

The Cryosphere Discuss., referee comment RC1  
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## **Comment on tc-2021-105**

Anonymous Referee #1

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Referee comment on "The instantaneous impact of calving and thinning on the Larsen C Ice Shelf" by Tom Mitcham et al., The Cryosphere Discuss.,  
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## **Manuscript Review: Cryosphere Discussions**

The impact of recent and future calving events on the Larsen C Ice Shelf

*Tom Mitcham, G. Hilmar Gudmundsson, and Jonathan L. Bamber*

### **Summary:**

This is a well presented and detailed study of the instantaneous impact of ice-shelf calving and ice-shelf thinning on the grounding line flux of the Larsen C Ice Shelf. The study uses the ice-flow model  $U_a$  to consider the impact of the calving of the A68 iceberg in 2017, as well as a set of idealized scenarios involving ice-shelf thinning, calving and undergrounding from pinning points. The impact of these changes is assessed by considering the instantaneous change in grounding line flux. The authors find that buttressing provided by the most upstream sections of the ice shelf, which are laterally constrained within smaller embayments, is the most significant contribution in the current configuration ( $\sim 80\%$  of buttressing). Furthermore, downstream calving or thinning of the ice shelf has relatively little impact on instantaneous changes to grounding-line flux.

This work adds to our understanding of ice shelf dynamics and buttressing. It focuses on a particularly relevant location with regard to potential future climate-induced change in Antarctica.

I feel there is a need to include some caution about these results as they are limited to instantaneous changes in grounding line flux. It would be helpful to either include additional experiments that considered the temporal evolution of the system. Or, emphasize clearly that this assessment is limited to instantaneous changes and could be considered as a sensitivity exercise rather than predictive of any future scenario.

### **Overall Comments:**

The manuscript is well written and the figures are informative and clear. The work stands on its own as making a notable contribution to the field. The study area is of particular interest as it is situated on the Antarctic Peninsula, an area of recent warming, where neighbouring ice shelves have collapsed, or changed dramatically, in recent decades. There is much interest in understanding what future changes may occur to the Larsen C Ice Shelf and what consequences this will have for contributions to sea-level rise. In this vein the initial scenario considered here is the calving on the A68 iceberg in 2017. There is good agreement between the modelling results and satellite observations, that demonstrate a negligible change in grounded ice flow following this calving event. This also agrees with previous modelling assessments. The second portion of the work considers idealized changes to the ice shelf, such as calving to within a set distance of the grounding line and uniform or proportional changes to the whole ice shelf. This framework provides a thorough and insightful assessment of the ability of the ice shelf to provide buttressing. All experiments consider the instantaneous change in grounding line flux.

I feel some additional caution is needed in presenting the findings as the results are limited to instantaneous changes. Other studies have done similar assessments in the past (Furst, Reese) and this instantaneous response could be considered as a sensitivity assessment. It would be very helpful to include some assessment or comment on the future evolution of the grounding-line flux following one of these imposed changes.

(One might expect that although there may not be an instantaneous change at the grounding line, acceleration downstream will lead to ice-shelf thinning, an increase in the ice-thickness gradient and further acceleration, which would propagate back to the grounding line. The thinning experiments hint at this process.)

I think it is important to emphasize to the reader that these conclusions/results are based on the instantaneous response and that it is unclear how the system will evolve temporally. (This point is mentioned at the end of the discussion, but it should be more prominent throughout.) An uninitiated reader may not realize this nuance. I think it is important that this point is addressed prior to publication.

I have included a commented PDF as part of my review. Here I include some more detailed points that require addressing:

### **Individual Comments:**

Title: Not sure that you can claim to be considering future calving events. But you are considering a whole range of possible scenarios (thinning and ungrounding).

Possible alternative: The impact of iceberg calving and ice-shelf thinning on the Larsen C Ice Shelf

Larsen C ice shelf -> Larsen C Ice Shelf. (Repeat this for Gipps Ice Rise and Bawden Ice Rise in text too)

Abstract:

I like how you've been able to quantify the buttressing capacity of the ice shelf. Again I think it would be good to emphasize the caveat that this is instantaneous, or emphasize that this is a sensitivity test to the current configuration of the ice shelf.

Lines 42 – 45: Both of these studies identify the need to simulate the temporal evolution of the system in order to accurately model the response to ice-shelf change.

Line 107: "The surface elevation was adjusted at a few points to ensure that at least 1 m of ice was present across the whole computational domain." Is this only relevant for areas of exposed bedrock (i.e. nunataks)?

Lines 109 – 111: What impact does accounting for firn density have on the results? Does the minimum ice density refer to the surface firn density?

Lines 113 - 114: You use MEASUREs velocities for model initialization, but Sentinel-1 SAR for ice velocity pre- and post- calving: how do these velocities compare? Could you use Sentinel for initialization?

Equation (6): Are you considering the difference in speed or velocity components here?

Equation (7) first term on RHS: Do you mean that you constrain the gradient in the difference between  $A$  and  $\hat{A}$ ? Or just the gradient in  $A$ ? (which I think is the usual approach).

Line 126: How are prior estimates  $\hat{A}$  and  $\hat{C}$  chosen?

Line 127: Is it appropriate to use the same regularization parameters for  $A$  and  $C$ ?

Section 2.4 Calving experiments – good explanation of procedure.

Line 152-153: “the ice shelf became afloat without changing the ice thickness” Does this result in areas of thicker ice (that were formerly part of the ice rise) within the ice shelf that might induce flow “backwards” i.e. upstream relative to the large-scale flow?

Section 3 Results – I think it would be good to include an initial sentence here that states that this section is split into subsections reporting the results of each of the scenarios outlined in the methods.

Line 176: “no observable, transient response to the calving of the A68” – it would be good to add that from the dataset spanning 5 years there has been not appreciable change in velocity and no long-term response to calving.

Lines 185 – 188: “Therefore, Fig. 4a and b show what proportion of the total buttressing is provided by each section of the ice shelf removed in the series of calving perturbations. From this, we see that over 95% of the total buttressing is provided by ice in the first 25 km downstream of the GL, and that over 80% is generated in the first 5 km of ice immediately downstream of the GL.” Statements like these are where I feel there needs to be some further note that this is just based on the instantaneous response. This could be framed in terms of a sensitivity, or the contribution to buttressing made by the current configuration of the ice shelf.

Section 3.3 Ungrounding experiments: Again these results should be treated with caution. Studies such as Favier & Pattyn 2015 have demonstrated the influence of an ice rise on the temporal evolution of grounding-line flux and position.

Line 202: “over 200 m of thinning is required to produce a doubling of GLF” – how does this compare in terms of areal extent to the idealized calving experiments? A doubling in GLF seems huge, how does this translate into contributions to sea level rise? I expect it would be more than a doubling in SLR contribution.

Lines 203 – 204: “The maximum ice thickness in the shelf was 1,400 m, so a thinning perturbation larger than this had to be applied to reduce the ice shelf to the minimum thickness of 1 m everywhere.” I think there must be a typo here – thinning of 1,400m would lead to no ice shelf remaining?

Lines 228 – 231: “Therefore, the dynamic response to the detaching of the nascent A68 iceberg will have already taken place in this region, and this response is included in the ice velocity data used to initialise our model. Finally, in the model we essentially force the

already detaching iceberg to have contact with ice upstream, inducing an artificial 'pulling' effect on this upstream ice, which is removed when the iceberg is calved from the domain." This is evident in Fig 2C where the model assimilation produces speeds less than observations.

Lines 238 – 242: Again important to emphasize that this assessment is based on instantaneous response.

Lines 246 – 247: "We argue that it is this second definition, the integrated impact of changes in ice-shelf geometry on stresses at the GL and consequently on GLF, that is the key measure of the buttressing capability of ice shelves." The buttressing capacity of the ice shelf in its current configuration. It is noted by Furst et al., 2016 that after a calving event occurs the stress field within the shelf will evolve, such that the initial assessment is no longer valid.

Lines 253 – 254: "by removing the entire ice shelf and calculating the instantaneous response in GLF we are able to quantify the total amount of buttressing that the LCIS provides" Good point!

Lines 254 – 256: Again important to emphasize that this based on instantaneous response.

Lines 269 – 274: This seems like an artifact of the modelling rather than something that would occur in the real world - surely the 1m (and even more so with 0.001m) thick ice shelf would break or buckle when trying to resist the flow of 1000+m ice streams. I think it is important to acknowledge this.

Lines 275 – 279: How does this magnitude of basal melting compare to surface accumulation? By how much is the ice shelf actually thinning?

Lines 286 – 288: “This suggests that, whilst these two ice rises may exert a significant control on the flow of the shelf upstream of the pinning points, they do not exert a strong mechanical control on the ice flux at the GL, and only contribute a small amount to the total buttressing capability of the shelf.” This statement is again based on the instantaneous response. In a temporal sense removing the ice rise would have a massive effect on the flow of the shelf, changing its geometry and thickness, and later impacting the flow at the grounding line.

Lines 293 – 299: This is a very important point, which should be highlighted much earlier.

It is good that you have acknowledged this point, but I think you need to explore this point more or at least note that these results are not complete.

Someone reading this may easily assume that the large parts of the shelf can be removed without increasing discharge, which is not the case! Instantaneously maybe, but once the geometry/thickness of the shelf has adjusted to the imposed change the GLF will change too. You have only explored the buttressing generated by the current configuration of the LCIS.

Lines 311 – 313: “Here, again, we found that large changes to the geometry of the ice shelf are required to produce significant changes in GLF, with 30 m of thinning across the shelf inducing a 10% increase in GLF and over 200 m of thinning required to produce a doubling of GLF.” It may be good to put these changes in GLF into context in terms of the total mass balance of the catchment, i.e. total accumulation - GLF. What does a 10% increase in GLF mean for sea-level contributions?

Lines 315 – 317: “This suggests that whilst these pinning points control the local ice-shelf dynamics, they only provide a small amount of the total buttressing of the LCIS.” I don’t think this is a good sentence to end on. The statement is based on the instantaneous response. And it’s probably not the most significant finding from the study.

Appendix B: Linearity of GLF response to thinning: It would be good to compare this with theoretical results such as Pegler 2018 and Haseloff & Sergienko 2018 as the buttressing force in these cases features an integral along the length of the ice shelf with an integrand containing the vertical integrated (i.e. thickness) longitudinal stress.

#### References:

Favier, L., & Pattyn, F. (2015). Antarctic ice rise formation, evolution, and stability. *Geophysical Research Letters*, 42(11), 4456–4463. <https://doi.org/10.1002/2015GL064195>

Haseloff, M., & Sergienko, O. V. (2018). The effect of buttressing on grounding line dynamics. *Journal of Glaciology*, 64(245), 417–431. <https://doi.org/10.1017/jog.2018.30>

Pegler, S. S. (2018). Marine ice sheet dynamics: The impacts of ice-shelf buttressing. *Journal of Fluid Mechanics* (Vol. 857). <https://doi.org/10.1017/jfm.2018.741>

Please also note the supplement to this comment:  
<https://tc.copernicus.org/preprints/tc-2021-105/tc-2021-105-RC1-supplement.pdf>