi.org/10.48670/moi-00001) uses 100 members in a 3D baroclinic model. Also, Ohishi et al. (2022) use 100 members. We are currently implementing the system described in this study for operational use at the Italian Institute for Environmental Protection and Research, ISPRA. The computational server has 96 cores, so that the 80+1 ensemble simulations run perfectly in parallel (the code allows this), with no slowdown compared to a single simulation. In a daily simulation, 24 analysis steps are performed, each taking about 30 seconds. Finally, it takes about 5 minutes in the beginning to create the perturbed atmospheric forcing and the perturbed boundary condition. In total, the 81 2D barotropic simulations with DA take about 25 minutes to provide a final analysis state, which is more than reasonable for operational purposes. Such a fast modelling system can be applied several times per day using real-time observations for improving the forecasts (ideally each time new observations are available).

Although the parameter estimation technique can bring improvements in the model error, it is also necessary to use DA in the traditional way, to improve the initial state, especially in the case of seiche oscillations, as discussed in this paper.

- *It is really hard to intensify the meshes in Figure 1. Could you zoom in to some critically locations to show the spatial variability of resolution?*

Indeed, it is difficult to distinguish the resolution of the grid. As suggested we will zoom the grid in some areas (probably north Adriatic, Gibraltar).

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