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The Cryosphere Discussions

Interactive comment on "Modeling the response of Greenland outlet glaciers to global warming using a coupled flowline-plume model" *by* Johanna Beckmann et al.

Anonymous Referee #1

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1 Summary statement

The paper by J. Beckmann et al. analyses the response of 12 glaciers in Greenland to future warming over the next 100 years using a 1D flowline and plume models. The forcing is based on atmosphere and ocean model results from CMPI5, and used in the flowline and plume models. The manuscript is usually clear and well written, and the figures are appropriate. However it is surprising to still rely on flowline models when buttressing and lateral effects can play such a big role in the evolution of glaciers terminating in narrow fjords. The comparison to previous modeling results (especially regional models other than Nick et al. [2013] is rather limited and the implications of the

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assumptions made in the models are not discussed. Also, the reasons to use ocean temperatures at 400 m depth are not clear: the depth of the water properties used in the plume model should depend on the fjord and ice front properties (depth of the fjord, presence of sills, depth at the grounding line, ...) and not be identical for all the glaciers. I therefore think that the numerous simplifications made in this paper are not well argued or justified, and the implications on the model results are not assessed and presented in this manuscript.

2 Major comments

As mentioned by the authors, scaling sea level rise at the scale of Greenland using results from only a few glaciers is highly speculative. However, this is still what is done in this paper without assessing the uncertainty of such a scaling. It would be important to quantify the uncertainty in the scaling by comparing results obtained with a subset of models. Also, do you think that 12 glaciers are representative of Greenland? They are many kind of different glaciers, with or without marine terminating fronts, with or without ice shelves, with completely different geometries and fjord conditions; some glaciers are mostly impacted by changes in ice front position, or subglacial hydrology (with different types of subglacial hydrology regimes, ...)? So is it reasonable to use such a small sampling of glaciers and consider that their behavior is representative of the âĹij200 glaciers of the Greenland ice sheet?

I don't understand why the water conditions at 400 m depth are used in the plume model for all the glaciers. All the fjords and glaciers have very different geometry conditions (with sills, ...) that should be taken into account in order to have the right conditions for the plume model.

It looks like the authors are trying to set-up the initial conditions so that the glaciers are in steady state. Many glaciers experienced large changes over the past coupled of decades and they are therefore not in steady-state. I think it is more important to have initial conditions close present state than close to a steady-state, especially as initial conditions impact the system for a very long time (much longer than the simulation time in this paper). Furthermore, it is difficult to add the present trend to the simulated changes as glaciers are not exactly linear systems.

I don't understand why only one atmosphere model is used for the future forcing while several ocean models are used. There is also no clear distinction between the spread in results caused by the different climate scenarios and the different initial states, and their relative importance for the different glaciers. Is it more important to improve the external forcings (and which one) or to improve the initial conditions to reduce the uncertainty in future glacier's evolution?

It seems like the authors read a coupled of references [Nick et al., 2013; Goelzer et al., 2013], and keep using them all over the manuscript. They are also many regional models (that are not 1D) that should be used to compare the results of this study.

Finally, I must say that I am a bit tired of seeing studies based on flowline models in 2018. I agree that such studies are still very useful to investigate new processes for example, but they should not be used to do future projections of ice sheets, given the importance of buttressing, lateral effects, complex topography ... when 2D regional models can be run at high resolution and provide more accurate results.

3 Line by line comments

p.1 l.6: crudely → simplistic (models use simple parameterizations because the processes remain unknown as mentioned at the beginning of the sentence)

p.1 l.10: Is the regional climate model used only for the SMB or also for other properties?

p.1 l.12 (and l.14 and l.15): use present tense instead of past in the abstract: used → used.

p.1 l.22: the scaling is quite speculative. What happens if you do the scaling with a smaller set of glaciers? What is the uncertainty in this scaling?

p.1 l.19 and l.23: If I understand correctly, the numbers given here do not include the current trend in mass loss from the Greenland ice sheet (13.8 cm in the conclusions). This is rather confusing and provides numbers smaller than expected.

p.2 l.4: “Two processes are largely responsible”: What are the other processes that account for mass loss to a lesser extent?

p.2 l.6: “marine-terminating” → “marine terminating”

p.2 l.8: It is not just warming of the ocean, but also changed in the circulation.

p.2 l.9: I doubt that the lower contribution in Fettweis et al. [2013] is 0 cm, it should be 50 mm (9 ± 4 cm). This seems rather contradictory with the actual contribution.

p.2 l.13: Adding references to papers that detail the limitations of modeling of the Greenland ice sheet would be appropriate (e.g. Goelzer et al. [2017]; Khan et al. [2014]).

p.2 l.18-20: I think this is disregarding all the efforts made to improve continental scale models, as some models now have a resolution of about 1 km in marine terminating glaciers [Goelzer et al., 2018]. This is also a bit oversimplifying the problem: the limitations of numerical models are not just resolution, there is also limited observations, external forcings not appropriate, ... So this part of the introduction has to be more balanced.

p.2 l.21-25: Following along the same line, I think jumping from continental scale 3D models to 1D flowline models is a bit reductive, as they are many things in between. Several regional models with 2D or 3D models are starting to show interesting results [Muresan et al., 2016; Bondzio et al., 2017]. Some studies even included representation of ocean with a plume model [Vallot et al., 2018]. So I think the introduction should be improved and not just reduced to Goelzer et al. [2013] and Nick et al. [2013].

p.2 l.32: “that that”

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p.3 l.1: You just mentioned that the approach from Nick et al. [2013] is not appropriate, but you follow the same one, just with slightly more glaciers. I am not sure I understand the logic here.

p.3 l.28: “with 3D ice sheet model” → “with 3D ice sheet models”

p.3 l.30: “we used instead” → “we use instead”

p.3 l.31: I agree that continental scale Greenland models are not the best tool to study these processes, but why not use 2D basin models that would at least include lateral deformations and buttressing is important to correctly capture the behavior of narrow outlet glaciers terminating in fjords.

p.4 Eq.2: Can you explain the choice made to incorporate the lateral stress?

p.4 l.9: Where does the basal sliding coefficient come from?

p.4 Eq.5: How different is this from simply applying water pressure at the front?

p.4 l.21: So is there a point exactly at the grounding line position? This should be better explained. Also, how is treated the stretching of the grid, in particular the variables assigned to the new grid points?

p.4 l.27: How about the ice front? Does it evolve with time? And following what criteria? You need to describe the subgrid-scale treatment of the ice front.

p.5 l.2: A quick explanation of the plume model in a few sentences should be added.

p.5 l.8: How is a vertical profile of melt applied to a 1D model, in which there is basically no vertical dimension? So what values is used for the melt (maximum, average, ...)?

p.5 l.12: What happens above the plume? Zero melt?

p.5 l.17: I don’t understand “added to the vertical mass balance term B”. Is the melt applied to retreat the ice front? Or just to thin the ice close to the ice front? This melt should cause ice front retreat.

p.6 l.1: “Also, did we include” → “We also included”

p.6 l.9 “BedmACHINEev2” → “BedMarchine v2”. Also there is new version [Morlighem et al., 2017] that compiled all existing bathymetry data around the Greenland. p.6 l.15: “in the ice sheet” → “in a previous ice sheet”

p.6 l.24: Why not use the mask in Calov et al. (2018)? Combining difference sources for the different datasets might lead to some inconsistencies between the datasets.

p.6 l.26: Explain that the change in “basal melt” refers to ice shelf basal melt and not grounded ice basal melt. I was initially confused given that the previous paragraph talks about subglacial hydrology.

p.7 Eq.9: To be honest I don’t like this flux correction in the SMB. The problem of inconsistent datasets and initialization procedures is a real problem that we are facing as a community, and that deserved better treatment than a simple flux correction. This is calibrated for the initial state, but as the glacier evolves with time it is most likely not to be valid anymore. How does this correction impact the results?

p.8 l.19: I am confused about this comparison at different depths? Why not use temperature profiles over the entire depth? Also how did you choose these depths? Do they correspond to the depth of warm or cold water? Or the changes in the thermocline? What is the rational for this choice?

p.8 l.23: This is also the case for Jakobshavn (figure 4).

p.8 l.26-32: I have the impression (and this is not very clear in the manuscript) that you don’t use the sill depth in the fjords to determine the water properties in front of the glacier. The sills block the warm water at depth, which can significantly impact the water properties. This should be included for the plume model. Why not use that instead of an arbitrary depth of 400 m? Accurately including the fjord properties in important to separate the response due to the trend in climate changes from the impact of local conditions of the glaciers and the fjords.

p.8 l.29: “larger” → “deeper”

p.9 l.10: Again here, why used the temperature at 400 m depth and not the temperature at the grounding line depth? I think the value used should be designed to best represent the conditions in each and every fjord instead of using a generic value systematically applied to all the fjords.

p.9 l.16-21: It would be great to see the values of the different results, and especially how the different runs agree with the observations. More details on the choice of runs selected should also be added.

p.9 l.22-26: This paragraph is not clear.

p.9 l.27: scaling of what? How is that done?

p.10 l.6: What is 3.3?

p.10 l.14-18: I think this could be easily simplifies in saying that you use the volume above flotation.

p.10 l.21: Mention that is the present-day simulated state.

p.10 l.21: It is not clear what you mean by calving ratio.

p.10 l.23: The grounding line position is not clear on the figure, the ice front position is. Also most of these glaciers do not have any floating tongue, so it would be better to use the term ice front in this case.

p.10 l.21-30: Do you actually want the glaciers to be stable or to be representative of the present-day conditions? Because many of these glaciers are losing mass and retreating today, so how much should a spin-up with present-day conditions lead to stable conditions?

p.11 l.2: I thought that most of these glaciers did not have floating termini anymore!

p.11 l.6 “by Enderlin ..”

p.11 l.17: The numbers you provide do not include the present day changes? This is quite surprising and ends up presenting very low sea level change numbers that are not in good agreement with today's observations. It also questions the initialization procedure of the model, how much can we separate the present state and future changes given that the initial conditions have a lasting effect on the results.

p.11 l.26: "excluding" → "separating"

p.11 l.27: This is not very clear, try to better separate the numbers for SMB only, elevation feedback, climate change trend, ocean, ... as is done in figure 11.

p.11 l.30: "substantially" → "substantial"

p.12 l.13: The potential SLR and grounding line retreat are actually not listed in the tables.

p.12 l.15: "uncertainties" → "spread"

p.12 l.18: There is only one model used to generate SMB, so where is the spread coming from? It is not clear if is caused only by the different initial conditions used or if there is something else. Also, why is there only one model used to generate SMB and several for the ocean?

p.13 l.1: "1D line plume model" → "1D plume model" (same in other places in the manuscript). Also "Jenkins (2011)" → "(Jenkins, 2011)"

p.13 l.12: How does that compare to other 2D or 3D models of Jakobshavn [e.g., Muresan et al., 2016; Bondzio et al., 2017]?

p.13 l.19-20: remove

p.13 l.30-35: Use present tense instead of past tense

p.14 l.5: What are the numbers for the entire Greenland if you only take the same glaciers as Nick et al. [2013]? How are these numbers impacted by the choice of glacier? So, if you only include a subset of the 10 glaciers used in this study, how does the sea level contribution of Greenland vary? It would be interesting to compute some kind of uncertainty associated with this method.

p.14 l.7: “our our”

Fig.2: Is there a white dot in the fjord? It’s not very clear. I don’t understand the choice for the use of CTD profiles. Why not use all (or a combination of the different) profiles? “depth of 400 m” → “depth of at least 400 m”. “od” → “of”

Fig.3: The temperature from the reanalysis data at 700 m depth is quite off compared to the CTD. What are the implications for the plume model and the glacier evolution?

Fig.4: same as Fig.3

Fig.6: It would be better to label all the dots (they are only 12). Again here, why use the depth-averaged temperature and not the temperature that most impact the plume model?

Fig.8: Why present the results from only one ocean model and not from all of them? What is the implication of large discrepancy at 700 m depth between the model and the CTD measurement?

Fig.9: Is the observed bedrock directly taken from the BedMachine dataset along the centerline or is it representative of the entire glacier (of its entire width)? How many stable states are used for each glacier? I could not find this information in the manuscript. And as mentioned above, do you really want the initial configuration to be stable or to represent the current state of the glacier? I am not sure “transparent lines” is the appropriate term.

Fig.10: “median-range3”: repeat the superscript meaning here. Fig.11: “vom” → “from”

Fig.12: Try to use the same order as for Fig.11 for the lines. Fig.13: Would be better to repeat the entire caption.

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Fig.14: What is “ocean temperature trend 1”?

Tab.2: I thought that most glaciers in Greenland did not had floating termini any more, so why are there relatively large ratios of melting?

Tab.4: It is not clear what the sum of grounding line retreat represent. It is a rather unusual metric.

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