Author response to comments on “On Mode Water formation and erosion in the Arabian Sea: Forcing mechanisms, regionality, and seasonality" by Font et al., (Preprint egusphere-2025-468)

We thank the referee for critically reading this manuscript and providing helpful feedback, which has added a great deal to improve the manuscript and clarify certain sections.

We respond to all issues addressed in their comments below, as well as we add the revised changes in the manuscript. The Reviewer comments are included here in black, and the answers below the respective comments in blue. The text that has been modified in the manuscript according to the reviews is presented in *italic*. The line numbers in the answers refer to the new manuscript version after the suggested changes.

Referee #1

this paper is clear and well written; it is novel and useful to the community; the first figure is pedagogical

I recommend publication after addressing a few minor comments

1) what is the influence of the vertical mixing coefficient in the models, on the results?

The vertical mixing coefficient is crucial for stratification and significantly influences the model results. The selected mixing scheme for the 1D model—KPP (K-profile parameterization)—was chosen because it covers a wide range of open ocean conditions and allows for direct comparison and compatibility with the mixing scheme used in the 3D model (see line 126 in Section 2.3). Previous studies have evaluated the most suitable mixing schemes for Indian Ocean dynamics (Tirodkar et al., 2022), with a particular focus on KPP and K-epsilon mixing schemes. While K-epsilon performed slightly better and has been successfully applied in the Sea of Oman (Khalilabadi, 2024), we use KPP in our model to ensure consistency between the 1D and 3D configurations, and because it provides a robust representation of observations.

A detailed assessment of individual vertical mixing processes would require a dedicated study with a more refined approach. However, for our objective—characterizing seasonality and regional variability—the model successfully captures the observed cycle, giving us confidence that the chosen coefficients provide a realistic and robust representation within the model framework.

We have specified in the text that GOTM uses KPP mixing scheme *“... using the KPP mixing scheme (K-profile parameterization; Large et al., 1994)”*

Tirodkar, S., Murtugudde, R., Behera, M. R., & Balasubramanian, S. (2022). A comparative study of vertical mixing schemes in modeling the Bay of Bengal dynamics. Earth and Space Science, 9, e2022EA002327. https://doi.org/10.1029/2022EA002327

Khalilabadi, M. Turbulent Processes in the Oman Sea: A Numerical Study. Water Resour 51, 98–109 (2024). https://doi.org/10.1134/S0097807823600717

2) in a 1D hydrological (large-scale) model, potential vorticity PV will be directly related to N^2 but in a 3D model it has dynamical components; they may be of use in characterizing the MW in the 3D model simulations ; have you evaluated PV in the 3D model in the MWL - and its gradients above and below ?

We appreciate the reviewer's suggestion regarding potential vorticity (PV) as a diagnostic for the MWL in the 3D model. We initially explored this approach but found that differences in data sources, mainly due to variations in vertical and temporal resolution, resulted in noisy PV fields, making it challenging to use as a consistent diagnostic. Given these limitations, we opted for a density threshold approach that ensures consistency across datasets. Careful assessment of the density thresholds over the various datasets has given us confidence that this metric is well suited to define MW boundaries (Section 3.1).

That said, we agree that analyzing PV gradients in the 3D model could provide valuable insights into MWL structure and evolution. A future study focused solely on 3D model output could refine this approach, minimizing inconsistencies introduced by mixed datasets and improving MW detection. We appreciate this insightful suggestion and will consider it in future work.

3) concerning the difference between 1D and 3D results (fig.5-6) it may be of interest to plot MKE and EKE next to these figures to assess the local importance of horizontal advection

We agree that considering mean kinetic energy (MKE) and eddy kinetic energy (EKE) can help assess the role of horizontal advection in explaining the differences between the 1D and 3D results. Rather than adding these fields to the figures, MKE and EKE have been extensively studied in the region, partly because fieldwork difficulties have emphasised the importance of remote sensing studies in the region. We have included two citations (one specifying the figure we refer to, *Figure 1 in Zhan et al., 2020*), highlighting regions where MKE and EKE are particularly relevant. Additionally, we have expanded the discussion to clarify how horizontal advection plays a locally significant role and contributes to the observed biases:

Line 332-335: *"horizontal advection, particularly in high eddy kinetic energy regions, redistributes heat and momentum laterally, a process absent in the 1D model. In the western Arabian Sea, where eddy kinetic energy intensifies in summer near the Somalian coast (Figure 1 in Zhan et al., 2020; Sun et al., 2022), this likely contributes to the MLD differences between the 1D and 3D simulations (Figure 6c,g,k)."*

We believe this addition sufficiently addresses the reviewer's concern while maintaining clarity in the figures.

Zhan, P., Guo, D., & Hoteit, I. (2020). Eddy-Induced Transport and Kinetic Energy Budget in the Arabian Sea. Geophysical Research Letters, 47(23), e2020GL090490. https://doi.org/10.1029/2020GL090490

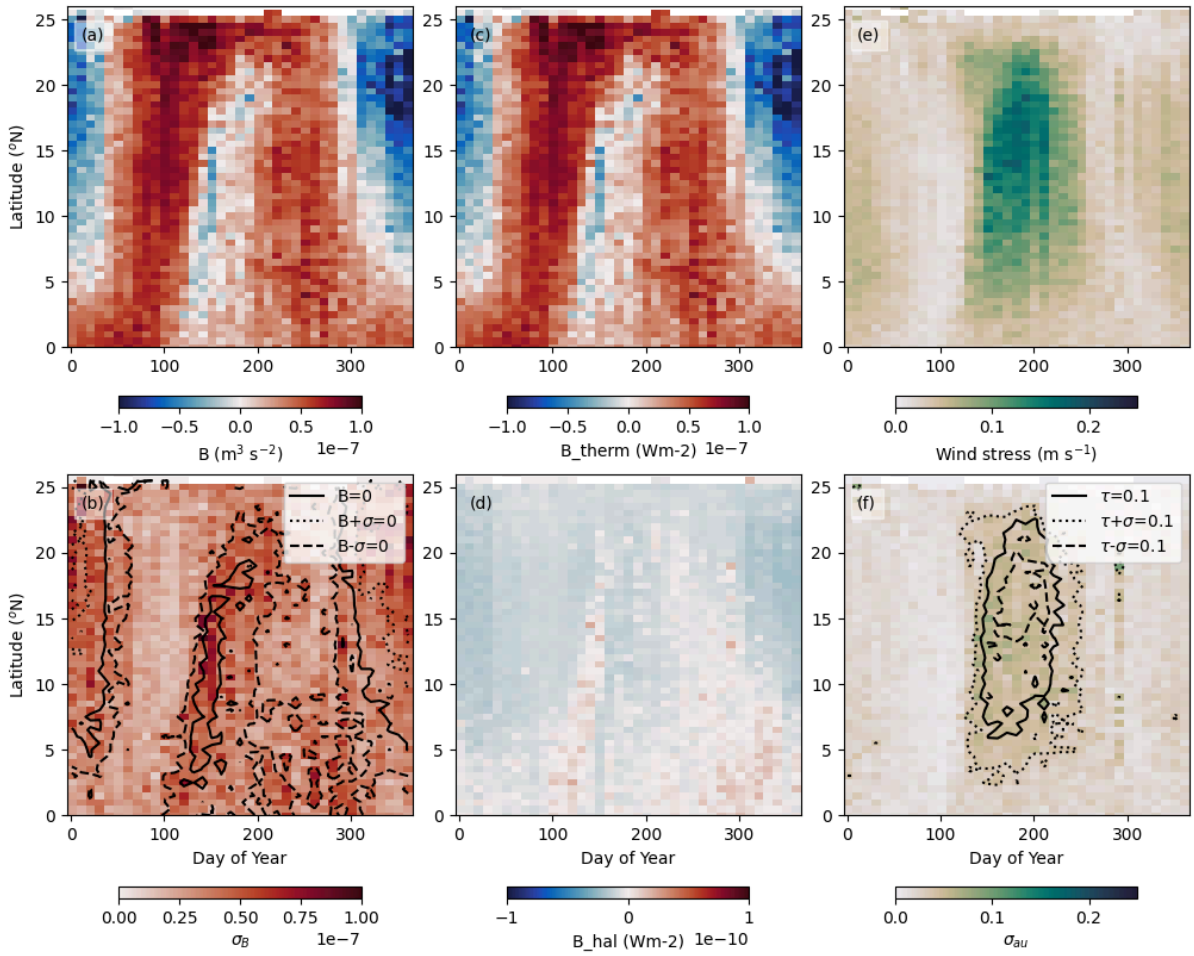
Sun, C., Zhang, A., Jin, B., Wang, X., Zhang, X., & Zhang, L. (2022). Seasonal variability of eddy kinetic energy in the north Indian Ocean. Frontiers in Marine Science, 9, 1032699. https://doi.org/10.3389/FMARS.2022.1032699/BIBTEX

4) in your equation (1) you merge the thermal and haline contributions to buoyancy ; what are their respective roles in MW formation and disappearance ; how uniform are T and S when rho is constantvertically ?

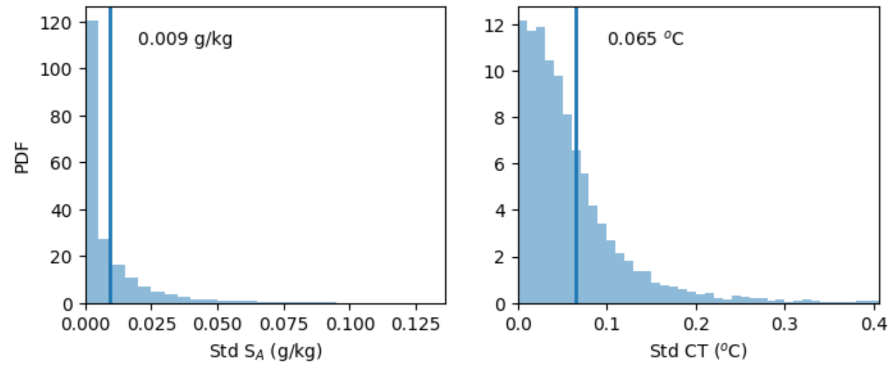
Indeed, this is a good suggestion. We have assessed the relative contributions of the thermal and haline components to the total buoyancy flux. The thermal component is two orders of magnitude larger, accounting for 99.5% of the buoyancy flux on average. We have added the following statement:

Line 248:"*The buoyancy flux is driven by its thermal component ((α·Q_NET)/(ρ_0·c_p)≫β·S_A·(E-P), Figure S2)*".

We have also updated Figure S2 in the supplementary material to include the contributions of each component.



To address the reviewer's point about T-S variability within the MW layer, we computed the standard deviation of temperature and salinity across the MWL. Both axes of the standard deviation plot are scaled by α/β=0.34 to reflect equal contributions to density changes (Δρ=10−4 kg m−3). Our results indicate that temperature variability within the MWL is larger than salinity variability in terms of their respective contributions to density, but overall, variations in T-S within the constant-density layer remain minor.



5) you mention barrier layers in relation with BBW; this latter flows along the eastern boundary of the AS ; how extended geographically (away from the coast) is the influence of these barrier layers on MW ?

The role of barrier layers formed by freshwater advection from the Bay of Bengal in the southeast Arabian Sea has been documented (Echols et al., 2020; Li et al., 2023) in recent studies, although questions remain about how far offshore barrier layer influence on MW remains extends. We feel that properly addressing this question, including understanding the seasonal variations and the drivers of variability of its offshore influence, would constitute an entirely separate study. To acknowledge this open question, we have added the following statement:

Line 546-551: *"This process has been previously described regarding barrier layers formed by freshwater advection from the Bay of Bengal in the southeast Arabian Sea (Echols et al., 2020; Li et al., 2023), contributing to the genesis of surface intensified marine heat waves (Saranya et al., 2022). Moreover, the interaction between freshwater Bay of Bengal barrier layers and MW is crucial and warrants further investigation. The extent to which barrier layers influence MW away from the coast remains uncertain, highlighting the need for targeted studies to better understand its geographical constraints and impacts."*

Echols, R., & Riser, S. C. (2020). The Impact of Barrier Layers on Arabian Sea Surface Temperature Variability. Geophysical Research Letters, 47(3), e2019GL085290. https://doi.org/10.1029/2019GL085290