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Sensitivity of grounding-line migration to ice-shelf pinning

Thomas Gregov[1,2], Frank Pattyn[2], and Maarten Arnst[1]
[1]Aérospatiale et Mécanique, Université de Liège, Liège, Belgium (thomas.gregov@uliege.be, maarten.arnst@uliege.be)
[2]Laboratoire de Glaciologie, Université libre de Bruxelles, Brussels, Belgium (frank.pattyn@ulb.be)

Marine ice sheets are essential components of the climate system, with dynamics strongly influenced by interactions with the atmosphere and the ocean. The grounding line, which separates the grounded region of the ice sheet from the floating region, plays a key role in the evolution of marine ice sheets. While numerous studies have focused on grounding-line migration and its sensitivity to physical processes, the influence of localized bedrock features, known as pinning points, remains less well understood. These pinning points can locally ground the floating ice, thereby altering ice flow by providing additional resistance.

Here, we investigate the impact of pinning points on marine ice-sheet dynamics using numerical simulations. The discontinuity in the momentum balance at the grounding line results in a component of the Jacobian matrix for the linearized problem becoming unbounded near pinning points. This behavior is intrinsic to the system and persists regardless of numerical discretization, even over smooth bedrock geometries and with friction laws that vanish at the grounding line. This suggests adopting a regularized approach that ensures a smooth transition between the grounded and floating regions. Based on numerical experiments in idealized setups, we show that a regularized formulation produces results that are qualitatively different from those of the original, unregularized formulation. Hence, the regularization appears a singular perturbation to the equations. This raises interesting questions about the treatment of grounding lines in marine ice-sheet models. Finally, we discuss potential approaches to mitigate this singular behavior and improve the modeling of marine ice sheets and of their grounding lines.