Review of “The characteristics of tides and their effects on the general circulation of the Mediterranean Sea” by McDonagh et al.

The manuscript "The characteristics of tides and their effects on the general circulation of the Mediterranean Sea" by McDonagh et al. presents a study investigating the effect of tides on the Mediterranean Sea circulation. To my knowledge, this subject has not yet been extensively investigated. Apart from Sannino et al. 2014, which provided a first analysis of the tidal influence on the large-scale Mediterranean circulation, previous studies have only focused on specific areas such as the Alboran Sea (Sanchez-Garrido et al., 2013) or the Sicily Strait (Oddo et al., 2023; Gasparini et al., 2004). As such, the present manuscript proposes a valuable contribution to reinforce and deepen the current knowledge on the tidal influence on the Mediterranean Sea.

In this study, the authors diagnose the effect of tides from a pair of 5-year-long tidal and non-tidal experiments based on very similar numerical configurations. The first and second sections of the manuscript investigate the influence of tides on the Mediterranean Sea dynamics through the prism of sea level and kinetic energy spectra. These analyses focus on three specific locations: the Strait of Gibraltar, the Tyrrhenian Sea, and the Cretan Sea. They reveal that tides impact high-frequency ($> 1\ day^{-1}$) dynamics through the propagation of the main tidal harmonics at work within the Mediterranean Basin and their interaction with various basin-scale modes. Then, the authors relate the tidally enhanced dynamics and mixing to the deepening of the mixed layer depth in the tidal simulation. The two final sections discuss the impact of tides on the thermohaline properties of the Mediterranean Sea and the transports through the Strait of Gibraltar.

Overall, the manuscript has the potential to provide valuable results on tidal contribution to Mediterranean dynamics. However, further work must be done before it can be accepted. More specifically, I think that although the two first sections of the manuscript provide valuable results, they focus on too specific areas to provide an overall picture of the tidal influence on the high-frequency Mediterranean dynamics. In addition, to assess the influence of tides on the "general circulation of the Mediterranean Sea", as stated in the the title of the study, the manuscript should investigate the influence of tides on the long-term, large-scale circulation. Regarding the impact of tidal dynamics, section 5 should more clearly distinguish the influence of local tidal mixing at the strait of Gibraltar, which impacts the Mediterranean mixed layer depth indirectly by changing the density of Atlantic water masses, and the less intense mixing induced by tidal currents throughout the Mediterranean Sea. The former is not directly related to the interaction of tides with the Mediterranean circulation, and it has already been investigated with similar model configurations (Sannino et al., 2014; Naranjo et al., 2014). Thus, I suggest not including it in this manuscript. On the other hand, the mixing induced by tidal dynamics is relevant to this study. Finally, sections 6 and 7 are, in my opinion, outside of the scope of this paper. Although interesting, the corpus of these sections has no apparent link with Mediterranean circulation and mainly emphasizes the conclusions of previous studies without additional results.

For these reasons, I am arguing for a major revision of the manuscript. Specifically, I would suggest:

- In sections 3 and 4: Add 2D maps of the tidal influence over the specific frequency bands mentioned in the text to give further confidence in the spatial extension of the results discussed.
- In section 5: If you intend to show that the tide-enhanced high-frequency dynamics are responsible for the deepening of the Mediterranean mixed layer depth, you should:
  (1) Mostly focus on the overall increase of the mixed layer depth rather than its local increase over deep convection areas, where the intensity of tidal mixing is unlikely strong enough to drive the deepening.
  (2) Look at the seasonal cycle of the mixed layer depth and stratification, as it would be easier to separate the effect of local vertical mixing from that of the tide-induced densification of Atlantic water masses at the Strait of Gibraltar.
- Add some results on the influence of tides on the Mediterranean large-scale circulation, or reformulate the title of the article only to consider the high-frequency dynamics.
- Put sections 6 and 7 in the supplementary materials or a "model validation" section, demonstrating the consistency of the model with previous studies.

I do encourage authors to make the necessary effort to improve this manuscript. You can find general and detailed remarks below.

General remarks:
- There is no model validation. At least a reference to the model validation should be included.
- The tidal and non-tidal simulations differ by other processes than tides. Please provide some information about the impact of these differences. The best would be to briefly analyze these impacts in the supplementary materials.
- Text clarity: Please use as few indirect forms as possible to make the manuscript easier to read.

Introduction:

General remarks:
The introduction is relatively well documented. I thank the authors for this time-consuming work. However, it would benefit from a more straightforward structure. As it is now, the introduction paragraphs discuss:

1. Tides in numerical models and their relevance to large-scale circulation
2. Influence of tides at the Strait of Gibraltar.
3. Influence of internal tides in the Mediterranean Sea.
4. Description of internal tides and their influence on the global ocean and the Mediterranean Sea
5. Basin modes of the Mediterranean Sea

I suggest you start with a general introduction, including the content in paragraphs 1 and 4, to introduce the various aspects of tidal waves, their influence on large-scale circulation and mixing, and how they are represented. Then, explain how the tides influence the Mediterranean Sea, as in paragraphs 2, 3, and 5.

Also, you should further motivate the need for a deeper understanding of the effect of tidal motion on the Mediterranean circulation. In the current version of the manuscript, this is only mentioned in one sentence “Many of these free oscillations could be affected or enhanced by tides, especially considering their proximity to tidal frequencies.”

Detailed remarks:

- “Tidal forcing is a rather recent addition to large scale circulation models that start to have horizontal and vertical resolutions that allow for an analysis of tidal motion on the circulation” => This sentence is unclear. Do you mean that horizontal and vertical resolutions are now fine enough to represent tides properly? Please clarify this.
- “Tides are now considered to be essential components of the large scale circulation” => You should provide references specifically investigating the influence of tides on the large-scale circulation, for example: Müller et al., 2010
- “Recently, Gonzalez (2023) has revisited the tidal dynamics in the Gibraltar Strait, concluding that there are several tidal-induced hydraulic control points and the authors developed a specific mixing parametrization for the Strait.” => The Ph.D. of Gonzalez (2023) does not directly investigate hydraulic control points at the Strait of Gibraltar. These were observed by (Farmer & Armi, 1985; Farmer et al., 1988) and discussed by Brandt et al., 1996; Vázquez et al., 2006; Vlasenko et al., 2009; Sánchez-Román et al., 2012; García Lafuente et al., 2013; Hilt et al., 2020.
- “Harzallah et al. (2016) and Naranjo et al. (2014) found that tides at the Strait of Gibraltar: (1) increase the baroclinic volume transport, (2) increase the salinity of Atlantic inflowing waters through the enhancement of mixing, affecting the water mass formation processes further downstream from the Strait and (3) change the Mediterranean deep water outflow.” =>
  (1) As I understand it, Harzallah et al. (2016) do not state that tides increase the baroclinic volume transport. In fact, we can read from the abstract of the paper: “It is shown that tidal oscillations reduce the two-way exchange by interaction with the subinertial variability.”. The fact that tides increase the baroclinic volume transport is not so evident to me. The paper of Gonzalez et al. 2023 shows that the computed transports through the Strait depend highly on the chosen definition for the interface between inflowing and outflowing waters. Instead of stating that tides increase the baroclinic transports, I suggest that you say they intensify the high-frequency dynamics of the Strait.
  (2)Tides also cool the Atlantic water masses, although to a lesser extent than they salten it.
  (3) You should specify what properties of the Mediterranean deep outflow are changed.
- I cannot find van Haren et al. (2014) in the references. Please add it.
- I think there is a mistake in the reference of the paper of Harzallah et al. (2016), which was published in 2014.

Data and methods:

Detailed remarks:

- “Lateral open boundary conditions are used in the Atlantic Ocean and Dardanelles Strait (see Fig. 1).” => What dataset do you use to force the model at these boundaries? Please provide a reference.
- “Additionally, 70 monthly mean climatological freshwater inputs from 39 rivers are added to the surface layer.” => Please provide a reference for this dataset.
- Please explain how you choose the constant values used in the vertical mixing parameterization.

Sea level energy spectra:

General remarks:

In this section, you should emphasize the innovative aspect of your work more clearly. One way to do so would be to discuss separately the interaction of tides with basin-scale frequencies highlighted in previous studies, which you confirm here, and those your study is the first to highlight. Also, a short recap on your findings and their impact at the end of the section would be welcome.

Detailed remarks:

- "energy is reduced in the tidal model at frequencies lower than 0.5 d−1 (longer than a period of two days)." => Please specify the frequency in days first, as done in the following.

Kinetic energy spectra:

General remarks:

- In my opinion, you should remove Figures 7-9 from the corpus of the manuscript. They are used only in a small paragraph, do not provide new information with respect to Figure 6, and focus on a relatively short period of 1 month.
- Figures 10-12 should be replaced by the equivalent of Figure 6 for the vertical velocities. This would make it easier to read the impact of tides on the frequency band mentioned in the text and make the results more robust, as they would integrate the 5 years of simulation instead of one month.

Detailed remarks:

- “We first calculate the rotary spectra for depth-averaged (barotropic) horizontal velocities” => Please include some explanation about the physical meaning of this spectra.
- “The spectra of kinetic energy density were split into vertical levels to consider baroclinic currents and internal wave modes. [...] characterising the Intermediate

Water circulation in the basin." => It is unclear which Figure you refer to. I assume it is Figure 6, but it is confusing since you introduce it later. If the figure you refer to is not in the manuscript, specify it with the mention "(not shown)".

- "implying the existence of internal tides as already shown by Gonzalez (2023)." => Here, you should refer to the paper of Gonzalez et al., 2023. Also, many studies investigated internal tides in the Strait of Gibraltar. It is consistent to cite Gonzalez et al. 2023 here, but if you want to cite it alone, you should write something like: "implying the existence of internal tides, recently highlighted in Gonzalez et al. (2023)."
- "Two zero crossings appear, one approximately at 150m, the lower limit of the inflowing branch of the zonal [...]" => Please detail the implications of this result.

Mixed layer depth and water mass formation:

Detailed remarks:
"There is an increase in mixed layer depth with tides throughout most of the basin, with notable exceptions in the Gibraltar Strait/Alboran Sea region, and in parts of the Aegean Sea." => Please explain why the mixed layer depth responds differently to tides in these regions.

Temperature and salinity:

Detailed remarks:
"As indicated in work by Naranjo et al. (2014) and Harzallah et al. (2016), inflowing salinity at Gibraltar increases when tides are introduced and upper layer temperature decreases" => You should also cite the papers of Gonzalez et al 2023, Sanchez-Roman et al., 2018, and Sannino et al 2014,

The Gibraltar Strait:

General remarks:
You should specify how you compute the inflow and outflow transports through the strait of Gibraltar. As discussed in Gonzalez et al. 2023, it significantly impacts the transport values obtained.

Detailed remarks:
"Gonzalez (2023) recently demonstrated that the required resolution for an accurate representation of the Gibraltar Strait would be about five times the one used in our model." => It is Sannino et al., 2009 who discuss the resolution needed to represent the Strait of Gibraltar, not Gonzalez et al., 2023.

Figures:

Fig1: Please adapt the colormap so it is possible to see the tidal amplitude in the Atlantic. I understand tidal amplitudes significantly differ over the Mediterranean and the Atlantic, making it difficult to plot both with one colormap. However, you could use one colormap for the Atlantic and one for the Mediterranean. Also, add the tidal phase in contours to display amphidromic points.

Fig. 2: Add the scale in days for the two lower panels. Please indicate the frequency you refer to in the text using dashed lines and display the labels of tidal harmonics next to the associated peaks.

Fig. 3: Please indicate the frequency you refer to in the text using dashed lines and display the labels of tidal harmonics next to the associated peaks.

Fig. 4: I do not find any reference to the bathymetry in the manuscript, so you should indicate the points specified here in Figure 1 and remove this figure.

Fig. 6: Please add a panel displaying the differences between the two simulations.

References:

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