A simple model for the buttressing of calving glaciers through ice mélange

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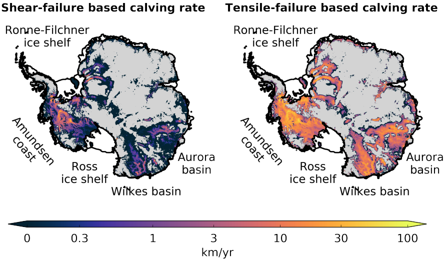
Calving parametrisations may give unrealistically large calving rates



Potential shear-failure based calving rates [1] and tensile-failure based calving rates [2] in the grounded, marine regions of the Antarctic ice sheet. Floating ice is shown in white and grounded ice above sea level in grey. In the marine regions, ice is assumed to be at floatation thickness, which gives a minimal estimate of the potential calving rates. Estimates for shear calving rates go up to 65 km/a and estimates for tensile calving rates go up to 75 km/a. If the grounding line retreat is faster than the speed with which the glacier terminus thins to floatation, calving rates could be even larger.

- Calving parametrisations based on the stresses in the vicinity of the calving front [1, 2] (including cliff calving) can give unrealistically large calving rates in Antarctica.
- Imposing an upper bound on the calving rates is necessary to prevent runaway ice loss and to conform with observed paleo ice retreat [3].

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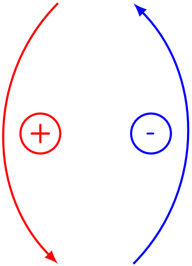
Negative feedback loop between calving rate and mélange buttressing

Ice mélange is a mix of icebergs and sea ice commonly found within the embayment in front of calving glaciers.

Calving rate

Ice mélange consists of icebergs and sea ice. Recently calved off icebergs feed into the mélange.



Mélange buttressing has been observed to completely prevent calving in winter [4, 5] when mélange thickness and rigidity are large. In general, mélange buttressing reduces stresses at the calving front and therefore reduces calving rates.

Mélange thickness

$\leadsto$ upper bound on calving rates

Mélange buttressing model

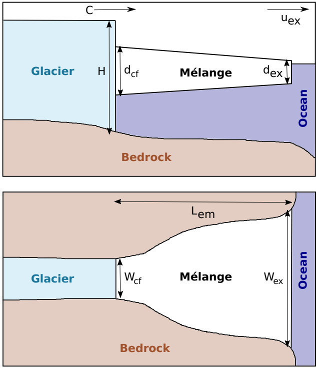
Assumptions

1. Calving rate C decreases linearly with increasing mélange thickness d_{cf}.
2. Mélange is in a steady state: mélange production through calving equals mélange loss by mélange exiting the embayment into the ocean.
3. Mélange thickness decreases linearly along the length of the embayment.

Buttressed calving rate C

$$C = \frac{C^*}{1 + C^*/C_{max}} \qquad (1)$$

where C^* is the unbuttressed calving rate.



Geometry of the glacier terminus, ice mélange and embayment as a side view and a top view. The side view shows the ice thickness H, the calving front thickness d_{cf} and exit thickness d_{ex} of the ice mélange as well as the calving rate C and the mélange exit velocity u_{ex}. The top view shows the embayment width at the calving front W_{cf} and the embayment exit W_{ex} as well as the length of the embayment L_{em}.

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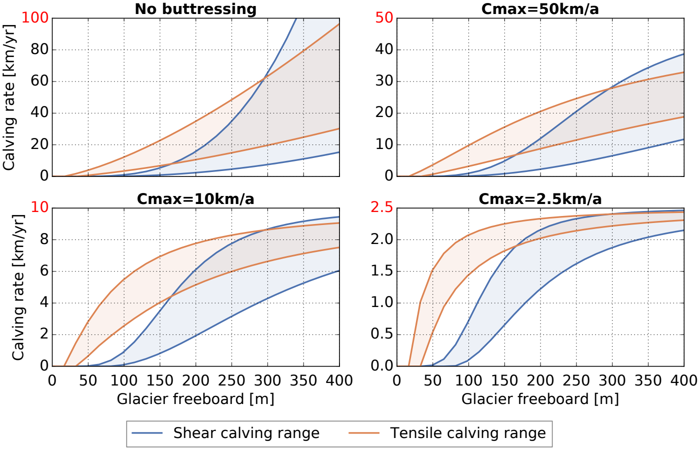
Application to two calving parametrisations



Calving rates as a function of glacier freeboard (ice thickness - water depth) in the unbuttressed case and for a range of upper bounds C_{max}. Shear calving and tensile calving rates depend also on the water depth: Two lines are shown for each configuration, the lower line for a dry cliff ($w = 0.0$) and the upper line for a cliff at floatation ($w = 0.8$). This spans the range of possiible calving rates for a given freeboard.

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Take home messages

- Stress-based calving parametrizations can give unrealistically large calving rates in Antarctica.
- Ice mélanges buttresses calving fronts and reduces calving rate.
- This negative feedback loop between calving rate and mélange thickness leads to an upper bound for calving rates.

For more details see

T. Schlemm and A. Levermann, "A simple model of mélange buttressing for calving glaciers," *The Cryosphere Discussions*, 2020. DOI: 10.5194/tc-2020-50.

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