Surface melt on the Shackleton Ice Shelf, East Antarctica (2003–2021)

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Review by Ian Willis for TC

This is a very interesting, novel, clearly structured and well written paper that was a pleasure to read. Thank you to the authors for spending the time to hone the material so that it was logically presented, the writing was succinct, clear, precise and accurate, and it contained very few grammatical errors as far as I could tell. I wish all papers I was asked to review were of this calibre.

The science is also robust, with one or two small exceptions the discussion does not overinterpret things, and the conclusions logically follow on from the results presented.

The paper uses the machine learning approach of self-organised maps (SOMs), which has been used in other branches of the environmental sciences (notably climatology) but has not previously been used, as far as the authors (or I) know, in the field of glaciology in this way. The method is not dissimilar to the EOF approach but, as the authors state on lines 124-6, has advantages. The method is applied to Advanced Microwave Scanning Radiometer data and used to investigate melt patterns across the Shackleton Ice Shelf over an 18-year period. The nine 'modal' patterns (Fig 2) are a useful way of reducing the complex spatial and temporal dataset into a series of manageable and interpretable outputs. The sequencing of these patterns throughout the melt seasons (Figs 3 & 4) are instructive in identifying how melt patterns typically evolve through the summer. This, together with the interannual variability in this sequencing, is helpful in terms of thinking about the processes driving melt across the ice shelf. The sensitivity analysis to model parameters (Sect 3.3 & Figs S4-S5) is valuable.

The paper also works with the original binary melt files to map patterns of 'seasonal metrics' that have been mapped on other ice shelves by others, notably melt onset, season length, season duration, melt season freeze up date and the fraction of the melt season experiencing melt (Fig 6).

Finally, the paper goes some way towards explaining the spatial and temporal melt patterns in terms of climate model output (esp. air temperature, albedo) and previous work (esp. that discussing katabatic winds).

I believe the paper makes a valuable contribution to the growing literature investigating melt variability on ice shelves and their drivers. This work is important since increased melting on ice shelves increases their vulnerability to break up and collapse.

The paper provides access to the SOM code (written in R-studio) and gives examples of how the approach could be altered and /or used in other similar contexts.

Like the writing, the Figures are produced to a high standard and are quickly interpretable and relevant.

I therefore find no major problems with the paper and suggest only that the authors consider the following moderate and small suggestions / questions and small editorial / typographical issues that I outline in turn below.

Moderate suggestions / questions

L175. You provide us with the average values for how much of the ice shelf is experiencing melt on days which conform to the 9 patterns. Would it also be useful to provide a measure of variability (e.g. S.D.) in this %?

L229-230. You describe a situation for 2008/09 here but what about 2007/8 where pattern 9 is also v low but pattern 3 not particularly high? Pattern 5 is high in 2007/8, which also has a dry centre. Is this significant and worth mentioning?

L234. This section 4.5 has done a nice job at looking at interannual variability in the patterns of melt. What are the correlations between the annual patterns? Could you calculate the correlation coefficients between the data in Fig 5 to quantify the extent to which the patterns co-vary directly, inversely, or not at all?

L243-4. I think the suggestion that melt patterns 1-8 are not climatically driven needs some qualification. The patterns themselves presumably are climatically driven, in the sense that when there's high melt in one place and not another, the climate will be different between the places? It is the number of days of the year with a particular pattern that is uncorrelated with average summer air temps at an interannual timescale. Are they correlated with some other aspect of air temp / climate?

L258. You say the “role of katabatic winds in driving melt is supported by patterns 3–7”. Is this true? Is it not just pattern 7 which supports it, with melt all along the grounding line and very little elsewhere? In the other patterns, how do you explain the occurrence of high melt in the N close to the edge but not at the GL? Is this not due to other mechanisms? How do intra and interannual variability of patterns showing absence of melt in centre match with variability of precip. as Fig 7d suggests months / years with high pptn. (assuming it is snow) would be associated with patterns 4 and 5 in particular. Perhaps you address these point in the discussion but of not it would be worth doing so.

L264-271. Given the focus on winds explaining patterns here (and in fact in this whole section 5.2), it seems odd that the wind vectors from RACMO are not shown in Fig 7. Could this be done? I think it’d be instructive. Could you also see if there are differences in the wind field during the different melt patterns?

L363. Could “…such as…” be changed to “…specifically…” and could you list all the local controls that you show / infer are relevant? Presumably wind field is relevant here? I suggested above that you might show the RACMO wind field vectors in Fig 7. You refer to

albedo here and show that in Fig 7. Could you also show a map of surface topography in the discussion section?

Small suggestions / questions

L1-2. add the intervening processes of ice shelf disintegration & grounded ice acceleration if room.

L2-3. As above, this sentence could be made clearer with a little more explanation if the word count allows.

L3. Clarify it is previous studies of surface melt on ice shelves here I assume?

L4. Can you explain better / give an example of a 'regional melt metric' as it's not obvious here [I know this is explained in the main body of text but not until Section 2.5 on lines 100-105, and it'd be useful if it were made more apparent in the Abstract].

L9-11. It's not obvious how you're able to identify a significant role for 'air tempertaures' and 'local factors' Can you state that you're using RACMO output and a DEM to do this?

L30. As above, clarify it is previous studies of surface melt on ice shelves here I assume?

L36. As above, can you explain better / give an example of a 'regional melt metric' as it's still not obvious here.

L41. Add Dell et al 2021 here? They show maximum melt extents and persistence for Roi Baudouin Ice Shelf, East Antarctica. Dell, R.L., Banwell, A.F., Willis, I.C., Arnold, N.S., Halberstadt, A.R.W., Chudley, T.R. and Pritchard, H.D., 2021. Supervised classification of slush and ponded water on Antarctic ice shelves using Landsat 8 imagery. Journal of Glaciology, 68, 401-414.

L45. "… and thus identify the influence of local controls on the occurrence of surface melt" As written so far, it's not clear precisely what you mean by this and how exactly you'll identify such controls. From what you said previously it looks like you're talking about albedo and air temperatures? Do you compare the melt patterns and variations with patterns and variations in albedo and air temperature? Useful to explain this a bit more clearly here.

L46. This sentence is rather lazily written and vague. Can you more precisely explain this?

L49. "…in relation to the local controls on surface melt" See comments above. We still don't have a sense of precisely what this means.

Fig 1. A nice map but check the legend against what's displayed and add more to the heading. Perhaps it's just my computer screen but I see brown as well as orange lines depicting the shelf boundary but just orange in the legend. I assume the thin line depicting the grounding line is consumed beneath the orange/brown line for most of the shelf but is

there for the eastern part. State in the heading where the grounding line data come from. Also, I don't see Mask Pixels on the map. And what are the large black linear features towards the edges of the two lobes of the Denman Glacier?

L82. "…annually and spatially adaptive threshold" Can this be explained a little more?

L84. "…dry snow is defined recursively" Expanding on this a little would be useful too.

L95. It doesn't look like 25 km has been removed from the front of the Denman Glacier in Fig 1.

L179-180. As this point is not specific to patterns 9 and 8 should this generic point be made outside these sentences about 9 and 8?

Fig 4 is v interesting. One thing that strikes me is that pattern 8 is 20-30% likely to progress to pattern 9 but not the reverse. What does this tell us about melt processes on the ice shelf? Also, melt pattern 9 is approx. equally likely (0-10%) to become any other pattern (except pattern 1). What does this tell us about melt processes? Perhaps you discuss these points later in the text so apologies if that is the case. But if not, it may be useful to address them?

L204-5. How to explain pattern 2 (melt at N edge) being most common early and late season but pattern 4 (which doesn't have much melt towards N edge) being most common overall? What is control on "switching on and off" melt at N edge?

Table 1. This is quite instructive. ~1/3 of the time there's virtually no melt; ~1/3 of the time there's virtually 100% melt; ~1/3 of the time there's one of 7 other patterns, ranging in freq. between c. 3% and 8% of the time.

Fig 6. Vs Fig 7. Is there a reason why summer is defined as NDJF for Fig 6 but just DJ for Fig 7?

L272-3. Yes, see my earlier comment (against L258) on this.

L284-5. Yes, I agree the higher elevation and the fact that the centre of the ice shelf experiences more pptn (Fig 7d) is likely important here.

L332-3. Banwell et al 2021 could be added to this ref list. I believe they used SMMR, SSMI as well as ASCAT.

L339. How do you do this correlation given the different spatial resolutions?

L342. You say RACMO overestimates melt cf. QuikSCAT Is this also true here in your study with the AMSR data? I don't think you tell us whether RACMO melt is over or underestimated.

L348-350. "…because meltwater fluxes would help to differentiate between melt behaviour considered equivalent here and could help identify how important different processes are for melt." I don't follow this. Can it be rewritten to make clearer?

L364. I suggest change "show" to "suggest" here. I think you need to be more circumspect. I'm not convinced you've really proved beyond doubt the role of feedbacks as you state here.

Small editorial / typographical issues

L27 Suggest change 'force' to 'stress' here.

L36. '…describe quantitatively…'

L39. Suggest "Studies using melt metrics that have focussed…"

L156. Should strictly be "data have….and are thus…" [i.e. plural]

L170-182. These three short paragraphs (inc. 2 x 1 sentence paragraphs) could be merged. Check entire document for this.

Fig 1 Heading. Suggest say "…the shelf boundary adapted from the MEaSURES dataset…"

L61-2. Suggest say "Understanding the response of the Denman Glacier and wider Shackleton system to climate variability and change is therefore an important area of research".

L73. Suggest change to "pre-processed in the same way as the AMSR datasets"

Fig 3 Heading "…data are plotted…"

L223. 'observe' to be consistent (present tense) with L218.

L228. Suggest "…summer (Fig. 5; Fig. S8) provides a snapshot"

L286. Suggest change to "summer melt usually begins later in the centre of the shelf than over the surrounding shelf" which is more grammatically correct.

L287. Suggest "…much smaller fraction…"

L319-20. Suggest delete words "occurring" and "between them".

L328. "…do not always agree…"

L345. Strictly "data exist" [plural]

L347. Suggest "…approach could be adapted…"

L353. “…on the Larsen C…”

L356 “… do not…”

L369. “…work could use…”

L370 “…approach could also…”