UNIVERSIDAD COMPLUTENSE MADRID
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
PalMA
IGEO
INSTITUTO DE GEOCIENCIAS
itabone@ucm.es

A multi-approach procedure to optimize continental-scale ice-sheet models

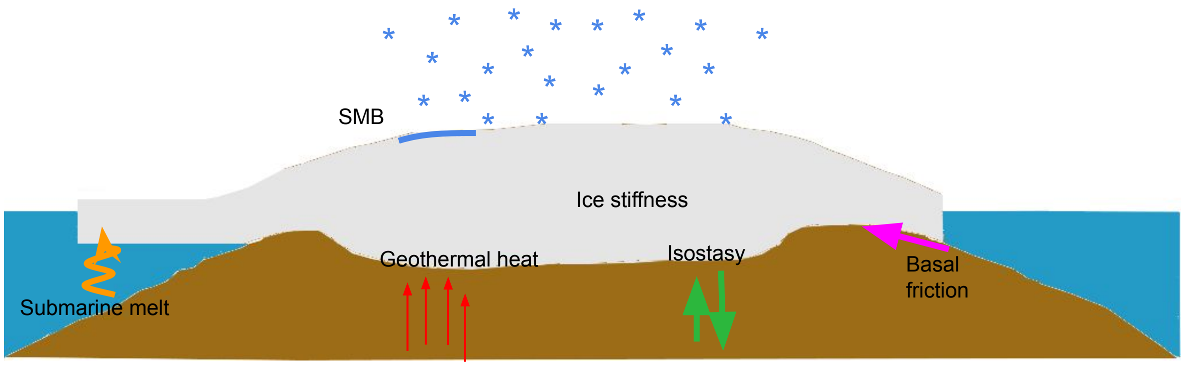
Ilaria Tabone

Alexander Robinson, Jorge Alvarez-Solas, Javier Blasco, Daniel Moreno and Marisa Montoya

Summary: Continental-scale ice-sheet models can make use of different friction laws available from the literature to represent drag at the ice base. Here we show how the choice of friction law may improve or weaken the performance of an ice-sheet-shelf model of coarse resolution (16 km) applied to the Greenland Ice Sheet in reproducing both present and past dynamics. Preliminary results suggest that laws that ensure a power dependence of friction to low basal velocities promote a good post glacial retreat into the present day.

Motivation

- Continental ice-sheet models are crucial to understand ice-sheets long-term evolution and their response to climate change.
- Yet, coarse-resolution models represent several physical processes and ice characteristics through model parameterisations.



- Model parameters need to be calibrated and validated against available observations -> ***models need to be optimized*** for reliable future projections and past reconstructions.

Ice dynamics optimization

- Availability of several friction laws with associated parameters makes the model optimization not straightforward and computationally expensive

$$\boldsymbol{\tau}_{\mathbf{b}} = -\beta\,\mathbf{u_b} = -C_{\rm b}\,f(|\mathbf{u_b}|, u_0)\,\mathbf{u_b} = \begin{cases} -\frac{C_{\rm b}}{u_0}\mathbf{u_b} & \text{linear law} \\ -C_{\rm b}\left(\frac{|\mathbf{u_b}|}{u_0}\right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|}, & \text{pseudo-plastic power law} \\ -C_{\rm b}\left(\frac{|\mathbf{u_b}|}{|\mathbf{u_b}|+u_0}\right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|} & \text{regularized Coulomb power law} \\ -C_{\rm b}\,\frac{\mathbf{u_b}}{|\mathbf{u_b}|} & \text{plastic law} \end{cases}$$

Is there any combination of friction parameters (and any law) that optimize the performance of continental ice sheet models at both present and past?

Experimental setup

- Ice-sheet-shelf model Yelmo (Robinson et al., 2019) applied to the Greenland ice sheet
- Basal friction parameterisations

$$\boldsymbol{\tau}_\mathbf{b} = -\beta\,\mathbf{u_b} = -C_\mathrm{b}\,f(|\mathbf{u_b}|, u_0)\,\mathbf{u_b} = \begin{cases} -\frac{C_\mathrm{b}}{u_0}\mathbf{u_b} & \text{linear law} \\ -C_\mathrm{b}\left(\frac{|\mathbf{u_b}|}{u_0}\right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|}, & \text{pseudo-plastic power law} \\ -C_\mathrm{b}\left(\frac{|\mathbf{u_b}|}{|\mathbf{u_b}|+u_0}\right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|} & \text{regularized Coulomb power law} \\ -C_\mathrm{b}\,\frac{\mathbf{u_b}}{|\mathbf{u_b}|} & \text{plastic law} \end{cases}$$

$$C_\mathrm{b} = c_\mathrm{f}\,N_\mathrm{eff} \qquad c_\mathrm{f} = f_\mathrm{temp}\cdot c_\mathrm{temp} + (1 - f_\mathrm{temp})\cdot c_\mathrm{frozen}$$

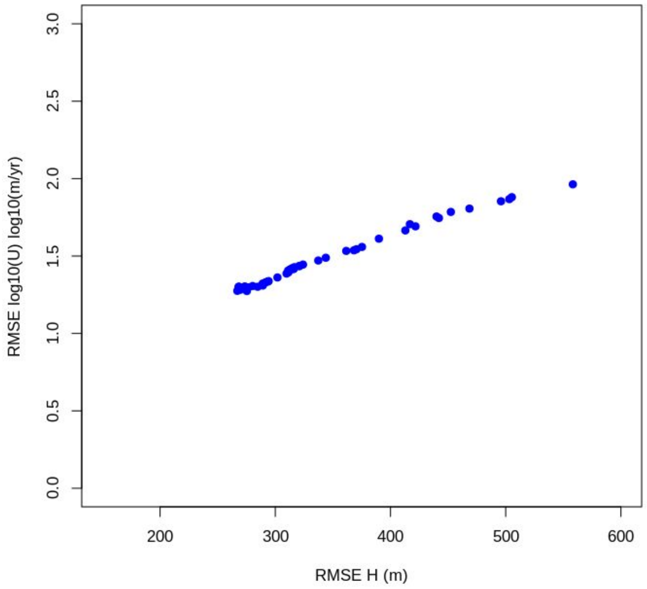
- Ensemble of 50 paleo (120 kyr ago-PD) simulations per law at 16 km res

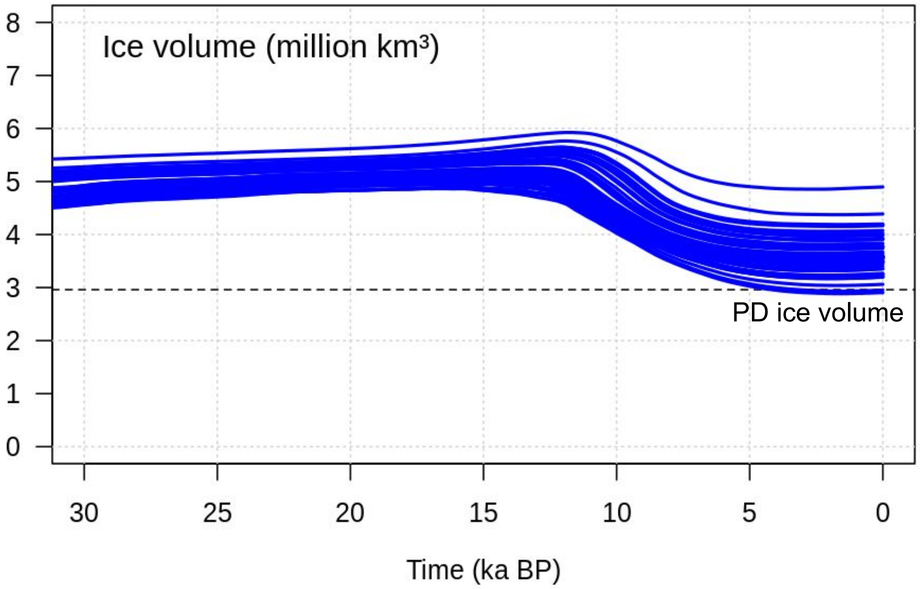
$c_{temp} \in (0.02, 0.2)$ $c_{frozen} = c_{temp}*10$ $u_0 \in (10, 400)$ m/yr $q \in (0.1, 1)$

sampled using the Latin Hypercube Sampling method

Linear law

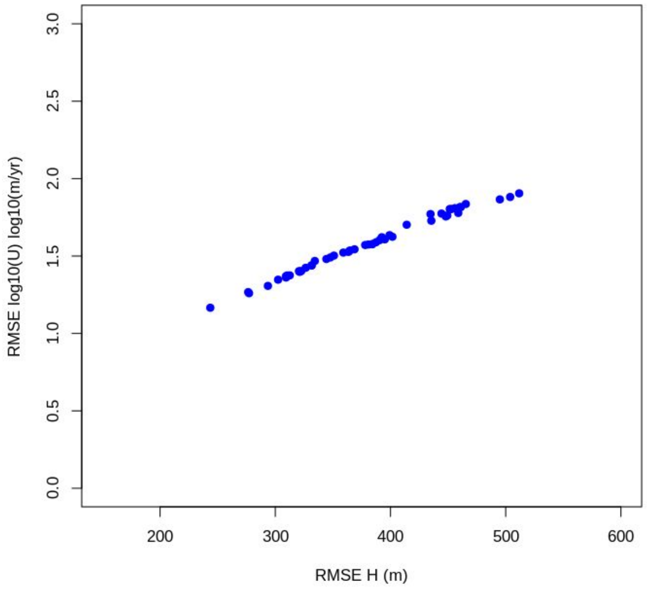
$$\tau_b = -\frac{C_b}{u_0}\mathbf{u_b}$$

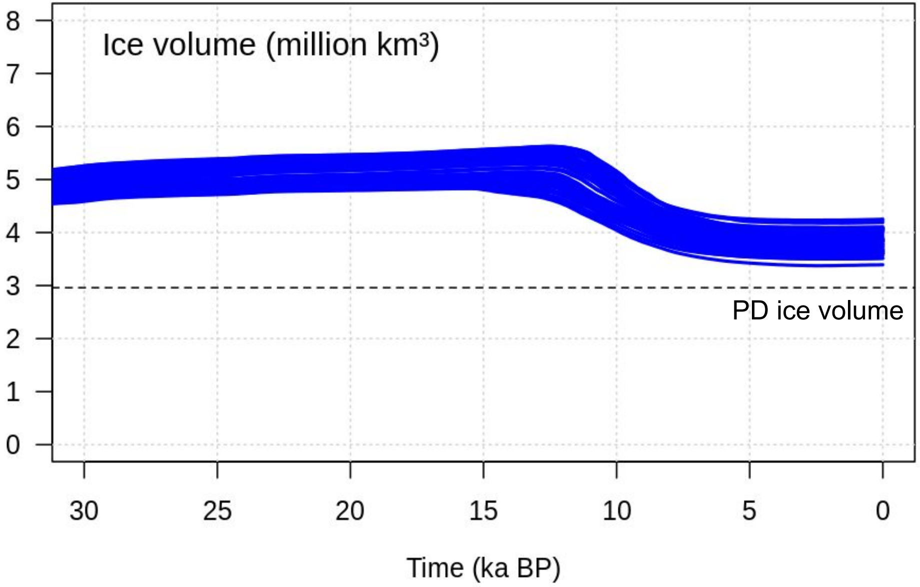




Plastic law

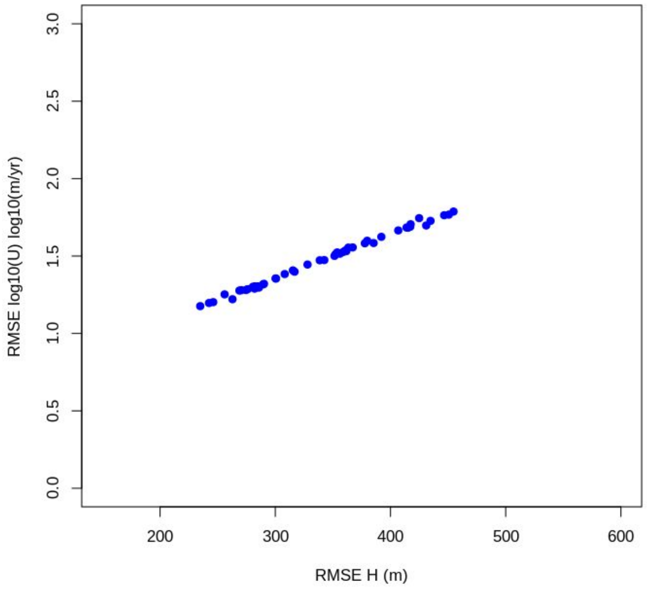
$$\tau_b = -C_b \frac{\mathbf{u_b}}{|\mathbf{u_b}|}$$

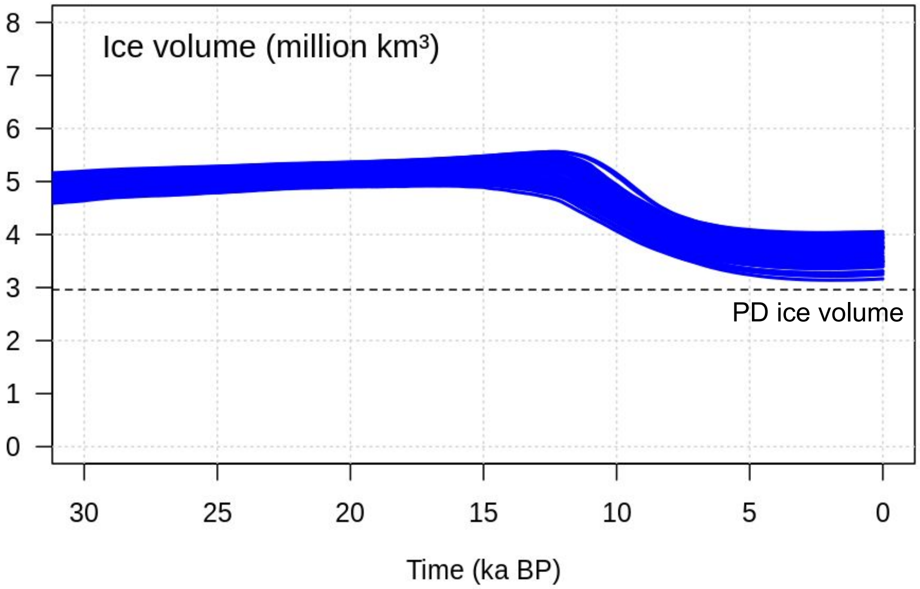




Pseudo-plastic power law

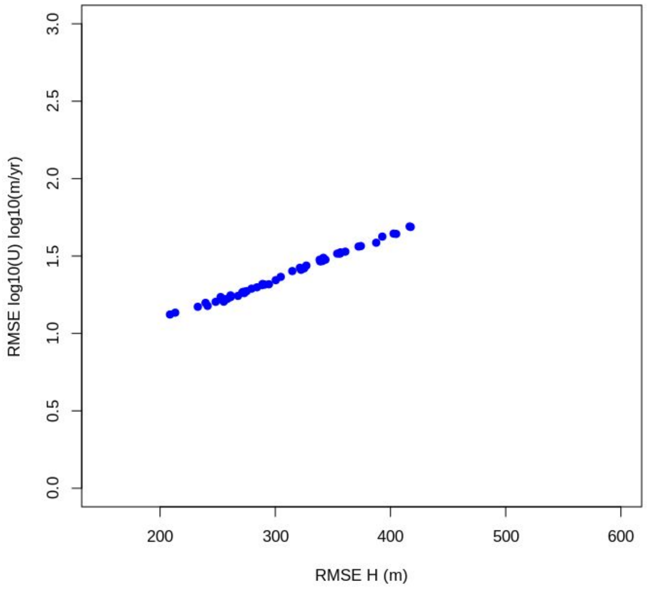
$$\boldsymbol{\tau}_b = -C_b \left(\frac{|\mathbf{u_b}|}{u_0}\right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|}$$

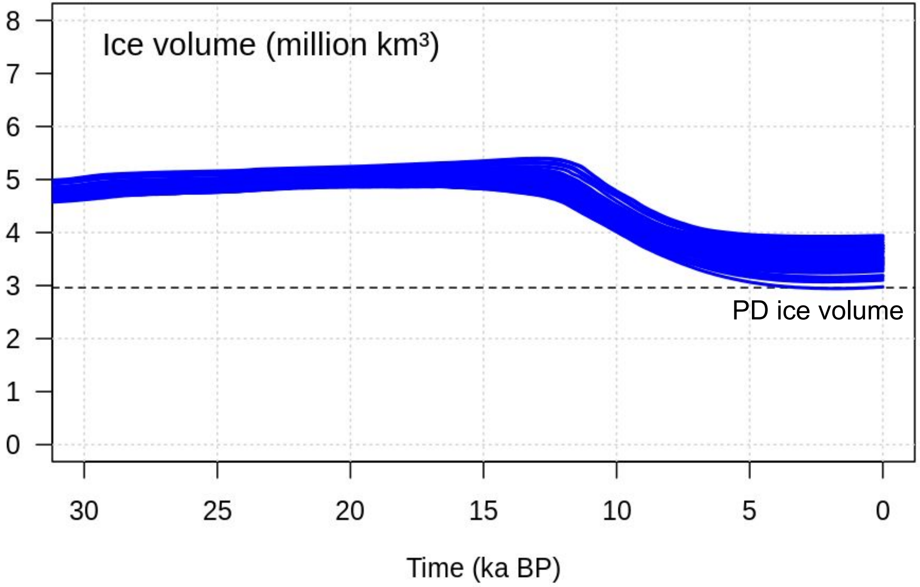




Regularized Coulomb law

$$\tau_b = -C_b \left(\frac{|\mathbf{u_b}|}{|\mathbf{u_b}| + u_0} \right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|}$$

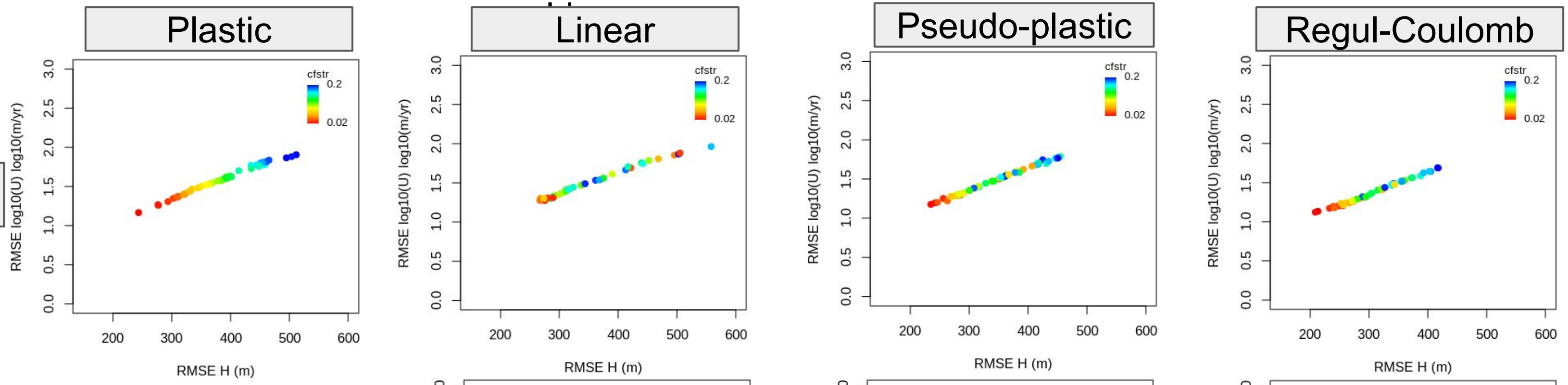




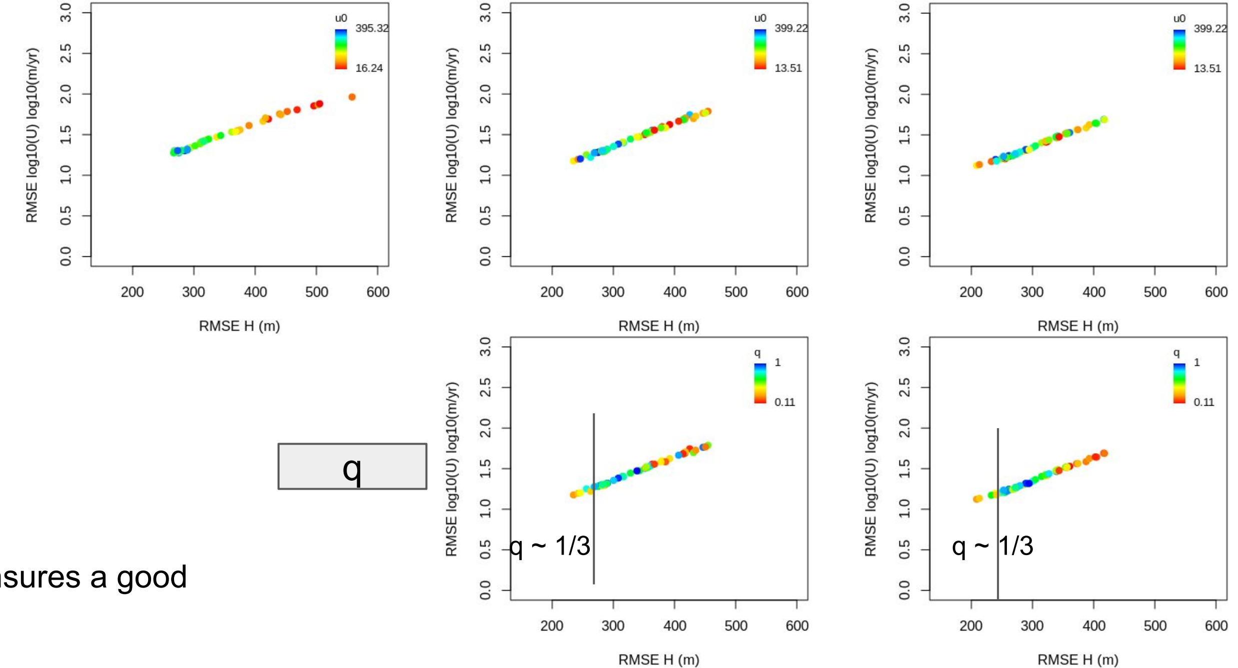
The performance, in terms of RMSEs and ice volume, improves from the linear to the regularized Coulomb law.

c_{temp}

No specific pattern for c_{frozen}



u_0

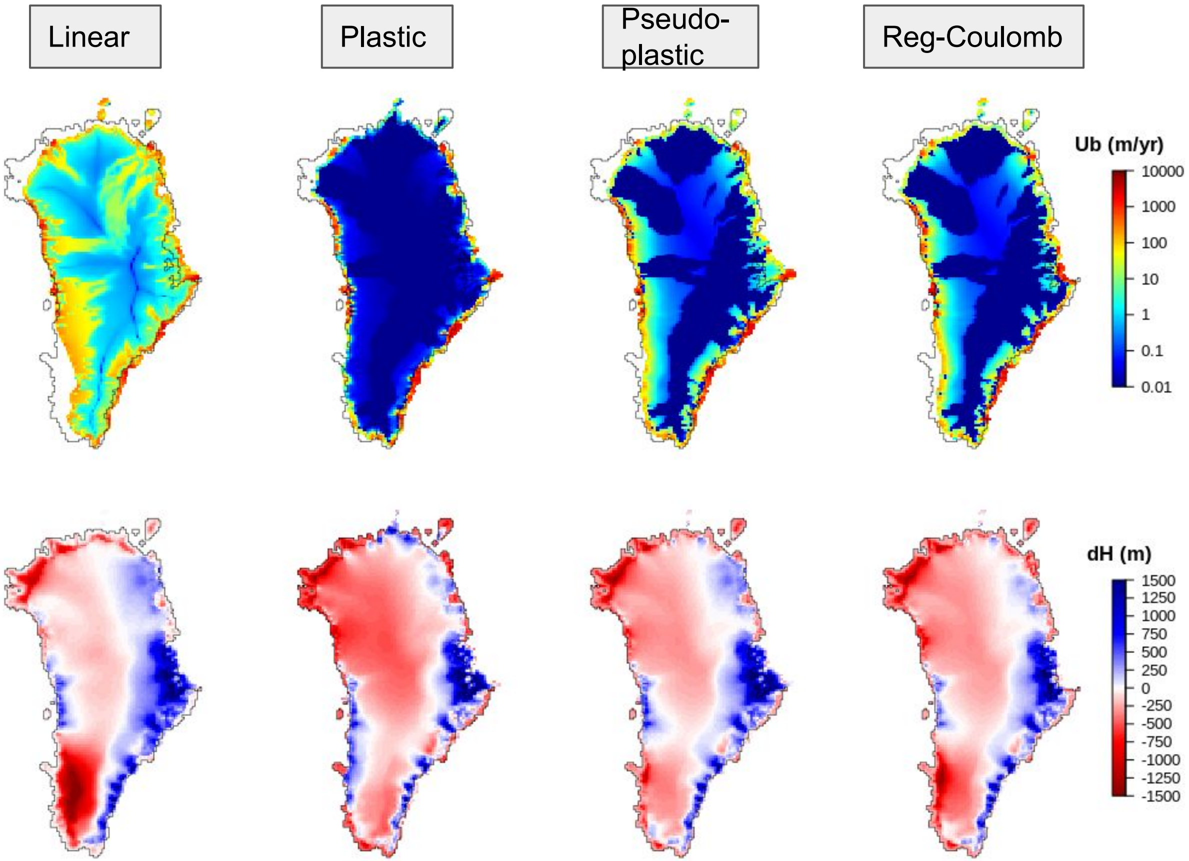


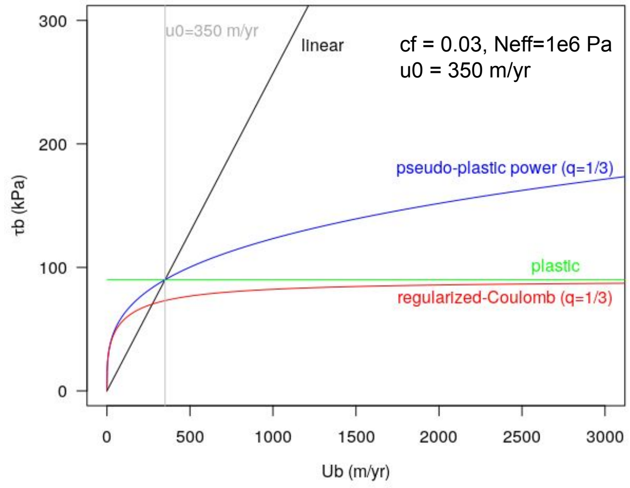
For a better performance:

- Low c_{temp} (all laws)
- High u_0 (linear)
- q~⅓ (power laws)

A constrained basal friction ensures a good glacial retreat into the PD.

Modelled PD from post-glacial retreat (best cases)



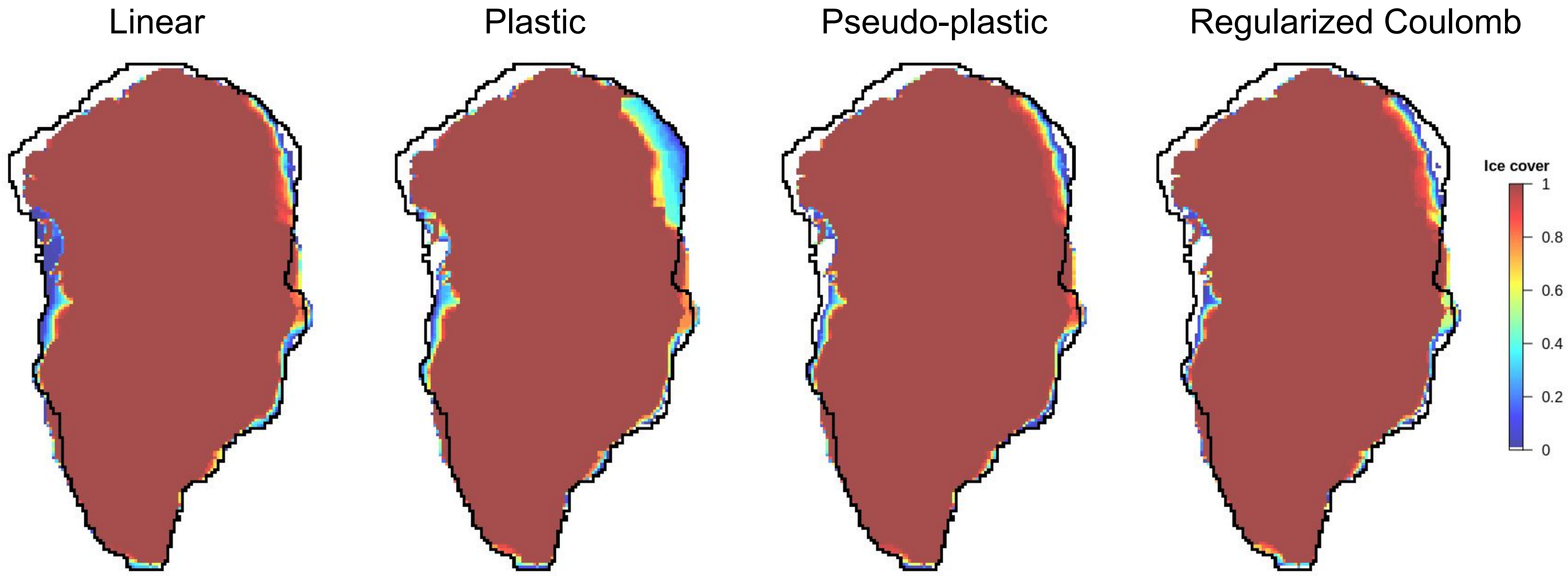


The goodness of the retreat strongly depends on the friction law behavior at low velocities.

- Linear function ensures rather low friction in the interior, leading to massive retreat.
- Plastic law: high friction for low U leads to low ice discharge and rather high dH
- Power laws (q~1/3): good balance between friction and sliding at low U.

Modelled glacial ice cover probability

Calculated for each ensemble of runs



The friction law plays a non-negligible role in areas with low bathymetry (e.g. North East and West).

Comments

- ***Model performance during the retreat into the PD depends on the applied friction law.***
- Common feature for a good post-glacial retreat: low friction coefficient Cb in temperate areas to limit friction.
- Generally, a power law for low Ub and plastic law-alike for high Ub promote a good retreat into the PD.
- Between linear, pure plastic, pseudo-plastic and ***regularized Coulomb law***s, we found that the latter (q~1/3) ***leads to the best PD configuration after a glacial retreat.***
- Yet, this fails for the glacial state, where the reg. Coulomb law limits the ice sheet extent.