Comments and **Responses**, RC2: Referee #2: Stef Lhermitte

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 conclusion that further fragmentation or unpinning does not have a large influence on mass loss from the Thwaites basin.

RESPONSE: We are very grateful for the summary.

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.

RESPONSE: We are very grateful for the kind comments.

SPECIFIC 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.

RESPONSE: We maintain (and the reviewer does not seem to disagree) that the highlighted mechanism for ice shelf failure is distinct from hydrofracturing and unpinning, and that is a key aspect of this paper. Nevertheless, he makes a fair point that the backstress is not the only factor. We will modify the language in the abstract to downplay the impression that a single factor is at play.

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.

RESPONSE: *We will modify the language to address this point.*

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.

RESPONSE: Figure 6 shows a change from stable to accelerating behaviour around the beginning of 2020; this trend has continued and Figure 6 will be updated with more recent data. We maintain that this discontinuity in behaviour is consistent with a threshold being crossed. This hypothetical threshold is a bulk property of the shelf and need not be quantitative to have meaning. *Nevertheless, we will tone down the language in relations to thresholds to reflect the imprecise nature of this change.*

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.

RESPONSE: Figure 5 shows the "failure of weakened ice" in detail. Further, it shows that ice on the pinned side of the shear margin slows down as the rift crosses the failure threshold. If pinning point weakening was important, this ice would be expected to speed-up. We maintain that this fully explains the behaviour with no need for weakening of the pinning point to be involved. *We will make these points clearer in the text and discuss the relative importance of pinning point weakening.*

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?

RESPONSE: The Sentinel-1 velocity observations are combined in different ways as explained on the preceding lines for different purposes (presented in Figures 2, 4, 5 and 6). Captions for the figures give more details about which combinations are used. Where velocity maps are averaged, we make no allowance for the fact that 12-days pairs coincide with two 6-day pairs as this would make no significant difference to the results. *What is missing from the explanation is how noise filtering allows individual velocity maps to be combined and we will correct this omission.*

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

RESPONSE: Mosaic. *Will be clarified in the text.*

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?*

RESPONSE: These calibrations are not yet published. They were conducted to calibrate the model for use in multiple investigations of failure dynamics at Thwaites Glacier. Jakobshaven Isbrae was used for the calibration because of the glacier's large ice thickness and the availability of remotely-sensed observations of calving.

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).

RESPONSE: The mosaic is delivered as a set of tiles. We refer to the tile covering TEIS because it allows us to be specific about the date. *We will review all of the text around REMA to make sure it is all clear.*

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.

RESPONSE: *We will improve the overview of experiments by moving the description of HiDEM experiments to this section and clarifying the description of BISICLES experiments. We will add a table that summarizes the experiment settings for HiDEM and BISICLES, as suggested.*

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.

RESPONSE: *We will clarify what is meant by the model lacking skill to simulate the acute fracture dynamics at TEIS. The model of Sun et al. (2016) attempts to evolve damage according to a simple relationship with local stress and damage advected from upstream, which proves too simplistic for to model TEIS and TWIT accurately.*

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

RESPONSE: *We will ensure that all simulations run to 2116 (i.e. for 100 years).*

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.

RESPONSE: *We will readily make this change.*

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.

RESPONSE: ***We will readily make this change.***

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

RESPONSE: This term is used frequently (at least on this side of the pond!) and seems readily understandable to us. If the editorial team thinks it needs changing, we will find an alternative.

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).

RESPONSE: ***This paragraph will be moved to Section 2.2 as mentioned in a previous response. We will provide further detail regarding HiDEM settings and will summarize the experiments run in a table.***

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

RESPONSE: We are using the term to mean something different – i.e. the first value from which we make changes. ***We will clarify the text to prevent this misunderstanding.***

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)

RESPONSE: We agree with the reviewer that an alteration is needed to ease the comparison of the model outputs. ***We will combine the original figures 8, 9 and 10 into a single, multi-panel figure. We decided to include the fracture plot directly under the corresponding displacement plot to ease comparison between fracture and particle displacement magnitudes. It was decided to not overlay the fractures on the displacement plots because of the congestion in the amount of information being presented.***

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.

RESPONSE: The purpose of Fig. 11 is to show that the observed speed up in TEIS can be explained by the introduction of a specific pattern of damage. This is what we mean by "The observed increase in speed in TEIS 363 between 2016 and 2020 can be reproduced in the model by minor changes in the basal traction and by a strip of damage coincident with the shear zone adjacent to the pinning point whose magnitude increases over time". ***We will rephrase that first sentence of that paragraph to make this more explicit.***

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

RESPONSE: ***We will make edits so that the equation is included as an equation on its own line of 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.

RESPONSE: Both reviewers commented on this. It occurs because our experiments simulate the reduction of the pinning point influence while the rest of the ice shelf remains close to present day conditions. The result is an initial acceleration followed by a gradual deceleration as the systems tends to a new equilibrium dependent on (for example) the buttressing provided by the ice shelf in the region of the present day grounding line. This is distinct from typical TG simulations (e.g. Hongju et al. (2018), as one reviewer mentions) that apply a melt rate sufficient to ablate the ice shelf substantially and prevent substantial future ice shelf formation. ***To allow the reader to relate our results to typical simulations, we have carried out and will present additional simulations, with a melt rate taken from Hongju et al. (2018).***

In these simulations we see that same sort of results as Hongju et al. (2018), i.e. sustained mass loss at rates at and above the present day, with some variation between them due to the unpinning.

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

RESPONSE*: We will add a conclusion section in which we will summarize our main results.*

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.

RESPONSE: *Will do.*

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.

RESPONSE: Apologies for the hasty figure! *All these aspects will be corrected.*

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.

RESPONSE: *Figures 8 and 9 will be included in the multi-panel figure with Figure 10. The colour bar will use a continuous colour scale.*

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

RESPONSE: *Will do.*

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

RESPONSE: It doesn't matter a great deal (the trends are clearly the same in each case), but we have nonetheless made sure now that all simulations end on the same date.