We thank Dr. Juan Muglia for his comment. His comments are reproduced in black, and our replies are provided in blue. We have also included the modified section of the revised manuscript below our response.

Comment SC1: Juan Muglia (16 January 2021)

In the Discussion section the authors state that "Despite significant differences in oceanic circulation in these two simulations, with weaker NADW and AABW in LOVECLIM2 compared to LOVECLIM1, the sea-ice cover differences between these two runs are much smaller than compared to other models. Apart from FGOALS-G2, which simulate a very strong LGM AMOC, the LGM AMOC strengths in the other PMIP3 models are similar at 21-23 Sv" Although the two LOVECLIM simulations have different AABW circulations, they both have weak AMOCs (taken from Menviel et al. 2017 table 1). So it is natural that the difference in sea ice cover between these two simulations is smaller than between them and the PMIP3 models, which all have stronger AMOCs. Could you please be more clear on how this result means that the "primary control on LGM austral summer sea-ice cover is not linked to the strength of the AMOC"? Especially taking into account that from Fig. 1c it looks like the two simulations that have the furthest reaching Summer sea ice are LOVECLIM1, LOVECLIM2 (both have weak and shallow AMOC), and CCSM4 (strong and shallow AMOC), which are the three simulations with the most distinct AMOC structures compared with the rest of the PMIP3 models which exhibit strong and deep AMOCs.

We thank Juan Muglia for this comment. Since most PMIP3 models (apart from FGOALS) have similar AMOC strengths but very different sea-ice areas (Fig. R1), other factors than AMOC must control the summer sea-ice extent. For the two LOVECLIM simulations originally included, we were mostly referring to AABW, which is much weaker in weakNA_AB (previously referred to as LOVECLIM2) than weakNA (previously referred to as LOVECLIM1). Nevertheless, we are now also including another LOVECLIM experiment following the PMIP4 protocol, which displays an AMOC strength of 26 Sv (compared to 14.7 Sv and 11.2 Sv for weakNA and weakNA_AB) to illustrate the fact that despite the very different AMOC states, differences in sea-ice extent simulated in these 3 LOVECLIM simulations are smaller than across models.

As shown in Figure R1 (below, Figure S1 in the new version of the manuscript), we are now also plotting the sea-ice extent as a function of AMOC strength and depth for all the simulations. Figure R1 shows that across PMIP3 and PMIP4 LGM simulations, there is no relationship between sea-ice extent and AMOC strength, and only a weak relationship between sea-ice extent and AMOC depth.

In the revised manuscript, the Discussion will be amended as follows, lines 338-345:

"In this study, we also included three LGM experiments performed with the Earth system model LOVECLIM. The oceanic circulation was varied in two of these experiments by adding meltwater in the North Atlantic and SO and weakening the southern hemispheric westerly windstress (Menviel et al., 2017). Despite significant differences in oceanic circulation in these three simulations, with weaker AABW transport in weakNA_AB compared to weakNA, and weaker Atlantic meridional overturning circulation (AMOC) in weakNA (14.7 Sv) and weakNA_AB (11.2 Sv) compared to the PMIP4

LOVECLIM experiment (26 Sv), the differences in sea-ice extent between these three experiments are much smaller than the inter-model differences between all PMIP3 and PMIP4 simulations. This indicates the limitations of performing model-data comparisons with a single model to infer SO climatic conditions."

The lack of relationship between sea-ice extent and AMOC strength, and the weak relationship with AMOC depth are now also mentioned in the Discussion, lines 346-351, and shown in Figure S2:

"We further assess the relationship between SO sea-ice extent and AMOC strength (Figure S2, Muglia and Schmittner, 2015; Kageyama et al., 2021), and find that there is no statistically significant relationship between the two (R^2 =0.04). There is however a weak relationship between sea-ice extent and AMOC depth (Figure S2, R^2=0.17), with a shallower AMOC generally associated with a larger sea-ice extent. SO sea-ice formation impacts AABW properties and therefore ocean stratification (Marzocchi and Jansen 2017), which can influence AMOC depth. To some extent, this can be seen in Figure 5, as models that simulate small amounts of sea ice (i.e. CNRM and MIROC-ES2L) show less stratification and a deeper AMOC, while models simulating more sea ice (i.e CCSM4 and CESM1.2) have more stratification and a shallower AMOC. However, climatic conditions in the North Atlantic are probably the principal driver of AMOC depth (Oka et al., 2012; Muglia and Schmittner, 2015).

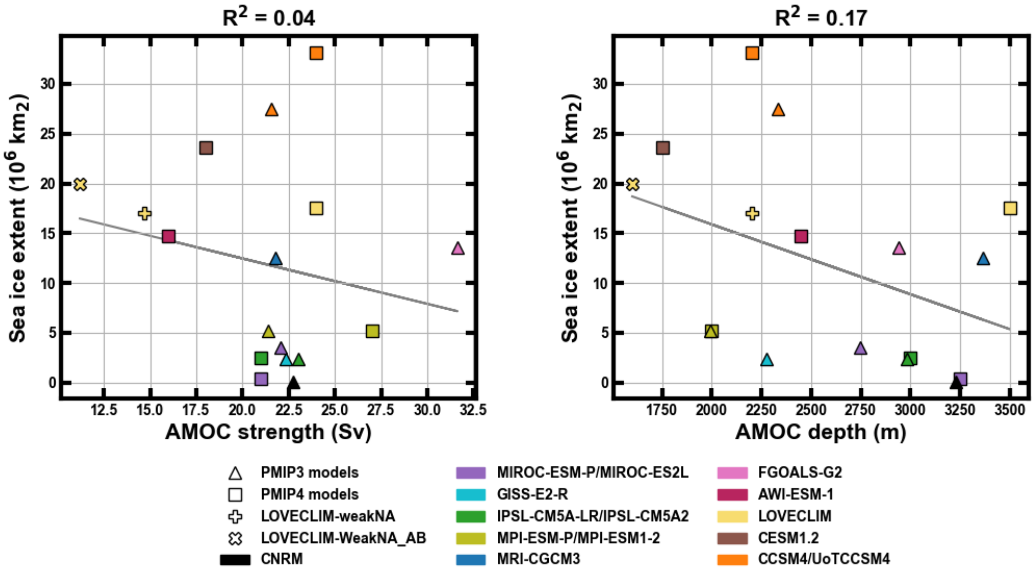

Figure R1 (shown in the manuscript as Figure S2). Scatter plot showing the relationship between austral summer sea-ice extent and Atlantic meridional overturning circulation (AMOC) depth and strength. Each R2 value is calculated and placed in the title of each panel.