

## ***Interactive comment on “Significant additional Antarctic warming in atmospheric bias-corrected ARPEGE projections” by Julien Beaumet et al.***

**Anonymous Referee #2**

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Review of “Significant additional Antarctic warming in atmospheric bias-corrected ARPEGE projections” by Julien Beaumet et al.

With great interest I have read this manuscript which is generally well written. I do not see the need summarize the content of the manuscript.

After reading the manuscript and collecting my comments, I've read the first review. I had also caught my attention that the discussion of tendency-corrected projection is less in depth as the discussion of the historical period. I know, verifying a projection is much more complicated as we do not know the future.

The approach proposed here assumes stationary of the model biases while the atmospheric mean state is changing due to anthropogenic forcings. It would be good if the

C1

authors provide more detail on the added/removed energy, moisture and momentum and how this relates to the total global energy, moisture and momentum budget. If the local/total tendency correction is significant compared to the local/total energy/moisture budget, this reduces the reliability of projections, as a different mean state would likely need a different mean tendency correction.

Other significant comments:

The title needs to be revised as it is not self-evident on with respect to what the additional warming has been observed.

I would propose to merge section 4.1 with 3.1 as 4.1 is an extended evaluation of discussion of the Present Climate, and hence the continuation of 3.1. It would connect 3.2 and 4.2 as well.

The discussion of SMB and precipitation (section 3.1.4) can be more clear, I propose to separate the discussion and figures concerning of precipitation and SMB. I would propose to dedicate section 3.1.4 on precipitation only, discussing the differences between ARP-AMIP-AC, ARP-AMIP, MAR and RACMO as is done now. Given the substantial differences between ARP-AMIP-AC and MAR (and RACMO), I would like to see figures of at least also the modelled precipitation (thus not a difference plot) of ARP-AMIP-AC and (MAR and/or RACMO). Possibly the new Figure 5 can combine these 2/3 precipitation plots with the old figures 5a, 6 and 7a,b. It would be good for the text, for example, as figures 5a and 7b are close/next to each other so that they can be compared easily. It might be worth considering reorganising P13L3 to P13L22 so that it becomes easier to read and grasp. Furthermore, anyone should be aware that MAR and RACMO2 are not the real truth of the precipitation, so in the discussion here the authors could take that into account. Hence, take the assessment of Agosta & van Wessem on the performance of their models against observations across the continent into account when MAR and RACMO2 disagree. In 3.1.5 (or at the end of 3.1.4 if 3.1.5 would become too short), the other SMB components and the SMB is discussed, e.g. Figure 5b,c.

C2

It would be good to connect the dots: too high surface temperatures (-> too high LW emission?), too strong exchange in the ABL, too high sublimation. Of course, if these dots connect in your view. (If not, please argue why so in the reply to the review).

Other textual comments:

P1L16: What's dramatically? It has an emotional load this sentence not necessarily needs. I'll prefer it to be changed into something like considerably.

P1L20: "Fails to compensate" I'll prefer a more neutral expression. Less drama, please.

P2L2: Compared to the "dramatically" at P1L16, this "dramatically" is justified. . .

P2L2: As you are going to argue this SMB increase per K is higher, I would formulate this sentence slightly different as it now reads as a closed case. E.g. "... , existing studies align on an increase of the SMB of 5+1 % K-1 (..."

P2L5: As models seems to align, which uncertainties are missed? Please expand. Similarly, please rephrase "In this regard" as it may seem to refer back to the SMB - Temp relation, but you do refer to the potential mass loss of the AIS.

P3L27: I would like to see a figure of the grid. A reference "(see <paper>, Fig. <#>)" will do.

P4L3: Please state clear that GELATO is only needed for a correct SEB over sea ice.

P5L7: Brackets is not the most elegant option. "...conditions, e.g. greenhouse gas concentrations, and ..."

P5L32: I can imagine arguments to use ERA-Interim here even though it is now superseded by ERA5 for about a year. Nevertheless, provide these/this argument here; briefly of course.

P8, T2: Give a reference to Eq. (4) for  $\Delta_r E$ .

P9, F1: add in the caption that Mean SLP is shown.

C3

P7L7: not the uncorrected ARP-AMIP run but the mean SLP of this run is low biased.

P7L20: Is there a specific process-based reason for the remaining warm bias in winter 200 hPa, near surface pressure bias over Antarctica and surface temperature errors (Sec 3.1.3)? Is it related to radiative problems (too much LW TOA emission, and hence too strong meridional circulation) or too strong horizontal (stratosphere) and vertical (ABL) mixing? If studied before, a reference and short note will do.

P8L11: If I read P6L6 correctly, these BMUs are derived using ARP-AMIP-AC data too. Is there a reason that typical states of ARP-AMIP-AC are nonetheless missed?

P14 F5: 1) The numerous overlays make the graphs hard to assess 2) There is a typo in the caption ".W.e" 3) I don't see the necessity to clip precipitation (Fig. 5a) to the continent only. Please show ocean values as well (without changing the plotted region). That request involves also figures 6, 7 and 10.

P17 F8: it would be good if the legend would make clear too which lines belong to historical simulations and which to projections. Now it doesn't.

P17L7: a larger displacement than with? (NorESM1-M likely).

P17/18 S3.2.2: This section is rather descriptive. What is driving the regional warming? Reduced LW TOA emission, better meridional exchange, or unmodified global warming. And why is much of the southern ocean not warming? I don't think it's wrong/err, but I'm missing explanations even brief.

P19F9: The panels are really small, please blow them up by 50% at least. Grey lines needs to be searched with zoom. . .

P21F10: for ARP-MIR-21-AOC, changes are well over 75% for about half of Antarctica. Please adjust the scale so that is "colormap clipping" is largely removed.

P21L4: Section. A is likely Appendix A.

P21L8: I personally don't see the logic in trying strong tendency correction on boundary

C4

layer processes if you haven't tried extending the current tendency correction on the boundary layer. Furthermore, it sounds logical to me that systematic errors in the boundary layer representation induce biases at 850 hPa even if this layer has tendency correction. Given that you now have an isolate region with biases (the ABL), retuning is now much more easy as indirectly induced global feedbacks of retuning can be removed by rerunning the tendency correction procedure on the retuned model.

P22L2: A reference to figure B1 (I presume) is missing. Make more clear in the text that you're comparing against MAR as I missed that on first sight. T2m temperature biases over land and ice sheets make only sense if the model topographies are (near) similar. An 100 m elevation difference gives a 0.5 to 0.8 K temperature difference, so the modelled biases over the smaller ice shelves and continent escarpment could potentially explain part of the biases. Of course, similar biases are observed over the larger ice shelves where topographic errors are unlikely. It would be good to add in the appendix a figure with local differences in the model orography along with Figure B1. If these orographic deviations are negligible, that should be stated clearly in the manuscript. Similarly, consider to add model and station elevations in Table B1.

P22L30: "Large discrepancies ..." This is a very indirect way of saying that MAR and RACMO2 do not agree, right? Please formulate more direct to take away confusion. Furthermore, nice to hear that MAR and RACMO2 don't agree, but what is the implication for this paper? Does ARP-AMIP align better with RACMO2?

P23L27: The conclusions of this paper are slightly more nuanced than this. RACMO2 ignores horizontal transport of falling precipitation and subsequently misses evaporation of snow advected into dryer or warmer locations. If ARPEGE has also no prognostic precipitation, this error could be shared. However, the induced error by missing precipitation advection decreases for decreasing model resolution.

P23L29: "... (15 min). Over the ..." Add something like Furthermore/Finally to make clear that the following is not directly related to the "first Agosta 19 comments".

C5

S4.2.1&4.2.2: It is good to add references to the figures that are discussed. Now the text is dry and requires the reader to have memorized all the graphs implicitly referenced. And, as discussed above, it is less thorough as the rest of the paper.

Figure 1, 8, 9, A1, A2: The labels and legend text in these figures are too small.

Table B1 and B2: I do not see why you cannot merge these two tables into one table.

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Interactive comment on The Cryosphere Discuss., <https://doi.org/10.5194/tc-2020-307>, 2020.

C6