We would like to thank the reviewers again for their second reading and constructive comments, as well as the editor for her helpful suggestions.
We are addressing the comments below (in blue), as well as keeping track of the corrections to the text (in green).

**Reviewer #1:**

The authors have thoroughly addressed my previous comments, and I have only two (related) minor remaining comments:

1) In l. 303-305 the authors now discuss that the strength and depth of the AMOC in the PI control simulation is broadly consistent with other PMIP simulations. However, the AMOC is too shallow compared to the real world. I still think this needs to be acknowledged.
To address this point, and following the editor's advice, we suggest completing this discussion in this manner:
The AMOC depth and strength in our PI simulation are within the PMIP3/PMIP4 ensemble (see Fig. S1 and S2 of Kageyama et al. (accepted, 2021)). In more details, the streamfunction of iLOVECLIM is fairly comparable to the pre-industrial streamfunctions of HadCM3, AWIESM2, MIROC-ESM and CNRM-CM5, and actually stronger and deeper than that of IPSL-CM5A2 (and IPSL-CM5A-LR). However, the pre-industrial AMOC strength simulated by the iLOVECLIM model is underestimated compared to modern observational data. Since 2004, the RAPID array at 26°N has measured an AMOC within the range of 13.5 Sv to 20.9 Sv, when interannual variability is accounted for (Moat et al., 2020), with a mean estimate of 17.2 Sv (McCarthy et al., 2015). The simulated AMOC strength at this latitude does not fall into this range in any of our PI simulations, which show a maximum of 10.1 Sv ('PI') and 11.2 Sv ('PI brines', Fig. S5), with both maximums occurring at depth 1225 m.
McCarthy et al. (2015) have also measured from the RAPID array a depth of the maximum AMOC generally (since they distinguished two depth modes) close to 1100 m. While we would have liked to also discuss the AMOC depth along with its strength, we find it difficult to do so considering the vertical resolution of the CLIO model at the depth of the maximum AMOC. The grid cell centered at depth 1225 m is indeed large, ranging from around 1007 to 1443 m.

2) Relatedly, in l. 367-368 it is argued that the PI4-brines simulation simulates a water mass distribution that is reconcilable with paleo proxy observations. That's an important point, but it should also be acknowledged that even with this setup the AMOC does not actually shoal between the PI and LGM simulations, which is probably inconsistent with the observational evidence.
We agree with the reviewer that stating this limitation adds a valuable nuance to this part of the discussion. Therefore, we suggest acknowledging this fact as follows:
Among our set of simulations, it is the only one simulating a water mass distribution which is reconcilable with reconstructions from paleoproxies. Nonetheless, this experimental design (like all the others tested in this study) does not result in a shoaling of the AMOC between the PI and LGM state (see Fig. S5), as is usually inferred from proxy data.

**Reviewer #2:**

In the updated manuscript, the authors have addressed the concerns of both reviewers thoroughly and in a satisfactory way, and I find their arguments for their choices to be sound. The manuscript is now clearer and easier to follow, particularly in the methods section, and the addition of a few extra simulations makes me more confident in the conclusions. I only have a few minor comments, and thus recommend publication of the article after these adjustments.

Specific comments

Line 103, parenthesis: I would put 'New P2' first in this parenthesis, to present the abbreviations in the same order as they are discussed in the text that follows. This simple change makes it easier for the reader to keep track of the different abbreviations and what they mean.
We are thankful for the reviewer's attention for details, which will surely make our paper more understandable to the reader considering the number of simulations involved. This simple change has been made.

Line 214-215: Refer here to Section 3.4, e.g. add "(see section 3.4)"
Correction implemented as suggested.

Lines 248-251: The way this is phrased now, sea-ice extent is defined twice. While the second definition is a follow-up to the first, this is not immediately clear and I had to read it multiple times to actually understand what you mean. I would recommend replacing "defined as" by "here," (or similar) in the parenthesis on line 250.
We meant for the 'second' definition to have more elements than the official – and more simply phrased – 'first' definition, in order to (1) make a clear distinction with the simulated sea-ice area defined shortly after, and (2) connect the sea-ice edge (showed in Fig. 6) to the sea-ice extent (showed in Fig. 5). We also thought that reminding the boundaries used in the computation of the sea-ice extent (sea-ice edge and Antarctic continent) might be useful for the reader to recall the methods described in Sect. 2.4 (l.160-180), which explained the source of uncertainties at play during the model-data comparison of the sea-ice extent. For these reasons, we would like to keep these elements, but we will indeed modify the phrasing as suggested to avoid confusion, as well as make a few simplifications:
Only the sea-ice extent, defined as the surface with a sea-ice concentration over 15%, is strictly comparable to our data estimates. We however chose to present both the simulated sea-ice extent (here, the total surface between the northernmost 15% concentration limit and the Antarctic continent) and area (the sea-ice concentration multiplied by the area of the grid cell for all ocean cells south of the equator) in Fig. 5.

Line 442: I still have a small issue with this sentence. The choice of the words "the correct simulation of convection processes" gives the impression that the parameterization of sinking brines indeed achieves this (even if you actually are actually rather referring to the decrease in open ocean convection). I recommend replacing "correct" by "improved".
Correction implemented as suggested.

Throughout manuscript: Check the spelling of the word 'parameterization'. It has been misspelled on several occasions.
Correction implemented as suggested.

Figure 3. Unnecessarily small font for labels, axes, and legends.
A larger fontsize is now used for Fig. 3 in the revised manuscript.

Figure 7. To illustrate some of the given (potential) explanations to the results in Section 3.4 (lines 322-324), and to connect this section more strongly to the previous about sea ice, it could be interesting to add to this figure the average sea-ice edge (given the circular shape of the sea-ice extent, the edge should be in a similar location all around the Southern Ocean, and thus the average should be reasonably representative for the entire area). This is not a requirement, simply a suggestion.
We agree that this illustration of the average sea-ice edge can be helpful to the reader, as it provides another opportunity to compare the winter and summer sea ice between simulations. When integrated to Fig. 7, these values indeed connect Sect. 3.3 and 3.4 more strongly. We have added

thin vertical lines to locate these average sea-ice edges (summer and winter) on the streamfunctions plotted in Fig. 7. The caption of the figure was modified accordingly.

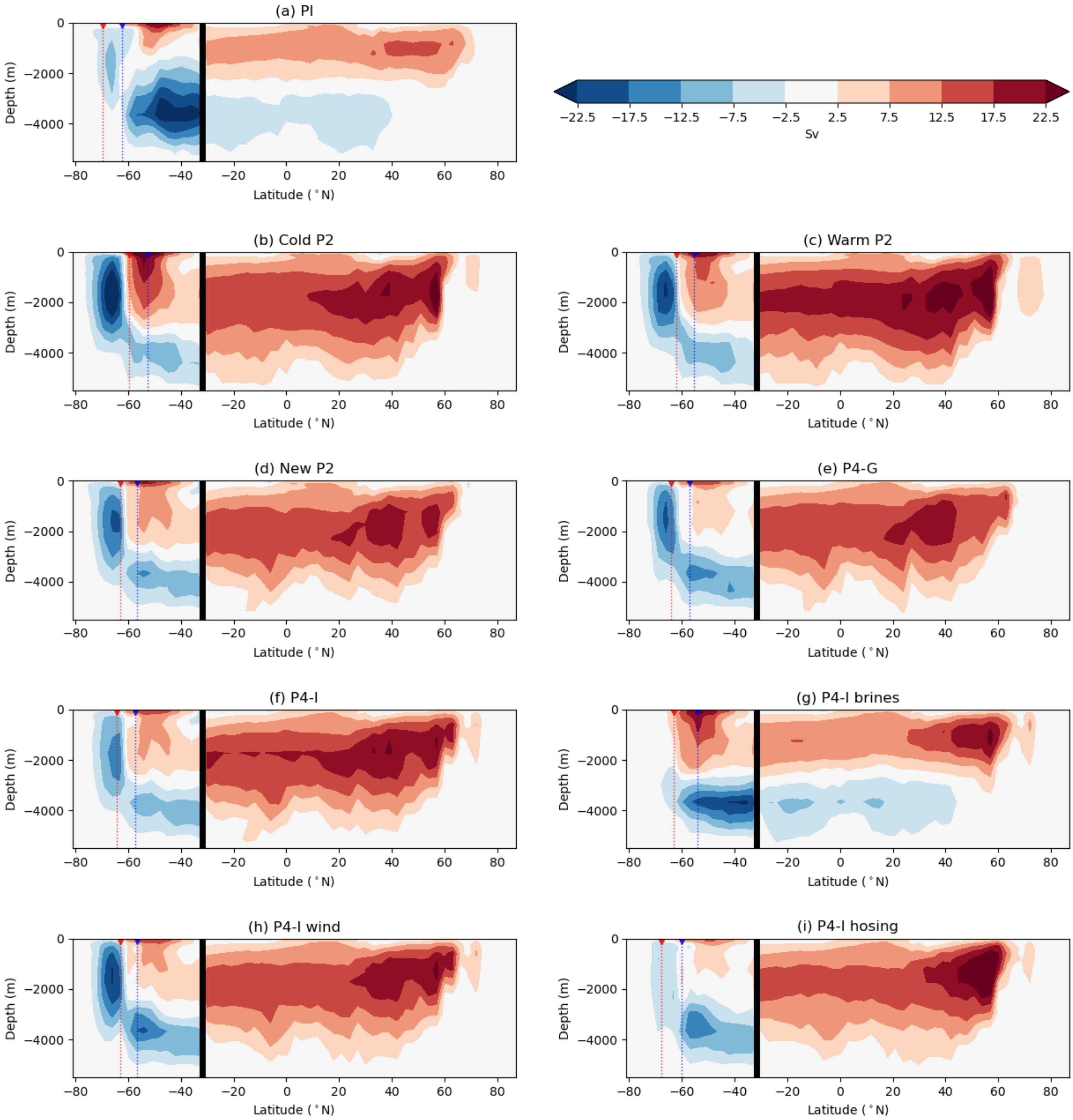



Figure 7. Streamfunctions (Sv) in the Atlantic (North of 32°S) and Southern Ocean basins (South of 32°S). The black vertical line represents the limit between these two basins, chosen at 32°S. The thin dotted lines show the latitude of the average sea-ice edge in austral summer (red) and winter (blue) for each simulation.

Figure 8. Please specify that the grey line is a linear fit to the model results. Also, I would recommend making it slightly thicker than the grid lines.

We have modified the width of the grey lines so that they more clearly appear as black dotted lines. Before that, the thinly dotted black lines representing the linear fits did indeed look like the grey grid lines. We have also specified in the caption:
Relationships between the mean SST in the Southern Ocean (averaged up to 36°S) and the Southern Ocean (a, b), bottom (c, d) or NADW (e, f) overturning cell maximum, for all simulations except 'P4-I brines' and 'P4-I hosing'. The y-axis is inverted for the two anticlockwise cells (a, b, c, d). The dotted line represents the linear fit to the model results plotted here.
The same changes have been done to Fig. S7 in the SI.

Figure S3. Please specify that the grey line is a linear fit to the model results. Also, I would recommend making it slightly thicker than the grid lines.
Typo in second sentence 'he' should be 'The'.
The same changes as in Fig. 8 have been done to Fig. S3 and the typo is now corrected.

**Editor:**

Dear Fanny Lhardy,
I have received 2 reviews of your revised manuscript. Based on these reviews, your manuscript may be suitable for publication in Climate of the Past after some minor revisions.
Once again, both reviewers provided constructive comments and suggestions, so please address those as thoroughly as possible.
Reviewer 1 is requesting some clarifications/discussion about the AMOC for both the PI and LGM simulations and the changes (or lack thereof) between the two states; I agree that these are necessary.
When addressing their point 1, also compare the AMOC strength to available observational estimates (e.g. from the RAPID array) and explicitly report the range of the mean AMOC strength for the different experiments and how this differs from the observations.
Reviewer 2 is suggesting some additional minor changes and improvements, so please also address these.
In addition, it may also be useful to compare some of your results to the (physical) changes observed in the recently-published PI and LGM simulations of Morée et al. (CP, 2021 - doi.org/10.5194/cp-17-753-2021), where the two ocean states and model biases are evaluated against a broad range of proxy-based estimates and climate simulations.
I look forward to receiving your revised manuscript.
Best regards,
Alice Marzocchi

Dear Alice Marzocchi,

We are thankful for your work on this manuscript.
We hope we have addressed above the comments of both reviewers in a satisfactory way.

Following your complementary advice to the first comment of reviewer #1, we have used the modern AMOC strength calculated from the RAPID array (Moat et al., 2020) to quantify its underestimation in our PI simulations.

Please note that we also updated Fig. 2 (see below) on account of a computing error which was found in the mean SST calculation.

Finally, we thank you for introducing the Morée et al. (2021) study to us, which we were not aware of. The perspectives brought forward by this study are indeed insightful in the context of our paper, as the authors extensively evaluated biases, including biogeochemical ones. Although they simulate with the NorESM-OC model an AMOC in better agreement with paleotracer reconstructions than iLOVECLIM, they still find that the remaining biases (in particular radiocarbon ages of southern sourced water, MLD at PI…) may be linked to deep water formation and convection processes in the Southern Ocean. We also find it interesting that the authors have simulated a Southern Ocean sea ice of high seasonal amplitude (their Fig. S12), and actually with a good match between the simulated winter sea-ice extent and our reconstructed estimate of $32.9 \times 10^6$ $km^2$ (as opposed to the $43.5 \times 10^6$ $km^2$ value in Roche et al., 2012). For these reasons, we would like to discuss some of the elements in Morée et al. (2021) in our Sect. 4.2, immediately following the correction related to point 2 of reviewer #1:

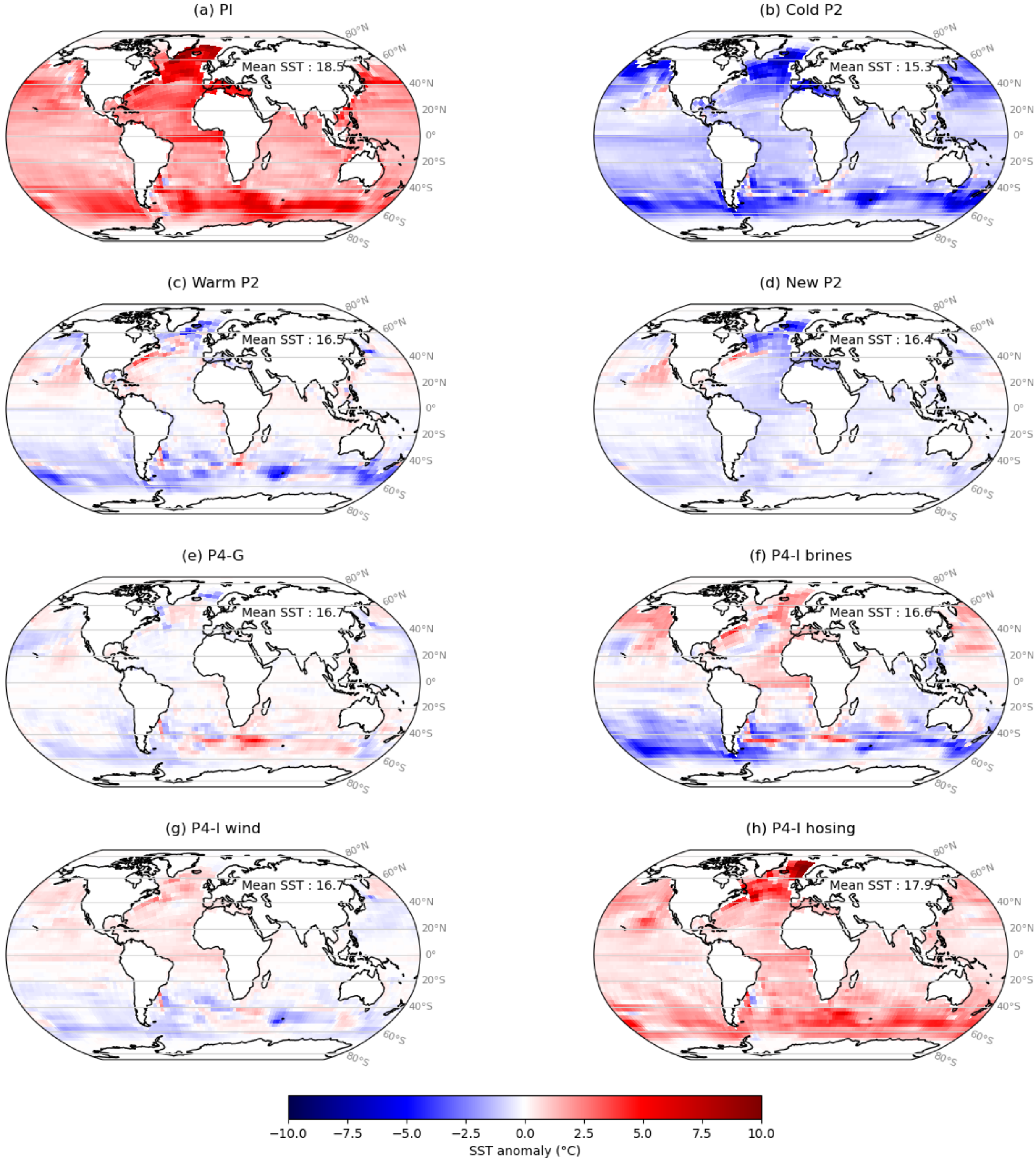
Among our set of simulations, it is the only one simulating a water mass distribution which is reconcilable with reconstructions from paleoproxies . Nonetheless, this experimental design (like all the others tested in this study) does not result in a shoaling of the AMOC between the PI and LGM state (see Fig. S5), as is usually inferred from proxy data. In contrast, Morée et al. (2021) were able to simulate with the NorESM-OC model a shoaled and slightly weaker AMOC at the LGM compared to their PI state. As the radiocarbon ages simulated in southern source waters were too young compared to data, they however suggested that the ventilation at the LGM was still overestimated, possibly in relation to a too small Antarctic sea-ice extent in their LGM simulation (see their Fig. S12). However, if we consider our new estimates of $10.2 \times 10^6$ $km^2$ and $32.9 \times 10^6$ $km^2$ (respectively for the summer and winter sea-ice extent inferred from proxy data), instead of the ones presented in Roche et al. (2012), the sea-ice extent simulated by Morée et al. (2021) is only slightly underestimated. Therefore additional processes might be involved to explain the weak ventilation of Southern Ocean sourced deep water at the LGM.

Sincerely,
Fanny Lhardy, on behalf of all co-authors

## References

Moat, B. I., Smeed, D. A., Frajka-Williams, E., Desbruyères, D. G., Beaulieu, C., Johns, W. E., Rayner, D., Sanchez-Franks, A., Baringer, M. O., Denis Volkov, D., Jackson, L. C., and Bryden, H. L.: , Ocean Sci., 16, 863–874, https://doi.org/10.5194/os-16-863-2020, 2020.

McCarthy, G. D., Smeed, D. A., Johns, W. E., Frajka-Williams, E., Moat, B. I., Rayner, D., Baringer, M. O., Meinen, C. S., Collins, J., and Bryden, H. L.: Measuring the Atlantic Meridional Overturning Circulation at 26°N, Progress in Oceanography, 130, 91–111, https://doi.org/10.1016/j.pocean.2014.10.006, 2015.


(a) PI
Mean SST : 18.5
(b) Cold P2
Mean SST : 15.3
(c) Warm P2
Mean SST : 16.5
(d) New P2
Mean SST : 16.4
(e) P4-G
Mean SST : 16.7
(f) P4-I brines
Mean SST : 16.6
(g) P4-I wind
Mean SST : 16.7
(h) P4-I hosing
Mean SST : 17.9
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
−10.0
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0
SST anomaly (°C)