The Weddell Gyre heat budget associated with the Warm Deep Water circulation derived from Argo Floats

Overall Assessment

This study presents a heat budget of Warm Deep Water across the Weddell Gyre based on in situ Argo float data. Though the main results are not qualitatively surprising, they provide a valuable observations-based benchmark for the processes that distribute heat across the gyre. The main weakness of this analysis is that it relies on relatively sparse in situ data and crude parameterizations for unresolved eddy mixing. Though the authors are thorough in acknowledging the limitations of their analysis, certain key results remain insufficiently constrained. Nevertheless, with some revisions, this work will be a valuable addition to the literature.

My main criticisms are as follows:

- **Treatment of transient processes**: This study adapts the heat budget used by Tamsitt et al. (2016), who assessed zonal variations in heat fluxes along the Antarctic Circumpolar Current. Tamsitt et al. (2016) used five-day averaged output from the 1/6th-degree Southern Ocean State Estimate (SOSE). In this framework, "turbulent diffusion" has a clear physical interpretation. Since SOSE resolves time-mean and transient variations in the large-scale flow and mesoscale eddies, "turbulent diffusion" describes unresolved, subgrid-scale mixing. Here, the underlying dataset only provides (smoothed) time-averaged temperature and horizontal velocities, and all other processes (not counting vertical advection) are implicitly parameterized as "turbulent diffusion". While it may be reasonable to characterize eddy stirring as a diffusive process, it is problematic to treat transient variations in the large-scale circulation and temperature field in the same manner. There needs to be a more careful treatment of the heat fluxes associated with temporal correlations in the temperature and velocity field. The discussion in Section 3.1 should distinguish time-averaged from transient processes (i.e., via Reynold's decomposition) and clarify that only the former is resolved. If transient processes cannot be considered negligible, they should be treated as residuals rather than lumped with turbulent diffusion.

- **Representation of eddy-mixing and turbulent diffusion**. To account for unresolved eddies, the authors assume their net effect on the time-mean heat budget can be parameterized as a diffusive process. While this is a reasonable and standard approach, I am unconvinced that the effects of eddy mixing are within the bounds of uncertainty presented here. I particularly question the validity of the heat budget analysis east of Maud Rise, where numerous studies have demonstrated that mesoscale eddies have leading order control of heat transport in this region (Ryan et al. 2016, Wilson et al. 2022). Since these eddies mix water-mass properties on sub-seasonal scales and create spatial gradients much smaller than the smoothing filter used to create the temperature climatology, it is no surprise the heat budget does not come to closing in this area (Figs. 2-5). While it is useful to see Figure 2 in its current form, the subsequent analysis should be limited the analysis to the open-ocean areas east of Maud Rise, where the horizontal temperature gradients are weak and the eddies are not as energetic. In my opinion, the data are insufficient to provide a valid heat budget elsewhere. Additionally, I would like to see stronger acknowledgment in the Abstract that the effects of eddy mixing are highly uncertain.

- **Over-reliance on arbitrary and ad hoc methods**: While budget analyses like this study inevitably involve some amount of arbitrary decisions, this study does so to an excessive extent. For example, in line 188, the authors arbitrarily define an uncertainty range for the diffusivity coefficients, and no rationale is given beyond the unsupported claim that these values are sufficiently large. Another example is when the authors split the Weddell Gyre into "interior cell" and "southern limb," where the former is eventually subdivided into northern and southern limbs. There is no clear rationale for why this is done, and the differences among these regions are sensitive to how the parts are defined. For the last example, if the goal is to highlight these meridional variations in the heat budget balance, a cleaner approach would be to compute a zonal average of the budget terms west of Maud Rise. I document other instances of these arbitrary and sometimes perplexing methodologies below.

Detailed comments:

- Lines 25-: The plain language summary reads more like a second abstract. I think this needs to be more concise and less technical.

- Line 34: "Warm Deep Water, however, varies in its properties too strongly to tease..." It is unclear what "varies too strongly" means.

- Line 39: "interesting features..." Please replace "interesting" with a more objective adjective.

- Line 53: "The CDW that enters the Weddell Gyre is commonly referred to as Warm Deep Water (WDW)..." This is a nitpick, but I understand WDW to be a modified variant of CDW rather than simply CDW that exists in the Weddell Sea.

- Figure 1: Add contour labels for the streamlines, specifically the ones used to define IC SL subregions.

- Line 152: Please briefly state how Sevellec et al. (2022) obtained their diffusivity estimates.

- Lines 135-138: A couple of things here:
    - Figure S1a and a summary of the accompanying discussion regarding the definition of the vertical boundaries of WDW should be included in the main text.
    - For Figure S1a, it would be helpful to include additional profiles to illustrate the variability of temperature profiles and the location of the upper boundary.
    - Regarding the previous point, are there regions where the lower boundary temperature is cooler than the upper boundary temperature?

- Line 154: add "a" between acknowledging and lack.

- Lines 203-205: Please provide a more physical motivation for defining the IC and SL regions. These seemingly arbitrary definitions undermine the robustness of these results.

- Lines 254: I would rephrase "useful information" more objectively and state specifically why we should trust the spatially averaged values when the local details are not considered reliable.

- Figure 3: Apologies if I missed this in the text, but what fraction of A_H goes north versus southward to the shelf?

- Line 319: I would argue that the budget does not close anywhere in the domain.

- Lines 323-324: It is odd to disregard the easternmost values in this section and not elsewhere. More consistency is needed. See my third major comment.

- Line 494: I am not sure what "ellipses" refer to.

- Lines 510-513: I suspect unresolved mesoscale eddies have a leading order impact on the mesoscale heat budget. In addition to the observational studies referenced in the following sentence, idealized modeling studies indicate that transient eddies (e.g., Wilson et al. 2022) are responsible for most of the southward heat transport in the eastern limb of the gyre.

- Line 543: To be more precise, there is a Taylor Cap rather than a Taylor Column over Maud Rise. It is also inaccurate to say that the water column above the Rise is "stagnant" since it does exchange water mass properties with the ambient fluid.

- Figure 8: This is a lovely summary figure.

References:

Ryan, S., Schröder, M., Huhn, O., and Timmermann, R.: On the warm inflow at the eastern boundary of the Weddell Gyre, Deep-Sea Res. I, 107, 70-81, https://doi.org/10.1016/j.dsr.2015.11.002, 2016.

Wilson, E. A., A. F. Thompson, A. Stewart, and S. Sun (2022), Bathymetric control of the subpolar gyres and overturning circulation in the Southern Ocean, Journal of Physical Oceanography, 52, 205–223, https://doi.org/10.1175/JPO-D-21-0136.1.