Comment on egusphere-2023-3076
Anonymous Referee #1
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.

- L4: I would suggest adding "different" to the realistic initial conditions to make it more clear. (as mentioned in L63)
  It has been added.

- L22: Is it possible to have riverine boundary impact for the intrinsic effects? Obviously atmospheric boundary is the most important, but if the riverine boundary could have an impact on the intrinsic effects. If there is large riverine input, it might lead to a different intrinsic effect.
  We thank the reviewer for their comment. Even though it is expected that differences in the riverine boundary conditions could have impacts on the intrinsic variability (i.e river plumes, river-induced coastal currents), we argue that at the Mediterranean basin scales the atmospheric forcing is the most effective driver of the internal variability at seasonal time scales. Alessandri et al. (2023) [4] have recently devised an ensemble approach for a coastal region in the Adriatic Sea influenced by riverine inputs. Their study indicates that uncertainties in river forcing do not exert a notable influence on the internal variability of sea level. In instances where such uncertainties do affect sea level, their impact is predominantly localized near the mouths of rivers.

- I believe L24-25: The sentence regarding the mesoscale eddies and flow instabilities is breaking the flow of the paragraph regarding Hasselmann's study. I would suggest moving this sentence to/towards the end of the paragraph. Maybe connect with energy cascade of meso to submesoscale eddies/flow.
  We propose the following modification from line 24 to ensure a smoother transition between paragraphs for better readability:

“The understanding of how internal variability can affect climate predictability, and justify the observed red profile of the climate variance spectra, was first achieved by Hasselmann (1976). To demonstrate the importance of internal variability in climate models, Hasselmann formulated a stochastic climate model whose main assumption is that the climate system may be divided into rapidly varying, random components and a slowly responding part. Climate variability is then shown to be due to the internal random components. The slow component behaves as an integrator of these inputs, whereas the fast component supplies the slow component with energy allowing the existence of internal variability in the climate system. Moreover, Hasselmann proved that climate variability would grow indefinitely without a stabilizing internal feedback mechanism. Consequently, the investigation of climate variability must be shifted from looking for positive to negative feedbacks that allow the climate system to reach stationarity in the absence of any external forcing. In the same years as Hasselmann’s study, mesoscale eddies and flow instabilities were mapped for the first time in the ocean (Harrison and Robinson (1978), McWilliams (1996)) and the presence of intense ocean internal variability was verified to exist.”

We have considered the reviewer’s comment on the energy cascade from mesoscale to submesoscale. However, after discussion among the authors, we would prefer not to incorporate it into the manuscript. While we acknowledge the importance of energy cascades in ocean dynamics, we believe that, in this case, it could be misleading. We did not resolve the sub-mesoscales and our resolution is only partially effective at the mesoscales. We believe that discussions on energy cascade from and to smaller scales would be beyond the scope of our work.

- L49-50: What is the basis of Tang's study in the scale/grid resolution? It would be helpful to mention that the capability of high-resolution ocean models to resolve the subgrid scale processes compared to the coarse resolution models.

  We noticed that the sentence from L47 to L51 was a little convoluted. We suggest the following modifications to explicitly highlight the ability of high-resolution models to resolve subgrid processes, thus introducing more intrinsic variability:

  “Lastly, as regards the scale dependency of the internal variability, it was demonstrated by Tang et al. (2019) that additional intrinsic variability is produced by increasing the horizontal spatial resolution of ocean models from 1° to 0.04°. Furthermore, Tang et al. (2020) analyzed the ratio of the externally forced response and the internally generated variability in the South China Sea and showed that the external forcing is dominant at large scales, while most of the variability is internally generated at smaller scales.”

- L80 mentions 0.1 degrees resolution for ECMWF. Coppini et al. (2023) mentions the same resolutions 0.125 degrees before 2020, and 0.1 degrees after 2020. Given the simulation period of Jan 2016 to Oct 2020, is there a possibility of a mismatch in the resolution?
  The ECMWF atmospheric boundary condition indeed experienced a change in the horizontal resolution in 2020 from 0.125° to 0.1°. However, we argue that our conclusions are not dependent on this change since all ensemble members were forced by the same atmospheric input. However, to demonstrate this point we repeated the same analysis for the year 2020 (see Supplementary material Figures S12 - S15). Even though we used a smaller ensemble of 16 members, the results were consistent and comparable, and the conclusions of our study still hold.
  We propose the following modifications in the manuscript at line 74 and following:
  "The model is forced by momentum, water and heat fluxes computed through bulk formulae using the operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF). The ECMWF atmospheric boundary conditions have a horizontal resolution of 1/8° up to December 2020 and of 1/10° after. This change in the forcing's horizontal resolution is irrelevant since during the analyzed period all simulations are forced by the same atmospheric fields."

- L85-90: It is not very clear that the initial condition is used from the previous simulation (Assuming to my understanding). If this is the case, wouldn't the model carry some of the intrinsic variability through initial conditions to the next simulation? I believe this should be clarified.
  Each simulation is initialized using an independent analysis from the operational system (Clementi et al. 2019 [1]). The initial conditions are as realistic as they can be since analyses are the optimal combination of the numerical model solution and observations.
  We propose the following changes in the paragraph from line L83 to L89 to make the explanation of the strategy used in our study clearer:
  "Each simulation is initialized every three months starting from January 2016 to October 2020. The initial conditions are taken from the Copernicus Marine Service analyses (Clementi et al., 2019 [1]) and all simulations last up to December 2021, as explained in Fig. 2. The ensemble spread, related to internal variability, is generated by the different initial conditions."

- L164: I think one of the most important (albeit expected) results of this study is this line. I would discuss or emphasize this result more.

We sincerely thank the reviewer for their interest in our results. We believe that the large values of the ensemble spread at the thermocline level in summer are due to the strong vertical temperature gradient that amplifies small differences among the temperature fields of the simulations (explained in lines L157-L160). Moreover, differences in the velocity fields, such as the position or strength of eddies, can cause local upwelling or downwelling of the water column thus determining variations of the Mixed Layer Depth (MLD), and of the seasonal thermocline mid-depth. In the Mediterranean Sea, the thermocline disappears during winter and thus the relationship does not hold.
We suggest adding Fig. A1 and Fig. A2 below to Section S3 of the Supplementary material. Figure A1 shows the mean Mixed Layer Depth resulting from our ensemble in both summer and winter and it shows how dramatic the difference is between the two seasons. Figure A2 instead is a zoom-in on Figure 6 in the first 70 m where both the ensemble mean of the MLD and the MLD resulting from each simulation are provided to show the differences among them. These Figures should be called S10 and S11 in the Supplementary material given the present numeration.
We then suggest the following modification in line 164:

"We argue that, during summer, thermocline processes exhibit significant internal variability and the spread observed at the peak of the vertical temperature gradient may arise from various mechanisms. First, baroclinic instability localized there can generate internal variability. Secondly, changes in the position and strength of eddies can cause upwelling or downwelling, thereby influencing the mixed layer depth and consequently, the mid-depth of the thermocline (Figures S10 and S11 in the Supplementary material)."

- L168-170: should be rewritten to make it more clear. There seems to be a missing word or two.
  We propose the following modifications to lines 168-170:
  "The N/S for T is smaller than 1 up to 100 m (about 0.3 at the surface) and it increases with depth. In the surface layers, it shows greater values in winter, whereas at greater depths it attains systematically larger values (approximately equal to 6) in summer."

- I would argue in some part of the manuscript the number of ensemble simulations. Tang uses 4 simulation ensemble and Penduff uses 50 as large ensemble. It would be helpful to argue how the number 20 came up for the ensemble simulations? [See next point]
- Depending in this how many ensemble simulations would make a difference to be able to identify the intrinsic variability?

In ensemble studies, there is no absolute criterion to find the perfect ensemble dimension and, obviously, the more the ensemble members the better the estimation. We had a similar concern about the dependency of the accuracy of our estimation of the intrinsic variability on the number N of ensemble members, but we did not perform a rigorous study to define the most convenient N. However, initially, we had only 5 runs starting on January 1st of each year from 2016 to 2020, since we were following more closely the example by Tang et al. (2020) [2]. Then, to increase the accuracy of our estimation we added more simulations increasing N up to 20 in the way presented in Section 2 of the manuscript and we found no significant differences in the results, especially as regards the pattern of the intrinsic variability (please refer to Figures A3 and A4 at the end of this document).
We suggest adding Fig. A3 and Fig. A4 below to Section S1 of the Supplementary material. These Figures should be called S4 and S5 in the Supplementary material given the present numeration.
We suggest adding the following sentence at the end of the paragraph at line 91 to further clarify this point:
"It is important to notice that the choice of having an ensemble of 20 members was somewhat arbitrary, even if it was the largest number of members compatible with our computational resources and returned results similar to a smaller ensemble of 5 members (Figure S4 and Figure S5 in the Supplementary Material). "

- In general it is an important first step analysis towards understanding the intrinsic variability in the Mediterranean Sea. In addition, the tides would definitely add an interesting approach to the study and the results as mentioned in L215-. Overall all it is a good manuscript and I would recommend it for publication after the minor revisions mentioned.

We sincerely thank the reviewer for their interest in our work and in the further developments that we proposed.

References:

[1] Clementi, E., Pistoia, J., Escudier, R., Delrosso, D., Drudi, M., Grandi, A., Lecci, R., Cretí, S., Ciliberti, S., Coppini, G., Masina, S., & Pinardi, N. (2019). *Mediterranean Sea Analysis and Forecast (CMEMS MED-Currents, EAS5 system)* (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_ANALYSIS_FORECAST_PHY_006_013_EAS5

[2] 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

[3] Coppini, G., Clementi, E., Cossarini, G., Salon, S., Korres, G., Ravdas, M., Lecci, R., Pistoia, J., Goglio, A. C., Drudi, M., et al.: The Mediterranean forecasting system. Part I: evolution and performance, EGUsphere, pp. 1–50, 2023

[4] Alessandri, J., Pinardi, N., Federico, I., & Valentini, A. (2023). Storm Surge Ensemble Prediction System for Lagoons and Transitional Environments. *Weather and Forecasting*, *38*(9), 1791-1806.

Added Figures:

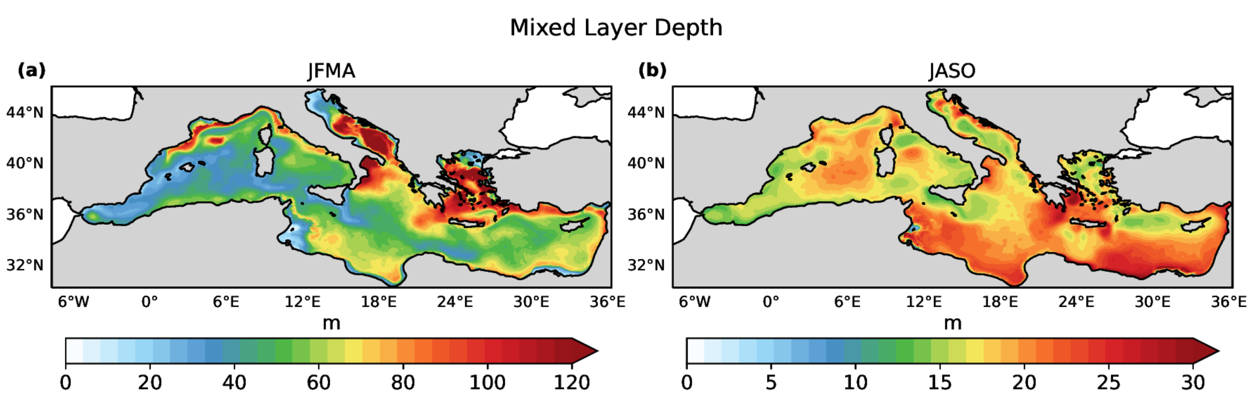

Fig. A1: Seasonal average of the Mixed Layer Depth in both winter **(a)** and summer **(b)** in the year **2021**. Please note the different scales used in the two sub-plots.

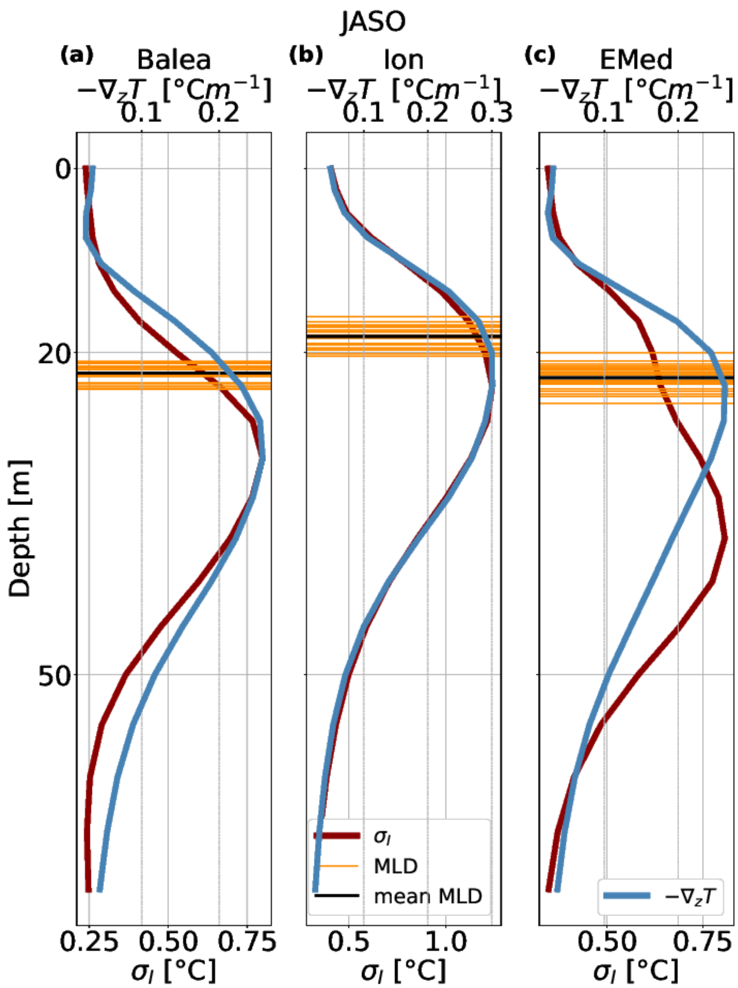

Fig. A2: Seasonally averaged vertical profile up to 70 m depth of the ensemble spread $\boldsymbol{\sigma_I}$ (red) for potential temperature and of the vertical temperature gradient $\boldsymbol{-\nabla T_z}$ (blue) in summer at Balea **(a)**, Ion **(b)** and EMed **(c)**. Horizontal lines indicate the seasonally averaged Mixed Layer Depth: black corresponds to the ensemble mean, while orange indicates the ensemble members.

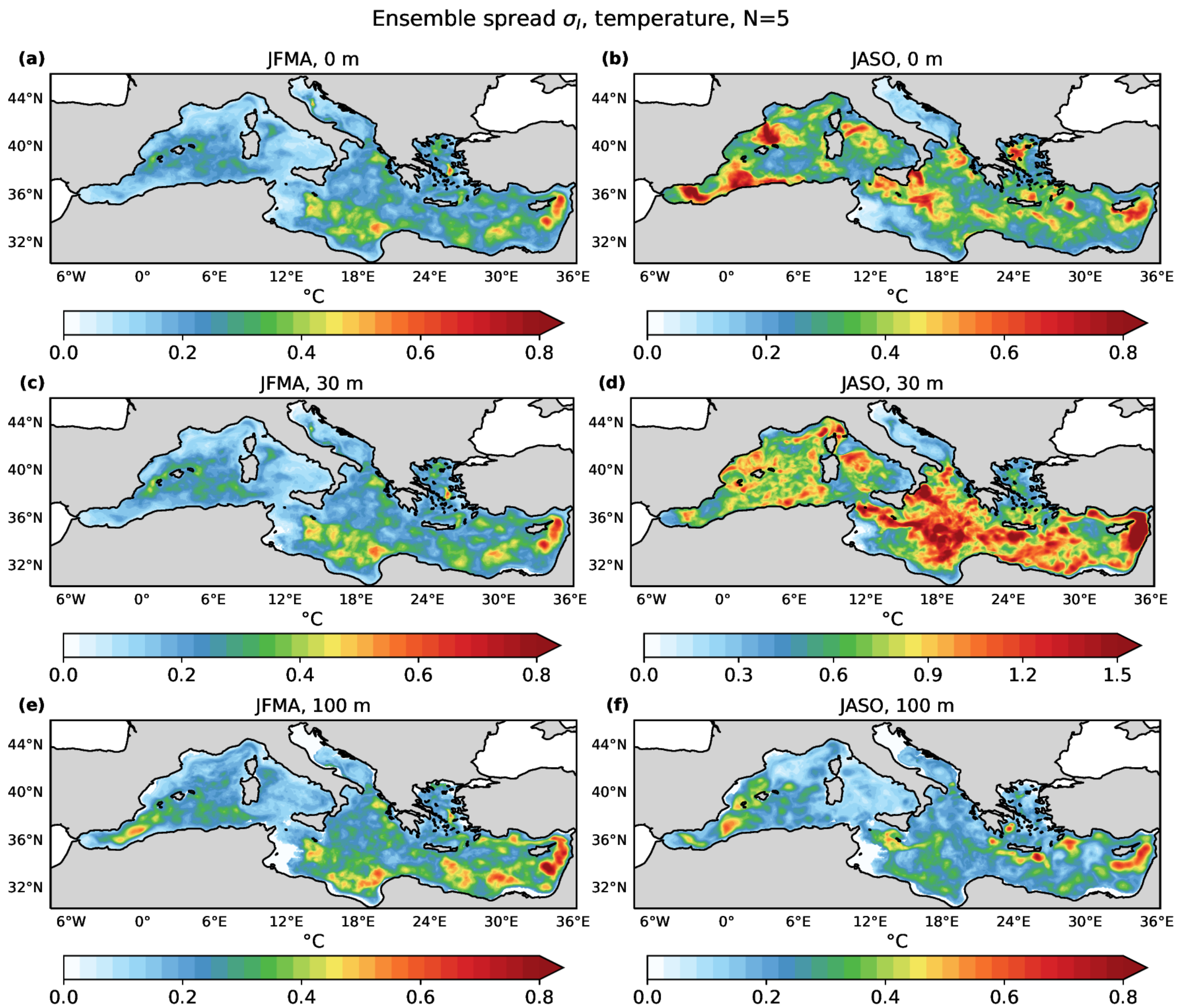

Fig. A3: Seasonal average of the ensemble spread with **N=5** for potential temperature T at different depth levels for the year 2021: at the surface **(a)**, at 30 m depth **(c)** and at 100 m depth **(e)** for winter and similarly in **(b)**, **(d)** and **(f)** for summer. Please note the different units used at different depths.

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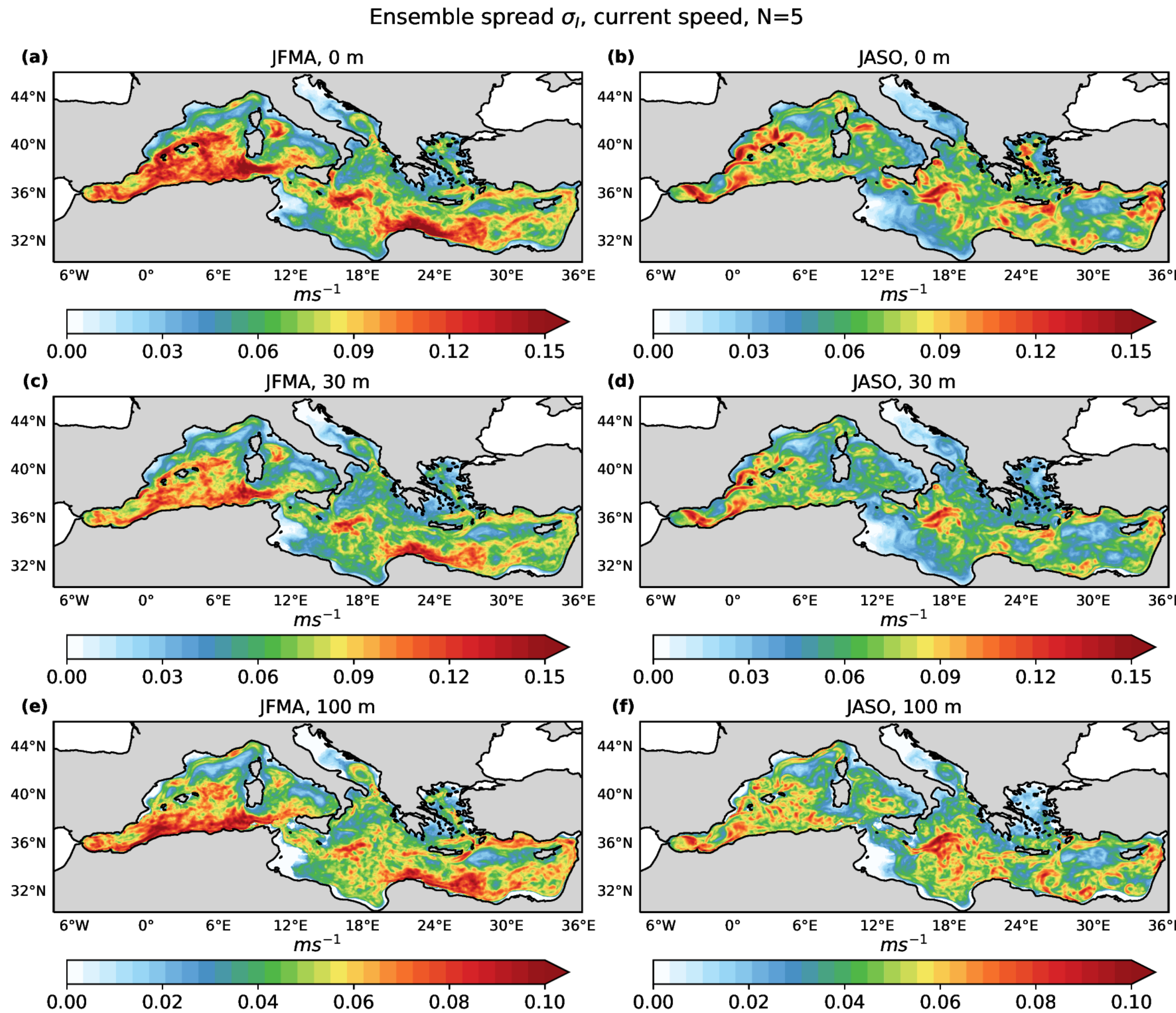

Fig. A4: Seasonal average of the ensemble spread with **N=5** for current speed v at different depth levels for the year 2021: at the surface **(a)**, at 30 m depth **(c)** and at 100 m depth **(e)** for winter and similarly in **(b)**, **(d)** and **(f)** for summer. Please note the different units used at different depths.