A physically-based crevasse-depth calving model applied in two dimensions to marine outlet glaciers: implications for predicting future ice sheet dynamics

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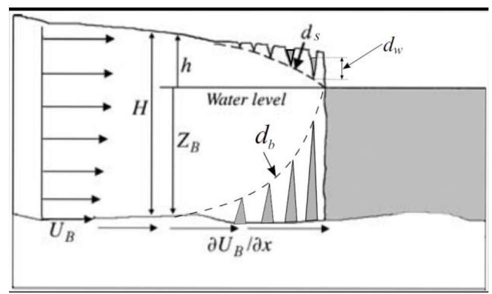
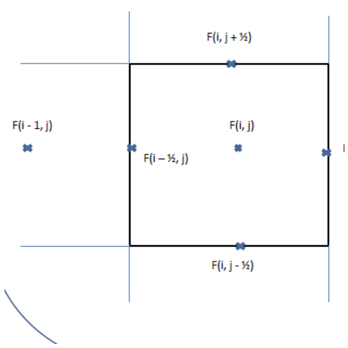
Why investigate Calving?

- Total Greenland mass loss has been reported at 0.76 mm yr^{-1} sea level equivalent over the last 10 years (Rignot et al., 2011).
- Much of Greenland drains through large tidewater terminating glaciers that have large confined ice shelves that buttress upstream ice.
- Calving events therefore influence grounding line movement and thus sea level change.

Crevasse Depth Calving Model (Adapted from Benn et al., (2007) and Nick et al. (2010)).



$$d_s = \frac{\sigma_1}{\rho_i g} + \frac{\rho_w}{\rho_i} d_w \qquad d_b = \frac{\rho_i}{\rho_p - \rho_i}\left(\frac{R_{xx}}{\rho_i g} - H_{ab}\right)$$



$$F(i,j) = H(i,j) - C(i,j) \qquad \textbf{(3)}$$

$$F(i,j) = h(i,j) - C(i,j) \qquad \textbf{(4)}$$

Upwinding Calving Scheme in BISICLES

$$F\left(i-\frac{1}{2},j\right) = \begin{cases} F(i,j) & u\left(i-\frac{1}{2},j\right) \le 0 \\ F(i-1,j) & u\left(i-\frac{1}{2},j\right) \ge 0 \end{cases} \qquad \textbf{(5)}$$

Calving occurs if $\sum F\left(i-\frac{1}{2},j\right) \ldots < \epsilon$ **(6)**

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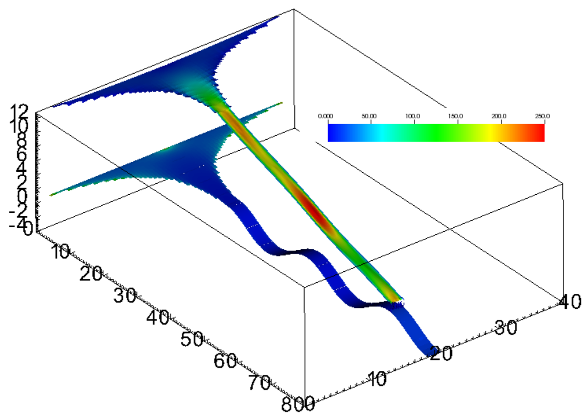
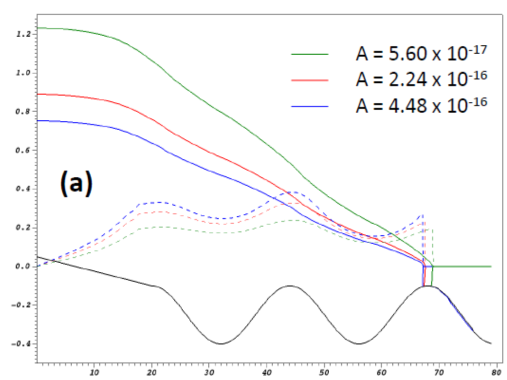
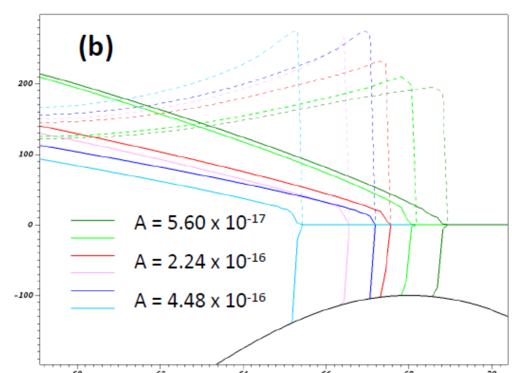
Model Testing



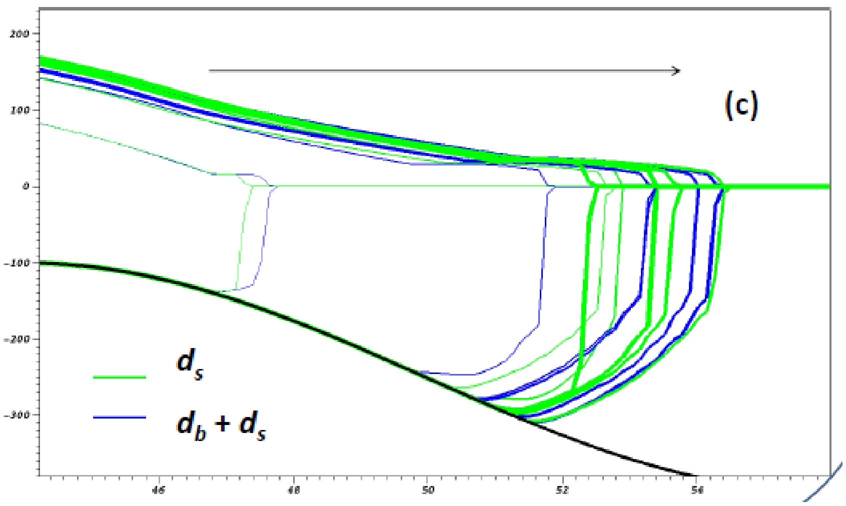
- Calving parameterisation applied to the 2D BISICLES ice sheet model
- Idealised experiment used based on 1D experiments of Nick et al. (2010).
- Adaptive meshing of BISICLES allows for 125m resolution in 2 km wide outlet channel.
- Shallow shelf approximation used.
- Zero-slip lateral boundary at ice margin with vertical rock walls. Effective pressure determines basal traction.





(a) Value of A determines initial surface profile. $A = 4.48 \times 10^{-16}$ corresponds with profile of Nick et al. (2010), in which $A = 5.6 \times 10^{-17}$

(b) Increasing the value of d_w to simulate glacier retreat



Advance experiments

- Start at profile at L=46 km
- Advance simulated by decreasing level of water in crevasses
- Results similar for both surface-waterline (ds) and full-thickness (ds + db) calving models.
- Note thickest lines not always furthest advanced. Repeated advance and collapse of floating ice

Discussion and Conclusion

- Crevasse-depth calving model can be successfully applied to a 2-dimensional time-dependent model.
- Upwinding scheme overcomes problem of fixed-grid models. Allows ice to advance when crevasse depth of thin ice advected into downstream cell would normally calve the advected ice.
- Surface crevasse (d_s) and full thickness (d_b + d_s) models produce similar advance patterns. Advance is slower than advance produced in Nick et al. (2010).