EGUSphere-2024-665 – Response to referee 2

February 12, 2025

We thank the reviewer for the constructive comments that have helped us improve the manuscript. Below we provide a detailed discussion of the comments and proposed changes. We use blue colour to indicate **comments**; our **replies** are in black.

1 General comments

In summary, I would be glad to recommend the manuscript to publication if the authors shift its focus from the drainage of the lake on Amery Ice Shelf to a more general question of tidally induced stresses at the grounding line in the presence of supraglacial water.

Thank you for suggesting refocusing our study on the broader question of tidally induced stress and grounding-line migration. We have reorganized the manuscript as following:

- The Introduction and Results sections now emphasize the general viscoelastic grounding-line model. In the Results section, we present a reference case, analyze its sensitivity to the Deborah number (i.e., the ratio of the Maxwell time of ice to the tidal period) and bedslope, and introduce a hydrofracturing model incorporating tidal stress.

- In the Discussion, we explore an application of this model to the Amery Ice Shelf grounding zone while addressing the limitations of this approach, which include neglecting the lateral stresses and confinement that may contribute to discrepancies between our model and the observations reported in Trusel et al. [2022].

2 Specific comments

Many statements appear to be at odds with themselves. For instance, sentences in lines 61-62 state that the semi-diurnal period of 12 hrs is close to the Maxwell time.

Thanks for pointing out this inconsistency regarding the Maxwell time. We agree that the estimate of 120 hours is significantly larger than the semi-diurnal tidal period, meaning the ice behaves predominantly elastically in the reference case. We have revised the relevant text accordingly.

Taking another close look at Fig. 1, it is not clear to me how strain rates shown in panels (c) and (d) have been computed for the portion of Amery Ice Shelf where the lake is located.

We apologize for the confusion here. We have clarified our method to calculate the along-flow and transverse strain rates. At each grid point, we calculate the ice velocity direction from the data as a unit vector $\left(\hat{v}, \hat{t}\right)$. The along flow strain-rate component $\dot{\varepsilon}_p$ and the transverse component $\dot{\varepsilon}_t$ are then computed as

$$\dot{\varepsilon}_p = \hat{\boldsymbol{v}} \cdot \dot{\boldsymbol{\varepsilon}} \cdot \hat{\boldsymbol{v}}, \quad \dot{\varepsilon}_t = \hat{\boldsymbol{v}} \cdot \dot{\boldsymbol{\varepsilon}} \cdot \hat{\boldsymbol{t}}, \tag{1}$$

where $\dot{\boldsymbol{\varepsilon}}$ is the strain rate tensor, and "$\cdot$" denotes dot product. As the reviewer pointed out, this approach does not account for changes in ice flow direction, such as the right turn where the ice flow encounters the shear margin of the Amery Ice Shelf. Thus, we might underestimate the transverse stress near the grounding line. However, $\dot{\varepsilon}_p$ and $\dot{\varepsilon}_t$ remain useful indicators of local stress in ice for the outlet glacier upstream of the grounding line. The previous Fig. 1 (now revised Fig. 7) showing ice flow in the Amery grounding zone is simplified to avoid this confusion.

It appears that there are continuing confusions about the leading-order momentum balance of ice flow in particular geometric settings...As apparent from this expression, despite the fact that shear at the centerline is zero, the ice flow along it, as well as through the glacier width, is strongly affected by the lateral shear at its sides, and the narrower the width, the larger its effects are...The tidal response of narrow outlet glaciers is also strongly affected by their lateral confinement.

We agree that lateral shear stress and lateral confinement of ice flexure can contribute to the momentum balance along the flow line and modify the tidal response at the outlet glacier studied in our manuscript. To address this, we have moved the application of our model to the Amery Ice Shelf from the Results section to the Discussion, where we assess its performance against the only available observational benchmark (to the authors' knowledge). Additionally, to explain the discrepancies between our model and the data, we have expanded the discussion to include the effect of missing lateral boundary conditions and relevant references.

However, this study and its results as they are, can be applied to many other locations where ice flow upstream of the grounding line is laterally unconfined. Without claims that the results explain this particular lake drainage, the manuscript is a solid and very useful contribution to the literature. By moving away from this specific location, the authors can use a much wider range of parameters and consider circumstances, for which Maxwell rheology is not only appropriate but also necessary. Their sensitivity analysis to the Maxwell time becomes more valuable as they can consider many locations with broader range of the ice viscosity values.

The sensitivity of our results to the Deborah number De is evaluated in Figure 1. We employ two parameterization schemes to vary De: modifying the shear modulus μ (circular markers) or the prefactor A_0 (square markers) in Glen's flow law ($\eta \propto A_0^{-1/n}$). The variation in μ accounts for crevasses and damage that weaken the ice shelf, while the variation in A_0 represents thermally controlled viscosity variations.

As shown in Figure 1, variations in A_0 have minimal impact on Δx_g and $\sigma_{xx,max}$. Increasing A_0 slightly reduces tidal stress due to the associated decrease in viscosity. In contrast, by fixing A_0 and increasing the shear modulus ($\mu \rightarrow \infty$), the tidal stress increases as ice becomes viscous. Finally, we benchmark our results against the viscous contact problem in Stubblefield et al. [2021].

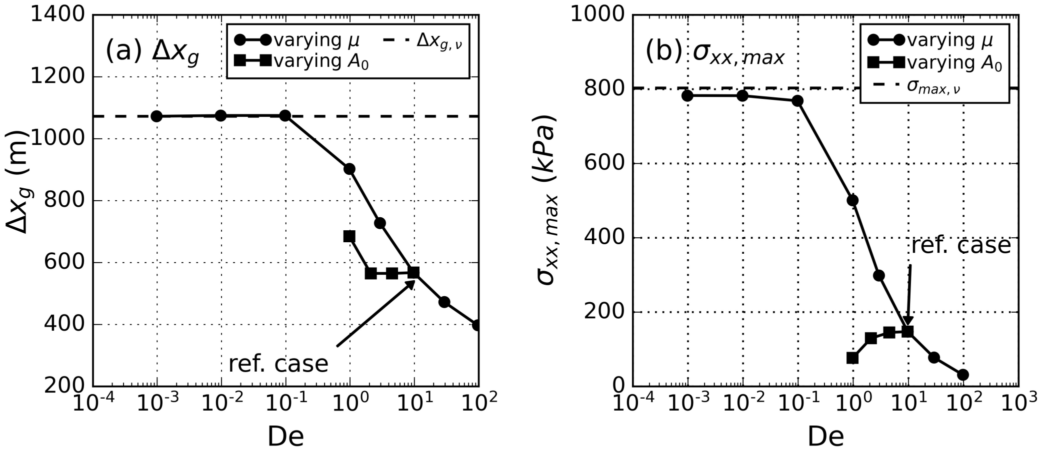

Figure 1: **(a)** The grounding-zone width Δx_g (solid lines), defined as $\Delta x_g = \max\{x_r\} - \min\{x_l\}$ as a function of De. We vary De by using two different schemes: (1) varying μ (round dots) from $\mu = 3 \times 10^7$ (right) to 3×10^{12} Pa (left); (2) varying A_0 (square dots) from 1.2×10^{-25} (right) to 1.2×10^{-22} Pa^{-3}s^{-1} (left). The dashed line is $\Delta x_{g,\nu}$, the grounding-zone width in the viscous limit ($\mu \to \infty$, $A_0 = 1.2 \times 10^{-25}$ Pa^{-3}s^{-1}). **(b)** Maximum tensile stress $\sigma_{xx,max}$ versus De through a varying μ (round dots) or a varying A_0 (square dots). The dashed line is the tidal stress calculated by the viscous model [Stubblefield et al., 2021]. The numerical reference case is labelled in both panels.

References

Aaron G Stubblefield, Marc Spiegelman, and Timothy T Creyts. Variational formulation of marine ice-sheet and subglacial-lake grounding-line dynamics. *Journal of Fluid Mechanics*, 919, 2021. doi: 10.1017/jfm.2021.394.

Luke D Trusel, Zhuolai Pan, and Mahsa Moussavi. Repeated tidally induced hydrofracture of a supraglacial lake at the amery ice shelf grounding zone. *Geophysical Research Letters*, 49(7): e2021GL095661, 2022. doi: 10.1029/2021GL095661.