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Interactive comment on "Diagnosing the sensitivity of grounding line flux to changes in sub-ice shelf melting" *by* Tong Zhang et al.

Anonymous Referee #2

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In this study, Zhang et al. present a detailed and thorough analysis of the relation between local ice-shelf buttressing numbers, how they are affected by local perturbations and how they relate to the flux response at the grounding line induced by such a local perturbation. They find that correlations between the flux response (see Reese et al., 2018) and the local buttressing numbers (see Fürst et al., 2016) can be found in very specific cases, but break down for more complicated geometries and when considering regions close to the grounding line. In a second step, they show how the adjoint method could be used to assess the sensitivity of grounding line flux to local perturbations which is shown to be consistent with the computationally more intense perturbation approach (except at the grounding line).
This study presents very interesting results that will help to advance the understand-

ing of ice-shelf buttressing significantly. However, I think that some points should be addressed before it could be published.

Major comments

- Your manuscript would be much easier to read if the central questions and related main findings of your paper were formulated more clearly. This shows for example in your abstract, where you state that you search for causal connections between sub-shelf melting, buttressing and grounding line flux. However, there is no clear answer to that, you rather switch to presenting an alterative method to calculate the grounding line flux sensitivity in the second part of the abstract. This is also reflected, for example, in the formulation of the research questions on page 2, line 47-52.
- Section: 4.5: You state that the differences between the adjoint approach and the pertubation approach near the grounding line arise from 'nonlinearities' - more clarification is required at this point. In particular, Figures 13 and 14 show that the adjoint-sensitivites are negative along the grounding line, while Figure 15 indicates in general positive sensitivities in the perturbation approach. I think that the treatment of the grounding line in the sensitivity assessment could be key in explaining these differences. So please explain (1) how you specify the grounding line position in your experiments / model and how grounding line flux is calculated (can the grounding line move in your perturbation experiments?), (2) if these differences arise only for cells directly adjacent to the grounding line, and (3) how this is reflected in the adjoint method.
In addition, issues might arise due to the discretization. Perturbations in the ice shelf should theoretically not be able to change the ice thickness at the grounding line or the surface slope upstream, but they do so in numerical models, so it could be argued that including these regions is anyway problematic.

Further comments

- Title. In the manuscript you are not so much analysing the sensitivity of grounding line flux to perturbations itself, but you are rather (1) trying to relate the concept of buttressing numbers to the concept of locally-induced grounding line flux changes and (2) showing that the adjoint method is consistent with the pertubation approach. So I would suggest to reformulate your title to reflect the content better, maybe something in the direction of 'On the complicated relation between local ice-shelf buttressing and induced grounding line flux changes', 'Are there causal connections between local ice-shelf buttressing and locally-induced grounding line flux changes?' or 'Adjoint-based sensitivity of grounding line flux to sub-shelf melting...'

- page 1, line 7: I'm not sure if this is the correct argument to debunk a correlation between grounding line flux changes and local buttressing numbers.
  If the ice shelf is locally perturbed and buttressing at the grounding line is reduced, this speeds up ice flow at the grounding line up to the perturbation location. However, the perturbation will reduce the spreading rate and hence tends to reduce velocities at and downstream of the perturbation location. This shows in your figure 7 where velocities increase up to the perturbation location and decrease downstream of it, which is then reflected in a local reduction in longitudinal stresses. This is then interpreted as an increase in the local buttressing number based on, e.g., the flow direction. From this point of view, a reduction in buttressing at the grounding line can consistently be related to an increase in the local buttressing number.
  Your point here is supported by the fact that you cannot find correlations once you include regions close to the grounding line or you analyse Larsen C. Don't get me wrong, I think that it is a very important point to make that local perturbations increase locally measured buttressing numbers, as I do not think that many

people are aware of that (I was not).

- page 1, line 20 and other: please check your references, e.g., Schoof (2012) does not use idealized modelling and Asay-Davis et al. (2016) do not include experiments showing MISI, also Royston and Gudmundsson (2016) analyse diagnostic responses to ice-shelf collapse.

- page 2, line 43: 'diagnostic, forward experiments'

- page 4, line 86: you could add a subsection 'Initial configuration' here to improve readability.

- page 5, line 120: You need to multiply N_{rp} with a time interval (e.g., one year if your flux is given in units per year) to get a dimensionless number.

- page 5, line 120: Do you exclude changes in grounding lines of ice rises in the Larsen C domain?

- page 5, line 121: you could add a subsection 'Local buttressing number' here to improve readability.

- Figure 2: labels for the colorbars are missing and it would be easier to understand your message if you added the normal directions in the panels (also in Figure 3 and others).

- page 7, line 156: Why 12km? Does the relation already improve if you remove only cells that are directly linked to the grounding line?

- Figure 4: Please add p-values for your correlation statistics.

- page 8, line 174, isn't this a contradiction to your statement in p7., line 58?

- page 11, line 195, maybe better state that the thickness gradients magnitude increases / decreases, since this is the relevant quantity to drive ice flow.

- page 11, line 204: I do not understand your sentence in brackets, please clarify.
- Figure 8: why do you analyse buttressing changes in neighboring cells and not in the cell itself? This should not make a difference, given Fig. 7 etc, or do I miss some argument here?
- page 12, line 218: you could add that this negative correlation is in line with the general understanding of how buttressing reduction affects ice flow.
- Section 4.3.2.: when calculating buttressing at the grounding line, you have an additional direction that emerges naturally, which is the grounding line normal as used in Gudmundsson (2013). In fact, since the boundary condition at the calving front is formulated in terms of the calving front normal, this is the only direction that guarantees that you get a value of 1 if and only if you do not have any buttressing at the corresponding grounding line location. It is worth checking, how using that normal affects your findings.
- page 13, line 235: I do not understand your statement here as there is a difference between the first principal component along the grounding line and within the ice shelf?
- page 14, line 245: you state that you test experiments with and without perturbing elements that are crossed by the grounding line, but you never refer to these experiments again.
- page 15, line 266: It might be worth checking the flow and normal directions as well (similar to Figure S8 for the p1-direction).
- page 17, line 300: I suppose that you repeat the perturbations for the different thicknesses?
- page 17, line 314: you refer here to the other methods discussed in the previous sections, i.e., the local buttressing numbers etc?

- page 17, footnote: Are you comparing here with different perturbation experiments than those presented in the sections before? Please clarify.
- Figures could be improved substantially by adding labels and units, making sure that font size allows for readability etc.
- page 20, line 332: In addition, the analysis by Fürst et al. (2016) might be based on 'maximum buttressing' since the second principal stress is related to the notion of the compressive arch.
- page 23, line 401: this could be misundertsood ('ice thickness vector'), maybe easier if you specify $(H_n)_{n \in nodes}$ and $(u_n, v_n)_{n \in nodes}$ or something like this? And shouldn't the grounding line flux depend on the velocities (not just their magnitude/speed)?
- page 23, line 404: please specify i and j

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