Review

Rapid fragmentation of Thwaites Eastern Ice Shelf, West-Antarctica

Summary

Benn and colleagues present a set of observations (velocity changes, fracture observations, strain) to document the weakening and fragmentation of the Thwaites Eastern Ice Shelf (TEIS) and combine that with two models (HiDEM and BISICLES) to assess the role of the submarine pinning point on that fragmentation. By comparison of HiDEM with the observations, they conclude that the observations best match the 'no slip' scenario, leading to the conclusions that the high backstress conditions from the pinning point causes the observed fragmentation. Secondly, they use different BISICLES scenarios to assess the role of further damage, thinning or unpinning on ice sheet discharge and come the the conclusion that further fragmentation or unpinning does not have a large influence on mass loss from the Thwaites basin.

General remarks

The paper is well written, touches an important and timely topic and provides several new insights on the role of pinning points on ice shelf stability. Therefore, I think the paper can be recommended for publication in TC, given that the authors address the detailed comments raised below. Most of these comments relate to rewording statements, weakening some claims and/or adjusting figures to make them publication-proof.

Detailed comments

P1 - L43: "*backstress triggered failure"* I am personally not 100% convinced this failure mechanism can be considered a third mechanism that can be compared on an equal level to hydrofracturing and unpinning. The failure observed here is a combination of factors (as also highlighted in the discussion) and these are I think the drivers/mechanism, not the backstress as such. The backstress basically stays equal and the rest changes, so I believe the different changes are the drivers/mechanism and not the backstress as such.

P2 - L66: "*southward*"; it is perhaps a semantic comment wind directions are always relative in Antarctica. In my humble opinion, moving from the Peninsula to West Antarctica corresponds mostly to going westward and not to going southward.

P2 - L86-87 "*threshold-crossing behaviour*": the observed changes are indeed important etc. but I do not see any analyses/proof of threshold-crossing behaviour. What is the threshold for considering an ice shelf fragmented? One rift? Multiple rifts? Where is the threshold between stable/unstable? I think the observed changes correspond to gradual changes and I do not see any analysis on the paper of where the threshold is. Having such a quantitative threshold would be meaningful for future studies but is not part of the paper.

P2 - L87-89 "*we show that this threshold-crossing behaviour was not the consequence of progressive unpinning, but occurred due to the failure of weakened ice in response to stresses associated with the pinning point*" I am not convinced that the experiments completely support this claim. The HiDEM scenarios are two (unrealistic) extremes and I agree that it corresponds better to the no-slip condition, but this not necessarily mean that it is not the consequence of progressive unpinning as the reality might be somewhere in between.

P3 - L 13: how are the different velocity data combined? Do the authors account for double counting some observations in the 6-12 day pairs?

P3 – L16: Which REMA product? Mosaic or strips?

P3 – L41-42 "*that were calibrated against observed fracture and calving patterns on the 142 Greenlandic glacier Sermeq Kujalleq (Jakobshavns Isbrae)"* Based on which study? Reference?

P4 - L64 "*REMA tile*" which tile? Why tiles and not the mosaic? Could be clarified with better description of which data is being used (see also earlier comment).

Section 2.2: I miss a clear overview of the experiments being performed. E.g. there is no description of the HiDEM experiments (this is postponed to section 4.1), whereas there is a (difficult to follow) description of the BISICLES experiments. I would be very helpful for the reader to have a complete, uniform overview for the different HiDEM/BISICLES experiments (and their motivation) in section 2.2. Adding a table with the experiment settings would also increase readability/interpretability.

P4 – L89-90 "That model lacks the skill" I guess the standalone model without inversion? If so, please clarify that, because it not clear where "that model" refers to. Additionally, what is meant by "*lacks the skill*"? Clarify.

P4 – L97 "*simulation to 2100*" Not all time series in Fig 13 go to 2100. Some go further and others stop earlier.

P5 – L27: "*above*" description of directions can be misleading. Is that above in figure direction or above in stream direction? Please use consequently directions relative to flow directions.

Section 3.2 and Figure 3: I did find it not easy to see the described features in the panels. I would be helpful to indicate that on the respective panels and not only in the last panel.

P6 – L67+79 "*upglacier*" Not sure if this is correct English.

P7 L20-27: should be part of the method section and the settings for HiDEM for these runs should be better explained (time period, friction, pinning points, etc).

P7 – L30: "*baseline friction*" This implies in my opinion that there is friction and does not correspond to the earlier statement of "*progressive unpinning*".

Figure 8-10: it would be helpful for comparison if Fig-10 would be merged showing:

- on left panel: baseline friction condition of Fig. 8 (with fractures like in Fig.10 superimposed)
- on right panel: no slip condition of Fig. 9 (with fractures like in Fig.10 superimposed)

P8 - L59: I wonder what the added value of Fig 11 is. It is not really used in the paper, except to show that BISICLES makes sense. Could be moved to the SM.

P8 - L88 Equations should be added as equations and not as part of the text.

Fig. 13 + Section 5.3 is counterintuitive and differs in my opinion strongly from state-of-the-art. Why would the discharge in ice above flotation decrease with time to half of the initial values? This counters moreover the work of Hongju et. al. (https://tc.copernicus.org/articles/12/3861/2018/) which show a constant or increasing discharge of ice above flotation. This should be discussed in much more detail

This counterintuitive decrease, moreover, raises doubt about the validity of the claim that further damaging and/or unpinning will not have any significant impact on the future ice discharge. This would also imply the current buttressing effect of the ice shelf is negligible, which would surprise me.

Conclusion: I miss a conclusion section where the results are repeated and summarized.

Figure 2+4: Color bars, legends etc cannot be read as they are too small. It would be beneficial for the readability of each figure to have one common colorbar for similar panels.

Figure 3: figure seems gathering of individual figures (from other sources like twitter ;-)) and should be adapted from distracting features to be publication ready. Suggestions:

- remove *Sentinel-1 ESA* statements
- remove *Luckman, Swansea University* statements
- remove Antarctica, study area subpanels as they are part of Figure 1 already.

Fig.8-9. Color bar should be updated to scientific colorbar which is more homogeneous. Now there are sharp color contrasts for some differences (e.g. between 70m (purple), 80m (pink) and 90m (orange)) whereas they are gradual for others (100-160m is all orange). There is no reason why the 20m difference between 70-90m is more important than 100-120m so the color panels should also be continuous. I suggest reading https://www.nature.com/articles/s41467-020-19160-7 for proper colorbar selection.

Fig.10. fractures in black have the same color as maximum elevation, which makes interpretation difficult. Please use different color for fractures or elevation.

Fig.13 why do each of the simulations have a different end date? Does that matter?