Author's response to Referee #1

egusphere-2026-2588

The well-written manuscript under consideration presents important results about multidecadal periods of strengthening and weakening of the North Atlantic circulation. The authors furthermore make a qualitative distinction between the pre- and post-1985 weakening events with compelling evidence. The emphasis in this paper is on subpolar gyre, inter-gyre, and basin-wide thermodynamic drivers of circulation anomalies.

However, I think the authors should also discuss the synchronous, coherent coevolution of the maximum overturning between the subpolar and subtropical latitudes seen very clearly in their results. The authors should furthermore discuss the role of the salinity anomalies along the western boundary of the Labrador Sea in driving these coherent overturning anomalies. These salinity anomalies stand out in some of the figures showing the authors' results. In addition to their present analysis of inter-gyre thermodynamic gradients, the authors should also examine in greater detail the horizontal density gradients between the western boundary and the interior of the subpolar gyre. I therefore recommend minor but strongly recommended revisions.

We thank the the referee for a clear and thoughtful reading of the manuscript, and for the supportive assessment of our study. Below, we explain how we will address each point individually: referee comments are shown in italics, followed by our reply.

Comment RC1.1

Figures 4 and 9: The authors should discuss and interpret the synchronous, coherent coevolution of the maximum overturning between 55N and 26N seen in these figures.

Author's reply:

We agree and will add a discussion of the synchronous, coherent co-evolution of the maximum overturning between 55°N and 26°N shown in Figures 4, 7, and 9 to the revised manuscript. We will also examine the lead-lag relationship between these two metrics in more detail, including at the level of individual ensemble members.

Comment RC1.2

Figures 3, 6, and 8: The authors should discuss the role of salinity anomalies along the western boundary of the Labrador Sea seen in these figures, and the role of these anomalies in driving meridionally coherent overturning variability in the context of Kostov et al. (2023).

Author's reply:

As suggested, we will discuss the salinity anomalies along the western boundary of the Labrador Sea seen in Figures 3, 6, and 8, and their role in the meridionally coherent overturning variability, in the context of Kostov et al. (2023).

Comment RC1.3

> *Figure 10: Once again, in this figure, the western boundary of the Labrador Sea is a region of particularly strong density anomalies that also extend along the intergyre boundary. Please discuss in the context of Kostov et al. (2023) and the possible fast mechanism that give rise to the coherent response you see between 55N and 26N.*

Author's reply:

We agree and will add this discussion, citing Kostov et al. (2023).

Comment RC1.4

> *Lines 225-229, 257-260, and 275-276: You talk about "density within the SPG", "in the STG", the "inter-gyre density gradient," and "the meridional gradient." However, you do not mention the dynamical importance of density anomalies along the western boundary. What about the horizontal density gradients between the western boundary and the interior?*

Author's reply:

We will quantify the horizontal density gradient between the western boundary and the gyre interior and intend to present it as a timeseries alongside our existing density metrics. This would complement a meridional density gradient metric we will also introduce to characterise the inter-gyre density gradient between the SPG and STG. We will be more careful throughout in defining and distinguishing between the different density metrics used.

Comment RC1.5

> *Lines 293-294: Finally, there is a brief mention of the western SPG margin in this single sentence. Could you also cite Kostov et al. (2023) here in the context of fast north-to-south connectivity along the western boundary?*

Author's reply:

We agree that this is a useful addition and will add this citation.

Comment RC1.6

> *Lines 41-42: "in the subtropical gyre (STG), where it loses heat and salt." – How is salt lost in the subtropical gyre? I think freshwater is lost there, evaporatively.*

Author's reply:

We agree and will correct this: freshwater is lost evaporatively in the STG, which increases salinity rather than removing salt directly. We will revise the text accordingly.

Comment RC1.7

Lines 51-52: "it is ultimately density that governs the movement of water masses" – The statement should be qualified in the context of the study. Otherwise, winds play a first order role.

Author's reply:

We agree and will clarify that this statement refers specifically to density gradients as the primary driver of multidecadal circulation variability in this study, not a general claim about water mass movement.

Comment RC1.8

Line 85: "a pressure of 2000 dbar" – Is this reference level appropriate for subpolar North Atlantic overturning

Author's reply:

The 2000 dbar reference pressure has been shown to work well for characterising overturning in the subpolar North Atlantic (e.g. Sidorenko et al., 2020) and follows the convention outlined by Foukal and Chafik (2024), who reference density to 2000 m depth for this reason; we will add these references to the manuscript. We have also tested the sensitivity of this metric to the choice of reference pressure level and confirm that 2000 dbar is an appropriate choice for characterising the overturning in this study.

Comment RC1.9

Lines 92-93: "by taking the maximum of the annual mean overturning strength at 55N in the annual mean" – Is the maximum overturning strength close to a depth of 2 km or in a density layer that includes that depth.

Author's reply:

As noted above, the 2000 dbar reference pressure has been shown to work well for density-space overturning streamfunctions and follows standard convention in this field. The maximum overturning strength itself, however, occurs at a depth of approximately 1000 m, not 2 km. We tested several reference levels and found that 2000 dbar best captures the variability investigated in this study.

Comment RC1.10

Line 110: "sea surface height" – Cite Yeager et al.(2021) and Kostov et al. (2023) who discuss the importance of sea surface height anomalies in the North Atlantic and their role in setting the variability in overturning.

Author's reply:

We will add these citations.

Comment RC1.11

Figures 4 and 9: Define the positive direction.

Author's reply:

We will define the positive direction in the revised figure captions.

Comment RC1.12

Lines 300-301: Could you please cite Buckley and Marshall (2016) in the context of the Mann Eddy and inter-gyre exchange. Could you please cite Buckley et al. (2023) in the context of eddy exchange between the boundaries and the gyre interior?

Author's reply:

We will add these citations and discuss our results in the context of them.

Additional references

Buckley, M. W. and Marshall, J.: Observations, inferences, and mechanisms of the Atlantic Meridional Overturning Circulation: A review, Rev. Geophys., 54, https://doi.org/10.1002/2015RG000493, 2016.

Buckley, M. W., Lozier, M. S., Desbruyères, D., and Evans, D. G.: Buoyancy forcing and the subpolar Atlantic meridional overturning circulation, Philos. T. R. Soc. A, 381, 20220181, https://doi.org/10.1098/rsta.2022.0181, 2023.

Foukal, N. P. and Chafik, L.: Consensus around a common definition of Atlantic overturning will promote progress, Oceanography, 37, 10–15, https://doi.org/10.5670/oceanog.2024.507, 2024.

Kostov, Y., Messias, M.-J., Mercier, H., et al.: Fast mechanisms linking the Labrador Sea with subtropical Atlantic overturning, Clim. Dynam., 60, 2687–2712, https://doi.org/10.1007/s00382-022-06459-y, 2023.

Sidorenko, D., Danilov, S., Fofonova, V., Cabos, W., Koldunov, N., Scholz, P., et al.: AMOC, water mass transformations, and their responses to changing resolution in the Finite-volumE Sea ice-Ocean model, J. Adv. Model. Earth Sy., 12, e2020MS002317, https://doi.org/10.1029/2020MS002317, 2020.