Estimating surface melt in Antarctica from 1979 to 2022, using a statistically parameterized positive degree-day model

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We gratefully thank the Editor for the time that he spent reading and reviewing the manuscript and the responses to the referees. We respond to each of the Editor's comments below. The Editor's comments are shown in **bold text**, replies are shown in normal text, text from the original manuscript and the responses is shown in blue, and proposed changes to the manuscript are shown in red.

Dear Yaowen Zheng and co-authors,

Thank you very much for uploading your responses to our two referees. In their reviews, both referees recommend making the paper more concise, simplified, and clarified in places. I agree with these general comments, which should be reflected in your revised manuscript.

I appreciate your efforts to address both reviewers' concern about the impact of biases in satellite/climate model products on estimating "optimal" PDD parameters (T0 and DDF). Please, make sure that your proposed sensitivity experiments remain consistent with the new local estimates of PDD parameters (grid-cell scale) that you suggested to reviewer #2. It remains however unclear how this procedure change, i.e., estimating PDD parameters locally (grid-cell scale) instead of regionally (sector scale), could impact your results.

It is also unclear how additional Figures displayed in your response letter will fit in the revised manuscript, as they are not always discussed or referred to in your answers. Are these illustrations for the reviewers'/editor understanding, if so this should be clarified in your response letter. When using new Figures in your revised manuscript, please comply with the above comment on conciseness, i.e., focusing on relevant results that best convey your message. For instance, additional Figure 2 in the review of referee #1 shows details that may not be essential.

As a general note, please answer each comment separately (even with a brief sentence), and avoid combining them as in Comment 6, 21, 23 and 24 of reviewer #2. Doing so makes it hard to assess how each point comments are addressed. The same holds for removed or restructured sections as in Comment 24 of reviewer #2. You will find some minor comments from the editor below.

Note that both referees and the editor will re-assess your revised manuscript before potential acceptance in TC.

Best wishes,

Brice Noël

Thank you very much for these very constructive comments. In the new version of the manuscript, the regional scale parameters and discussions will not exist. We will entirely focus on our proposed novel cell-level PDD model parameterization. This does not cahnge the overall finding of our research, but will bring more details and help us to refine the parameterization of the PDD model. We will majorly change the manuscript. Please then refer to our proposed new manuscript and the track-changes file.

Thank you very much for the information about writing response letters, it will help us to write better response letters in the future.

Minor editor comments:

When preparing your revised manuscript, please pay particular attention to the wording to avoid confusions.

In your response to reviewer #1, please consider the followings:

L56: "overlapping period" instead of "overlapped period"

Thank you for pointing this out. We will replace the "overlapped period" with the "overlapping period".

L65: "reconstructing" instead of "replicating"

Thank you for pointing this out. We will replace the "replicating" with the "reconstructing".

L68-68: Do you mean: "However, biases in satellite products are likely due to frequent equipment replacements, i.e., at least 4 times in the period YYYY-YYYY" or something equivalent?

Thank you for pointing this out. We agree. We will replace the sentence: "However, bias is suggested to arise due to the frequent replacement of satellites that happened at least four times during the satellite-era (Picard et al., 2007)." with "However, biases in satellite products are likely due to frequent equipment replacements, i.e., 4 times in the period 1979–2005 (Picard and Fily, 2006; Picard et al., 2007).".

L70-79: Do you mean? "To explore the sensitivity of PDD parameters and model outputs to biases in both the satellite and RACMO2.3p2 products, we perform two sensitivity experiments. In the first sensitivity experiment, we explore the response of T0 and the PDD melt-day (and CMS) outputs to perturbations in satellite estimates. We increase/decrease (HIGH/LOW run) satellite CMS estimates by 10% (Figure 1a) for each grid-cell then repeat the T0 parameterization as described in Section 3.2.1, respectively. In the second sensitivity experiment, we explore the sensitivity of the DDF and the PDD melt amount outputs to perturbations in RACMO2.3p2 melt estimates. We increase/decrease (HIGH/LOW run) the RACMO2.3p2 melt estimates by 10% (Figure 1b) for each grid-cell then repeat the DDF parameterization as described in Section 3.2.2, respectively. Based on these experiments, we obtain an optimal parameterization for T0 and DDF which are thereafter used in the CONTROL run." Please, clarify what you mean by "satellite estimates" (i.e., CMS) and "RACMO2.3p2 simulations" (melt amount estimates) to avoid confusions.

Thank you for this suggestion. We agree, but apart from the last sentence. We will change at Lines 70–79 from: "In order to explore how much the biases from satellite estimates and RACMO2.3p2 simulations will influence the parameterization of the PDD model and the outputs from the parameterized PDD model, or in other words, how sensitive the parameterization and PDD model are to the satellite estimates and RACMO2.3p2 simulations, we perform two sensitivity experiments. In the first sensitivity experiment, we explore how sensitive the T_0 and the PDD melt-day (and CMS) outputs are to the satellite estimates. We increase (HIGH run) and decrease (LOW run) the satellite estimates by 10% (Figure 1a) for each computing cell then repeat the T_0 parameterization as described in Section 3.2.1, respectively. In the second sensitivity experiment, we explore how sensitive the DDF and the PDD melt totals are to the RACMO2.3p2 simulations. Again, we employ an increase and decrease of 10% of the RACMO2.3p2 simulations (Figure 1b) for each computing cell and repeat the DDF parameterization as described in Section 3.2.2. Note that in the context of the sensitivity experiments, our optimal parameterization of T_0 and DDF in Section 3.2.1 and Section 3.2.2 constitutes our CONTROL run." to "To explore the sensitivity of PDD parameters and model outputs to biases in both the satellite and RACMO2.3p2 products, we perform two sensitivity experiments. In the first sensitivity experiment, we explore the response of T0 and the PDD melt-day (and CMS) outputs to perturbations in satellite estimates. We increase/decrease (HIGH/LOW run) satellite CMS estimates by 10% (Figure 1a) for each grid-cell then repeat the T0 parameterization as described in Section 3.2.1, respectively. In the second sensitivity experiment, we explore the sensitivity of the DDF and the PDD melt amount outputs to perturbations in RACMO2.3p2 melt estimates. We increase/decrease (HIGH/LOW run) the RACMO2.3p2 melt estimates by 10% (Figure 1b) for each grid-cell then repeat the DDF parameterization as described in Section 3.2.2, respectively. Note that in the context of the sensitivity experiments, our optimal parameterization of T_0 and DDF in Section 3.2.1 and Section 3.2.2 constitutes our CONTROL run.".

L80-84 These lines are unclear. Do you mean? "In addition, these sensitivity experiments enable us to explore potential applications of our PDD model to predict Antarctic surface melt in the future. Although our PDD parameters remain stable for the contemporary climate, it is uncertain how they could change in a warmer climate. Exploring the variations in PDD parameters by performing the above sensitivity experiments provides some insights on the model ability to simulate melt under future warming scenarios. "

Thank you for this suggestion. We agree. We will change at Lines 80–84 from: "In addition, these sensitivity experiments allow us to explore the validity of our PDD model for calculation of future Antarctic surface melt. Even if our PDD parameters are temporally stable for the period that we investigate in this study, the validity of our PDD model for the calculation of future Antarctic surface melt is still ncertain given that the future predictions of Antarctica indicate a warmer climate than at present. Therefore, quantifying the behaviour of our PDD model between these HIGH/ LOW runs will shed a light on the applicability of the PDD model to the warmer climate scenarios." to "In addition, these sensitivity experiments enable us to explore potential applications of our PDD model to predict Antarctic surface melt in the future. Although our PDD parameters remain stable for the contemporary climate, it is uncertain how they could change in a warmer climate. Exploring the variations in PDD parameters by performing the above sensitivity experiments provides some insights on the model ability to simulate melt under future warming scenarios.".

L186-187: "... calculated by multiplying the cell area (km2) by the total annual melt days (day) in that same cell..."

Thank you for this suggestion. We agree. We will change at Lines 186–187 from: "...calculated by the product of cell area (km^2) and the total annual melt days (day) in that cell..." to "... calculated by multiplying the cell area (km^2) by the total annual melt days (day) in that same cell ...".

In your response to reviewer #2, please consider the followings:

L70: What do you mean by "fidelity"?

Thank you for pointing this out. We agree that the text is unclear. We will replace the "fidelity" with "accuracy".

Comment 4: I agree with the two reviewers that L29-47 could be shortened to focus on the impact of melt on the mass balance (e.g., runoff and ice shelf hydrofractures).

Thank you for your suggestion. We agree. We will remove the Lines 29–47. We will add the impact of melt on the mass balance at Lines 21–28. We will repalce at Lines 21–28 from: "Surface melting is common and well-studied over the Greenland Ice Sheet (GrIS) (e.g. Mernild et al., 2011; Colosio et al.,2021; Sellevold and Vizcaino, 2021), and is known to play an important role in the net mass balance of the ice sheet and changes in global mean sea level (GMSL), both now and in the past (e.g. Ryan

et al., 2019). It is likely to become even more important in the future. Even though Antarctica is currently much colder than Greenland, projected Antarctic near-surface warming (e.g. Kittel et al., 2021) means that increased surface melting is to be expected over coming decades – both in terms of area and frequency of melting. However, these are currently less understood over Antarctica than Greenland, either in the past or at present. This is concerning as surface melting will likely become an increasingly important component of Antarctic Ice Sheet (AIS) mass balance through this century and the next." to "Surface melting is common and well-studied over the Greenland Ice Sheet (GrIS) (e.g. Mernild et al., 2011; Colosio et al., 2021; Sellevold and Vizcaino, 2021), and is known to play an important role in the net mass balance of the ice sheet and changes in global mean sea level (GMSL), both now and in the past (e.g. Ryan et al., 2019). It is likely to become even more important in the future. Antarctica is currently much colder than Greenland. Antarctic ice shelves show no statistically significant trend for the annual melt days (Johnson et al., 2022) and also no significant increase in melt amount in East Antarctica in the past 40 years (Stokes et al., 2022). However, climate projections have suggested that surface melt will increase in the current century (e.g. Trusel et al., 2015; Kittel et al., 2021; Stokes et al., 2022) – both in terms of area and volume of melting (Trusel et al., 2015; Lee et al., 2017). Studies have suggested that Antarctic surface melt can impact ice sheet mass balance through surface thinning and runoff, surface meltwater draining to the bed, and increasing ice shelf vulnerability (Bell et al., 2018; Stokes et al., 2022). However, these are currently less understood over Antarctica than Greenland, either in the past or at present. This is concerning as surface melting will likely become an increasingly important player to Antarctic environment through this century and the next.".

Comment 5: Here, referee #2 means that previous studies show that surface melt has not shown a significant increase/acceleration since 1980, but rather even a decrease as mentioned by referee #2. In view of this, the sentence "surface melt has most likely been accelerated by the rapid increase of atmospheric temperatures" could be inappropriate, please elaborate.

Thank you for pointing this out. We agree. We will change at Lines 47–51 from: "Although the warming taking place over the Antarctic Peninsula has not been consistent over the past two decades (Turner et al., 2016), surface melt there has likely been accelerated during the period by the rapid increase of local atmospheric temperatures through the late 20th century (Vaughan and Doake, 1996; Turner et al., 2005, 2016; Hogg and Gudmundsson, 2017). Atmospheric warming in the Antarctic Peninsula during the late 20th century may also have contributed to acceleration of outlet glaciers in the region (Tuckett et al., 2019)." to "Although the warming taking place over the Antarctic Peninsula has not been consistent over the past two decades (Turner et al., 2016), the global mean surface temperature is predicted to increase (Meinshausen et al., 2011).".

Comment 8: "ERA5 performs better at representing near-surface temperature than its predecessors . . . "

Thank you for this comment. We agree. We will replace: "ERA5 performs better at the near-surface temperature than its predecessor ERA-Interim..." with "ERA5 performs better at representing near-surface temperature than its predecessors...".

Comment 9: in L298-300, why not simply stating that 151 numerical experiments were carried out for T0 ranging from -10°C to +5°C with a 0.1°C interval?

Thank you for pointing this out. We agree. We will replace: "We use the ERA5 2-m air temperature data to force the model and run 101 numerical experiments with a heuristic set of T_0 ranging from -5.0 °C to +5.0 °C with 0.1 °C intervals. Practically, we find a number of cells that exceed the low boundary at -5.0 °C, we therefore expand the lower boundary to -10.0 °C and add another 50 numerical experiments to traverse from -10.0 to -5.1 °C." with "We use the ERA5 2-m air temperature data to force the model and run 151 numerical experiments for T_0 ranging from -10.0 °C to +5.0 °C with a 0.1 °C interval.".

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