

Review of: “Brief communication: Impact of the recent atmospheric circulation change in summer on the future surface mass balance of the Greenland ice sheet”, by A. Delhasse et al., submitted to *The Cryosphere*.

Since the 2000's, the Greenland ice sheet (GrIS) has experienced a circulation change toward more frequent anticyclonic conditions in summer, resulting in warmer near-surface conditions and increased melt. While regional climate models (RCM) forced by present-day climate re-analyses successfully reproduce this recent change, general circulation models (GCM) from the CMIP5 effort fail to do so, questioning their ability to provide reliable projections of the GrIS surface mass balance (SMB) if the ongoing circulation shift persists through the next decades. Using the regional climate model MAR forced by ERA-Interim re-analysis (1980-2016) and by RCP4.5 scenarios from three CMIP5 members (MIROC5, NorESM1 and CanESM2; 1980-2060), the authors investigate the impact of a persistent circulation shift (as currently observed) on GCM-forced projections of future GrIS SMB.

To that end, a set of sensitivity experiments consisting of MAR forced by perturbed ERA-Interim forcing (1980-2016), i.e. +1, +1.5, +2°C hereafter called “warmer reanalysis”, are conducted. Then the authors compare SMB anomalies derived from these “warmer reanalysis” experiments to MAR simulations forced by three GCMs over selected 20-year periods experiencing a similar temperature increase in the free atmosphere (+1, +1.5, +2°C) relative to the reference period 1980-1999, i.e. before the onset of the recent circulation shift.

No significant difference in SMB can be found between the “warmer reanalysis” experiments for the reference period (1980-1999) and the GCM-forced simulations over the corresponding selected periods (+1, +1.5, +2°C). For 2000-2016, i.e. including the recent circulation change, the “warmer reanalysis” experiments suggest a significant increase in meltwater runoff compared to the corresponding GCM-forced simulations, further resulting in two times lower SMB estimates. This highlights the importance of capturing current (and future) circulation change in GCM scenarios to provide reliable RCM-based projections of the GrIS SMB.

General comments

This is an original study based on a state-of-the-art, thoroughly evaluated climate model that will be of great interest to the cryospheric community. Additional clarifications and more detailed analysis of the results are necessary in places. The manuscript is sometimes confusing due to repetitions and lengthy sentences, which should be shortened/reformulated before acceptance. I deem that **minor revisions** are further required before publication in the *Cryosphere*. Hereunder, the authors can find suggestions listed as substantive, point and stylistic comments.

Substantive Comments

1. As mentioned by reviewer #1, additional information on how temperature perturbations are applied to the ERA-Interim forcing are necessary to better understand the results. Were the temperatures increased only at the surface or at each MAR atmospheric vertical level? This should be clearly mentioned. Section 2.1 should also explicitly state how many atmospheric vertical levels are used in these simulations.
2. Section 2.1 should also briefly discuss how the snow pack was initialized for the different sensitivity experiments. Is the initial state of the snow pack similar for each sensitivity experiment (MAR forced by ERA-Interim and GCM scenarios)?
3. In Section 2.2.2, the authors should explain in more detail why these three specific GCMs were selected. The authors should also clarify why the 20-yr periods experiencing +1, +1.5 and +2°C are sometimes very different for the three GCMs, i.e. especially for CanESM2.

4. At P5 L3-5, the authors state that capturing the circulation change results in a massive runoff increase “nearly two times higher” relative to the reference period. This is an interesting result that is not further discussed. The authors should consider discussing the potential mechanisms driving this significant runoff increase. See also the corresponding point comment at P7 L4-6.

Point Comments

P1 L4: Add “North” before “Atlantic”. **L8:** For consistency, replace “forced with” by “forced by”. This comment holds for the whole manuscript. **L23:** The authors could add: “[...] snow grain metamorphism and further decreasing surface albedo [...]”.

P2 L1: The authors could add: “[...] in summer leads to longer exposure of bare ice at the GrIS margins [...]”. **L4-7:** The authors certainly mean that as GCMs fail to capture the current circulation change, the resulting recent melt increase modeled by RCMs forced by GCM “historical climate” is underestimated compared to observations. Could the authors clarify this and reformulate? **L21-27:** This paragraph should better be moved to Section 2.1. Section 2.2 could start at L27: “We performed two sets [...]”. Information about the number of atmospheric vertical levels and initialization of the snow pack could be briefly discussed in Section 2.1, see also substantive comments.

P3 Sections 2.2.1 and 2.2.2 could be titled “ERA-Interim forcing” and “GCM forcing”, respectively. **L18:** How are temperature in the free atmosphere estimated at 850-700 hPa when these pressure levels cross the surface topography of the GrIS interior?

P4 L25-28: I do not fully understand the analogy between SMB anomalies in Noël et al. (2014) and the present study. Could the authors clarify and reformulate? I also suggest: “These differences at the ice sheet margins are similar to SMB anomalies found [...], who obtained insignificant impact [...]”.

P5 L5: I understand: “The SMB anomaly in MARera2k+1 [...] more negative than the warmer reanalysis over the reference period (MARera+1, resp. MARera+2) and the corresponding GCM-forced future experiments (Table 2)”, could the authors clarify? **L6-7:** Could the authors consider: “This suggests that capturing the recent circulation change simulated by warmer reanalysis in GCM-forced experiments would enhance the projected SMB decrease.” Then at **L9:** “This is illustrated [...] of +2°C over 2000-2016 (Fig. 2b), i.e. including the recent circulation change, compared to the reference circulation over [...]”.

P6 L9: I read 3.7 W/m² in Table 2. The authors certainly mean “~4W/m²”. **L9-11:** The second part of this sentence is poorly written (i.e. after as well as), could the authors reformulate?

P7 L1: Table 2 shows that absorbed SWD is **more** than two times higher for 2000-2016 compared to the reference period. I suggest: “is more than two times”. **L4-6:** As mentioned in the substantive comments, this is an interesting result which is unexploited. The authors should briefly elaborate on how increased melt lead to enhanced runoff, the authors could refer to Machguth et al. (2016). **L31:** Following my previous comment, melt is not a direct component of SMB. It is the runoff increase that drives the decrease in SMB.

Stylistic suggestions

P1 L5: Remove “in a warmer climate”. **L6-9:** I would suggest to reformulate as follows: “We compare GrIS [...] MAR forced by perturbed ERA-Interim reanalysis over 1980-2016, i.e. with a temperature increase of +1, +1.5, +2°C relative to 1980-1999, to future [...] forced by three GCMs over selected periods experiencing a similar temperature increase.” **L11:** Remove “However,”. **L18:** I would suggest: “multiple melting records have been broken [...]”. **L19:** Replace “have been” by “can be”. **L20:** Maybe “resulting from” instead of “gauged through”. **L21:** Maybe “enhanced” instead of “heighten”.

P2 L3: Remove “when they are” and add “climate” before reanalysis. **L7-8:** I would suggest: “This raises the question of how RCM-based projections of future GrIS SMB are affected by the GCM forcing if the recent shift to negative NAO phases in summer persists through the next decades.” **L9:** Maybe: “we use the Modèle Atmosphérique Régional (MAR), especially developed for modeling the SMB of polar regions, to perform [...] with perturbed ERA-Interim reanalysis (+1, +1.5, +2°C) and three [...]”. **L18:** Relative to the version [...]. **L19:** “consists of”. **L20:** “radiation [...] precipitation”. **L23:** Replace “a global forcing dataset such as reanalysis” by “climate reanalyses”. **L27:** Remove “only” and replace “in relation to” by “with respect to”.

P3 L9: “[...] lateral boundaries is conserved by estimating the specific humidity changes as a function of temperature increase”. **L10-11:** Either “[...] with warmer [...] atmospheric conditions” or “[...] with higher [...] atmospheric temperature”. **L6-13:** I suggest: “Therefore we compare anomalies of these GCM-forced [...] and $\sim +2^{\circ}\text{C}$ to the corresponding GCM-forced [...]. As for the sensitivity experiments [...], the mean SMB anomalies associated with these GCMs [...] x equals 1, 1.5 or 2 corresponds to $+1^{\circ}\text{C}$ [...] warming (Appendix [...]). Contrary to ERA-Interim forced experiments, no humidity correction [...] and the SSC are directly prescribed from RCP4.5 [...]”. The authors certainly mean “humidity correction” at L12?

P4 L16-19: I would suggest: “[...] future SMB projections, we evaluate analogies between MAR forced by warmer reanalysis and by GCM future scenarios over periods experiencing a similar warmer climate. Figure 1 shows the difference in SMB anomalies between MARera+1 (resp. +2) and MARmir+1 (resp. +2, using MIROC5 as forcing) over 1980-1999 [...]”. **L28:** “Because GCMs fail [...]”, **L29:** “similar SMB anomalies as MAR”, **L31:** I guess the authors mean “a circulation change on the projected GrIS SMB”.

P5 L3: The authors could remove “in summer” as it is already suggested by “JJA temperature” at L4. **L13:** “As for SMB anomalies,”.

P7 L12: I would suggest: “The goal [...] the impact of unresolved recent atmospheric circulation change in GCMs on RCM-based projections of future GrIS SMB.” **L22:** “for which a similar temperature increase of”. **L23:** “by these GCMs in the free atmosphere.” **L24:** Replace “that the results are similar” by “similar results”. **L28:** Maybe: “suggests that capturing the circulation change leads to SMB anomalies two times higher on average for a similar [...]”. **L32:** “The results [...] suggest”

P8 L2-3: “of examining whether GCMs can predict [...] if so, evaluate [...]”.

Figures and Tables

Table1: For consistency, replace 1 ± 0.39 by 1.00 ± 0.39 in the second row of the second column.

Table2: The authors should consider to explicitly mention MARera and MARera2k instead of/in addition to ERA-Interim in column 3 and 4.

Figure1: To improve readability, could the hatches be displayed in a darker color e.g. grey?

Figure2: As this figure also shows anomalies, a red-to-blue color scale centered on 0 should be used. As for Figure1, hatches could also be displayed in grey for better visibility.

Appendix A1 and A2: For consistency, replace “forced with” by “forced by”. The same applies to the two similar tables in the Supplementary Material.

Additional reference and DOI

Machguth et al. (2016) DOI: [10.1038/NCLIMATE2899](https://doi.org/10.1038/NCLIMATE2899)