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 the text. We respond to all issues addressed in their comments below, as well as adding the revised changes in the manuscript. The Reviewer comments are included here in black, and our answers below their 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 marked-up manuscript version with tracked changes

RC2

General comments

This study uses a water mass transformation framework to investigate drivers of mode water volume change in the Sea of Oman. The variables used to define water masses are potential density and spice which allows the mode water volume budget to be decomposed into isopycnal transformation, diapycnal transformation and an exchange flux across the boundary of the region considered. The methods are applied to a dataset derived from ARGO floats to produce a climatology, and data from a high resolution glider, with the aim of investigating drivers of volume changes on shorter timescales. The water mass transformation methods used in this study have not previously been applied to higher temporal resolution data making this an important study for people who may wish to carry out similar analysis in the future.

The key findings indicate that the climatology produced from ARGO floats smooth out mode water volume changes on shorter timescales. Specifically, the presence of mesoscale eddies greatly enhances isopycnal transformation, which is then followed by diapycnal transformation, over time periods shorter than a week. Such periods of high variability are not captured in the climatology produced from the ARGO data. The need for higher resolution sampling is highlighted so that shorter periods of high variability in volume changes of mode water, particularly due to the presence of mesoscale eddies, are captured. This is important both for understanding what is happening the ocean, as well as the parametrisation of such processes in models.

Overall this is a high quality and well written study that I think the community will benefit from provided the comments below are addressed with a particular focus on improving the explanation of the water mass transformation framework in section 2.2.

Josef Bisits

Specific comments

Line 15: Please clarify if the statement Mode water predominantly transforms along isopycnals is something that is already known or a finding from this study.

It is a finding from our study. We have changed the sentence to explicitly state that these are our results. Now it reads as follows in L15: *"Our study shows that mode water..."*

Line 20: Is the methodological approach new? Certainly it has not been applied to higher resolution glider data but the theoretical framework was established in Evans et al. (2014).

Thank you. We agree and have rephrased the sentence to state it*:*

L19: " This study provides a novel application of the water mass transformation framework to high-resolution underwater gliders, and shows that this methodology can be used at higher resolution than traditional climatological products or models."

Line 84: Please clarify if the density threshold was calculated using potential density or in-situ density.

We used potential density. We have clarified it now as: *"...potential density threshold of..." (L86).*

Line 148: What is the reference pressure used to calculate potential density? If it is the same throughout the study, please include what the reference pressure is here, or with an earlier mention of potential density. Same goes for spiciness, please indicate what reference pressure is used.

Thank you. We have clarified in the methods: *"Potential density and spice are referenced at 0 dbar." (L88).*

Section 2.2: There are some inconsistencies in the explanation and mathematical expressions in this section which made it hard for me to follow. Equation (1), from the text, is the volume change for a specific σ - τ class. On line 154 the expression dV/dt = Ax equates the change in volume to a linear system. On line 155 the vector x is defined as x = (Uσ + Uτ + Ψ), which appears to be a scalar value. This means that Ax is not a linear system as it is currently defined. I think what the authors mean is that each component of x describes the change in volume of a specific σ − τ class for a given process so x = (Uσ,Uτ , Ψ). To consider all σ - τ classes I think x should then be $\mathbf{x} = (U_\sigma^1, \ldots, U_\sigma^m, U_\tau^1, \ldots, U_\tau^n, \Psi^1, \ldots, \Psi^l)$

where m and n are the number of σ and τ classes, respectively, and l is the number of Ψ terms. Then, the left hand side of dV/dt = Ax needs to be updated, perhaps by defining the vector V of all volume classes, to reflect that the result is a vector so the expression for the residuals on line 178 is consistent.

I appreciate the methods used in this study are outlined in Evans et al. (2014) and Portela et al. (2020) but this study still needs to correctly set up the theoretical framework either in the text in this section or perhaps add an appendix with the full expressions for the linear system i.e. define the matrix A and vector x.

Thank you. We apologise for the inconsitencies in the mathematical expressions and explanation of the method. We have decided to add a detailed explanation in the Supplementary Information that includes the equations and provides a more clear outline. Please see the new version Supplementary Information.

To address your suggestion, we have changed the explanation to not only one sigma-spice class, but written the expression for all sigma-space classes in a vector form as per Evans et al., 2014. We have made the changes in the manuscript accordingly (See Section 2.2, L165):

*"Using equation (1), a set of linear equations can be built to link the volume trend to the interior water-mass transformation in σ-τ coordinates as d**V**/dt=**Ax**, where d**V**/dt is the observed change in volume of each sigma-spice class, divided by the relevant time interval; **A** is the matrix of coefficients of the linear equations; and **x** is the vector of the resulting diasurface transformations and exchange flux. This system is solved by means of a least squares regression for the unknown transformation and exchange flow. The detailed methodology has been added to the Supplementary Information. The solution **x** was then*

decomposed into the transformation across spice and density surfaces and the exchange flux across the geographical domain."

Line 186: Including the meaning of "mintier" in parentheses would be good for readers not familiar with the spice variable.

Thank you. We have clarified in L209*: "mintier (i.e., fresher and colder)".*

Line 234: Please clarify what the "true" high-resolution mean is.

We have changed the "true high-resolution mean" to *"the 3-day mean*" in lines 267 and 273.

Line 236: A probability should be between zero and one so I think replacing probability with likelihood is appropriate here (this also matches terminology to what is used on line 238).

Thank you. We have changed it. (L267)

Line 314: Would cyclonic eddies produce a similar modulation to vertical and lateral mixing? A short comment here on if there are any expected differences between cyclonic and anticyclonic eddies would be appropriate.

Thank you for raising this point. The aim of this work is to highlight the general role of mesoscale eddies in modulating vertical and lateral mixing. Our current datasets (and scope of the study) cannot be used to explicitly distinguish between the effects of cyclonic and anticyclonic rotation of eddies on the processes we describe. Most notably, our glider dataset intersects anticyclonic eddies only, thereby our interpretations are constrained to this polarity. Given ongoing data collections efforts, it may be possible in the future to address this topic and complete a further investigation.

Technical comments

Line 58: I think the word "used" should be use here.

Changed, thank you.

Line 146: Equations 1.1 and 1.2 should have the same symbol for Π, currently 1.1 has a bold symbol. Related to this, could a single expression be written for Π? Something like

$$\Pi(\sigma,\sigma') = \Pi(\tau,\tau') = \begin{cases} 1 \text{ if } \sigma \in \sigma' \text{ and } \tau \in \tau' \\ 0 \text{ otherwise.} \end{cases}$$

then only σ′ and τ ′ need be defined (which they are on line 147).

Thank you. We have changed Π to "not bold" for both equations and also written Π as a single expression as you suggested as Eq. 2. (L158)

Line 159: Please update tracer surfaces to tracer iso-surfaces or indicate they are surfaces of constant tracer (perhaps it is implied but I think worth explicitly stating the first time).

Thank you. Updated to tracer iso-surfaces (L173)

Line: 174: I think "(two sections)" could be removed, the clarification that it is a week is sufficient.

Removed.

Line 188: Should the second sentence be “Thus, there is mode water volume formed from ...”? As written I found it unclear.

Thank you. We have changed it to your suggestion (L214).

Line 195: Is the word scale missing after smaller here?

Yes, we have added it (L220).

Lines 200, 201, 204, 205: tranf. should be transf.

We have changed all of them accordingly.

Line 267: This is the second use of coincide in this sentence. I think replacing “coinciding” with “along” would improve readability here.

We have changed it to “along”.

Figure 5 caption: The description of the “red lines” could include they are the potential density range for the mode water.

Changed to L363: *“red lines denote the potential density range of mode water (25 and 25.25 kg m^{-3}).”*

Line 414: Should the first use of “their” be the?

Changed.

Line 422: In line with an earlier point, I think probability should be replaced with likelihood.

Thank you. Changed (L445).

Line 426: Expanding on what is in the parentheses would be good here, e.g. (as the schematic in figure 6 shows).

We have changed it as you suggested (L449).

Line 429: Rather than have “(sub)” I think it worth including the word submesoscale e.g. “assess the role of submesoscale and mesoscale dynamics..”

Explicitly included as you suggested (L453).

References

[1] Dafydd Gwyn Evans et al. “The imprint of Southern Ocean overturning on seasonal water mass variability in Drake Passage”. In: Journal of Geophysical Research: Oceans 119.11 (2014), pp. 7987-8010.

[2] Esther Portela et al. “Interior water-mass variability in the Southern Hemisphere oceans during the last decade”. In: Journal of Physical Oceanography 50.2 (2020), pp. 361-381.