Review: Spatio-temporal scales of mode water transformation in the Sea of Oman

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.

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).

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

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.

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 $\sigma - \tau$ class. On line 154 the expression $\mathrm{d}V/\mathrm{d}t = A\mathbf{x}$ equates the change in volume to a linear system. On line 155 the vector $\mathbf{x}$ is defined as $\mathbf{x} = (U_\sigma + U_\tau + \Psi)$, which appears to be a scalar value. This means that $A\mathbf{x}$ is not a linear system as it is currently defined. I think what the authors mean is that each component of $\mathbf{x}$ describes the change in volume of a specific $\sigma - \tau$ class for a given process so $\mathbf{x} = (U_\sigma, U_\tau, \Psi)$. To consider all $\sigma - \tau$ classes I think $\mathbf{x}$ should then be $\mathbf{x} = \left(U_\sigma^1, \ldots, U_\sigma^m, U_\tau^1, \ldots, U_\tau^n, \Psi^1, \ldots, \Psi^l\right)$ 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 $\mathrm{d}V/\mathrm{d}t = A\mathbf{x}$ needs to be updated, perhaps by defining the vector $\mathbf{V}$ 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 $\mathbf{x}$.

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

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

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).

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.

Technical comments

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

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

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

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

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).

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

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

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

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

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

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

Line 414: Should the first use of "their" be the?

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

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

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

References

[1] Dafydd Gwyn Evans et al. "The imprint of S outhern O cean overturning on seasonal water mass variability in D rake P assage". 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.