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Interactive comment on "Tracking the spread of a passive tracer through Southern Ocean water masses" *by* Jan D. Zika et al.

Anonymous Referee #2

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Overview

This paper estimates meridonal mixing of a passive tracer released in the Southern ocean, and tracked over $\sim$3 years. Previous analyses from the same experiment measured mixing via conventional x-y (longitude-latitude) distance coordinates. The present work utilizes salinity variations and large-scale salinity gradients on isopycnals to infer irreversible mixing rates of the tracer in salinity space, and then relates this back to physical space spreading via climatological salinity gradients in the region. Results are roughly consistent with previous published results based on traditional second-moment diffusivity calculations, as well as diffusivities inferred from floats.

General Comments

The authors present an interesting approach for inferring irreversible mixing on isopycnals, arguing that analysis in salinity space along isopycnals provides a measure of irreversible mixing as the tracer advects through varying meridonal salinity gradients. The rationale for the present analysis is that as the meridional gradient of salinity changes along the path of mean tracer advection due to meridonal convergences and divergences, which in physical space cause the tracer to widen, then narrow, then widen again as it is transported zonally. The authors liken the analysis in salinity space along isopycnals to analysis in density space when measuring diapycnal mixing, the advantage of the latter being that it enables the separation of spreading by isopycnal straining from that caused by irreversible diapycnal mixing.

While the approach will readily make sense to those familiar with this type of tracer analysis, I share the other reviewer's sentiment that there are a number of aspects of the method that could benefit from further discussion. First, when comparing the salinity coordinate approach to the isopycnal coordinate approach used to measure diapycnal mixing, the latter is used to account for spatio-temporal trends in stratification as well as high frequency variations from one profile to the next caused by internal waves. While the salinity method certainly addresses larger-scale trends in the meridional salinity gradient, it is not clear whether there are also smaller-scale variations, e.g., due to smaller-scale frontal meanders within the ACC or any of its smaller fronts? If so, this would be useful to point out as one of the distinctions between the salinity-space derived estimate of Kh and other estimates. Also regarding the larger spatio-temporal trends, it would appear that the salinity-space approach is directly analogous to accounting for the convergence and then divergence of the flow as it traverses the Drake passage. This then can be likened to the strain-diffusion balance that is often used to estimate small-scale diffusivity either from the streaking phase of large-scale tracer experiments, or for smaller shorter-time scale fluorescent dye experiments. Effectively, diffusivity estimated in stream-wise coordinates, allowing for converging and diverging strain, should yield similar results. Finally, another difference between the present salinity coordinate analysis and isopycnal coordinate analysis is that the latter typically is converted back to physical space coordinates using the mean density-depth relation computed from the same data. The use here of climatological salinity data presumes that the salinity gradient during DIMES was similar to the climatological gradient computed from all previous records. While this may be a reasonable (even if necessary) assumption, and any differences likely to be small, a sentence mentioning this as another source of error is warranted.

A second aspect of the results that could benefit from further discussion are some of the nuances of the difference between this salinity space estimate of Kh and other physical space estimates, particular as relates to the difference between mixing and stirring. The authors argue that the present analysis measures “irreversible mixing”. By this, they strictly mean mixing that crosses isohalines. However, in practice, by virtue of its random nature, stirring by mesoscale eddies is also irreversible. Beyond semantics, one can consider the phases of stirring and mixing described by Garrett (1983) and cited in the paper. During the early stirring phase, eddies re-distribute the tracer and increase is variance in x-y space, but do little to it in salinity space (e.g., per Section 3, line 111 of the paper). The salinity space “diffusion” occurs due to small-scale diffusive processes that rectify the stirring motions by smoothing out the wisps and streaks across what are then also wisps and streaks in salinity. Once the tracer has begun to fill in across many eddy stirring events, the large-scale variance approaches its linear eddy diffusivity growth regime, and absent spatio-temporal changes in the large-scale salinity gradient, this result should be similar to a physical space analysis of diffusivity. However, before the tracer has filled in between the streaks, wouldn’t the salinity space vs. physical space dispersion estimates be expected to differ significantly? What new information about stirring vs. mixing can be gleaned from this? Some clarification would help the reader understand what the salinity space analysis is telling us for these early vs. late times in the tracer evolution.

Specific Comments (Relating to above General Comments)

Line 30: But isn’t rearrangement by mesoscale flows, if they are random and/or in

practice do not reverse, what we consider mesoscale eddy stirring, which is its own form of mixing?

Lines 101-102: This is not a problem if one knows the meridonal convergence or strain rate. If this is known, the changing width of the patch in spite of this strain can be computed, which is presumably what the analysis in salinity space will facilitate.

Lines 111-112: “. . . preserve their temperature and salinity values” . . . Except for mixing along mixing lines in T-S space?

Lines 126-128: “. . . in density versus salinity anomaly coordinate the tracer spreads out more monotonically.” . . . As it must, since there is no way to mix to different salinities except along mixing lines.

Lines 213-214: Is there a way to assess whether increased diffusive flux is due to greater diffusivity or larger tracer gradient caused by flow convergence?

Review Summary and Rating

Overall I find this paper interesting and worthy of publication in Ocean Science. I have noted above a few points that the authors might consider adding to the Discussion of the paper – among these are some things that would help clarify the analogies between the present approach and previous ones, and also things that might help readers better understand the differences between the present diffusivity estimates and more traditional physical space estimates.

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