

Reply to comment by Jens Terhaar on section “9. Reanalysis data” by Michael Mayer, Leopold Haimberger, Susanna Winkelbauer, and Hamish Prince (University of Vienna)

We thank Jens Terhaar for providing his reply (Reply_JT). We take this opportunity to clarify some of our points.

- 1) This concerns adjustments of surface energy flux. We agree with Reply_JT that a regional adjustment is preferable over a uniform global adjustment. Actually, Pan et al. (2026) did make a regional adjustment to their inferred surface flux estimate using a variational approach that takes into account spatial uncertainty structure of the input data. Their results for OHT at the RAPID section are similar to those obtained using a globally uniform adjustment (such as used by Mayer et al. 2022; see below for correlation results) which demonstrates that a low baseline bias (as is the case for the inferred surface flux, see our previous comment) helps to limit uncertainties introduced by any adjustment.
We also agree with Reply_JT that the approach by Sohail and Zika (2025) to adjust surface flux estimates in principle is an interesting one. However, we are unconvinced that the required observational subsurface temperature and salinity data are temporally sufficiently consistent to avoid spurious temporal discontinuities in the diagnosed water masses. Note that Sohail and Zika extended their analysis back to 1979, but it is well-known that the ocean subsurface observing system (also of the relatively well-observed North Atlantic) was much sparser in the 1980s than it is since the introduction of Argo. However, temporally coherent water mass properties (ideally down to the bottom of the ocean) are a prerequisite for this method as any spurious change will inevitably project on the surface flux adjustment. It is unclear how large this effect is on the spatio-temporal structure of their adjustments to model-based surface flux, and as a result, on OHT inferred by Terhaar et al. (2025).
- 2) This concerns validation of OHT inferred from the ocean heat budget. A main problem with assessing the realism of indirectly estimated OHT is the relatively short observational record at the RAPID section. Nevertheless, RAPID observations can be used to at least validate interannual variability of estimated OHT. Still, good agreement of any OHT estimate with RAPID strengthens confidence in this estimate. Reply_JT did not provide a correlation coefficient of their OHT/AMOC series with RAPID observations, but it is evident from Fig. 1a of Reply_JT (pasted below) that it is low. This is in contrast with the correlation values provided by works using inferred net surface energy flux (e.g., Pan et al. 2026 obtain $r=0.65$ and Mayer et al. 2022 $r=0.74$). The low correlation evident from Reply_JT's Fig. 1a may arise from the fact that they omit d/dt OHC in their framework but inferior representation of interannual variability of model-based surface flux compared to inferred surface flux likely plays a role as well.

In conclusion, we do not disagree that teasing AMOC trends out of available atmosphere reanalysis data via the ocean heat budget is a challenge. Adjustments are needed no matter which data set one uses, but we are also convinced that data sets with a demonstrably smaller bias (where demonstration means via hard physical constraints and not via low spread across data products which possibly share similar structural errors) than other products are the preferable starting point for such an effort. Inferred surface energy fluxes do have a smaller bias compared to modelled surface energy fluxes (see our earlier comment and references therein). Further, validation of the variability of any inferred OHT estimate with observations as far as possible is also crucial to gain confidence, and this is also an aspect where OHT estimates based on inferred surface energy fluxes appear to excel those based on model-based fluxes.

Finally, this discussion makes clear that more work is needed to demonstrate the benefits of the use of inferred surface fluxes for inference of ocean heat transports. Extending the time series back in time and the use of multiple new and upcoming reanalyses (both work in progress) will help to make progress in this direction.

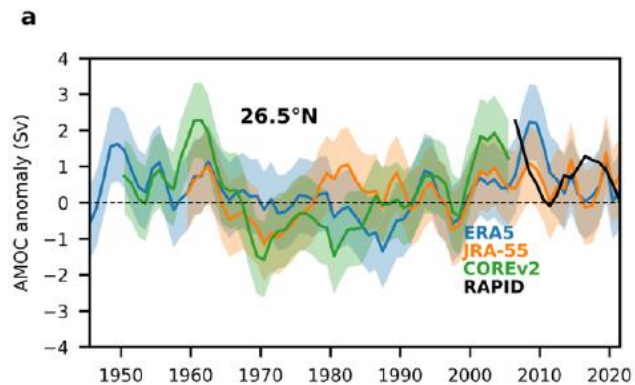


Fig.1 copy of Fig. 1a from Reply_JT.

References

- Mayer, J., M. Mayer, L. Haimberger, and C. Liu, 2022: Comparison of surface energy fluxes from global to local scale. *J. Clim.*, **35**, 4551–4569.
- Pan, Y., and Coauthors, 2026: Ocean meridional heat transport estimated from energy budget constraint. *J. Clim.*, **39**, 3001–3019.
- Sohail, T., and J. D. Zika, 2025: Global air-sea heat and freshwater fluxes constrained by ocean observations. *Earth Syst. Sci. Data Discuss.*, **2025**, 1–24.
- Terhaar, J., L. Vogt, and N. P. Foukal, 2025: Atlantic overturning inferred from air-sea heat fluxes indicates no decline since the 1960s. *Nat. Commun.*, **16**, 222.