Comment on egusphere-2023-3076
Anonymous Referee #2
Referee comment on "Internal and forced ocean variability in the Mediterranean Sea" by Benincasa et al, EGUsphere, https://doi.org/10.5194/egusphere-2023-3076, 2024.

We sincerely thank the referee for reviewing our manuscript and providing many constructive suggestions for improving the overall quality of the manuscript. A detailed report describing how the comments were addressed can be found below.
Reviewer's comment is shown in black color and italic font style. Our responses are shown in red color, and text from the manuscript, added or modified, can be identified by blue color and quotation marks.

"In the paper by Benincasa et al. 20 simulations of the operational forecasting system of the Mediterranean Sea are used, through an ensemble approach, to assess the internal/intrinsic ocean variability. It is shown that such a variability is associated with the mesoscale activity and that, with the exception of the Adriatic Sea and the Gulf of Gabes, is larger than the response to surface forcing in all the Mediterranean Sea. Internal variability has a clear season cycle for temperature in the surface layers while, for marine current velocities, it is always dominant and largest at the surface.

The paper is clearly written and well organized and I have only a major concern related to the model resolution and the ability of resolving mesoscale instabilities. The model horizontal resolution is about 4km (1/24 deg) which may be not enough for a full development of mesoscale instabilities: in many Mediterranean areas the Rossby radius (Rd) is less than 8km (i.e. less than 2 model grid cells, see Fig.1 of Beuvier et al. 2012). This seems to be confirmed also by the Rd estimates provided in Grilli and Pinardi (1998) that in some cases are even smaller and closer to the model grid resolution. One may argue that the significant presence of internal variability found in this paper in some areas (e.g. the southern parts of the basin, see Fig.5) is just imputable to the model ability to fully resolve there mesoscales features. Indeed the southern parts of the basins are characterized by larger Rd values (see always Fig.1 of Beuvier et al. 2012). I suggest that the authors discuss such an important limitation of their methodological setup and the sensitivity of their results to horizontal resolution. As the authors themselves report at L48-49, the higher is the horizontal resolution the larger is the intrinsic variability."

We sincerely thank the reviewer for pointing out this missing information. The reviewer's main concern of whether the model's horizontal resolution is sufficient to resolve mesoscales homogenously over the basin is very appropriate. Indeed, the model's horizontal resolution of 1/24° allows it to be mesoscale eddy-permitting for most of the areas. As Beuvier et al. (2012) [1] detail, the Rossby radius of deformation in the Mediterranean Sea varies from 3 to 13 km. It is clear that an increase in the horizontal resolution (presently at 3.5 - 4 km) would imply higher values of internal variability. Nonetheless, we argue that within the model resolution limitations, the results are indicative of the relative importance of internal and forced variability.

We suggest the following addition to the *Model setup and simulations* after line 100:

"It is important to notice that the model we used is not everywhere eddy-resolving but mainly eddy-permitting. This is a consequence of the fact that the first Rossby radius of deformation in the Mediterranean Sea varies from 3 to 13 km (Beuvier et al., 2012) with larger values in the basin's interior and the southern areas. In contrast, in the Adriatic Sea and the Gulf of Gabes, the Rossby radius is generally smaller than the model's horizontal resolution thus possibly artificially decreasing the importance of internal variability."

And to the *Discussion and conclusions* after line 214:

"A limitation of our study is the underestimation of the internal variability stemming from the model's horizontal resolution of 1/24° which results in being too coarse for resolving mesoscale eddies everywhere in the Mediterranean Sea. Such underestimation could be particularly significant in the Adriatic Sea and the Gulf of Gabes where the spatial scales of mesoscale eddies tend to be smaller than the model's horizontal resolution. Thus, this could be an additional factor causing the small values of the ensemble spread in these regions. Nonetheless, the present study shows the importance of internal processes as opposed to the atmospheric influence compatible with the model resolution."

A process of revisions is suggested to address also the following minor concerns:

1. L9 "probably": it should not be so hard to assess whether or not the peak at 30m is really connected to the thermocline formation. Monin-Okubov depth?
   We thank the reviewer for pointing out this inaccurate statement. We have now eliminated the word from the abstract and we suggest to add at line 144 the following lines that reports on the 30 m thermocline depth findings in the literature:
   "In the literature, Hecht et al. (1988) [4] have described the Eastern Levantine thermocline seasonal variations showing it to be located between 20 and 40 m depth. Thus, we refer to 30 m as the average depth of the seasonal thermocline."
2. L42-43, just a curiosity: is there any quantification of the role of submesoscales in setting up intrinsic variability?
   Submesoscale variability has been mapped and studied at sub-basin scales, in limited areas, due to the resolution required (200 – 600 m). For instance, Trotta et al. 2017 [5]

studied the submesoscales associated with a large-scale anticyclonic gyre in the central Gulf of Taranto using realistic high-resolution submesoscale-permitting simulations obtained via multi-nesting techniques. CALYPSO (Coherent Lagrangian Pathways from Surface Ocean to Interior - https://calypsodri.whoi.edu/) was an international Research Initiative from 2018 to 2022 aiming at studying surface-to-interior 3D transport structures and pathways with advanced observing technologies in the Alboran Sea in the Western Mediterranean. Many of the projects and publications derived from it dealt with submesoscale variability and predictability, frontogenesis, and the link between mesoscales and submesoscales. Last but not least, Solodoch et al. 2023 [7] studied ocean variability in the Eastern Mediterranean Sea from basin-wide to submesoscales, with a particular focus on the latter.

We suggest adding the following phrase after line 225:

"Lastly, given the importance of submesoscales in several regions of the Mediterranean Sea (Trotta et al. 2017 [5], CALYPSO [6], Solodoch et al. 2023 [7]) future work could include the addition of submesoscale variability as a source of ocean internal variability."

3. L77, no tides: this is also reported in the conclusions at L215-216 and may represent an important future extension. But tides are important also in other areas apart Gibraltar (e.g. in the North Adriatic) where the intrinsic variability of this study may be underestimated.

   We have now replaced the phrase in *Discussion and conclusions* at line 216 "within the Gibraltar Strait" with:

   "[..] on the whole Mediterranean Sea (McDonagh et al., 2024 [8]), including the Gibraltar Strait (Gonzalez et al. 2021)."
4. L96-97: is there a specific reason to stop at 1000 m and not to perform the analysis for deeper layers?

   The choice of 1000 m was justified by several factors. First, we indeed performed the analysis also for deeper levels of the water column, but we realized that the spread decreases with depth. Similarly, the influence of the atmospheric forcing decreases considerably at deeper layers, resulting in large values of the N/S that do not have the same meaning as the surface ones.

   In conclusion, even if arbitrary, we believe that confining our analysis in the first 1000 m of the water column introduces a lower bound to the N/S for the largest area possible in the basin.

   We added after line 98 a phrase to justify our choice:

   "Limiting the analysis to the first 1000 m of the water column was justified in order to capture a meaningful N/S. The deeper levels showed decreased spread and decreasing atmospheric influence, as expected for the large-scale circulation. Despite its arbitrariness, this boundary ensures a practical balance between vertical variability and statistical significance."

5. L108 \sigma_A formula: if \tau is the chosen period I am not sure I fully understand why t starts from 1 and there is a minus 1 in the denominator. My guess is that the total number of discrete timesteps making up the whole period should have been used instead.
   In Equation 2 of the manuscript, the temporal standard deviation is computed for each grid cell over a season, i.e. 90 days, using Bessel's correction. However, given $\tau = 90$, the difference between τ or $\tau - 1$ is insignificant. Thus, in line 108 we added:
   "[..] is the temporal average of the ensemble mean over the chosen period τ, i.e. 90 days corresponding to a season."
6. L132: similar considerations on the \sqrt(\sigma^2) and RMSE formulae as the point above
   Equation 4 is used to measure the dispersion of the ensemble, which is done to evaluate the quality of the spread of the ensemble of simulations (please refer to Fortin et al., 2014 [9] for a thorough explanation of why this is the right relation to consider). The equation links the square root of the average of the ensemble variance to the RMSE of the ensemble mean with respect to the reanalysis over the same period. Points below (above) the linear relation of Eq. 4 characterize an underdispersive (overdispersive) ensemble. It is important to notice that Eq 4 holds only for τ that goes to infinity and that is the reason we considered the entire 2021 for this estimation. Thus, in this case $\tau = 365$ days, making the difference between using τ or τ-1 even more irrelevant than before.
   We added in line 132:
   "[..] since this relation holds for large values of τ and this the reason we considered $\tau = 365$ days corresponding to the entire 2021."
   We corrected also the typo in line 129: "members" must be changed with "mean".

7. L231: typo Eurosea project
   We corrected the typo.

Lastly, we suggest adding [1], [4], [5], [6], [7] and [8] to the References of the manuscript.

References:

[1] Beuvier J., Béranger K., Lebeaupin Brossier C., Somot S., Sevault F., Drillet Y., Bourdallé-Badie R., Ferry N., Lyard F. (2012). Spreading of the Western Mediterranean Deep Water after winter 2005: Time scales and deep cyclone transport. Journal of Geophysical Research: Oceans, 117 (C7)

[2] Tang, S., von Storch, H., Chen, X., and Zhang, M.: “Noise” in climatologically driven ocean models with different grid resolution, Oceanologia, 61, 300–307, 2019.

[3] Tang, S., von Storch, H., and Chen, X.: Atmospherically forced regional ocean simulations of the South China Sea: scale dependency of the signal-to-noise ratio, Journal of Physical Oceanography, 50, 133–144, 2020.

[4] A. Hecht, N. Pinardi, A. R. Robinson, "Currents, Water Masses, Eddies and Jets in the Mediterranean Levantine Basin", Journal of Physical Oceanography, Vol. 18, No. 10, pp. 1320-1353, (1988), doi:10.1175/1520-0485(1988)018<1320:CWMEAJ>2.0.CO;2

[5] Trotta, F., Pinardi, N., Fenu, E., Grandi, A., & Lyubartsev, V. (2017). Multi-nest high-resolution model of submesoscale circulation features in the Gulf of Taranto. *Ocean Dynamics*, *67*, 1609-1625.

[6] Coherent Lagrangian Pathways from Surface Ocean to Interior - https://calypsodri.whoi.edu/

[7]Solodoch, A., Barkan, R., Verma, V., Gildor, H., Toledo, Y., Khain, P., & Levi, Y. (2023). Basin-Scale to Submesoscale Variability of the East Mediterranean Sea Upper Circulation. *Journal of Physical Oceanography*, *53*(9), 2137-2158.

[8] McDonagh, B., Clementi, E., and Pinardi, N.: The characteristics and effects of tides on the general circulation of the Mediterranean Sea, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, 2023. https://doi.org/10.5194/egusphere-egu23-14117, 2023.

[9] Fortin, V., Abaza, M., Anctil, F., and Turcotte, R.: Why should ensemble spread match the RMSE of the ensemble mean?, Journal of Hydrometeorology, 15, 1708–1713, 2014.