Reviewer 2

We thank the reviewer for insightful comments that have improved the manuscripts. Our response to individual comments are below in blue.

The authors present a comprehensive and well-executed evaluation of regional climate features—such as snow accumulation, surface air temperature (SAT), sea surface temperature (SST), and the ENSO index—that influence surface mass balance (SMB) over Antarctica. The comparison across multiple PMIP past1000 models and CESM-LME, alongside proxy reconstructions, is thorough and highlights important mismatches between models and observations. A key takeaway is that no single model performs consistently well across all variables, and even the best-performing model (CESM-LME) only marginally outperforms others in projecting future SMB increases.

Overall, the manuscript is well written, and I don't have any major concerns.

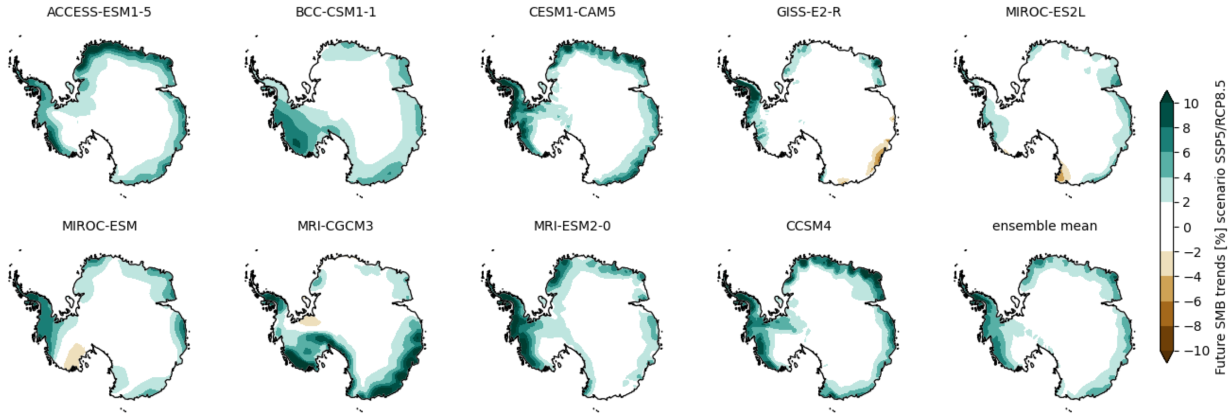
We thank the Reviewer for their positive comments.

Minor comment: I believe the manuscript would benefit from a clearer articulation of the scientific implications of its findings. While the motivation to understand SMB variability is well established in the introduction, the discussion section could more explicitly address how the model evaluation enhances our understanding of SMB and its relevance for future sea level projections. For instance, the abstract notes that CESM-LME predicts higher SMB by 2100, but the implications of this projection are not explored. To what extent does an increase in SMB contribute to sea level rise? These are critical questions that would help contextualize the study's broader significance. Based on the title of the paper, I was expecting a stronger emphasis on these implications. At present, the manuscript is heavily focused on model evaluation (which is good), but the connection to the larger scientific or societal relevance —particularly in the context of sea level rise— is underdeveloped.

We agree with the reviewer that providing a more detailed discussion of the scientific implications of increased Antarctic SMB for future sea level rise would improve the manuscript. To address this comment we will include a new figure in the results section showing the spatial pattern of SMB changes in an SSP5-8.5 high-emissions scenario. This will allow us to discuss Antarctic mass balance from a regional perspective:

"Figure 12 shows the projected regional changes in SMB over the AIS under the high-emission SSP5-8.5 scenario. Most of the future SMB changes are concentrated along the coast, with some smaller changes in the WAIS interior. The vast majority of coastal SMB changes are positive, with only a few models showing negative changes — notably GISS-E2-R in WL, MIROC-ES2L in VL, MIROC-ESM in WAIS and MRI-CGCM3 in WS. The ensemble mean only displays positive changes, with maxima in the AP, western WAIS, DML, and WL. The best-scoring model, CESM1-CAM5, projects positive changes along nearly all coastal regions except for VL and eastern WAIS, and shows strong agreement with ACCESS-ESM1-5 and CCSM4, two models that score slightly better than the model mean."

Figure 12



Spatial plot of the future [2025-2100] SMB change in [%] under the high-emission SSP5-8.5 scenario.

We will also include a more detailed review of the literature in the discussion named "Implications for 21st-century sea level rise", which will better contextualise the study's broader significance:

"Previous studies have considered the historical time period to constrain future projections of Antarctic SMB. Palerme et al., (2017) showed that models that best capture observed historical snowfall rates tended to project larger snowfall increase; although Gorte et al., (2020) found a similar increase in SMB under the high-emission scenario, their subset of best-scoring historical models suggest smaller increases. Our sample size of available models is too small to be as conclusive as those studies, but with respect to the LM, the model that performs the best across multiple SMB-relevant variables projects greater future increases in AIS SMB. To strengthen the study, we encourage more climate modelling groups to participate in experiments such as past1000 so that projections can be constrained over longer time scales.

A positive SMB trend means mass gain over the surface of the ice sheet, a negative contribution to the global sea level (Ligtenberg et al., 2013). According to the best-scoring model, over grounded ice, most of the SMB change at the year 2100 is concentrated along coastal regions, with maxima in the AP, western WAIS, DML and WL. The AIS interior remains relatively unchanged with the exception of small changes in the WAIS interior. However, at present, the ongoing dynamic ice loss in West Antarctica dominates the AIS mass balance (Shepherd et al., 2018), and under high-emission scenarios. Medley and Thomas (2019) demonstrate that the increase of snowfall over the AIS during the 20th century did not offset the ocean-driven ice mass loss and only mitigates the AIS sea level rise contribution. Some studies have projected that ice discharge from West Antarctica will continue to dominate Antarctica's sea level contribution in the future even under low-emission scenarios (Lowry et al., 2021; Deconto et al., 2021). While some parts of the AIS will likely experience mass gain by the projected increase in SMB (Winkelmann et al., 2012; Seroussi et al., 2020), this will likely not be enough to counteract the loss of mass from the marine basins of West and East Antarctica, even though the best-scoring model in our analysis shows an increasing SMB trend of 13 ± 0.5 $Gt.yr^{-2}$ over the next century.

Although Antarctic SMB is projected to increase overall, there is still a question of how SMB changes may impact ice shelf stability in the future. Kittel et al., (2020) discuss how atmospheric warming may lead to diverging SMB responses between grounded ice and lower elevation ice shelves. Using an RCM to better represent changes in mass and energy fluxes at the surface, they find that the projected higher temperatures are likely to decrease SMB over ice shelves, mainly due to increased run-off and meltwater that can cause ice shelves to hydrofracture. Ice shelf collapse substantially increases the AIS sea level contribution in ice sheet model projections over the next three centuries (Seroussi et al., 2024). This highlights that regional downscaling these global models is essential to fully grasp the implications of these long-term SMB processes."

We will also add a few sentences in the conclusions with respect to these future implications:

"For the models where future scenarios were available, they all show an increase in the spatially integrated AIS SMB by the end of the 21st century. The model that performs the best in simulating regional climate features over the LM and its range of natural variability implies that increases in SMB will more strongly mitigate future dynamic ice loss and sea level rise contribution from the AIS.".

Line 361–363: Not sure if the statement "all models generally agree" is true here. For example, CESM-LME shows no change in coastal East Antarctica, while other models show notable anomalies. Consider softening this claim.

We will revise this sentence accordingly:

"While there are some regional differences, particularly in coastal East Antarctica where CESM-LME is the only one that shows no notable anomalies, most of the best-scoring models show the greatest precipitation changes along the coasts."

Line 372–373: Again, all models mostly agree for West Antarctica, but not for East Antarctica.

We will revise that sentence.

"All four models agree and display similar correlation patterns in West Antarctica, ..."

Line 378: Consider removing the parentheses around "Bellingshausen and Weddell Seas".

We will remove the parentheses.

"For SSTs, here we show that models exhibit opposite correlations with high positive correlations between local SST in the Bellingshausen and Weddell Seas and AP precipitation."

Line 381: ".......changes in the West Antarctica"

In a revised version, this will be added.

"According to the four best-scoring models, regional precipitation patterns in West Antarctica are highly sensitive to local temperature and Southern Ocean conditions (SIC and SST) changes."

Line 381–384: This point appears to repeat content from lines 362–363.

In a revised version, we will remove this repeated content.

Section 5.3: I think much of this section could be moved to results.

We agree with the reviewer that much of this section is better placed in the Results. We plan to name this section “4.7 Relationship between climate variables”. Part of the section that will not be moved and is related to the relative importance of decadal climate variability in driving the precipitation will be kept under the same discussion name, “Process understanding gained from the best scoring models”.