

Comments on Precursor of disintegration of Greenland's largest floating ice tongue, by Humbert et al.

Nina Kirchner, December 2022

This manuscript contains a lot of interesting findings for recent observed change at the floating tongue of 79 NG, northern Greenland. For instance, how frontal changes are connected to position of ice rises and ungrounding of previously grounded areas, how tides lead to potential weakening of the floating tongue, and how crack development can be explained in a fracture mechanical framework. Connections between supraglacial melt water features and crack propagation are mentioned, but not considered to have a large impact. Data analysis is complemented by diagnostic numerical modelling focusing on the effects which possible future mass loss due to calving at the terminus of 79 NG will have on its stability.

In my opinion, major revisions are needed before the manuscript can be re-assessed and considered for possible publication in TC. Major points and detailed comments are given below. The manuscript will benefit from language edits throughout, and there is room for considerable improvement in almost all figures.

Major comments

The **introduction** is not well structured and not concise (for detailed comment, pls see below). It is essential to better explain the configurational change at 79 NG, and why this motivates to study a regime change.

The section **Transition in calving regime** needs to be better streamlined and organized, too, and both figures and text need to be improved (for detailed comments, pls see below). Hydrofracture as a potential link between supraglacial melt features and crack propagation is dismissed, however, with insufficient arguments. The fracture mechanical context employed to describe crack formation lacks context necessary to follow the argumentation. It is essential to rework this section so that the wealth of useful information can be correctly understood.

The **Impact** session suffers from two drawbacks. First, there is repetition as some information is already given in Appendix B and can be removed from the impact session. At the same time, Appendix B is incomplete and would benefit from additional information. Second, the text in the impact section is lacking important detail concerning the justification of model choice, description of results and metrics used, and that needs to be added (for detailed comments, pls see below) to allow for a better understanding of the results presented.

The **Discussion** section appears incomplete and needs to be expanded, for suggestions pls see the detailed comments.

The **Conclusions** reflect the manuscript in its present form, and may need to be revised slightly during the revision.

The **Appendices** appear to replace a full-fledged "Methods" section, which I found a bit surprising for this type of manuscript. Appendix A and B are introduced in the main text at appropriate locations, however, Appendix C and D are not, and actually should not, either, because they belong

to Appendix A. Pls see detailed comments below. Almost all figures need improvements, and Appendix B lacks necessary detail describing the diagnostic model setup.

Detailed comments (text from the manus is given in italics)

Abstract

Line 9: *“are a precursor”* -> may be a precursor

Section 1 - Introduction

Lines 18-19: provide names of the three floating tongues left. Return to these in the Discussion, see my comment lateron.

Line 21: I understand ice rises as features at the surface of an ice mass that are caused by iceflow over a bathymetric high at the seafloor. Could the text *“Its ice front is still in contact with ice rises...”* be reformulated along the lines of e.g.: Parts of the front are grounded on ice rises, acting as pinning points, also because later (eg. in line 24 and in Fig.1) the ice rises are referred to as pinning point.

Line 23: *“Calving and basal melting...”* References for this should be added. Also, basal melting is barely addressed later in the manuscript, so it should be mentioned that the focus here is on calving only.

Line 24: A ref is needed re *“calving ... is often governed by the existence of ice rises”*, and a more nuanced formulation is needed as well. Yes, ice rises could be related to calving if they are in the frontal zone of an ice tongue. But I do not see how ice rises that are far from the frontal zone should be related to calving? Pls clarify.

Lines 24-25: *“When the ice mass moves passes by ...”* -> When the ice mass moves past ...

Line 25: *“ ... rifts (cracks that are separating the ice entirely....”* -> rifts (cracks that penetrate through the entire ice thickness)

Line 26: *“which grow laterally into the floating ice sheet”* -> which may also propagate laterally.

Line 27: *“This calving style can be found at many locations....”* Pls provide references.

Lines 27-28: *“Tongue-type calving is a normal process and is very distinct from break-up of disintegration events”* -> Shorten to: Tongue-type calving is very distinct from disintegration events

Line 29: *“During these events, a large part is shattered...”* -> During these events, a large part of the floating tongue is shattered.

Lines 30-32: In addition to modern disintegration, there is also evidence of similar ice shelf collapses in the past that should be mentioned, see eg. Jakobsson, M, et al. (2011). *Geological Record of Ice Shelf Break-up and Grounding Line Retreat, Pine Island Bay, West Antarctica*. *Geology* 39(7), pp. 691-694, doi:10.1130/G32153.1

Line 35: Insert space before *“(ZI)”*

Lines 39-44: Several issues here. 1/ This info would fit better in the context of the description of 79 NG that is initiated in line 19 ff. 2/ Also, some basic numbers (length and thickness of floating tongue, depth at grounding line etc) would be useful to have upfront around lines 19 ff. 3/ line 41: remove “act as pinning points”, has been said above (eg. line 24). 4/ “... *Calving event ... in 2020, still in the same style as in the 1980’s*”: this is not helpful because the “1980’s style” isn’t described (yet). 5/ Incorrect grammatical reference in “*Changes of calving front ... style... have not gone beyond the line of these pinning point*” (how can a style go beyond a line?) 6/ “Line of pinning points” should be reformulated. 7/ Incorrect tense: “A transition ... can...destabilize ... and eventually triggering ” -> A transition ..can.. destabilize ... and eventually trigger.

Lines 45-50: Consider combining this paragraph with lines 33-38. Explain “*load situation*”. Reformulate “*response ... in stresses ... of glaciers*”. Mention “Antarctica” in connection with Pine Island Glacier. That Petermann is in Greenland is known once you introduce the glaciers name in the context of lines 18, see my comment above.

Lines 51-52: “*We leverage...of the floating tongue in the vicinity ...*” -> Here, we leverage ... of the floating tongue of 79 NG in the vicinity....

Line 55: “*... are complemented by numerous numerical*” -> complemented by numerical

Line 56: What do you mean by recent changes of 79NG configuration? From line 42 we know that something changed CE 2020, but not really what exactly. What exactly is the configurational change that motivates to study a regime change? This needs to be better explained, see my major comment.

Line 60: Decide whether to refer to 79NGs tongue as a tongue or an ice shelf. This needs to be checked throughout the manuscript.

Figure 1: Several issues. 1/ Pls provide an overview map of Greenland with the location of 79 NG marked. 2/ Caption (a): “*IB marks an ice bridge (see text for details).*” -> add more precisely where in the text, eg. Section 2. 3/ Panel b: Pls provide some context for Fig 1b already in the introduction. Currently, the reader needs to wait for this until Section 2. Label (b) and scale bar are poorly visible. Consider rendering them in different color and at position with better contrast. 4/ Panel b: Could cracks A-F be colored with individual colors? Explain in the caption what a stippled line vs a solid line means for the crack. Also, cracks are referred to as rifts in Fig 2. Decide on one terminology. 5/ Panel b: I guess IR1 and IR2 stand for IceRise1 and IceRise2. In panel a, they are referred to as pinning points. This should be homogenized, alternatively, say that you use the terms as synonyms. Consider adding the outline of the blue ice rises in panel a to panel b - may be useful for orientation. 6/ Add something about the supraglacial lakes.

Section 2 – Transition in calving regime

Figure 2: This figure shows changes in the frontal configuration 79NG. Pls consider modifying the figure such that configurations (outlines, prominent features) from 2010 and 2020 are overlain onto the 2000 configuration. This will make the comparison more visually straightforward. A central flowline could be added, as you refer to it later on (eg. line 72).

Lines 64-74: Generally, the text here would benefit from streamlining and better organization. A simple guideline could be the chronology of events/calving front changes, from 1975 to present. Specifically, I have the following comments. 1/ Line 64: In this generality, I don’t think this is correct.

One can eg. not say anything about changes in subaqueous calving based on calving front positions from optical satellite imagery. I think this needs to be reformulated. 2/ Ensure easy matching between text and abbreviations used in figures. Replace “*between the two ice rises*” -> between the two ice rises IR 1 and IR2. 3/ Lines 66-67: “*Calving is initiated by the lateral rifts*”: It would be helpful to indicate the rifts in Fig 2. Pls see comment above re Fig 2. Length of rifts in 2020 need not be given in the text if rifts A and D are indicated in Fig 2. 4/ Line 70-71: “*From the mid 2010’s onwards, the calving front situation has changed tremendously*” – How does that go together with line what is stated in line 43: “*calving ... took place in 2020, in the same style as in 1980*”. Is the 2020 event an exception from the new, post 2010 state? Pls clarify.

Lines 75-91: These paragraphs link to Figs. 3 to 5 and focus of the floating tongue becoming ungrounded at a certain location. I have several comments. 1/ “*Based on our database*” -> Based on the data analysed here. 2/ “*between the two ice rises a small grounded spot...*” What you are saying is that there is another ice rise, at the location marked by a blue star, correct? The formulation is not clear. Why don’t you refer to this grounded area as an ice rise? Does an ice rise have to be of a certain size? Other criteria? This is confusing, pls clarify. 3/ “*Our assumption ...*” do you mean: our suggestion? To avoid repetition, you can replace “*suggest*” by “*propose*” in line 75. 4/ The text and **Fig. 3** don’t go very well together. Starting point is 8 Aug 2013 (panels a and b). Pls add length scale to panel a and date to panel b, or combine them into one panel. Legend in panel b is m asl, pls add. Panel c has date 1 July 2013 so is showing a state prior to the one shown in panel a. When panel c is mentioned in line 80, no date is mentioned but it is natural to assume that it is a date after August 2013, which causes confusion. In line 80, reference is made to panel d, providing evidence for the ungrounding which is mentioned in line 76, however, without referring to panel d. Rather, because the sentence continues timewise with describing 2021 situation, there is risk that confusion arises (again) as to what actually is shown in panel d (obs scale is missing) and whether it is really necessary (from the caption to Fig. 3, it appears to provide geographical context only?). Also, it would be helpful if current Fig. 6d would be combined into current Fig. 3. Pls review Fig. 3 and caption and harmonize with the text. 5/ Line 81: “*Since 2013 such dome-like structure...*” -> Since 2013 such a dome-like.... 6/ Line 82: “*An alteration...*”: Wouldn’t that fit better in the discussion section? Alongside an explanation why? 7/ Line 83: Grammar: become -> became. 8/ Line 84: “*Ungrounding can be a result from two instances:*” Ungrounding can results from at least two processes. And yes, indeed, at the ice rises, a lowering of ice tongue surface elevation must come from surface melt or dynamic thinning. However, at floating locations, even basal melt should reduce to surface elevation lowering because reduced buoyant forces cannot sustain the same ice thickness above the waterline? You have mentioned basal melt in line 23 but don’t seem to pick up on it any further? Pls clarify. There are some remarks later in the discussion re suspected low basal melt rates where the issue could be discussed nicely in appropriate detail. 9/ **Fig 4.** Please provide an inset to the current figure showing where the profiles are located. The calving front position of 2013 is nowhere shown, and the 2021 position could be inferred from Fig 1.a, but it gets cumbersome if this becomes a to-do for the reader. Why are supraglacial lakes included in the figure? If they were introduced in Fig 1, it would be easier to see a red thread (since lakes are mentioned later, too). What about lakes in 2013? Pls provide sufficient information regarding Fig. 4. Caption: Pls check grammar. A location cannot correspond to a Figure. 10/ Lines 89-91: Could this be better placed in line 82, before “*we conclude*”? 11/ Fig. 5. Pls add lines showing the approximate location of the underside of the floating tongue, and the seafloor. Same applies to Figs. C1 (a-c).

Line 92: “For the sake of ...” This is repetition from Fig.1 and can be replaced by a ref to the Fig instead.

Line 95: “*lower ice rise*” Do you mean “southern”?

Line 98: “*unification*” -> do you mean that the northern and southern branch of crack E joined? Pls reformulate.

Lines 103-106: “*None of the cracks is a hydrofracture*”. How can you be sure? This is quite a strong statement, and the simple mention “*we did not find evidence*” is in this brevity not a satisfactory argument. What did you do to arrive at your conclusion? You have bothered to indicate lakes in Fig. 4, why? “*either from surface melt of facilitation supraglacial lake drainage*”: Even the latter are related to surface melt. Pls reformulate and check grammar, and also add a ref to at least Fig. 1b.

Line 108: “*at 79 NG’s interesting part*” -> remove interesting and reformulate sentence.

Lines 109 - 124: Several issues here. 1/ line 109-111: Provide a reference. Why mention mode III – it is not relevant for the following? 2/ Lines 111-112 and Fig 6: Explain briefly how shear and tensile stresses are related to mode I and mode II, and to first and second principal normal stress and maximum stress mentioned only in the caption to Fig. 6. Otherwise, this part and the following discussion cannot be understood. 3/ Why do ice rises induce shear stress and why does tensile stresses increase downstream of the ice rise? How is this related to velocities? This must not be left to the reader to find out but needs to be explained. 4/ Line 114. Grammar and terminology. What is an unstable crack and can a crack (a void) detach an ice berg? The latter is detached from the tongue and crack propagation accelerates – is that what you mean? Reformulate. 5/ Line 117 ff: “*Velocity field of 2014-2016*” Why a two-year averaged one? From where are these stresses? From ISSM? This needs to be explained. Line 129: “*descend*” -> decreases. 6/ Fig 6. Add to the caption that the scale in panel c is valid even for panels a and b. I think that would be helpful. Consider having panel d in Fig 3 instead, see my earlier comment. Pls show the floating tongue in panel d a lighter grey so a better contrast to the arrows and the star is achieved. 7/ Did you provide evidence for your statement that (line 121) “*Loss of contact to the grounded spot is leading to an increase in main flow*”? If yes, please refer to it, if not, pls add and/or explain. Pls also check grammar in lines 121-124, there is a mix of tenses that should be checked for correct use.

Lines 125 – 140: Here cracks and supraglacial water and fatigue failure is discussed. Several issues: 1/“*River*” – has nowhere been introduced. You should mention (eg. in the context of Fig 1b) that supraglacial lakes can be connected by supraglacial streams. Is it “*stream*” or “*river*”? There is a lot of literature on supraglacial hydrology at the Greenland Ice Sheet so it should be easy to find the correct terminology and add a couple of references. 2/ “*de-watered*” -> drained. Also in Fig. D2. 3/ Add a line showing the base of the floating ice tongue to Figs 5, D1. Otherwise it is hard to see that the crack is not intersecting the entire ice thickness. 4/ “*Forming a non-intersecting crack*”. I don’t understand the terminology chosen. Crack E is rendered as a stippled line in Fig 1b, with individual ends propagating towards each other. In Fig. D2 their expected joining location is highlighted (btw how did you predict this location? And pls add a north arrow to Fig. D2) So why “*non-intersecting*”? And how is that linking to the fatigue fracture? I understand the latter, but not how the connection to the not-yet joined crack is made. 5/ Maybe it would be better to group this part as section on supraglacial meltwater features and cracks (lines 125-133) and a section on oceanic forcing of crack propagation (lines 133-140)? 6/ Pls add missing information to the caption of Fig. 7. What is ranging between $-\pi$ and π (if the symbol is π)? Pls add a pointer to cracks A and E. 7/ Line 137: “*The ice plate*” do you mean the floating tongue? I don’t fully understand why you need to argue that grounded and floating ice are connected at the ice rises (lines 136-139). Because you have fractures around the ice rises? Isn’t it sufficient that the tides work on the floating part? Pls clarify.

Lines 141-143: This is a bit unconnected, pls consider moving, providing additional context, or removing.

Line 145: “*detaching...*” -> reformulate eg as: will detach about 20 km² of ice but leave the ice bridge (IB, Fig. 1a) unaffected.

Fig 8 and caption. Use either chaos zone or chaotic zone, it is not homogenous in the text. What does the red line denote? Add north arrow. Panel d shows locations for which no hinge zone is visible in interferograms. Are the latter shown? What is the meaning of the easternmost interferogram location – it is in the ocean?

Lines 152-157. Consider providing this information as a diagram (staples, or similar). This provides a more attractive means of conveying the info than in repetitive text.

Line 158-159: Add info on WIS IB to line 147 instead (and remove here).

Line 159-161: Lambert Land has not been introduced. Perhaps just remove? Sufficient that two glaciers drain into the 79 NG from the south? Do you show evidence of the bulging zone?

Section 3 Impact – response of the 79 NG instability of the calving front

Lines 166-167: “*We attempt ...discharge*” -> This is repetition from line 163. Shorten and mention ISSM directly, eg: We address this question using ISSM (add ref to App. B). Then: continue to describe the three experiments (line 170 onward).

Line 167-170: Repetition from Appendix B. Remove.

Lines 170-178: Here, the three experiments should be described, as well as model output variables and metrics used to derive conclusions, eg. the buttressing parameter that is so far only mentioned in the caption to Fig. 9. Pls justify why you run diagnostic experiments only when the temporal evolution of the changes at 79 NG clearly are in the overall focus. Pls also explain why a Blatter-Pattyn (BP) model was favored over a Full Stokes (FS) model, when in a recent study of the NEGIS, , ‘considerable differences at the grounding line’ were found and that ‘results from non-FS models should therefore be viewed with caution’ (tc.copernicus.org/articles/16/1675/2022/). Maybe the error is systematic and so not so important in terms of % increases in discharge, which is the main takeaway in the following. But, I would suggest that either running an FS simulation as a comparison or including a discussion of the potential errors / motivation of the model set-up is necessary. Moreover: 1/ Line 171: Remove number concerning grounding line flux for the init run. 2/line 175: “Bottleneck”: Do you mean in term of the fjord geometry narrowing? Pls explain better. 3/ Line 176: Incorrect Fig ref, needs to be corrected to Fig 9f. 4/ Fig 9: parts of the floating tongue that are removed in the two perturbation runs should be rendered hatched (or otherwise highlighted) in panels b,c,e,f. All panels can be cropped to instead focus on the relevant model domain. Insert a frame showing the extent of eg. Fig 1a in Fig 9a.

Lines 179-185: Several issues. 1/ Explain buttressed vs overbuttressed. The Borstadt parameter ranges between 0 and 1 according to the caption to Fig 9. So why is the scale in Fig 9d,e,f from 0 to 2? 2/ Move grounding line flux for init here. Consider comparing your findings to the other modelling study which you cite in the Introduction wrt grounding line fluxes (de Rydt et al., 2021). 3/ Velocities are not discussed at all, this needs to be added. Especially since velocities and their changes after ice tongue breakups are mentioned several times in the Introduction. Modelled results are presented at the ice surface only, correct? What about their distribution in the vertical which is also a direction in

which the cracks evolve. 4/ Panel 9a shows a modelled region southeast of 79 NG, in all other panels, this is not shown. As it is not relevant, I suggest to remove it in panel a, and also in Fig B1. If not, pls motivate and explain why it is kept.

Section 4 – Discussion

Line 187: “First...” does this opening refer to lines 190-210? One does expect a “Second”, which would perhaps be the discussion of the modelled ISSM results in terms of experiment design (lines 213-214), as well as a “Third” which would be changes in regional climate and their potential impact on 79 NG (lines 215-220)? And what about adding a “Forth”, see below. Re “first”, my specific questions are: 1/ line 194: provide the year during which this mass loss occurred. 2/ Line 200: For consistency, start a new paragraph when ZI is described. Regarding “Second”, the discussion should be extended to include more nuanced reflections on the limitations of diagnostic simulations and to offer an explanation as to why prognostic simulations were not addressed here. Also, it would be useful to include reflections on whether or not a crack propagation (instead of removing parts of the floating tongue based on observational evidence and some extrapolation) could be captured in a prognostic setup? Also, are results from similar numerical simulations regarding the buttressing of JI, ZI and WIS available in the literature? This would be an interesting comparison. Likewise, the grounding line fluxes modelled here could be placed in observational (and modelling, if available) context, which would provide a broader picture with regards to future expected changes at 79 NG. If no additional FS simulations are run for comparison (see my comment above) a discussion concerning the potential shortcomings of the BP model simulations needs to be included. Regarding “Third”, why is the impact of expected future climatic change on 79 NG in a rapidly changing Arctic not discussed, especially with a focus on supraglacial melt features that have been mentioned a number of times in the manuscript? Regarding “Fourth”: in the introduction it is mentioned that 79 NG is one of three remaining ice tongues at the northern Greenland margin. I suggest adding a discussion focusing on a comparison with the other two, Ryder and Petermann. That is at least as relevant as comparing to ZI, WIS and JI.

Section 5 – Conclusions

Line 234. I recommend to weaken this to “may be at the onset...”

Appendix A: Data

A1 is very well written. But I find the figures not as helpful as they could be because of a lack of overall structure. So, before setting out with A1, pls consider presenting an overview figure like the present Fig. C2 (or a variant thereof, perhaps with more zoom into the relevant region?) as a main orientation figure for the Appendix, before you present data along the various profiles in subsequent figures and dive into the various appendices A1, 2, 3 etc. Minor changes: Line 260: “*was formed which is shown in Fig 7*” -> was created. Line 247: “*Furthermore, we apply*” -> Furthermore, we use. Line 257: “*Here we apply SAR interferometry*” -> Here we apply InSAR.

A2 is very well written. My major question is: Why is there a separate Appendix C with Figs. C1 and C2, and a separate Appendix D with Fig, D1 which all clearly belong to A2? Here in A2, you should continue to present Fig C1 (C2 should be taken care of at the start of the appendix, see above), and

then present Fig. D1. Line 272. What is the thickness of the floating tongue? I suggest to include that as base info somewhere in the introduction, see one of my comments above. Figure C2: Please add map showing location, orientation and length of the profiles in panels a, b c. Alternatively, perhaps introduce a new overview figure where all profile locations are given, see my comments below in relation to the Appendix. Pls specify whether the same equipment was used in 2013 (data in panel a), or add a ref where the data description can be found. Abbreviation EMR has not been introduced. Line 268: "antenna" -> antennas.

A5: Line 307 "*mosais*" -> mosaic

Appendix B: ISSM model setup

The ISSM model setup for the diagnostic runs in Section 3 is insufficiently described. Pls provide a more complete description. Specific comments/questions: Fig. B1: add location of 79 NG to the figure. Consider cropping to the relevant area, cf. comments in the context of Fig. 9. Line 315: Why are only winter surface ice velocities used for the inversion? Line 316 "*Since the surface velocity field have*" -> Since the surface velocity field has . Equation B3: What is the meaning of the plus side in front of γ_1 ?