Basal conditions of Denman Glacier from hydrology modeling and their application to various friction laws

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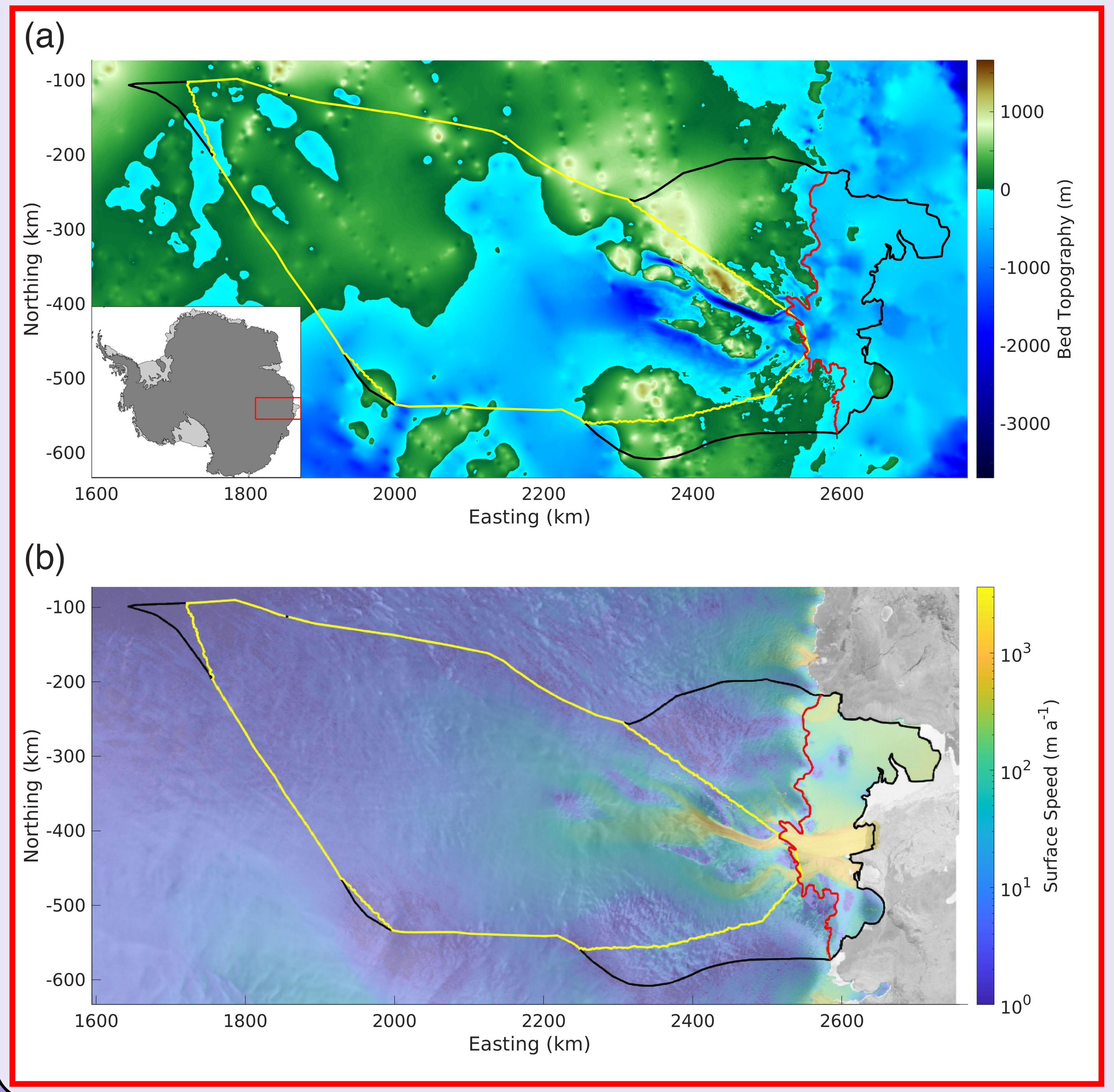
Introduction/Methods

Motivation/Plan

Basal hydrology plays an important role in basal friction/slipperiness, and hence the overall flow of ice sheets and glaciers[1]. Hydrological processes are often represented in basal friction/sliding laws via the effective pressure N (ice overburden minus water pressure). However, in the absence of subglacial hydrology model outputs, N is unknown, and this may impact the basal friction coefficient field when calculated using inverse methods. We investigate the impact of basal hydrology on the basal friction coefficients of the Budd[2] and Schoof[1] friction laws at Denman Glacier, East Antarctica. We produce an empirical parameterization of effective pressure to use in the abscence of a hydrology model.

Denman Glacier



Denman Glacier is located in East Antarctica where its grounding line has retreated by 5.4 km since 1996[3]. It has the highest ice shelf melting rate in the region of 116 m/a near the grounding line[4]. Denman drains an area of 1.5 m of sea level equivalent and lies on a deep subglacial trough extending more than 3.5 km below sea level[5]. Retrograde bed slopes lying below sea level can be found in the Denman/Scott Catchment.

Fig. 1: Denman-Scott catchment. (a) Bed elevation above sea level (m); (b) Ice surface speed (m/a). Black lines - ISSM domain and catchment outline; Red line- the grounding line; Yellow line- the GlaDS domain.

Friction

-Friction laws have “basal friction coefficients” which capture unknowns or uncertainties in the friction law.

-Basal friction coefficients that vary significantly from constant may indicate that there are processes not well captured by the friction law.

τ_b - basal resistive stress
α - Budd friction coefficient
N - effective pressure
u_b - basal velocity
C - Schoof friction coefficient
$m = 1/3$ - power law exponent
$C_{\max} = 0.8$ - Iken's bound

Budd[2]

$$\tau_b = \alpha^2 N u_b$$

Schoof[1]

$$\tau_b = \frac{C^2 |u_b|^{m-1}}{\left(1+(C^2/(C_{\max}N))^{1/m}|u_b|\right)^m} u_b$$

Objective

Goal: Test the sensitivity of the Budd and Schoof friction laws by inverting for friction coefficients while using a hydrology model output effective pressure and a typically prescribed effective pressure.

Models: Ice-Sheet and Sea-Level System Model (ISSM)[6] running stressbalance with SSA for inversion of friction coefficients, Glacier Drainage System (GlaDS)[7] for effective pressure output.

Results

Subglacial Hydrology

-Sizeable channels formed in the Denman and Scott troughs (max discharge = 15.8 m^3/s).

-Two subglacial lakes formed upglacier of the Denman and Scott troughs.

-Large areas of low effective pressure, and some areas where effective pressure becomes negative.

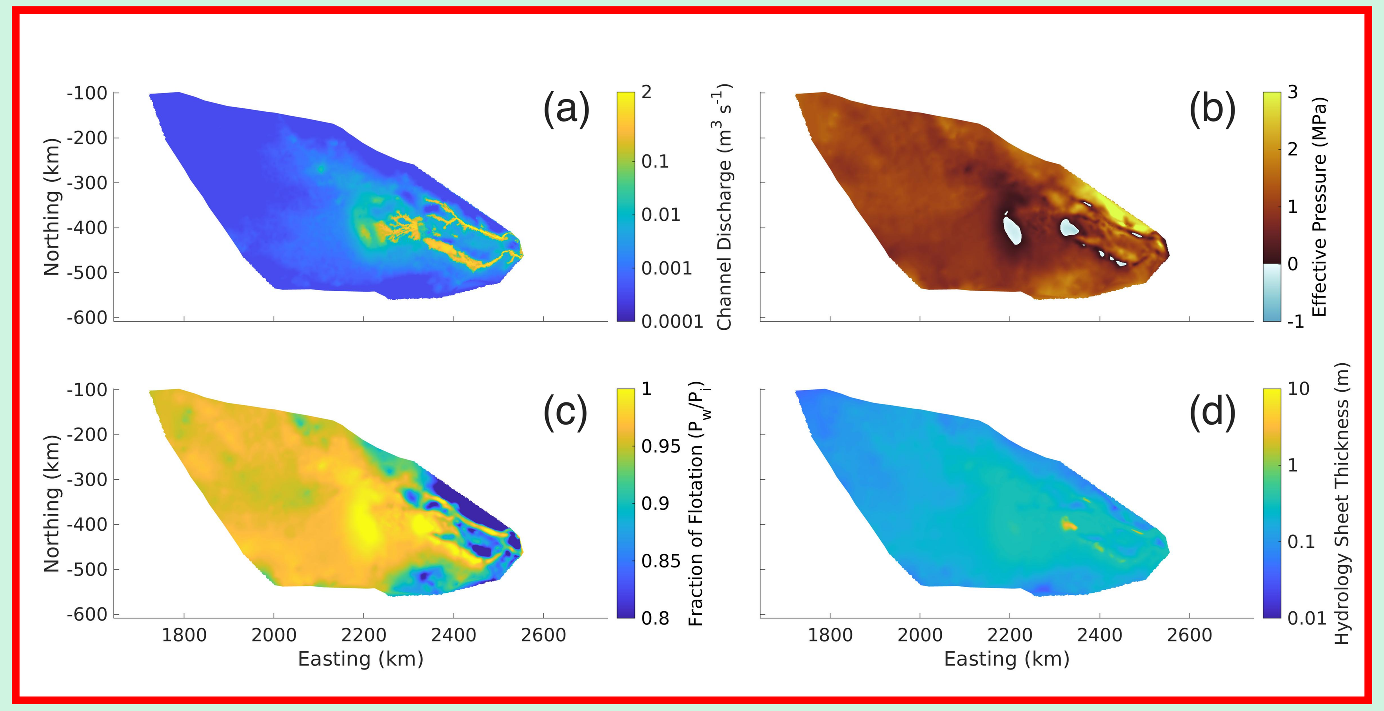


Fig. 2: GlaDS simulation results. (a) Channel discharge (m^3/s); (b) effective pressure (MPa); (c) fraction of flotation (i.e. water pressure divided by overburden pressure); and (d) water sheet thickness (m).

Friction Coefficients

-The Schoof friction law produced a friction coefficient with smaller gradients than the Budd friction law.

-The GlaDS output effective pressure (N_G) produced a friction coefficient with less local variability than the friction coefficient produced using the typically prescribed effective pressure (N_O equal to the ice overburden pressure minus the gravitational potential energy of water, with $N_O = \rho_i g H + \rho_w g B$).

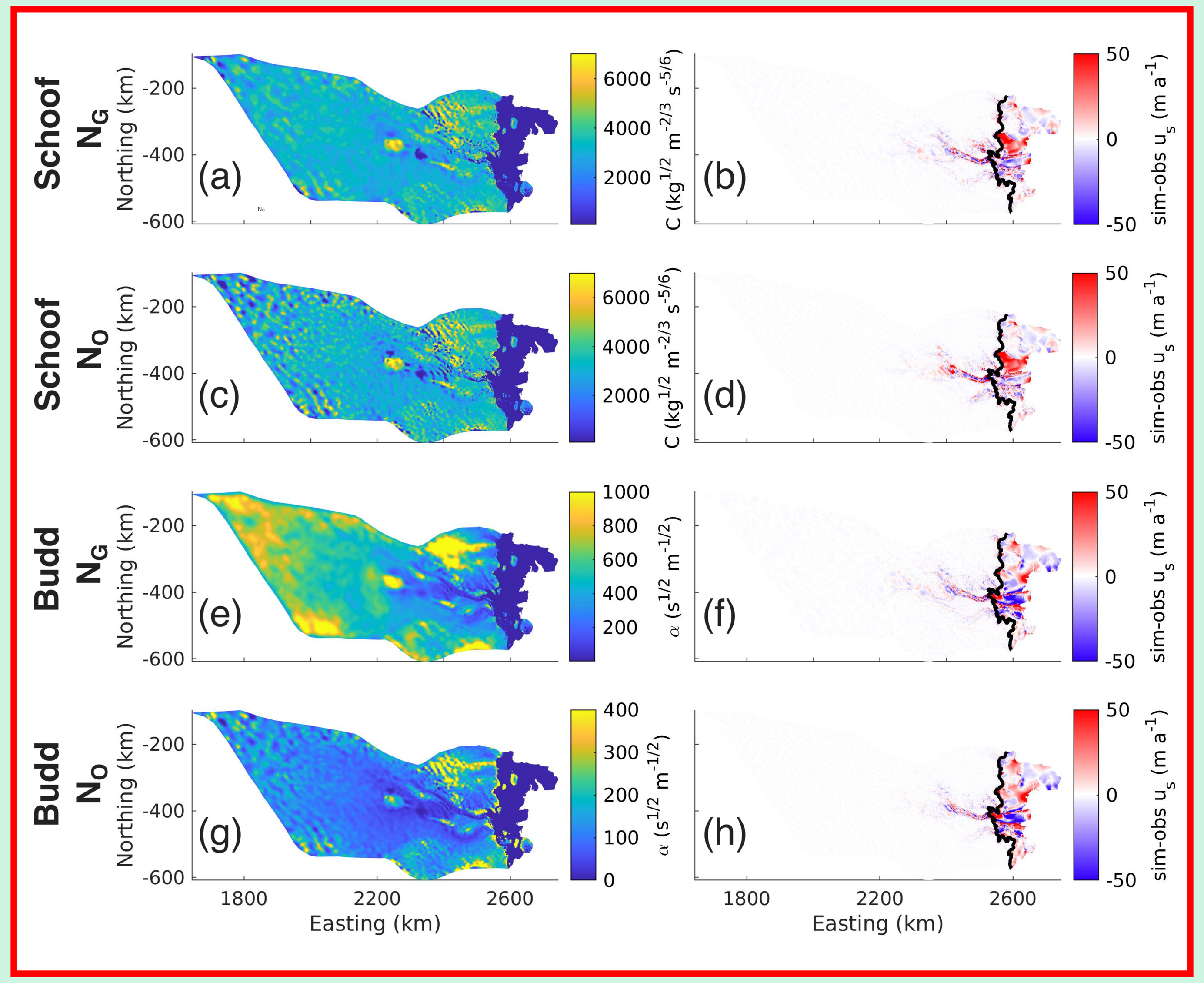


Fig. 3: Ice dynamics outputs. (a), (c), (e), (g) are friction coefficients, (b), (d), (f), (h) is the difference between the simulated and observed velocity (m/a). (a) and (b) show outputs from the Schoof law with N_G; (c) and (d) are from the Schoof law with N_O; (e) and (f) are from the Budd law with N_G; and (g) and (h) are from the Budd law with N_O.

Effective Pressure Parameterization

$$N_E = \rho_i g H (1-r_l)\frac{\tilde{H}^m}{\tilde{H}^m + H^m}$$

$$\tilde{H} = \left(\frac{1-\gamma}{\gamma - r_l}\right)^{1/m} H_t$$

$$m = \frac{\ln\left(\frac{1-r_l}{\epsilon} - 1\right) + \ln(\gamma - r_l) - \ln(1-\gamma)}{\ln(H_t) - \ln(H_s)}$$

ρ_i - density of ice
g - gravitational acceleration
H - ice thickness
$\gamma = 0.96$ - constant representing typical effective pressure as a fraction of overburden in areas of high ice thickness
$r_l = 0.7$ - water pressure as a fraction of overburden as the ice thickness goes to zero
$H_t = 2800\,\mathrm{m}$ - typical large ice thickness
$H_s = 500\,\mathrm{m}$ - a typical small ice thickness
$\epsilon = 0.05$ a small constant taken so that in areas of low ice thickness (H_s) the water pressure is at a typically low effective pressure $(r_l + \epsilon)\rho_i g H$

-The prescribed effective pressure used is actually the overburden hydraulic potential, this produces negative water pressure for beds above sea level and it implies a hydraulic potential equal to zero everywhere.

-The empirical effective pressure lacks complete hydrological connectivity to the ocean but produces physically realizable water pressures and allows for a non stagnant hydrology system.

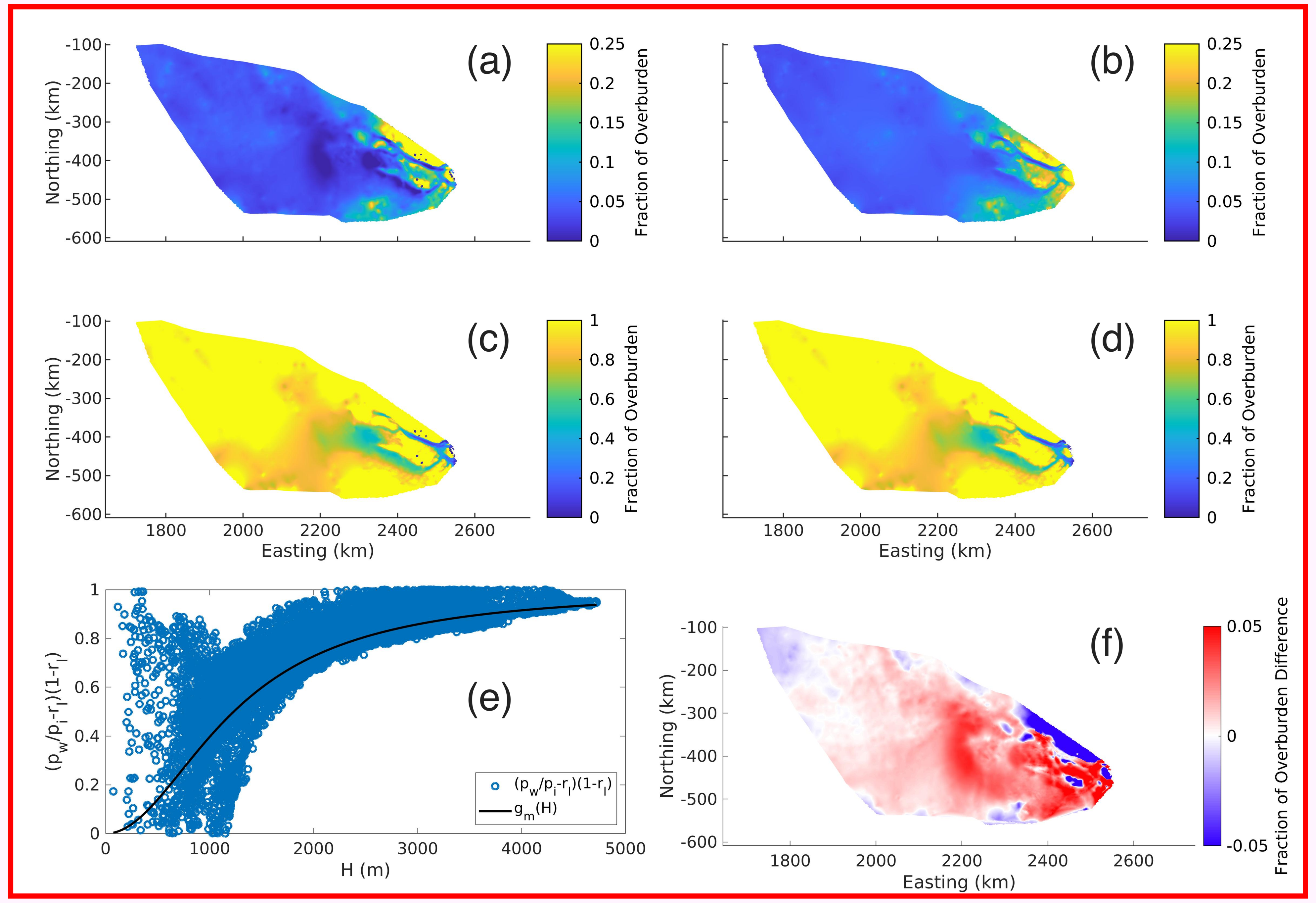


Fig. 4: Effective pressures from: (a) the GlaDS simulation, (b) the proposed empirical parameterization (N_E), (c) typically prescribed (N_O), and (d) Brondex (N_O with $N = \rho_i g H$ above sea level)[8]. (e) The saturation curve and the physically equivalent scatter for N_G. (f) The difference between the proposed empirical parameterization (N_E) and N_G as a fraction of overburden.

Conclusions

-On Denman Glacier a Schoof friction law with effective pressure from a subglacial hydrology model is best suited to model basal conditions.

-In the absence of a subglacial hydrology model, we propose a new empirical parameterization.

-Coupling of a subglacial hydrology model to an ice dynamics model is the next step towards more accurately including basal conditions in transient models.

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