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Interactive
Comment

Interactive comment on "Modelling the impact of submarine frontal melting and ice mélange on glacier dynamics" *by* J. Krug et al.

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This study investigates the effect of two important frontal processes on the calving rate and stability of synthetic grounded and floating calving glaciers. The model couples a novel damage model to a LEFM formulation of the crevasse depth calving criterion (Benn et al., 2007). An array of synthetic geometries are spun-up to 'quasi-steady-state' and then perturbed with various degrees of frontal melting and ice mélange buttressing. The results presented suggest ice mélange may be able to trigger frontal advance through suppression of calving. With regards to undercutting by melting, the results suggest that increased melting may actually result in terminus advance of the order of 1 ice thickness, contrary to previous studies.

Overall, I think this paper provides interesting insights into calving glacier dynamics and demonstrates the applicability of a novel approach to the issue of strain history in calving modelling. I have some comments, mostly relating to presentation, but once these are addressed, I feel this work certainly merits publication in The Cryosphere.

General Comments:

- There is a good coverage of the literature with regards to measurement of frontal processes around Greenland and their observed relationship with calving. However, for a modelling paper, I don't feel that the modelling literature is sufficiently addressed. I think the theoretical basis for the application of LEFM to glacier calving (van der Veen, 1998) should be better represented, as well as the development of the crevasse depth model (Benn et al., 2007, Nick et al., 2010).

- Related to my previous comment, I think the methods section should be expanded and its focus shifted somewhat. Currently, half the methods section describes the Stokes equations and Glen's flow law; these are well established in glacier dynamic modelling and, given that you don't refer to them elsewhere, I see little reason to include them. Instead, I think the calving model and particularly the damage model should be presented in more detail. Currently, it is very difficult to follow this paper without also having Krug et al. (2014) open alongside. I don't think it's necessary to present it in full detail, but the reader should at least be able to determine the meaning of the χ term and understand how to stress intensity factor is computed.

- You state that the damage scalar D 'tends to 1'. How is D prevented from reaching 1? By setting a maximum value or by a nonlinear source term? Are the model results sensitive to this choice? I think this should be discussed in the text.

-Two climate forcing processes are investigated, both of which cause the glacier to advance into the fjord. Were you able to find any forcings which resulted in retreat? If not, do you believe that this is a realistic result? Based on my own modelling work, I suspect that the lack of basal melting may be a factor here.

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-The results presented in Fig. 10 and discussed at the bottom of p.198 suggest that, following a calving event, the stress intensity factor near the terminus is too low for the initiation of a surface crevasse field here. The physical interpretation of this would be of uncrevassed surface ice near the terminus of an outlet glacier. As far as I'm aware, this is rarely, if ever, observed on real outlet glaciers in Greenland. Assuming that the geometries generated in this study were to be representative of Greenland outlet glaciers, I think this should be addressed in the discussion.

-Can you comment on the possibility of including the effect of basal crevasses into this modelling framework in future work? Do you foresee their inclusion altering any of your conclusions with regards to the importance of melting and mélange or calving glacier stability in general?

-Results from 3 of your QSS geometries appear to be missing (Figs. 6,8,11).

Line-by-line comments:

p.184.l.3: The authors might consider mentioning "water in surface crevasses". While there is obviously debate about its importance, it has been suggested to be important by many previous authors.

p.184.l.5: "and glacier dynamics" no need for "the"

p.184.l.9: "pluriannual" doesn't have much usage in English. Maybe "multiannual" or "decadal" would be better?

p.184.l.9 & 11: Better to be consistent with use of "more than" or ">". Also, perhaps "several kilometers" might be more readable.

p.184.l.15: Maintain present tense "Results also reveal"

p.184.l.16: "the largest forcings" or "most significant". "heaviest" isn't really appropriate here.

p.184.l.21: I think within the target audience of this paper, it would be sufficient to say

"(Representative Concentration Pathways)" only. At any rate, repetition of "pathways" should be avoided.

p.184.l.24 – p.185.l.1: It might improve the readability to refer to "Greenland Ice Sheet (GIS) mass loss" and then use positive rather than negative numbers. This also avoids the technical error of saying that a negative number 'increases'.

p.185.l.22: "ice block"

p.185.l.28: "Thus" here implies that the variation in summer melt rates is a logical result of the previous statement: "melting intensity is hard to measure accurately...", but this is not the case.

p.186.l.23: "used a fixed geometry"

p.186.l.28: "2D flowline geometries" might be better here? When I first read this, I had the impression of the geometry being both 2D and simplified.

p.189.l.3: "quantified by a scalar damage variable (D)" or "scalar variable D called the damage variable"

p.190.l.19: I think it'd be clearer to state that the "total depth-integrated flux through the inlet boundary" is kept constant (if this is indeed the case, this is what I infer from your description here).

p.190.l22-24: This sentence is a little unclear (multiple 'i.e.'s should be avoided, in my opinion).

p.191.l.4: lower-case "compared"

p.192.l.3: to me, the word "runoff" here implies water flowing supraglacially and falling into the fjord, as opposed to subglacial drainage into the fjord.

p.192.l.9: 0.6 to 3.8

p.192.l.16: I think you are implying here that you also use a linear variation of melt from

0 at sea level to MMR at the base, but you should explicitly state this.

p.193.l.11 and p.193.l.14: Is it appropriate to state that ice mélange "freezes" or "melts"? Given that almost the entire mass of the material is made from icebergs rather than sea ice, I would think "freezes together" or "becomes rigid" would be more appropriate. As for the disintegration, satellite imagery shows that the material tends to lose its rigidity and then flow out of the fjord in pieces, rather than melting. The use of "collapse" or "disintegration" as opposed to "melting" also avoids any confusion with discussion of undercutting by melting.

p.193.l.17: "did not obtain"

p.193.l.22: Here you switch to a different convention for reporting ranges. In the melt section you use (x m day to y m day) but now you use [x;y]MPa. I think consistency would be better.

p.193.l.25: Why under tension? Surely if you're considering the effect of mélange, the system is under compression?

p.194.l.3 "of time"

p.194.eq.5 I don't think it's necessary or useful to have the "(mod 365 days)" in each case. Also, it took me quite a while to work out what was going on here; it might clear things up to mention in brackets on p.193.l.18: five months (150 days).

p.194.l.19: "by more than a few tens of meters"

p.195.l.23: "cumulative loss" or "total loss"

p.196.l.13: The "position"/"advance" of the terminus was inversely correlated with velocity.

p.196.l.19: as it is, this seems to imply that there was an increase in velocity in the control run, but runs S2-4 increased more. I think what you intend to say is that the ice flow accelerates to a faster speed than the maximum in the control run?

p.196.l.23: “parallel to sea level”

p.197.l.5: The wording here implies that the maximum velocity observed by Walter et al. was 550m/a, as opposed to the magnitude of the speedup being 550m/a.

p.197.l.10: “does not have”

p.197.l.22: I don’t think it’s correct to say that no previous study has suggested an alternative effect of mélange on calving dynamics. To my knowledge, most studies investigating the effect of mélange (including our own) infer that ice mélange acts to reduce crevasse propagation and thus prevent or inhibit calving, rather than simply prevent the rotation of an already calved iceberg. Furthermore, you mention on p.186.l.12 that some authors argue that ice mélange directly resists ice flow. This would seem to contradict the statement that “no study has suggested another effect”

p.198.l.18: “ice mélange event” to me implies that this is a short transient occurrence, whereas it actually lasts ~ half the year. Perhaps “during the ice mélange season”?

p.198.l.24: “propagation to sea level”

p.198.l.25-29: The description here seems like Figure 10 was previously oriented 90 degrees from its current orientation, and the description hasn’t been updated.

p.199.l.8: I don’t think it’s correct to say the glacier “undergoes” ice mélange. Perhaps “when the ice mélange layer is present”?

p.199.l.21: The use of the word “directly” here may cause some confusion if it is interpreted as being the opposite of “inversely”.

p.199.l.27: “although they simulated... . . . longitudinal extent of the crevasse field near the front”.

p.200.l.3-5: Related to my comment on p.197.l.22, this seems to imply that this is a new hypothesis on the role of ice mélange, which is not the case.

p.200.l.23: Our prescribed melting overlapped somewhat with the presence of the floating tongue, but it would be accurate to say that our "geometry was grounded for most of the melt season"

p.202.l.6, 9: "pluri-annual": again, not sure if this is the best word. If used, be consistent with use of hyphen.

Table 1: "that starts damage" or "damaging"?

Table 2: "Name of run" or "Run name" rather than "name run"

Figure 1: Only a minor point: You have Ht and Hwt representing thicknesses of glacier terminus and water column, respectively. Why not have Hm for mélange thickness, rather than 'h'?

Figure 3: "... melt rate imposed at the bottom surface of the glacier front" implies, to me at least, basal melting. I think it'd be clearer to say "melt rate imposed at the base of the calving front".

Figure 4: I think (a) should have a scale bar, and an indication of vertical exaggeration (if there is any).

Figure 6:

- Three of the model setups listed in Table 2 appear to be missing.

- "Cumulative ice loss"

- I am confused by the combination of "cumulative over 5 years" "summer vs. winter" and "normalized daily". Perhaps you could lay out more explicitly (here or in the results section) how these data were produced.

- "The area of the disks represent..."

- The green looks to me like yellow, but perhaps it's just me.

Figure 8:

- As with Fig. 6, 3 of the model setups are missing.

- Is it possible to remove the vertical lines from within the circles, as they don't serve any purpose here?

- "Cumulative"

Figure 10:

- This may be slightly pedantic, but the x-axis label "front position" is only valid for (a). When applied to (b) and (c), it implies that we are not seeing profiles from a single instance in time, but rather that each curve represents the change in Ki and χ as the front advances (or retreats). Instead, I think the x-axis label should be "distance along flowline" and a legend should indicate that the black line in (a) represents front position.

- I don't think the glacier "undergoes" an ice mélange. Perhaps "for a glacier subject to an ice mélange backstress of..."

- It might be easier to follow the caption if you had "Red diamond: day 46 (. . .), Blue Diamond: day 140 (. . .), ...".

- "solid curves" rather than "thick curves".

Figure 11:

- As with Figs 6 and 8, there appear to be three simulations missing here.

- To me it seems counter-intuitive to have 11(a) y-axis as (CR – U2). Given that you are comparing a perturbation to a control run, and you discuss an increase in Sxx for the U2 case, why not present the data as (U2 – CR)?

- In the caption for (b), I think you could clarify: "Ratio between summer and winter event frequency (circles) and event size (crosses).

Figure 12:

"Front advances because of increased velocity"

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"Front advances because of calving cessation"

References:

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Nick, F. M., Van der Veen, C. J., Vieli, A., & Benn, D. I. (2010). A physically based calving model applied to marine outlet glaciers and implications for the glacier dynamics. Journal of Glaciology, 56(199), 781–794.

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Interactive comment on The Cryosphere Discuss., 9, 183, 2015.