Supplement of The Cryosphere, 18, 5887–5911, 2024
https://doi.org/10.5194/tc-18-5887-2024-supplement

The Cryosphere
Open Access

Supplement of

A fast and simplified subglacial hydrological model for the Antarctic Ice Sheet and outlet glaciers

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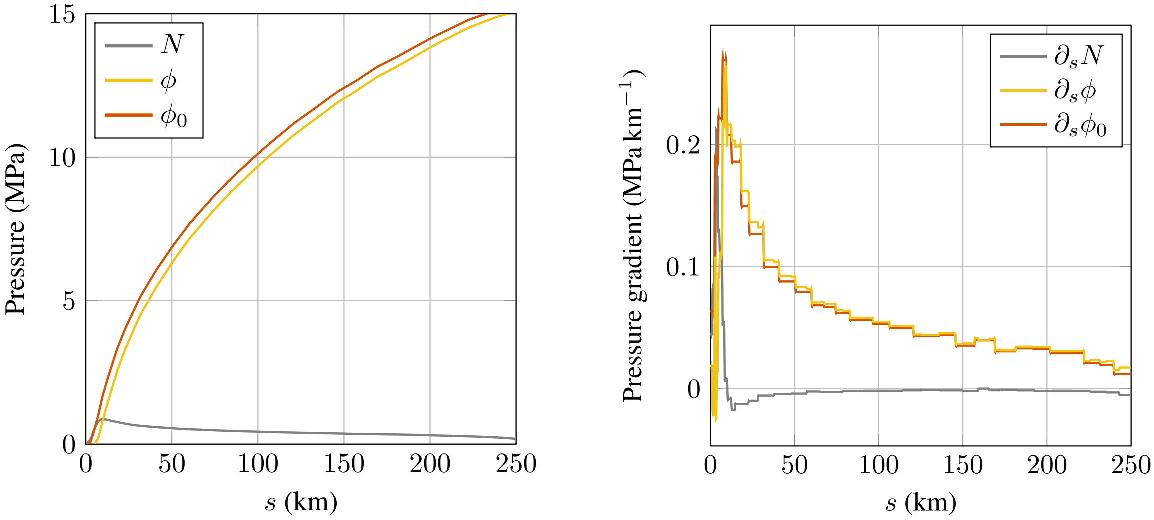
Contents

S1. Assessment of the hypothesis on the hydraulic potential using profiles from high-resolution subglacial hydrology models

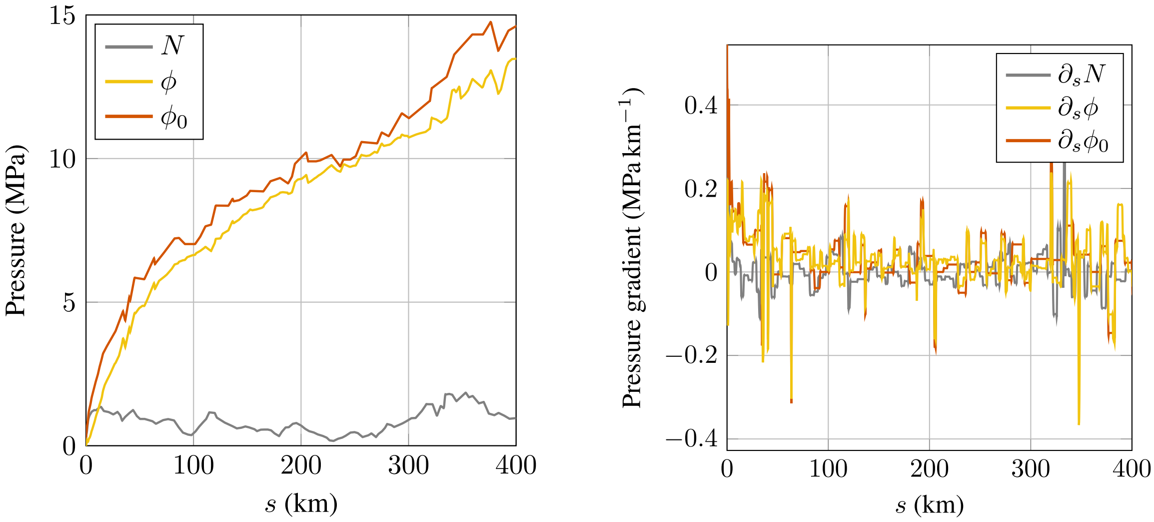
Here, we provide additional data to underpin the validity of the assumption that $\nabla\phi \approx \nabla\phi_0$ outside the range of influence of the grounding line, which is a few kilometers from it. Since there are no direct observations of the effective-pressure field in Antarctica, we have to rely on high-resolution models. A first test case comes from Lu and Kingslake (2023) who uses a high-resolution model that couples ice-sheet dynamics and subglacial hydrology for hard beds. Potential limitations of that study is that it considers a flow line and a smooth bedrock. The assumption that $\nabla\phi \approx \nabla\phi_0$ a few kilometers upstream of the grounding line is confirmed numerically (Figure S1).

A second test case comes from Hager et al. (2022) who applied the high-resolution model MALI (Hoffman et al., 2018) to Thwaites Glacier. They also consider a hard-bed hydrology. The computed effective pressures along a center-line transect are shown in Figure S2. Note that the signals are much more noisier compared to the first test case. This noise can be attributed to the model resolution, but also to the presence of localized hydrological features that cross the center-line transect at which the effective pressures are evaluated, therefore resulting in very localized variations. However, we observe a good correlation between $\partial_s\phi$ and $\partial_s\phi_0$ out of the vicinity of the grounding line (Figure S2): $\sim 80\%$ over the range $[10, 400]$ km, suggesting that the assumption that $\nabla\phi \approx \nabla\phi_0$ is valid in this region.



(a) Numerical results. (b) Computed gradients.

Figure S1: Data derived from Figure 4 of Lu and Kingslake (2023).



(a) Numerical results. (b) Computed gradients.

Figure S2: Data derived from Figure 8 of Hager et al. (2022).

S2. Initial conditions of Thwaites Glacier

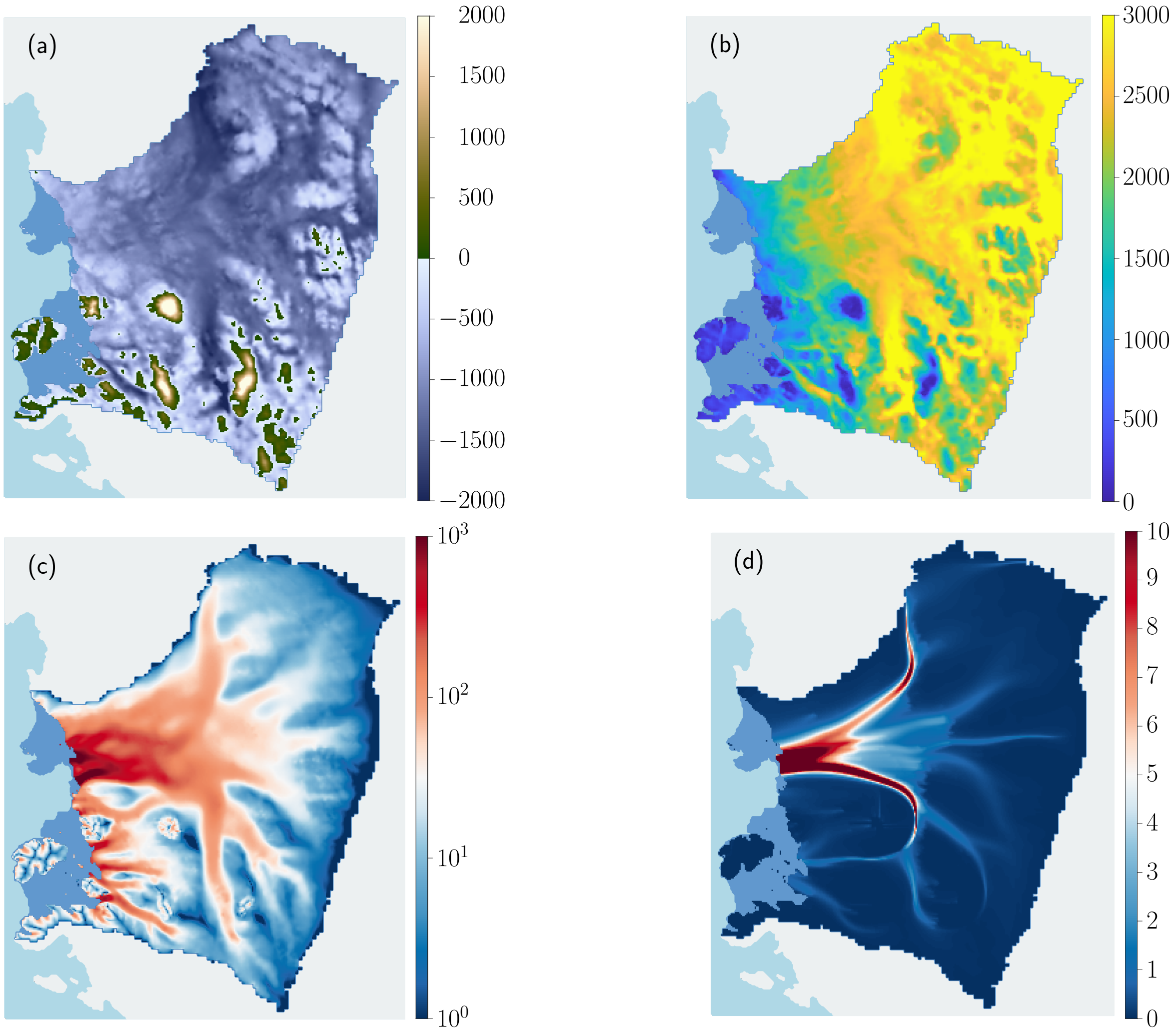


Figure S3: (a) Thwaites Glacier bedrock elevation (m), (b) ice thickness (m), (c) observed surface velocity (logarithmic scale, $\mathrm{m\,a^{-1}}$), and (d) distributed subglacial water flux ($10^4\,\mathrm{m^2\,a^{-1}}$). The bedrock elevation and ice thickness come from Morlighem et al. (2019), while the surface velocity and subglacial water flux are computed with the Kori-ULB model. Ice shelves are in blue, the Amundsen Sea in light blue, and grounded ice outside of Thwaites Glacier is in light grey.

S3. Friction coefficients after model initialization

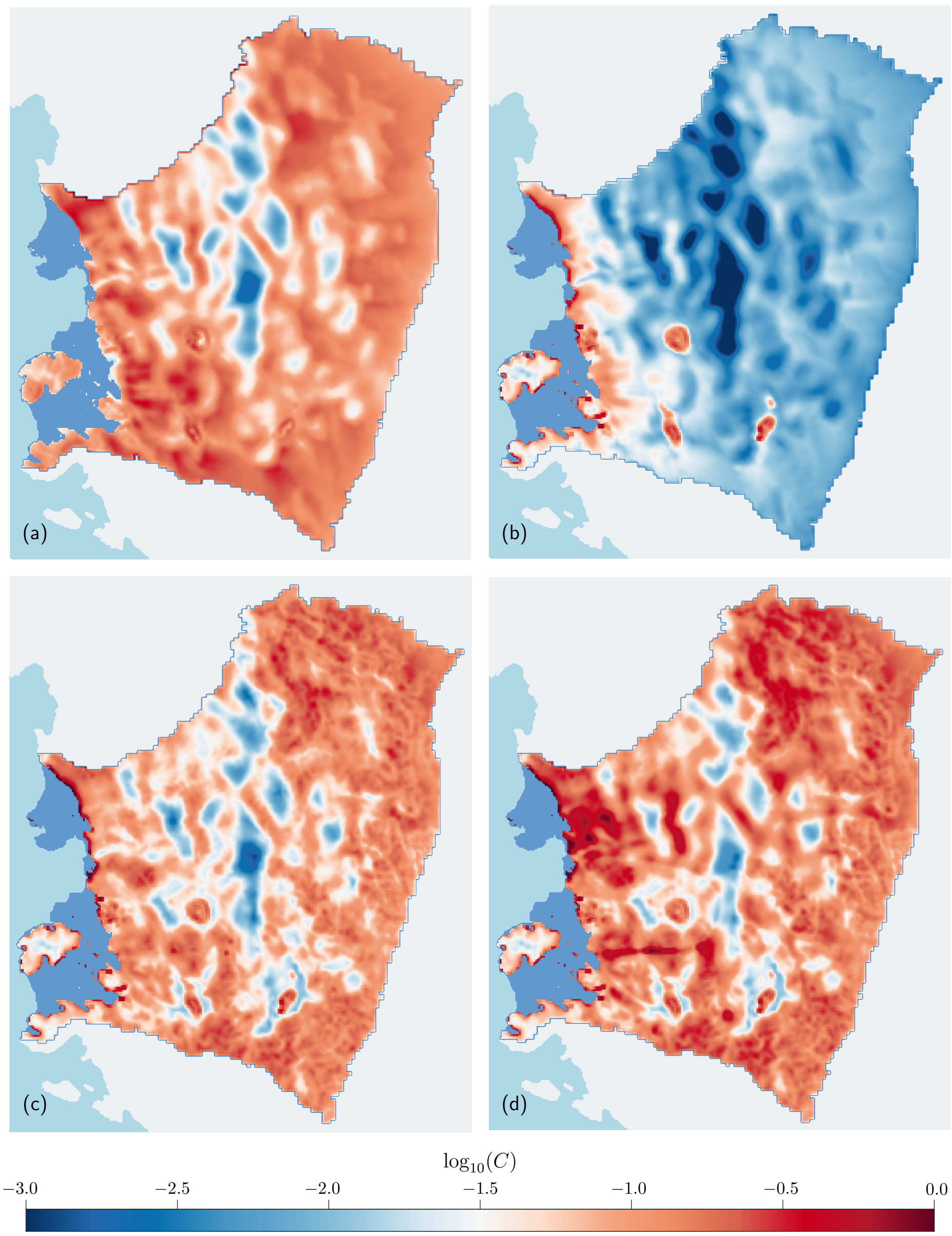


Figure S4: Friction coefficient C for (a) NON, (b) HAB, (c) HARD and (d) SOFT hydrological models, obtained after model initialization. Note that a logarithmic scale is used. For NON, N is set to 1 MPa to keep C dimensionless and comparable to the other friction fields.

S4. Effective pressure fields for HAB, HARD and SOFT models

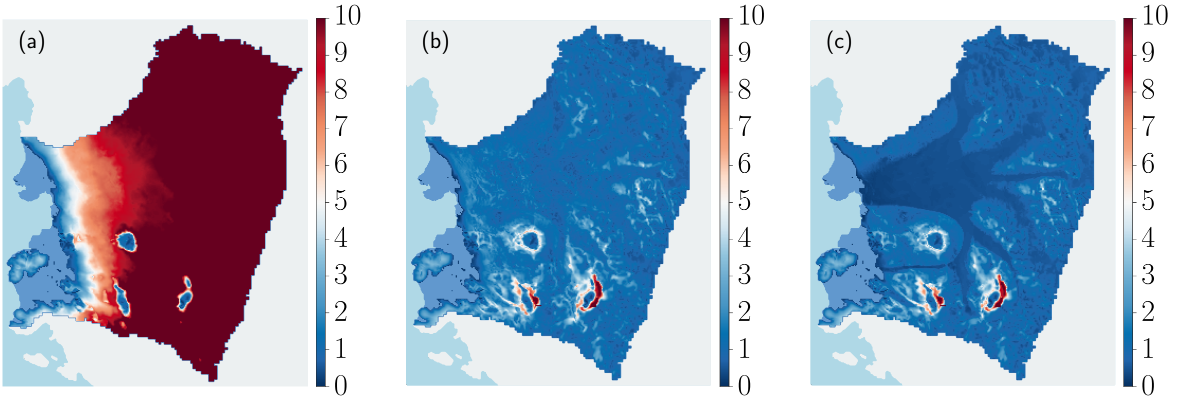
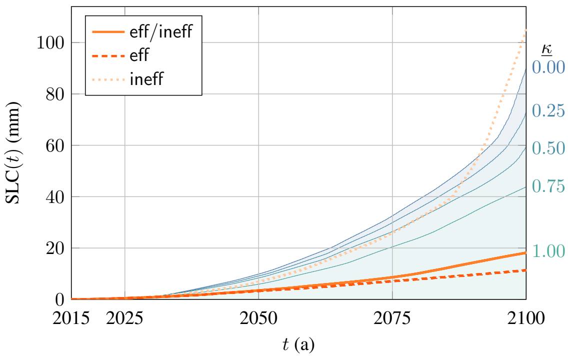


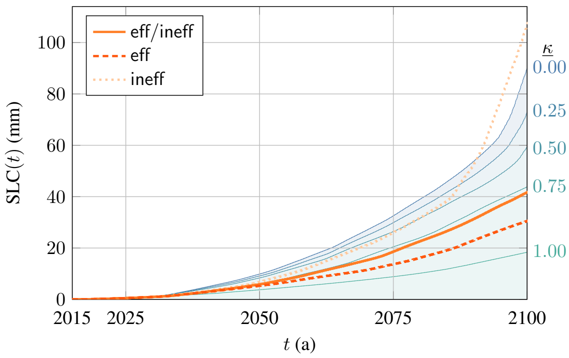
Figure S5: Effective pressure (MPa) for (a) HAB, (b) HARD and (c) SOFT hydrological models, in the initial configuration.

S5. Exchanging soft and hard bed regions

To confirm the hypothesis made in the results section of the paper, we inverted the location of hard and soft bed zones for heterogeneous beds, i.e., with hard beds occupying the depressions and soft beds on topographic highs. Although it sounds nonphysical and contradicts the data given in the literature, the idea is to test whether such configuration confirms our conclusions. Obtained sea-level contributions are similar to those obtained for a soft-bed system because the retreat of the grounding line has not yet reached the hard-bed zone. If we were to continue the simulation further in time, we would actually observe an acceleration when the grounding line would reach the hard-bed area, as expected.



(a) Sharp transition.



(b) Smooth transition.

Figure S6: Sea-level contribution of Thwaites Glacier from 2015 to 2100 under present-day climate conditions when a sharp (a) and a smooth (b) transition is made between a hard (in depressions) and a soft (on topographic highs) bed for combined inefficient and efficient (orange continuous line; default), entirely efficient (orange dashed line) and entirely inefficient (orange dotted line). Sea-level contributions in the case of homogeneous hard (blue), soft (green) and mixed (with $\kappa = 0.25$, $\kappa = 0.50$, and $\kappa = 0.75$; in a gradient of blue and green) beds are also shown.

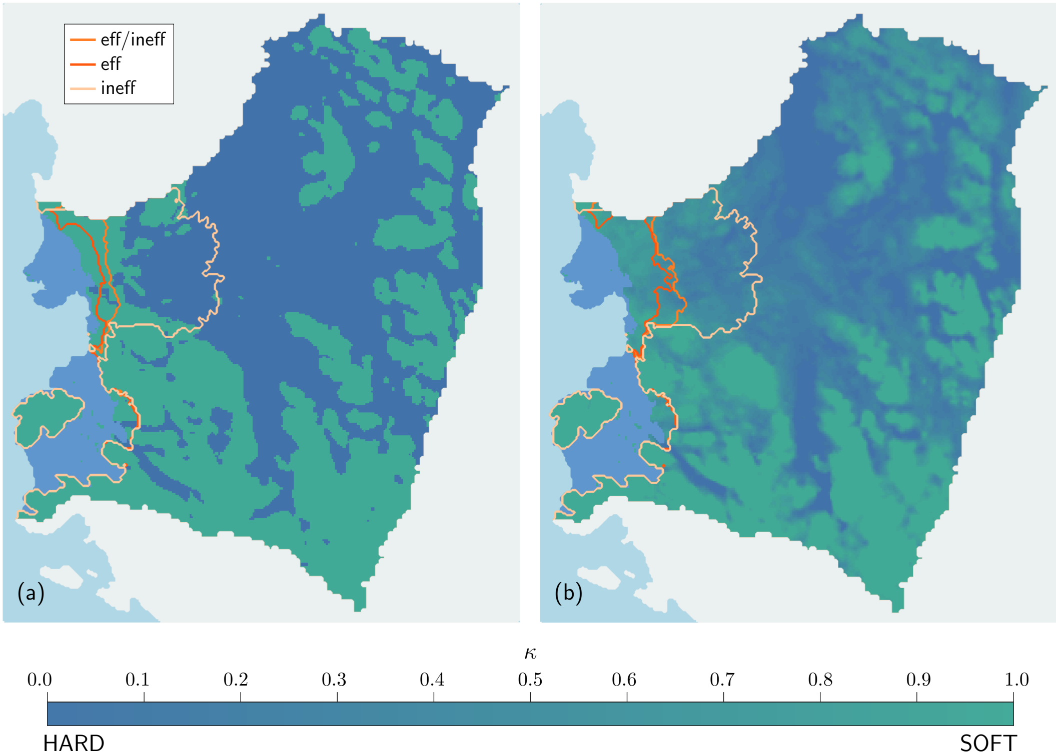


Figure S7: Grounding line position of Thwaites Glacier from 2015 to 2100 under present-day climate conditions when a sharp (a) and a smooth (b) transition is made between hard (blue,in depressions) and soft (green,on topographic highs) beds. Combined inefficient and efficient (orange), only efficient (red) and only inefficient (light orange).

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