Reviewer #2 - Tri Datta

We would like to thank the reviewer #2 for her interesting comments and suggestions which helped us to improve our manuscript. Please find our responses in blue below your comments. Italic text represents unchanged text from our manuscript while bold text highlights our suggested changes.

This manuscript presents an analysis of the importance of cloud properties in driving surface melt over Antarctic ice shelves in the future (to 2100) , comparing these to a 1981-2010 reference period. This uses the MAR model forced at the boundaries with 4 ESMs (ACCESS1.3, NorESM-1-M, CRNM-CM6-1 and CESM2) in the RCP8.5 (for CMIP5 models) and SSP585 (for CMIP6 models). The authors examine potential drivers for surface melt beginning with energy balance components, identify the importance of clouds, and present a strong analysis of properties which contribute most to differences in melt produced by each ESM-forced-version of MAR. I commend the authors on a very well organised argument and believe that this will eventually be a strong contribution to the understanding of future surface melt in Antarctica, although several important aspects are currently missing, which could be addressed with additional figures and analysis.

Specific Comments:
1) The integration of all ice shelves may be hiding processes which vary spatially

As an example, the authors specifically admit that the SEB is impacted by SHF values only in certain regions. We note that one such region is the Larsen C ice shelf, where a substantial amount of total surface melt occurs. At the 35 km spatial resolution, surface melt would necessarily be poorly-represented over the Larsen C ice shelf in this version of MAR. A more meaningful analysis (making this manuscript an excellent companion to Gilbert and Kittel, 2021) would be to essentially conduct the organisation of this study, but with ice shelves divided regionally.
We acknowledge a regional analysis could improve the manuscript, so that we will include it. See our response to #R1.

For plots (i.e. Figures 2,4, 6, S1, S2) these would benefit from a map showing differences (as in Fig. S3). We note that on line 164, the authors mention the thickening of the future planetary boundary layer over ice shelves of West Antarctica – it would be relevant to show whether this was demonstrated in East Antarctica as well independently.
Ok for the plots Figs.4,6, S1 and S3 (note that the main interesting part of this plot is the SHF anomaly that is already represented spatially in Fig. S4). We will also add maps of CC and COD changes. (also see our response to #R1 for the regional analysis)

Unfortunately we did not save the height of the PBL in our simulations and the variables at our disposal do not enable us to recalculate it afterwards either. We will ensure that PBL is added to the default outputs of the model.

Additionally, it would be beneficial to see similar maps of averaged values for forcing fields (in Supplemental Figures) to illustrate the spatial characteristic of the differences in forcing. By integrating, we have no picture on the spatial characteristics which are driving this (i.e.

are the differences in moisture at lower altitudes vs higher altitudes dominant in West Antarctica but not East Antarctica)
See our response to #R1. We will add those maps in Supplement.

2) A more rigorous account of changes in albedo

The differences in albedo are mentioned briefly, but this seems to be a major driver in the overall differences shown, and there is no discussion about how this is impacted by snowfall events. While I think that a thorough examination of precipitation trends is outside the scope of this manuscript, an analysis of albedo differences (in a map) as well as snowfall differences (in a map) would strengthen the manuscript significantly.
We also think that a thorough examination of precipitation is outside the scope of this manuscript, especially since it was already presented in Kittel et al., 2021. Snowfall and rainfall differences are discussed in their section 4.1.2 (including maps and tables). However, we acknowledge that a map with albedo differences will contribute to improve our manuscript and will therefore be added (as well as a map with rainfall changes as it was not included in Kittel et al., 2021).

About the role of snowfall on albedo, it was not originally discussed as Shortwave Net contribution is relatively close for a same warming rate suggesting that the effect of the surface albedo decrease is compensated by the "parasol" effect of clouds (also stronger in the experiment where the surface albedo decrease the most, ie MAR forced by CNRM-CM6-1). The regional analysis sheds light on discrepancies in the SWN contributions so that we will discuss the albedo differences where it matters. See our response to #R1 where we also discuss the influence of rainfall on the surface albedo.

3) A greater discussion of biases in cloud properties that are present in historical runs of MAR

To my knowledge, none of the evaluations of MAR present a comparison of biases in cloud properties (as compared to observations, i.e. CALIPSO). If I've missed something, a reference and a short discussion would be relevant. If not, then some level of validation of MAR's representation of cloud properties in the historical record would be directly germaine to this study.
See our response to #R1 (and suggested modifications of our manuscript accordingly).

Technical Corrections:

L 42: I could not find the reference to lower future melt changes in ESMs in Kittel et al., 2021. Could the authors clarify (identify a figure/section)?
This is notably highlighted in their Figure S13b where MAR simulations always suggest a stronger decrease in SMB than ESM simulations. This is certainly an extrapolation but that seems reasonable since SMB over the ice shelves will be dominated by runoff (due to melt) changes. We will however remove the sentence as we suggest to modify the introduction to better emphasise the aim of our study (understand why there are large melt differences even of the same warming rate). See our answer to #R1.

L 61: Use of the word “correct” twice in proximity. Additionally. I would suggest, “presents well” as opposed to “correctly”. Additionally, Kittel et al., 2021 refers to future runs, rather than an evaluation of a historical run. Perhaps referencing Agosta et al., 2019 would be more accurate.
An evaluation of MARv3.11 forced by ERA5 against weather station data is well available in Kittel et al. (2021) (while this kind of evaluation was not done in Agosta et al., 2019), see Section 2.1.2 and Supplementary Section S1 in Kittel et al. (2021). See also comment to reviewer 1 where we modified the sentence (avoiding using correct twice in proximity, thanks).

L 64: “difficult to assess”. This is a good way to declare this complexity without making dishonest claims. Thanks for that.
Thank you for noticing.

L 110: Make clearer exactly how these melt projections used climate models.
We suggest to change:
Most of the projections of the Antarctic melt have been performed in the frame of the 5th phase of the Coupled Intercomparison Project (CMIP5) \citep[e.g.,][]{Trusel2015}, while more recent climate models from CMIP6 now project stronger warmings at both local (Antarctic) and global scales.
to

*Most of the projections of the Antarctic melt **have been based on direct outputs of models \citep[e.g.,][]{Seroussi2020}** from the 5th phase of the Coupled Intercomparison Project (CMIP5), **or derived from them using statistical regression \citep[e.g.,][]{Trusel2015}**, while more recent climate models from CMIP6 now project stronger warmings at both local (Antarctic) and global scale*s.

L 171: Awkward sentence. Suggestion: “This could be explained by accounting for the ECS capturing the greater warming over the Antarctic region simulated by CNRM-CM6-1 (+8.5°C vs 7.7°C for CESM2 in 2100 compared to 1981-2010).
Thanks for the suggestion, we will change accordingly.

L 173: replace “this ESM” with “CRNM-CM6-1” for clarity
Changed, thanks.

L 176: relatively – (remove dash)
Corrected

L 182: “suggests a low influence on LWD”. Clarify the discrepancy by comparing the quantity
The sentence was unclear, there is no difference in LWD due to GHG as it can be considered as an supplementary effect that is equivalent between our simulations. We propose to remove this part of the sentence.

L 206: “southern” == “austral”
Changed.

L 210: Why are clear and cloud sky conditions treated separately? Could you clarify the reason or separate the analysis accordingly?
They are not treated separately. We mean that the COD as computed in MAR could then increase for three reasons: optically thicker clouds (but same occurrence), more clouds (but unchanged cloud composition), or a combination of both. Figure 2 indeed reveals a COD increase in MAR forced by CNRM-CM6-1 as CC increases, but it also shows that a same increase in CC in MAR forced by CESM2 leads to a higher increase in COD.

L 220: Could you demonstrate the saturation of LWD for large COD increases in supplemental?
Following your request, we extended the relations expressed in Fig. 3 for large COD increases. Since the relation is expressed with an exponential function, we computed the values given L220 by assuming a minimal variation of LWD for a COD change using a very arbitrary way. We tried to improve the computation by fixing the variation of LWD threshold to 0.1% associated with a change in the COD anomaly of 0.01. This gave a correct detection of the COD anomaly associated with negligible change in LWD (ie, where LWD anomaly could be considered to stop increasing) for at least the CESM2 and NorESM1-M experiments (Fig R13), and a satisfactory one for the other experiments.

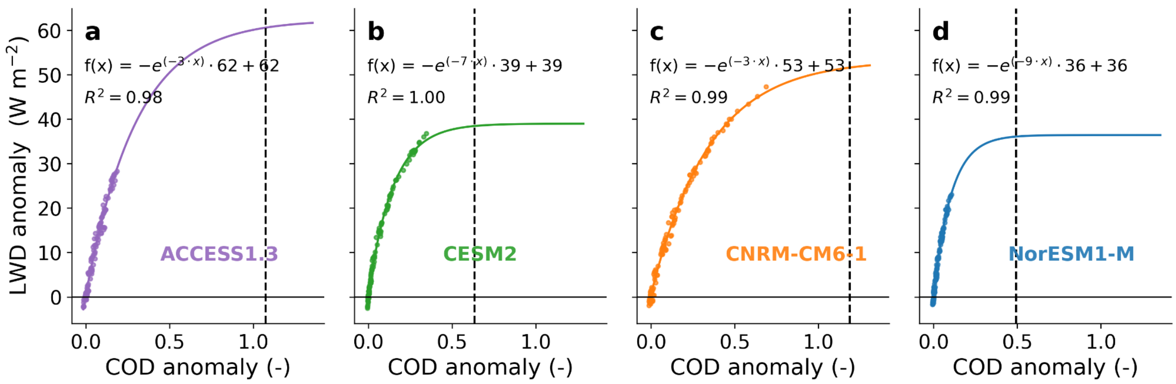

Fig. R13: Relation between LWD summer anomalies and COD summer anomalies. Summer longwave downwelling radiation (W m−2) versus mean cloud optical depth anomalies during summer (-) projected by MAR driven by ACCESS1.3 (a), CESM2 (b), CNRM-CM6- 1 (c), and NorESM1-M (d) compared to the summer reference period (1981–2010). The exponential regression as well as corresponding determination coefficient (R2 , p «0.01) is indicated for each experiment. A 5-year running mean has been applied on the anomalies. The vertical dashed line represents the COD anomaly where LWD anomaly could be considered to stop increasing.

However, these values (+1.07 for ACCESS1.3, +0.63 for CESM2, +1.19 for CNRM-CM6-1, and +0.49 for NorESM1-M) are based on the strong extrapolation of an exponential function that is likely very uncertain (difficult to fit) and still using an arbitrary methodology. Given all of that, we suggest to replace L221-L226 :

We extrapolate our projections based on equations from Fig. 3, to find that increase in LWD associated to an increase in COD would stop when COD equals 1.22 (+0.96 compared to present values) (ACCESS1.3), 1.10 (+0.96) (NorESM1-M), 1.78 (+0.91) (CNRM-CM6-1), 1.2 (+0.89) (CESM2). Since these values are not reached before 2100 in our simulations, the future LWD increase is supposed to remain sensitive to cloud optical properties during the whole 21st century, including for high warming rates as projected by CNRM-CM6-1 and CESM2.

by

The relations expressed in Fig. 3 suggest that the sensitivity of the LWD increase would progressively stop for (very) large increases in COD. *As these values are not reached before 2100 in our simulations, the future LWD increase is supposed to remain sensitive to cloud optical properties during the whole 21st century, including for high warming rates as projected by CNRM-CM6-1 and CESM2.*

References:

Agosta, C., Amory, C., Kittel, C., Orsi, A., Favier, V., Gallée, H., van den Broeke, M. R., Lenaerts, J., van Wessem, J. M., van de Berg, W. J., et al.: Estimation of the Antarctic surface mass balance using the regional climate model MAR (1979-2015) and identification of dominant processes, The Cryosphere, 13, 281–296, 2019.

Kittel, C., Amory, C., Agosta, C., Jourdain, N. C., Hofer, S., Delhasse, A., Doutreloup, S., Huot, P.-V., Lang, C., Fichefet, T., and Fettweis, X.: Diverging future surface mass balance between the Antarctic ice shelves and grounded ice sheet, The Cryosphere, 15, 1215–1236, https://doi.org/10.5194/tc-15-1215-2021, 2021.