# Implications of ice rises for marine ice sheet dynamics, stability and hysteresis

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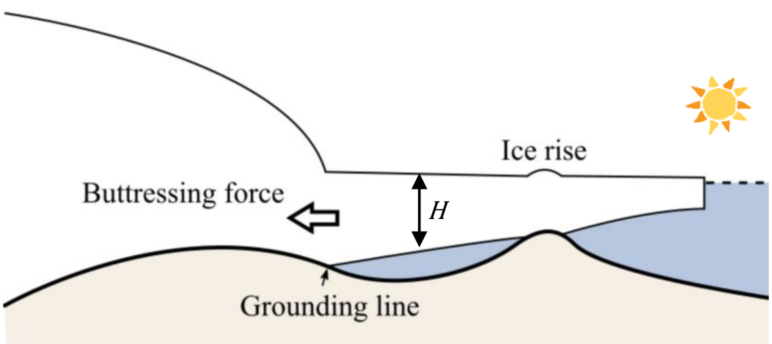
Our ability to predict the future evolution and potential collapse of the West Antarctic Ice Sheet (WAIS) – a colossal marine ice sheet – is constrained by resolving an effect of its ice shelves (the peripheral floating sections) in creating a **buttress** that supports its interior grounded ice from surging into the ocean. Recent work is showing that ice-shelf buttressing can completely control large-scale marine ice sheet dynamics and challenges some longstanding theoretical ideas in glaciology consistent with previous 1D analysis; this includes the possibility of completely suppressing the marine ice sheet instability mechanism [1]. Small details of 2D ice-shelf flow can in fact control the large-scale stability of the entire ice sheet and, via buttressing, provides the key link connecting oceanography and glaciology.

This project will explore the implications of ice-shelf buttressing generated by so-called **ice rises** – localized patches of grounded ice arising downstream of the primary grounding line – as well as the conditions for their development. The WAIS's Thwaites Glacier is perhaps the least stable glacier on Earth because its ice rise may be solely responsible for protecting its considerable drainage basin against surging into the ocean. This project will use analytical, numerical and asymptotic approaches applied to the governing thin viscous film equations to investigate the buttressing force generated by ice rises and their implications for critical transitions to ice-sheet collapse, and the conditions for irreversible change (hysteresis). Please feel free to come by and discuss, and I can send background reading by e-mail.




2D viscous film equations:

$$\overbrace{\nabla\cdot\left[\mu H\left((\nabla\cdot\boldsymbol{u})\mathbf{I}+\mathbf{e}\right)\right]}^{\text{Viscous stress}} = \overbrace{\frac{\rho g'}{2}H\nabla H}^{\text{Buoyancy}}$$

$$\frac{\partial H}{\partial t} + \nabla\cdot(H\boldsymbol{u}) = 0$$

**<u>Plan:</u>**

1) What are the **conditions for an ice rise to form** in steady flow? What is the **buttressing force** in terms of the height and width of an ice rise? (1D analytical analysis)
2) If an ice shelf thins (melts), calves or collapses so as to lose contact with an ice rise, **does it recover**? Warming may induce a critical detachment of the ice shelf from the ice rise, but does the marine ice sheet subsequently converge back to its original steady state if conditions return? A strong hysteresis effect is anticipated. Following ice-shelf collapse, a **race** initiates between grounding-line retreat and ice-shelf restoration; we can investigate the conditions under which either wins across a parameter space.
3) What happens in **2D**? Ice rises typically form localized "islands". In analogy with **2D Stokes flow**, even a single infinitesimal point of no slip has far-reaching implications that may dominate the buttressing force. We can explore the 2D dynamics using a premade numerical finite-element solver.
4) Another question concerns marine ice sheet dynamics in which the ice shelf is controlled dynamically by **coupling** with a lateral grounding line (rather than prescribing an ice-shelf width *a priori*, which is done in [2]). The new coupling between ice-shelf thickness and width creates a major new sensitivity between flux into the ice shelf and the buttressing force it generates. A generalization of the analytical theory of [2] could be developed alongside numerical investigations of the general case.

[1] S. S. Pegler, Suppression of marine ice sheet instability (*J. Fluid Mech.*, under review)

[2] S. S. Pegler, Marine ice sheet dynamics: The Impacts of lateral stresses (*J. Fluid Mech.*, under review)