First and foremost, we express our gratitude to the reviewers and the editor for their patience and comments. We are delighted that the improvements we have made to the content of our study, particularly the model design and simulations, have been recognized. After the second round of reviews, we have only seen explicit comments left by Anonymous referee #2 on the GMD author interface. This document is our response.

Referee #2

This is my second time reviewing the manuscript. I appreciate the efforts taken by the authors in expanding their numerical simulation of an idealized Southern Ocean. The new set of simulations now align much closer to reality. On the point of passive tracers, I appreciate their reply regarding the eddy transport tensor. My previous point was more on how robust the tracer distributions remain orthogonal with each other when the end state of initial-value problems of passive tracers is universally a complete homogenization. Their Fig. 12 is informative in answering this question in demonstrating the time scales of passive tracer homogenization. I think the manuscript is close to publication and I only have a single point I would like to have addressed.

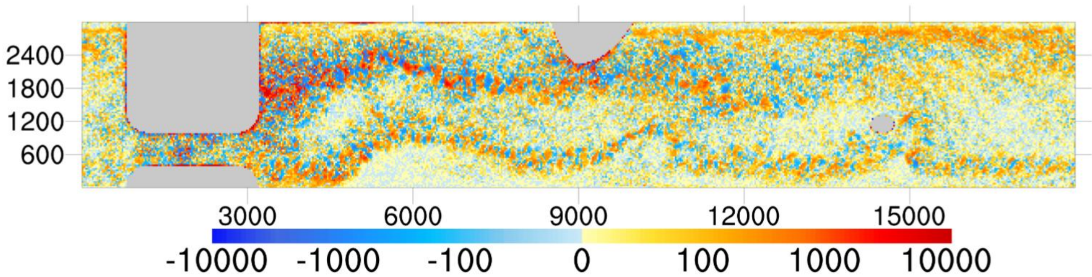
We thank the reviewer very much for the useful suggestions and patience, which helped us improve the research content and manuscript dramatically.

- Lines 359-365: This relation between KE and enstrophy spectra (Ens(k) = k^2 EKE(k)) is specific to two-dimensional (2D) turbulence. Given the first-order vertical isopycnal fluctuations in the Southern Ocean (e.g. Fig. 4), I find the justification to adopt spectral scaling laws of 2D turbulence difficult to justify. They should at least use quasi-geostrophic (QG) potential vorticity (rather than relative vorticity) if they wish to show the enstrophy spectra (Vallis, 2017; his Chapter 12). In my opinion, the authors should really just diagnose the QG enstrophy spectral flux and show whether the length scales they observe a -3 EKE spectral slope coincide with a forward enstrophy cascade.

The enstrophy (for the relative vorticity) spectrum has a spectral slope of -1 in the enstrophy inertial range, which is indeed the classical prediction of the 2D turbulence. We acknowledge that in the previous manuscript, we potentially assumed that the main processes simulated, especially the oceanic mesoscale processes, are quasi-2D, and therefore tend to approach the 2D turbulence. Another reason for choosing the current enstrophy spectrum is that we found that Chassignet and Xu (2017) provided the same (vorticity variance) spectrum for their simulation under similar horizontal resolution, and we did obtain qualitatively consistent results with theirs. After consideration, we decide to revise the content in the relevant paragraphs to avoid confusion between the concepts of geostrophic turbulence and 2D turbulence. The revised content in *Lines 359-366* in the new manuscript: "Similarly, we take 1024 km zonal segments at given locations and compute the surface enstrophy (or relative vorticity variance) spectrum Ens(k) (Fig. \ref{fig:f05}g-i). It shows a spectral slope of -1 for all simulations on large scales, and the dissipation effect removes enstrophy on small scales. The result is qualitatively consistent with \citet{Chassignet2017} (their Fig. 23) who studied the high-resolution model on the Gulf Stream. The scale range with a -1 spectral slope expands with finer horizontal resolution. In the 2-km simulation (Fig. \ref{fig:f05}i), the range of -1 spectral slope can extend to nearly 10 km, which fully covers the deformation radius scale. Further examination of the potential enstrophy conversion term between the large-scale flow and eddies in the enstrophy budget shows a holistically forward potential enstrophy cascade (Figure S9). The result further confirms that the 2-km-resolution ISOM can generate a type of MODNS dataset."

In addition, the reviewer hopes to verify the forward potential enstrophy (for potential vorticity) cascade in the simulation and has provided a relevant suggestion. The suggestion is thorough but not easily implementable at our current stage. Instead, we adopt a simple method, which is sufficient to illustrate that the potential enstrophy is transferred to small scales in our model. We diagnose the potential enstrophy conversion between the large-scale and eddy components of the flow and confirm that the simulation holistically exhibits a forward cascade of potential enstrophy. The relevant content is provided in Figure S9 in the supplementary material, and we also show it in the following.

Figure S9. The potential enstrophy conversion between the large-scale and eddy components of the flow, $-\overline{\mathbf{u}'q'} \cdot \nabla \bar{q}$ (unit: $10^{-30} m^2 s^{-3}$). $\mathbf{u}$ is the velocity. The potential vorticity $q = \frac{f+\zeta}{\rho} \frac{\partial \rho}{\partial z}$ as Holland et al. (1984). Bar and prime represent the Reynolds' time average and fluctuation, respectively. When the term is positive, there is a conversion of potential enstrophy from the large-scale to the eddying field on average (relevant discussion in Wilson and Williams (2004) or Eaves et al. (2024)). Though the term has spatial variation, the intense forward potential enstrophy transfer towards small scales can happen in regions with active eddy activities. The domain average of the term is also positive, which indicates holistically a forward potential enstrophy cascade in the model. [1] Holland, W., Keffer, T., and Rhines, P. (1984). Dynamics of the oceanic general circulation: the potential vorticity field. Nature, 308(5961), 698-705. [2] Wilson and Williams (2004). Why are eddy fluxes of potential vorticity difficult to parameterize? Journal of physical oceanography, 34(1), 142-155. [3] Eaves et al. (2024). An energy and enstrophy constrained parameterization of barotropic eddy potential vorticity fluxes. Authorea Preprints.



Reference

Chassignet, E. and Xu, X. (2017): Impact of horizontal resolution (1/12 to 1/50) on Gulf Stream separation, penetration, and variability, Journal of Physical Oceanography

Holland, W., Keffer, T., and Rhines, P. (1984). Dynamics of the oceanic general circulation: the potential vorticity field. Nature, 308(5961), 698-705.

Wilson and Williams (2004). Why are eddy fluxes of potential vorticity difficult to parameterize? Journal of physical oceanography, 34(1), 142-155.

Eaves et al. (2024). An energy and enstrophy constrained parameterization of barotropic eddy potential vorticity fluxes. Authorea Preprints.