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

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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.

\[ \mathbf{\tau}_b = -\beta \mathbf{u}_b = -C_b f (|\mathbf{u}_b|, u_0) \mathbf{u}_b = \begin{cases} -\frac{C_b}{u_0} \mathbf{u}_b \\ -C_b \left( \frac{|\mathbf{u}_b|}{u_0} \right)^q \frac{\mathbf{u}_b}{|\mathbf{u}_b|} \\ -C_b \left( \frac{|\mathbf{u}_b|}{|\mathbf{u}_b| + u_0} \right)^q \frac{\mathbf{u}_b}{|\mathbf{u}_b|} \\ -C_b \frac{\mathbf{u}_b}{|\mathbf{u}_b|} \end{cases} \]

linear law
pseudo-plastic power law
regularized Coulomb power law
plastic law

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

\[ \tau_b = -\beta u_b = -C_b f(|u_b|, u_0) u_b = \begin{cases} -\frac{C_b}{u_0} u_b & \text{linear law} \\ -C_b \left(\frac{|u_b|}{u_0}\right)^q \frac{u_b}{|u_b|} & \text{pseudo-plastic power law} \\ -C_b \left(\frac{|u_b|}{|u_b|+u_0}\right)^q \frac{u_b}{|u_b|} & \text{regularized Coulomb power law} \\ -C_b \frac{u_b}{|u_b|} & \text{plastic law} \end{cases} \]

\[ C_b = c_f N_{ef} \quad c_f = f_{\text{temp}} \cdot c_{\text{temp}} + (1 - f_{\text{temp}}) \cdot c_{\text{frozen}} \]

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

\[ c_{\text{temp}} \in (0.02, 0.2) \quad c_{\text{frozen}} = c_{\text{temp}} \times 10 \quad u_0 \in (10, 400) \text{ m/yr} \quad q \in (0.1, 1) \]
Linear law

\[ \tau_b = -\frac{C_b}{u_0} u_b \]
Plastic law

\[ \tau_b = -C_b \frac{u_b}{|u_b|} \]
Pseudo-plastic power law

\[ \tau_b = -C_b \left( \frac{|u_b|}{u_0} \right)^q \frac{u_b}{|u_b|} \]
Regularized Coulomb law

\[ \tau_b = -C'_b \left( \frac{|u_b|}{|u_b| + u_0} \right)^q \frac{u_b}{|u_b|} \]

The performance, in terms of RMSEs and ice volume, improves from the linear to the regularized Coulomb law.
For a better performance:
- Low $c_{\text{temp}}$ (all laws)
- High $u_0$ (linear)
- $q \sim \frac{1}{3}$ (power laws)

A constrained basal friction ensures a good glacial retreat into the PD.
Modelled PD from post-glacial retreat (best cases)

- 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 ($q \sim 1/3$): good balance between friction and sliding at low $U$.

The goodness of the retreat strongly depends on the friction law behavior at low velocities.
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 $C_b$ in temperate areas to limit friction.
- Generally, a power law for low $U_b$ and plastic law-alike for high $U_b$ promote a good retreat into the PD.
- Between linear, pure plastic, pseudo-plastic and regularized Coulomb laws, we found that the latter ($q \sim 1/3$) 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.