Author Response to
Reviewer 1 Comments on tc-2022-94

Reviewer 1: Jennifer Arthur

General Comments

We would like to thank Jennifer for her time reviewing our manuscript and for her helpful suggestions; addressing these will definitely improve our work and make the manuscript stronger. We appreciate Jennifer's overview and understanding of our work, and her acknowledgement of its interest to the cryospheric research community. We are also grateful for her comments on the manuscript being well written, and her recommendation that, after addressing her comments, the manuscript is suitable for publication in The Cryosphere.

Below we address each of Jennifer's comments in turn: Jennifer's comments are shown in *red italics*, followed by our Author Response (AR) in blue, and our suggested amendments.

Specific Comments

Line 29: *I think it is worth highlighting here how intense surface melt can precondition ice shelves for collapse by depleting their firn air content. Think about adding an additional sentence or two here about the specific role played by anomalously intense surface melt preceding the break-up of Larsen B (e.g. van den Broeke, 2005).*
AR: We will amend the text on lines 23-26 to better highlight the anomalous melt intensity and the role of melt in reducing firn air content:

"One of the most notable examples of ice shelf collapse occurred in 2002, when the Larsen B Ice Shelf disintegrated in six weeks (Rack and Rott, 2004), following intense surface melt (Sergienko & MacAyeal, 2005; van den Broeke, 2005) and extensive meltwater ponding across the shelf surface (Leeson et al., 2020). Such ponding occurs when the firn layer becomes saturated, depleting the firn air content of the shelf (Kuipers Munneke et al., 2014; Holland et al., 2011; Luckman et al., 2014), and allowing liquid water to collect in depressions on the ice shelf surface (Arthur et al., 2020a)."

Line 34: *'melt events' → specify timescale, i.e. over several days. Similarly on Line 35: 'longer records' → specify multiannual*
AR: We will amend the text to specify these timescales:

"...examining individual melt events (i.e. over several days) (Zou et al., 2019; Ghiz et al., 2021) or a few melt seasons (Elvidge et al., 2020; Turton et al., 2020), though some longer, multiannual records do exist (Jakobs et al., 2020)."

Line 36: *Specify melt metrics which are typically used (melt onset/freeze-up dates, melt season length, total number of melt days).*

AR: A similar comment was made by the second reviewer. We will amend the text to specify typical melt metrics:

"Secondly, previous studies describe quantitatively the occurrence and extent of melt in Antarctica using a series of melt metrics calculated from satellite observations. Typical metrics include the melt onset and freeze-up dates each summer, the total number of melt days, and the cumulative melting surface (e.g. Zwally and Fiegles, 1994; Torinesi et al., 2003). These metrics are often reported at a regional (e.g. Antarctic Peninsula, Wilkes Land) or continental scale, and usually show…"

Line 61: *I suggest citing Miles et al. (2020) here, who recorded acceleration of Denman Glacier since 1972, driven by grounding line retreat, ice tongue thinning and unpinning (see References below).*
AR: We will make a slight change to the text to include this reference:

"The Denman Glacier is estimated to have lost ~ 190 Gt of ice since 1979 (~ 0.5 mm of sea-level rise; Rignot et al., 2019), and has accelerated over both its grounded and floating portions (1972—2017; Miles et al., 2021), with its grounding line having retreated nearly 5.5 km between 1996 and 2018 (Brancato et al., 2020; Konrad et al., 2018)."

Line 71: *Define SSM/I and SSMIS acronyms.*
AR: We will add these definitions:

"… observations from the Special Sensor Microwave Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS) sensors: F13…"

Line 84: *I would perhaps clarify here how you define dry snow recursively?*
AR: This comment was also made by the second reviewer. We will expand our explanation and amend lines 82—85 to make it clearer:

"… algorithm used in Picard and Fily (2006). This algorithm uses a threshold approach to detect melt, with the threshold calculated for each pixel individually and redefined each summer. The threshold is calculated as the sum of the mean and 2.5 times the standard deviation of T_B observations for dry snow each year (1st April—31st March). Dry snow is defined recursively, iteratively removing any observations identified as wet snow and recalculating the melt threshold using only the remaining observations, until no further observations need to be removed; one or two iterations are sufficient to reach convergence. A full explanation can be found in Torinesi et al. (2003)."

Line 95: *It isn't clear to me what you mean by erroneously missing melt events – do you mean you want to exclude any melting that could be occurring on the sea ice?*
AR: The salt content of sea ice increases the emissivity of the surface, resulting in a higher T_B value even when the surface remains dry. If pixels affected by these higher dry T_B values subsequently melt, the increase in T_B from the dry surface to the wet surface (i.e. our definition of melt) may not be large enough to consistently trigger our melt algorithm, and therefore genuine melt events could be missed. Furthermore, a polynya is often observed off the western coast of the shelf, meaning that often the dry T_B values are actually the result of a varying combination of dry snow, sea ice, and open ocean. Because our algorithm is designed only for a wet vs. dry surface distinction, it is not suitable for

use on pixels which could also be influenced by these additional surface "types". We will amend the text and simplify our explanation to better reflect this situation:

"Secondly, we exclude the westernmost edge of the shelf, which is often bordered by a polynya (Nihashi and Ohshima, 2015). Manual inspection of the underlying T_B data indicates that the pixels along the western edge may have been contaminated by the inclusion of sea ice and open ocean in the sensor footprint, and are therefore not suitable for use with our algorithm, which is only designed to differentiate between wet and dry snow. The final shelf mask…"

We will add this reference to the bibliography:

Nihashi, S. and K.I. Ohshima.: Circumpolar Mapping of Antarctic Coastal Polynyas and Landfast Sea Ice: Relationship and Variability, Journal of Climate, 28, 3650—3670, https://doi.org/10.1175/JCLI-D-14-00369.1, 2015.

<u>Line 119:</u> *I would refer to Section S1 in the Supplement here, with the useful description for understanding the SOM output.*
<u>AR:</u> We will add a reference at the end of this explanation on line 123, pointing the reader to Section S1 for further details:

"… repeatedly fed into the algorithm until it converges to a solution (see Sect. 1 in the Supplement for further explanation). The self-organisation…"

<u>Line 165:</u> *I would change the order in which the different patterns are discussed, and displayed in figures 2 and 5 – it is slightly confusing to start with patterns 8 and 9 (though I can see why you have done this as they are the most prevalent). Consider re-ordering sequentially.*
<u>AR:</u> Our preference is to leave the structure of the results section unchanged because we feel that grouping the patterns in this way better highlights the main takeaways of these results. We also previously tried to present the patterns in order (i.e. 1—9) but received feedback that it was harder for the reader to follow.

<u>Line 176:</u> *Specify what you define as the melt season (i.e. I assume November to February?).*
<u>AR:</u> When we refer to the melt season in the results and Figure 3, we are referring to the period between the dates of melt onset and freeze-up each summer, meaning that the actual dates differ each summer. The difference in these dates between summers is why we have used the melt context in Figure 3, as it allows us to refer to the relative timing of the patterns within a summer. We will amend the text to clarify this here:

"Both of these patterns can occur throughout the melt season (i.e. any time between the melt season onset and freeze-up dates), but are most prevalent…"

<u>Line 192 (Figure 3):</u> *I think it would be useful to show calendar dates on this figure (i.e. merge Fig. S6 with this one). Would it be possible to add a second x axis to show this? The colours of SOM Patterns 1 and 7 are also very similar, consider changing one.*
<u>AR:</u> We do not think that it would be possible to merge the data from Figures 3 and S6 in a clearly presentable way because the different x-axes do not correspond exactly and thus the data are grouped differently in these two figures (see previous comment re: line 176). We agree that calendar dates (i.e. Fig. S6) are more immediately intuitive, but they also

present a slightly different story, particularly at the beginning and end of the melt season. For example, using the melt context (Fig. 3), we are able to see that any of patterns 1, 2, 4, 7, 8 and 9 can be observed right at the start of the melt season, whereas Fig. S6 shows that only patterns 1 and 2 occur early on. The differences between these two plots are interesting in themselves, but we felt that it made more sense to discuss the timing of the patterns in a relative way and thus used the melt context (Figure 3) in the main text, but included a reference to Fig. S6 in the caption to allow comparisons.

Regarding the colours of these plots, we used a colourblind safe palette but agree that some of the colours can be difficult to distinguish. We will therefore add hatching to help differentiate between similar colours (e.g. 1 and 7; 2, 3 and 6).

Line 217: *I think Figure S8 is interesting and should be brought into the main manuscript. While Fig. 5 is useful for demonstrating the large interannual variability, particularly in the two 'extreme' end members i.e. Patterns 9 and 1, I think Fig. S8 provides useful context for interpreting the temporal variability in melt patterns across the shelf.*
AR: We agree that Fig. S8 is interesting and are happy to move it into the main manuscript as suggested in place of Fig. 5. Both plots use the same underlying data but tell slightly different stories (as this comment acknowledges), hence why we included both. We will adjust references to these figures in the text accordingly.

Line 229: *Could you add Cumulative Melt Surface into the Table caption to remind the reader, given that the other acronyms are defined here.*
AR: We will add this to the Table caption as requested.

Line 261: *Add a brief summary of RACMO2.3p3 in Section 2, as it is not currently mentioned in the description of datasets. Is it forced with ERA5? And reference van Dalum et al. (2022).*
AR: We agree that this would be a helpful addition and will add a small subsection (Sect. 2.6) to introduce the data.

"2.6 Climate variables

We use monthly climate variables from the RACMO2.3p3 regional climate model (van Dalum et al., 2021; 2022), which is the latest version of the RACMO model that has been used extensively in Antarctica (e.g. Lenaerts et al., 2012; van Wessem et al., 2014; 2018). RACMO2.3p3 includes updates to the albedo scheme and multilayer firn module, as well as allowing subsurface penetration of shortwave radiation, which can be important for melt in Antarctica (Liston and Winther, 2005; Liston et al., 1999). The model is forced at its lateral boundaries by ERA5 reanalysis data (Hersbach et al., 2020)."

AR: We will add the following references to the bibliography:

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., Chiara, G. D., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., Rosnay, P. de, Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N.: The ERA5 global reanalysis, Quarterly Journal of the Royal Meteorological Society, 146, 1999–2049, https://doi.org/10.1002/qj.3803, 2020.

Lenaerts, J. T. M., van den Broeke, M. R., Scarchilli, C., and Agosta, C.: Impact of model resolution on simulated wind, drifting snow and surface mass balance in Terre Adélie, East Antarctica, Journal of Glaciology, 58, 821–829, https://doi.org/10.3189/2012JoG12J020, 2012.

Liston, G. E. and Winther, J.-G.: Antarctic Surface and Subsurface Snow and Ice Melt Fluxes, J. Climate, 18, 1469–1481, https://doi.org/10.1175/JCLI3344.1, 2005.

Liston, G. E., Winther, J.-G., Bruland, O., Elvehøy, H., and Sand, K.: Below-surface ice melt on the coastal Antarctic ice sheet, Journal of Glaciology, 45, 273–285, https://doi.org/10.3189/S0022143000001775, 1999.

van Wessem, J. M., Reijmer, C. H., Morlighem, M., Mouginot, J., Rignot, E., Medley, B., Joughin, I., Wouters, B., Depoorter, M. A., Bamber, J. L., Lenaerts, J. T. M., van de Berg, W. J., van den Broeke, M. R., and van Meijgaard, E.: Improved representation of East Antarctic surface mass balance in a regional atmospheric climate model, Journal of Glaciology, 60, 761–770, https://doi.org/10.3189/2014JoG14J051, 2014.

van Wessem, J. M., van de Berg, W. J., Noël, B. P. Y., van Meijgaard, E., Amory, C., Birnbaum, G., Jakobs, C. L., Krüger, K., Lenaerts, J. T. M., Lhermitte, S., Ligtenberg, S. R. M., Medley, B., Reijmer, C. H., Tricht, K. van, Trusel, L. D., van Ulft, L. H., Wouters, B., Wuite, J., and van den Broeke, M. R.: Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 2: Antarctica (1979–2016), The Cryosphere, 12, 1479–1498, https://doi.org/10.5194/tc-12-1479-2018, 2018.

Line 244 (Figure 6): *Consider in Panels (a) and (d) changing scale units from 'Days since 1st Nov' to Date, I think this would make it easier to see spatial variability through the melt season.*
AR: We agree that calendar dates are easier to read and will update the units of the figure as suggested.

Line 324: *Could you quantify how much RACMO overestimates melt along the grounding line? It looks like ~25-75 mm w.e yr-1 from van Dalum et al. (2022)?*
AR: We will add an approximate value for this overestimation based on Figure 12d of van Dalum et al. (2022):

"Comparisons with QuikSCAT-derived melt fluxes suggest that RACMO overestimates melt along the grounding line by ~ 25—75 mm w.e. yr^{-1} (see Fig. 12d of van Dalum et al., 2022), but melt observations…"

Technical/minor corrections

*Hyphenate 'sea-level rise' (e.g. **Line 15** – check throughout).*
Line 54: *I suggest replacing 'runs for' with 'extends for.'*
Line 55: *Replace 'lay' with 'lie.'*
Line 78: *19 GHz (space).*
Line 81: *Hyphenate 'horizontally-polarised.'*
Section 5.3: *Capitalise 'figure' throughout.*
Line 356: *don't → 'do not.' Same on Line 328.*
AR: We will correct these in the manuscript - thank you for noticing them!