We thank both reviewers for their second review and valuable suggestions, which would greatly improve the quality of the manuscript.

*Please see our point-by-point responses to each of the comments below in **blue and italic,** and suggested implementations in a revised manuscript in **green**.*

Response to Reviewer 2, Dr Marlene Klockmann:

2nd Review of Du et al - Non-linear Climatic Response to the weakening of the Atlantic Meridional Overturning Circulation During Glacial Times

The authors have performed a very thorough review and have addressed most of my concerns very adequately. I especially appreciate the more detailed explanation of the mechanistic link between AMOC weakening and Hadley cell changes via compensating atmospheric heat transport and ITCZ shifts.

I have a few remaining minor comments that could help improving the manuscript further before publication:

1. Once more on the issue of framing the study within the context of future AMOC changes: Do you expect the threshold to be the same for future AMOC weakening, given the non-linearity of the system? Are there ACCESS-ESM based simulations from NaHosMip that could be referred to for comparison to see whether AMOC shutdown under glacial climate and interglacial climates are similar (2-3 sentences in the discussion)?

Thanks for the questions.

Similar North Atlantic meltwater experiments performed under pre-industrial and Last Interglacial boundary conditions also suggest a threshold in between 0.3 and 0.4 Sv (Pontes & Menviel, 2024, Saini et al., 2025a). Unpublished experiments as part of NaHosMIP and TIPMIP-Ocean, under 2degC global warming, confirm this threshold within the ACCESS-ESM1.5.

Regarding the non-linearity response of the system for future AMOC weakening, more tests in different background climates are needed. We would expect differences in future climate response due to the large differences in the boundary conditions comparing to glacial climates; however, the amount of freshwater input to trigger the non-linearity response may be similar given that both PI and LIG simulations suggested the same rate of freshwater input to shut down the AMOC. However, future climate is variable and unprecedented, this study aims to provide some insights into the potential climate changes associated with AMOC shutdown.

References:

Pontes, G. M. and Menviel, L.: Weakening of the Atlantic Meridional Overturning Circulation driven by subarctic freshening since the mid-twentieth century, Nat. Geosci., https://doi.org/10.1038/s41561-024-01568-1, 2024.

Saini, H., Pontes, G., Brown, J. R., Drysdale, R. N., Du, Y., and Menviel, L.: Australasian Hydroclimate Response to the Collapse of the Atlantic Meridional Overturning Circulation Under Pre-Industrial and Last Interglacial Climates, Paleoceanog and Paleoclimatol, 40, e2024PA004967, https://doi.org/10.1029/2024PA004967, 2025a.

More discussion is now added in the revised manuscript.

Lines 564-572 (last paragraph in the conclusion section):

Our results suggest that the climate system responds linearly to a slowdown of the AMOC; but once the threshold of AMOC shutdown is crossed, a more complex atmospheric circulation and climate response emerges. We identify a possible threshold in the hosing strength between 0.3 Sv and 0.4 Sv for triggering an AMOC shutdown in the ACCESS-ESM1.5 model, ultimately leading to the non-linear response of the climate system under glacial conditions. Although the background state is fundamentally different from present or future warming conditions, the amount of freshwater input required to trigger the non-linear response may be comparable, given that a freshwater input of 0.4 Sv is necessary to shut down the AMOC under both PI and Last Interglacial (127 ka) background conditions (Saini et al., 2025a). Nevertheless, given the variability and unprecedented nature of future climates, additional simulations across different background climate conditions, as well as multi-model comparisons under glacial conditions, are needed to provide more comprehensive insights.

2.Once more on the absolute vs normalised anomalies: I understand the authors explanation for not using normalised anomalies outside of Fig. 3 (reply to my Comment 7 in the 1st review round). But I still want to point out that the visualisation in e.g. Fig.5 and S7 exaggerates the degree of non-linearity because the x-axis spacing implies a uniform forcing change. Taking the response of the Northern HC strength as an example: The absolute values imply a change in the HS simulation that is approx. 8 times as large as in the 0.3Sv DO simulation (20% vs 2.3%). But the response normalised by AMOC change would be only about 4 times as large (0.6%/Sv vs 0.16%/Sv), if I got the numbers right. You could leave Fig.5 as is, but you might add the normalised responses underneath or on top of the respective bars.

Thanks for the helpful suggestion, we agree that the current Fig 5 and Fig S7 can be misleading. Normalised values are now added on top of each bar in Figures 5 and S7 to clarify the changes per AMOC decrease.

New Figure 5:

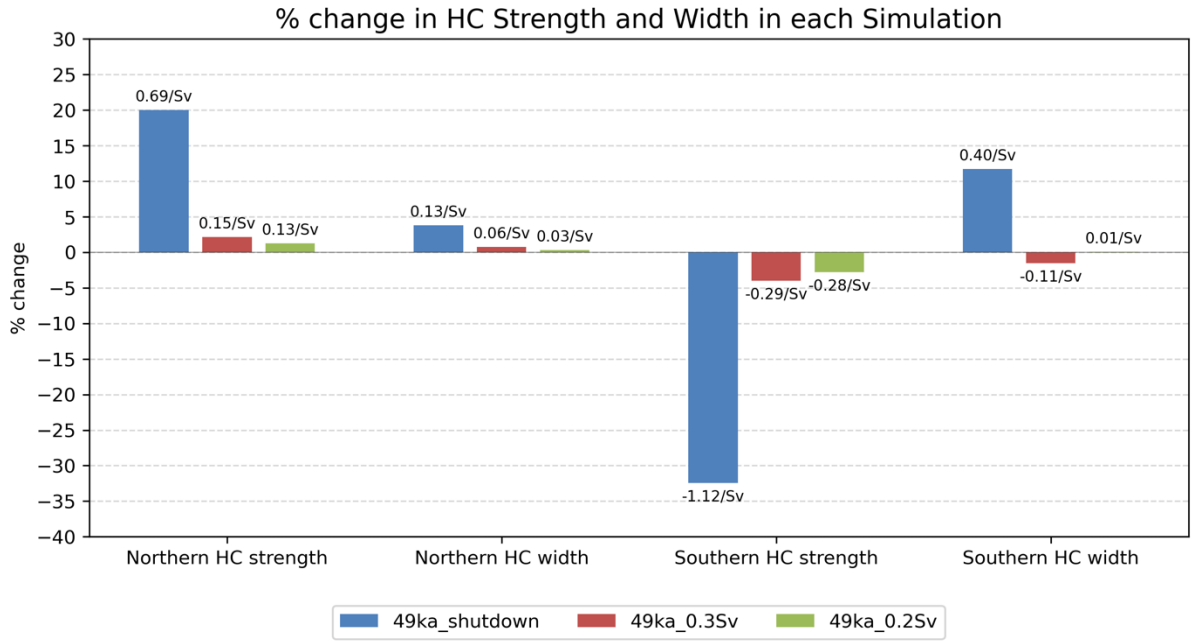

Figure 5: Percentage of absolute changes in the NH wintertime (DJF) HC and SH winter (JJA) HC strength and width at 500 hPa in the 49ka_shutdown, 49ka_0.3Sv and 49ka_0.2Sv simulations (values in Table S2). Normalised changes in percentage per Sv AMOC decrease are shown on top of each bar. Method for the calculations is described in Section 2.4.

New Figure S7:

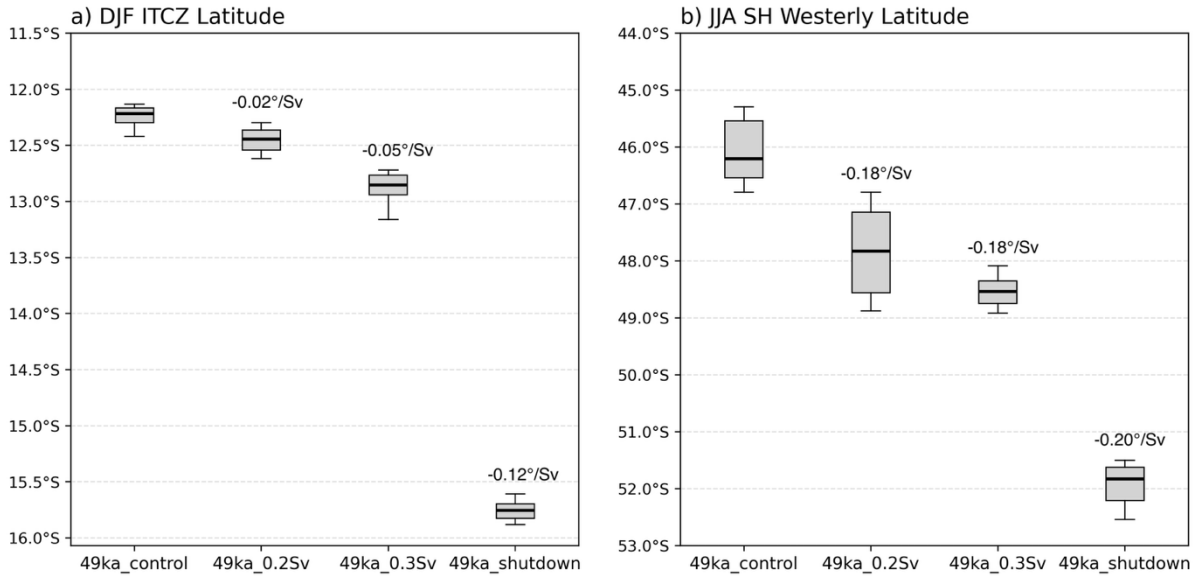

Figure S7: Box plot of 30-year mean across the last 150 years for a) DJF ITCZ latitudes, and b) JJA SH westerly wind latitude in each experiment. Within each box, the think line inside the box represents the median value (50th percentile) of each group; the top and bottom of the box shows the 25th and 75th percentile, respectively; the whiskers show 10th to 90th percentile. Normalised changes relative to the control in ° per Sv AMOC decrease is shown on top of each AMOC weakening experiment.

l.126 "greenhouse gas" instead of "greenhouse gases"

Modified.

l.184-186: The sentence is not 100% clear to me. The resulting position of the Hadley cell is similar but the dynamical link is better? How so?

Sorry for the confusion, the sentence is now modified.

Lines 185-188:

This definition provides a more direct dynamical linkage to HC variability than the conventional precipitation-based metrics (e.g. Braconnot et al., 2007), while yielding consistent ITCZ positions across both approaches (Bian and Räisänen, 2024; Bischoff and Schneider, 2014).

l.335-337 and Fig.6: From comparing Fig.6 b,d and f, I find it hard to judge whether the change from f to d is linear but the change from d to b is non-linear. The patterns look very similar in all three panels with a different magnitude in b, of course.

Thank you for the comment, we realize that this sentence was not well suited to this paragraph. We have now deleted this statement and added more relevant comparisons with the slowdown simulations regarding Fig. 6 for both seasons in their respective paragraphs.

Please note that we decided to rearrange the paragraph sequence in this section so that the DJF season is discussed first, in line with the ordering of the DJF panels in Fig. 6.

Lines 321-325 (DJF season):

A decrease in surface pressure in the SH subtropical regions is shown in the shutdown simulation (Fig. 6a) due to weakened DJF southern HC strength (Fig. 4a). The slowdown simulations show different patterns compared to the 49ka_shutdown experiment (Fig. 6c, 6e). This difference in the spatial pattern is most likely driven by the small changes in the DJF southern HC strength in the slowdown simulations.

Lines 331-336 (JJA season):

In the shutdown simulation, the subpolar low pressure belt shows negative surface pressure anomalies, while positive surface pressure anomalies of up to 5.7 hPa are found between 50° S and 70° S in the Indian and Pacific basins (Fig. 6b). The slowdown simulations display a broadly similar spatial pattern, albeit with reduced magnitudes (Figs. 6d and 6f). These differences in anomalies between the shutdown and slowdown simulations are likely attributable to the large shift in descending branch of the southern

HC in the shutdown simulation, despite a weakened HC strength being simulated in all simulations.

l.495-497: "This study provides a possible location of the threshold [...]" Can you be more specific about the quantity here? Threshold in hosing strength? Oceanic heat transport?

This has been added now.

Lines 500-502:

This study provides a possible location of the threshold in hosing strength between linear weakening and nonlinear shutdown, but it is important to note that the location is likely to differ between models and climate states both in the real world and in simulations.

Response to the editor's suggestions:

We thank the editor for her helpful editorial suggestions. All of the comments below have been addressed in the revised manuscript. Comments that required more substantial changes are responded to individually with indications of in-line changes.

The following refer to the manuscript with track changes:

line 16: should be "The climatic response to the/a weakening of the..."

line 52: should be "in the North Atlantic and in many..."

line 132: "coupled to the land... " this sentence has a strange formulation, I suggest starting a new sentence here

line 143: "starting from the PI simulation"

line 145: "and" missing before "ice-sheet extent and topography"?

line 146: insert comma before "with closest match"

lines 147-148: I do not think C3 crops is an obvious term, maybe rephrase or explain?

The sentence has been rephrased now.

Table 1: units are missing for greenhouse gas concentrations. Also please

line 158: should be "the 49 ka climate"

line 206: should start with "The ITCZ position.."

line 207: please expand a bit more: northern (DJF), southern (JJA)

line 239: should be "due to the large decrease"

line 242: here and in general I would replace "D-O" with "D-O stadial"; it is otherwise a bit confusing because D-O events are warmings

line 246: "that is beyond" - I don't know exactly what you mean here with "beyond"

line 267: I would replace "only" by "mostly"; also it should be "the eastern equatorial Pacific"

line 270: again, it should be "D-O stadial experiments". Also note that this drying, even opposite to what is found for a shutdown, is not really significant.

line 284: should be “while the SH” or “while SH temperature”

line 285: should be “than in the slowdown experiments” and “D-O stadial experiments”

line 303: should be “In response to the AMOC weakening”

line 304: you could say explicitly it is “reduced northward oceanic heat transport”

line 310: I think it would be better to start here with “In DJF” or “In boreal winter (DJF)”.

line 312: accordingly, remove “DJF season”

line 314: Do not break the paragraph here,

line 317: remove “In the boreal winter” (this and the previous paragraph all pertain to DJF); start with “The northern HC..”

line 318: again, remove “DJF”, not needed

line 320: should be “the AMOC shutdown”

line 334: the cross-equatorial transport in JJA is weaker indeed but the difference is much smaller that at 30N, please give numbers and refer to figure S4

Modified.

line 336: should be “due to the AMOC”

line 337: I don’t fully understand the new sentence with the “attributing…”, please rephrase. Maybe splitting the sentence would help.

line 341: again, should be “the AMOC shutdown”

line 365: “while positive surface pressure anomalies of up to 5.7 hPa are found between 50 and 70 S in the Indian and Pacific basins” - in my view this is one of the most robust changes. I don’t know if it is obvious but - is this related to the southward shift of the descending branch of the southern Hadley cell, despite its weakening? If so please say so, or try to explain what causes this pattern.

Yes, it is related to the southward shift in the southern HC descending branch. The discussion is now added with comparison to the slowdown simulations. This modification is consistent with one of the comments raised by reviewer 2 about Fig. 6.

Please note that we decided to rearrange the paragraph sequence in this section so that the DJF season is discussed first, in line with the ordering of the DJF panels in Fig. 6.

Lines 331-336 (JJA season):

In the shutdown simulation, the subpolar low pressure belt shows negative surface pressure anomalies, while positive surface pressure anomalies of up to 5.7 hPa are found between 50° S and 70° S in the Indian and Pacific basins (Fig. 6b). The slowdown simulations display a broadly similar spatial pattern, albeit with reduced magnitudes (Figs. 6d and 6f). These differences in anomalies between the shutdown and slowdown simulations are likely attributable to the large shift in descending branch of the southern HC in the shutdown simulation, despite a weakened HC strength being simulated in all simulations.

line 370: should this not be “cyclonic” instead of “anticyclonic”? You refer to the negative pressure anomaly in the North Pacific (Figure 6b) right?

Yes, it should be ‘cyclonic’. This is now corrected.

line 377: please replace “simulated in all simulations” by “shown in all simulations”. Also, again, what causes this decrease? The descending branches are easily understandable but the rest is maybe less clear.

More discussions are added to add clarification. This modification is consistent with one of the comments raised by reviewer 2 about Fig. 6.

Lines 321-325 (DJF season):

A decrease in surface pressure in the SH subtropical regions is shown in the shutdown simulation (Fig. 6a) due to weakened DJF southern HC strength (Fig. 4a). The slowdown simulations show different patterns compared to the 49ka_shutdown experiment (Fig. 6c, 6e). This difference in the spatial pattern is most likely driven by the small changes in the DJF southern HC strength in the slowdown simulations.

line 382: should be “due to the AMOC shutdown”

line 398: delete “simulation” and “season” (should be “in 49ka_shutdown in JJA”)

line 402: I would refer here to Figure S6, which shows seasonal fields. Also, I might have missed this but have you explained what causes this cooling? I realize there is warming in the southern hemisphere and over Antarctica but cooling over the ocean close to the Antarctic margin

We now added the plausible causes of this cooling in Section 3.1.

Lines 220:

Over Antarctica, significantly colder conditions are simulated in the Ross and Weddell Seas (Fig. 2a), which could be related to changes in sea ice extent or negative low pressure anomalies over the region (Fig. 6b).

line 403: should be “associated with the weakened”

line 496: should be “a reorganization”

line 500: should be “the JJA ITCZ position”

line 510: again is this not “cyclonic”?

line 651: should be “a slowdown”