Geometric Controls of Fjord Glacier Dynamics - response to reviewers III

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1 Response to editor

We would like to thank the editor for his additional remarks to improve our manuscript. We reply below by highlighting the editor's comments in italics above our answers. Changes made to the text are indicated under each of our answers in blue.

L144, 147 Please define S and dS in equation form.

Done.

The metric used to quantitatively link fjord shape with glacier retreat is the wetted area S: the submerged cross-sectional area of the fjord (Fig. 1b), which can be calculated at any point along an outlet channel according to

$$S(x') = \int_{y'_1}^{y'_2} D(x', y')dy' \tag{1}$$

where D is the water depth, y'_1 and y'_2 are the intersections of the water line in the fjord with the fjord walls so that $y'_2 - y'_1$ is the width of the outlet channel in a transformed coordinate system that is oriented such that the coordinates (x', y') are parallel and perpendicular to the center line of the outlet channel, respectively, at any given point. S combines information about the width and depth of a fjord and is thus a comprehensible parameter for comparing basal and lateral perturbations. Furthermore, it is straightforward to calculate its first derivative $\frac{dS}{dx'}$ (in the following written as dS for brevity) which yields information on the along-fjord change in width and/or depth.

L163, L180 Please consider using 'steady' instead of 'stable' (perhaps also a pet peeve of mine, and previously raised by reviewer 2, but stability should only be used when referring to the system-response of a steady state to small perturbations)

Done.

If the linear relationship between qGL/S and dS is indeed 'universal', and therefore applies to all laterally-confined glacier systems including the area of Jakobshavn identified in Fig 8c, why not overlay the data points from Fig 8d/8e on top of the results from idealized experiments in Fig 6?

As we state in the manuscript L348f, the relationship that we see for JI is of qualitative nature, "such that an increase in dS is generally associated with a decrease in Q_{GL}/S and vice versa". So the sign of the change in dS and Q_{GL}/S is inversely correlated for JI, not the actual values. Therefore, it would not be meaningful to plot the data points from Fig 8d/e on the same plot as the results from the idealized experiments - no visual correlation would appear.

We understand that we have not been clear enough in the usage of the word 'universal', i.e. whether we refer to it in the context of our idealized experiments only or also regarding the results for JI. We therefore suggest to remove the word universal from the section name 3.4, and make changes to the text as specified below to make it clear that the relationship is universal in the context of our idealized experiments, but not quantitatively universal to be applied directly to the results for JI.

L382f: Given these disparities between different settings, it is all the more compelling that we find the geometric relationship Q_{GL}/S over dS universal to all our idealized fjords.

L385: To the authors knowledge, this type of quantitative link between fjord topography and glacier response has not been established before,...

L11, L76. For clarity, consider replacing 'long-term study of the retreat' by '???-year simulation of the Holocene retreat of' ?

As given in L208f in the manuscript, the simulation of Jakobshavn Isbræ used here 'is a sensitivity experiment not meant to reflect the actual evolution of JI (Kajanto et al., 2020), [but] it is convenient for our purposes since it produces a long-lasting, dynamic retreat.' Since it therefore does not reflect the actual retreat of JI in the Holocene, we suggest to refrain from using the word 'Holocene' in L11 and L76 as it might give a false impression on the reader. However, we will add that the run simulates 8 kyr in section 2.5 'A real-world case study: Jakobshavn Isbrae'.

We focus on a 8000-year simulation of the retreat of JI from a sill at the fjord mouth of Jakobshavn Isfjord, to a point inland of today's GL position.

L87 Since spatial variations in shear stress form an important element of this study, readers less familiar with the parameterizations might like to see more detail on how viscosity is calculated in the model. E.g. can you provide an equation, which explicitly shows the dependency of the viscosity on the friction?

The phrase 'feedback between frictional heating and ice viscosity' simply refers to the fact that we use a thermal model to constrain ice viscosity, so 'frictional heating' here refers to the frictional heating between the ice crystals. Besides that, there is no specific feedback associated with friction between the ice and the fjord walls. We therefore suggest to rephrase and refer to Larour et al. (2012) where more details on the thermal model are given.

We use a thermal model (Larour et al., 2012) to constrain the ice rheology parameter, B, based on the temperature dependent relationship from Cuffey and Paterson (2010).

L93 Say 'Ice front retreat' instead of 'calving'? If $\sigma = \sigma_{max}$, the calving rate is equal to the ice velocity according to (1) and the ice front does not move.

Done.

L113 The description of the melt parameterization might need further clarification and/or an equation to describe its behavior. My understanding is that 30m/yr melt is applied to all floating nodes, and 200 m/yr to nodes along the ice front (effectively describing a fixed calving rate), is that correct? Also, do you use any of the sub-grid melt schemes in ISSM, which have been shown to influence GL dynamics?

ISSM accounts for mass loss through ocean induced melt in two different ways: 1) A melt rate (in this study 30 m/yr for the reference glacier) is applied to all floating parts of the glacier from below, thus thinning floating ice. Since ISSM assumes a direct connectivity between the ocean and the subglacial hydrology (not only for ocean melt rates, but also when calculating the effective pressure in the description of basal friction), this also applies to the elements in the basal cavities referred to in the last comment below. 2) A frontal rate of undercutting is applied to elements at the ice front if they are grounded, and thus effectively acts as an extra retreat rate. This parameterization in ISSM is grounded in the theory of ocean circulation in response to freshwater plumes at the grounding line, and experimentally derived using ocean model output (Rignot et al., 2016). The value chosen for this parameter encapsulates both the small scale calving events resulting from undercutting as well as the direct melt at the ice front. Morlighem et al. (2019) use salinity and water temperature outputs from ocean modelling to calculate the frontal rate of undercutting for glaciers in northwest Greenland, while we prescribe them as part of our idealized setup (using a conservative estimate of 200m/yr for the reference glacier).

We do use the sub-element melt scheme 'full melt on partially floating'. We have conducted experiments which indicate that the mesh is sufficiently refined in the vicinity of the grounding line that the type of subelement scheme for both friction and melt does not affect the simulations significantly.

L112ff: Ocean induced melting is parameterized through prescribed melt rates that are invariant of depth. On all elements that have a floating section, a fixed basal melt rate is applied, thinning the ice from below. The reference forcing for this subshelf melt rate used for model spin-up is 30 m yr^{-1}. All elements at the ice front are subject to a frontal rate of undercutting if they are grounded. This parameterization accounts for both small scale calving events associated with undercutting and direct melt at the ice front (Rignot et al., 2016; Morlighem et al., 2019). The reference forcing here is 200 m yr^{-1}. Both values are on the lower end of observed melt rates (Motyka et al., 2003; Enderlin and Howat, 2013; Xu et al., 2013), thus reflecting a configuration prior to recent warming when glaciers were more in balance with the ambient climate than today (King et al., 2020). For both friction and melt, experiments not shown here indicate that the mesh is sufficiently refined in the vicinity of the grounding line that the type of subelement scheme chosen does not affect the simulations significantly.

L149 Refer to Fig2 here as well as Table2

Done.

L168 'GL position remains largely unchanged' instead of 'stable'

Done.

L223 Do you apply basal melt in these cavities? I assume not, since they are not connected to the open ocean? Please specify as part of the description in L113 (see comment above).

see above

References

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