Antarctic ice-sheet hysteresis in a three-dimensional hybrid ice-sheet model

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Co-financed by the Connecting Europe Facility of the European Union

Experimental setup

The hybrid ice-sheet--shelf model Yelmo (Robinson et al., 2020) is forced towards an equilibrated present-day Antarctic ice-sheet (AIS) state (100 kyr).

Climate forcing: RACMO2.3 simulation driven by ERA-INTERIM, averaged over 1981-2010 (van Wessem et al., 2018)

Basin-average basal melting after Rignot et al (2013).

Uncertainty with respect to basal friction is explored. A plastic law is used:

$$\tau_{\mathbf{b}} = -c_b \frac{\mathbf{u_b}}{u_b}$$

$$c_b = c_f \lambda_b N_{\text{eff}}$$
$$N_{\text{eff}} = \rho_i g (H - H_f)$$

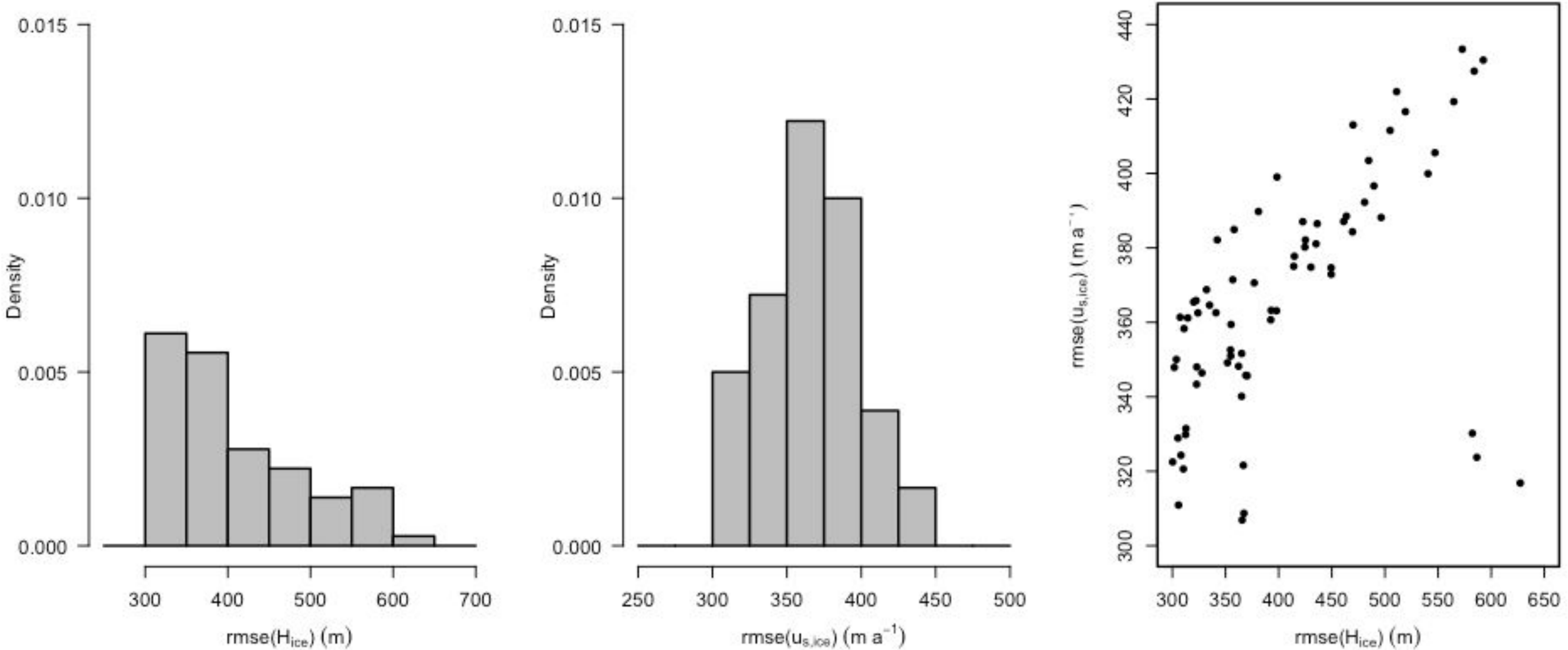
$$\lambda_b = \begin{cases} 1 & \text{if } z_b \geq z_1 \\ \exp\left(\frac{z_b - z_1}{z_1 - z_0}\right) & \text{if } z_b < z_1 \end{cases}$$

72-member ensemble for different friction parameters:

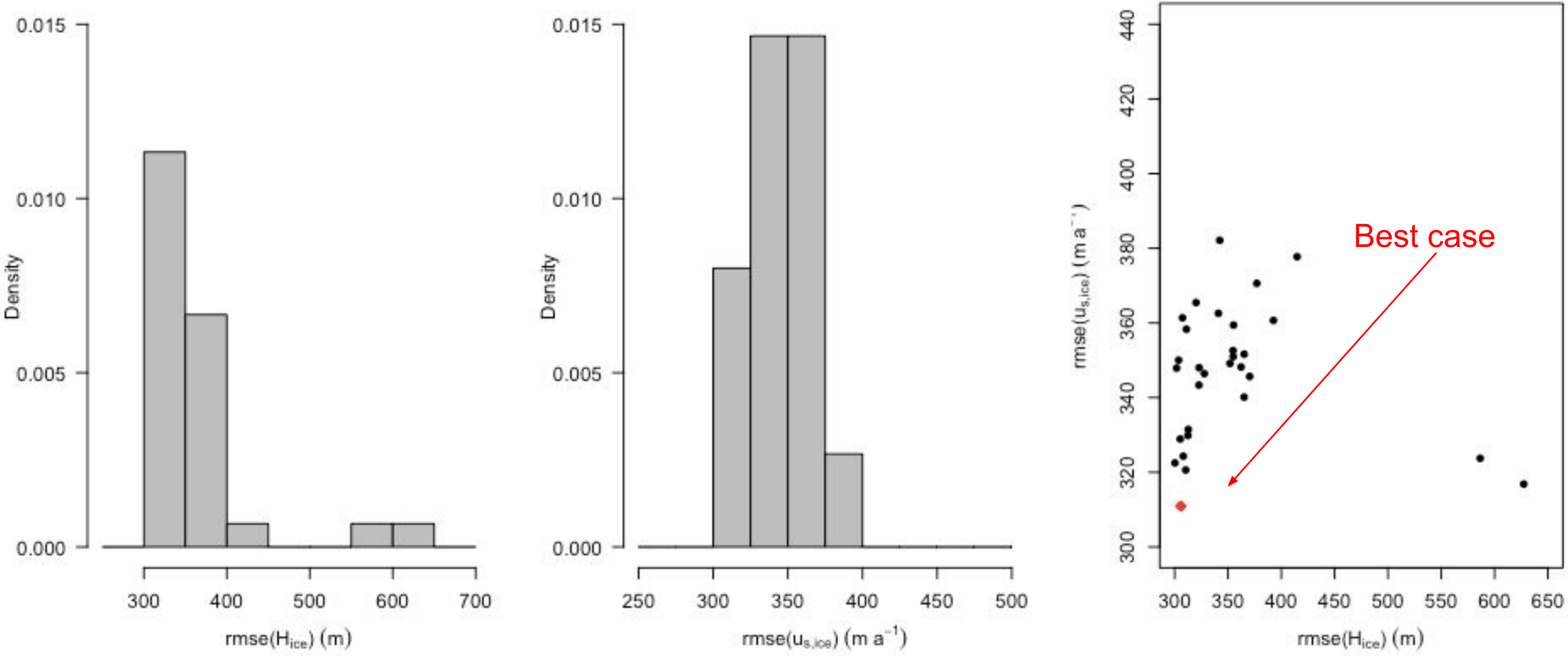
c_f = 0.1, 0.2
z_0 = -50, -100, -250 m
z_1 = 0, 50, 100, 250 m
E_{shr} = 1, 2, 3 (enhancement factor for shear flow)

Then → transient temperature forcing to investigate hysteresis of AIS volume with respect to temperature.

Present-day control runs after 100 kyr | RMSE for H and U

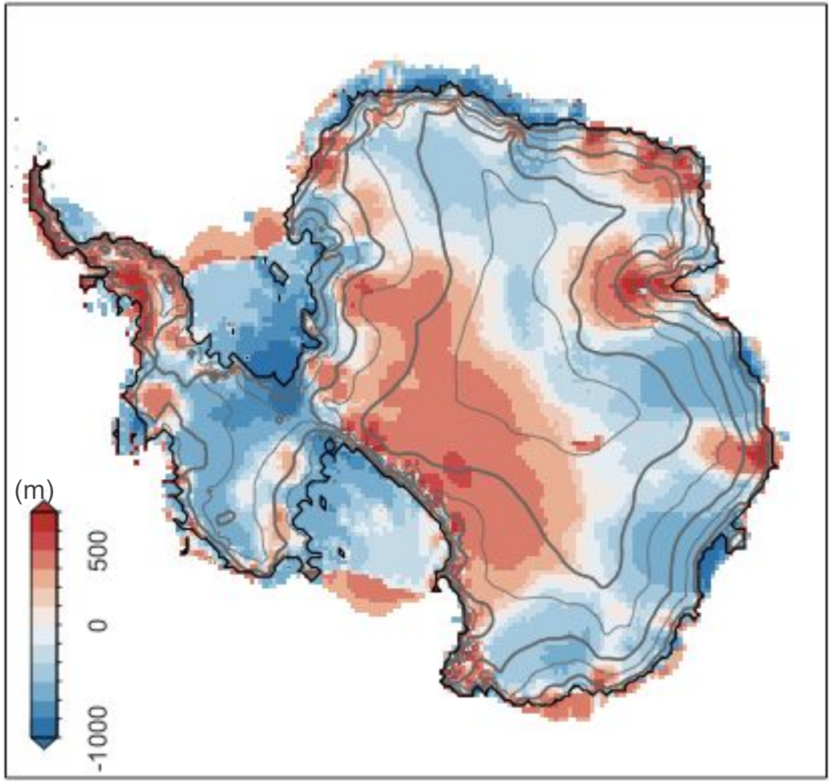


Present-day for selected control-run ensemble (within +/- 3m of observed SLE) after 100 kyr | RMSE for H and U

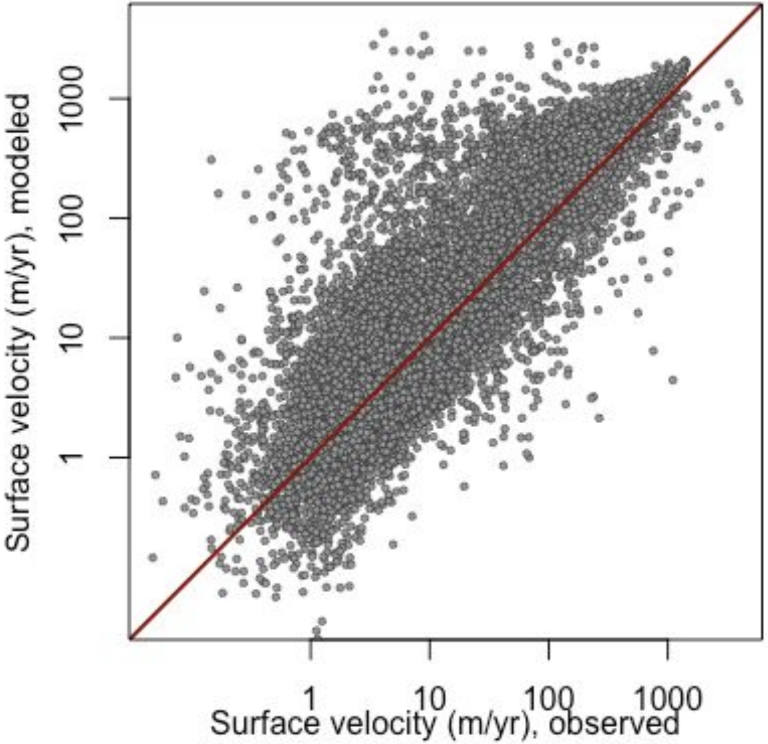


Best case against observations

Shaded: best case H_{model} -H_{obs} (m)
Contours: surface elevation (every 500 m)

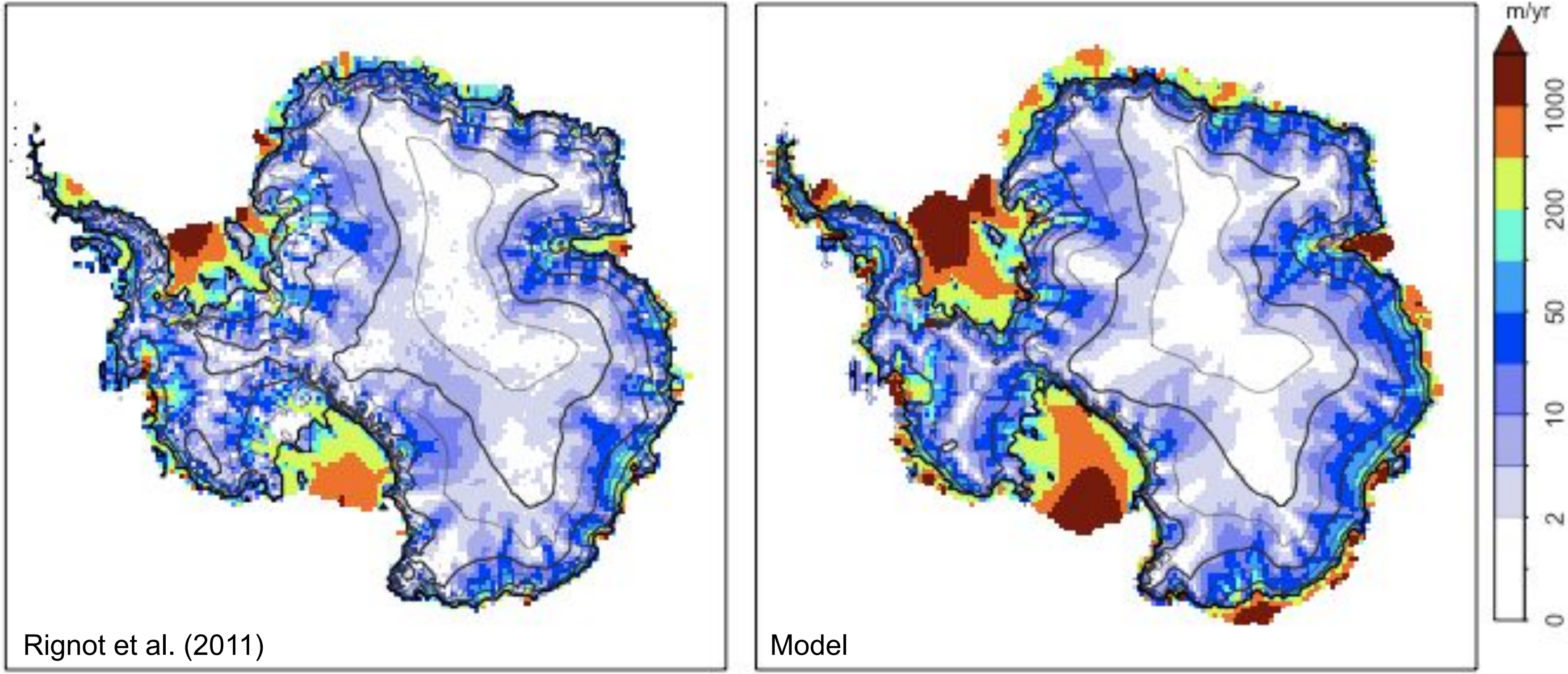


Best case modeled *vs* observed surface speed



Best case against observations

Shaded: surface ice speed
Contours: surface elevation (every 500 m)



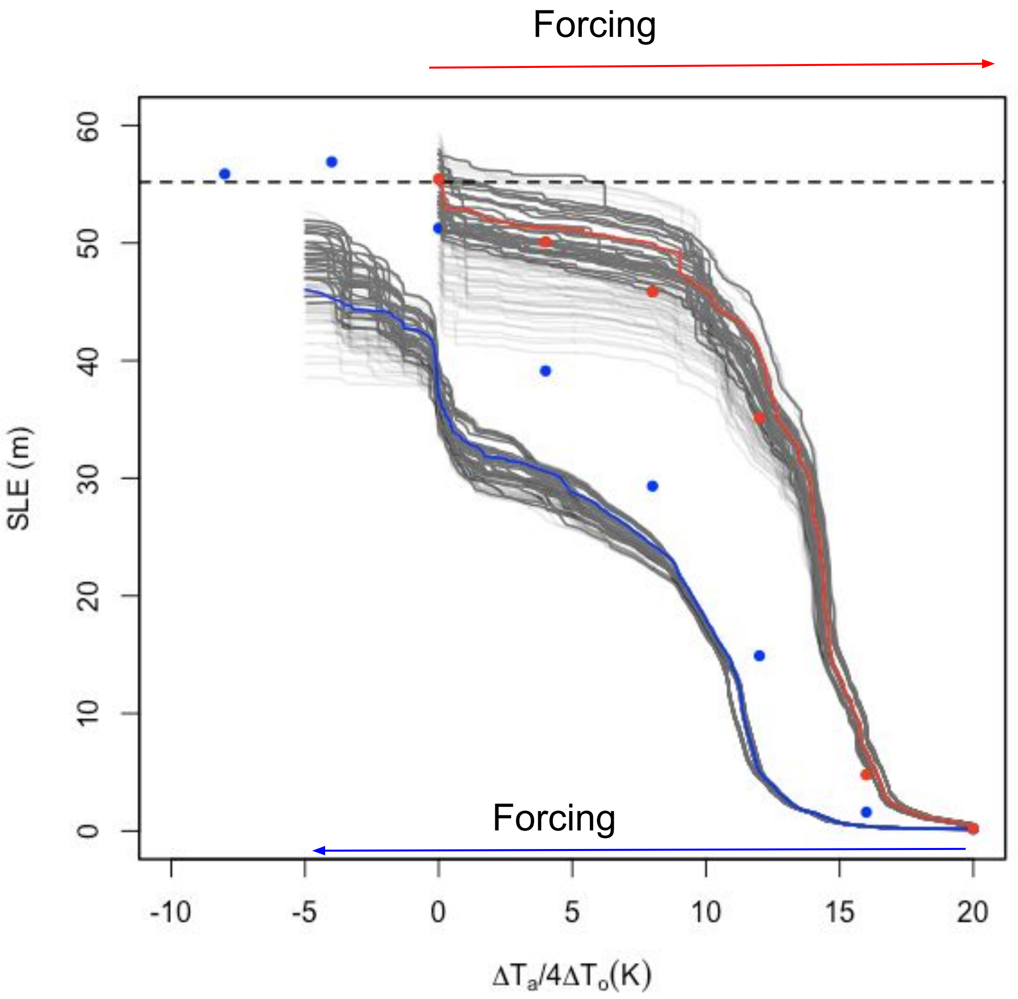
Ice volume hysteresis

Transient quasi-static, uniform temperature forcing applied, starting from present-day (rhs) and zero-ice, isostatically-rebounded (lhs) initial conditions.

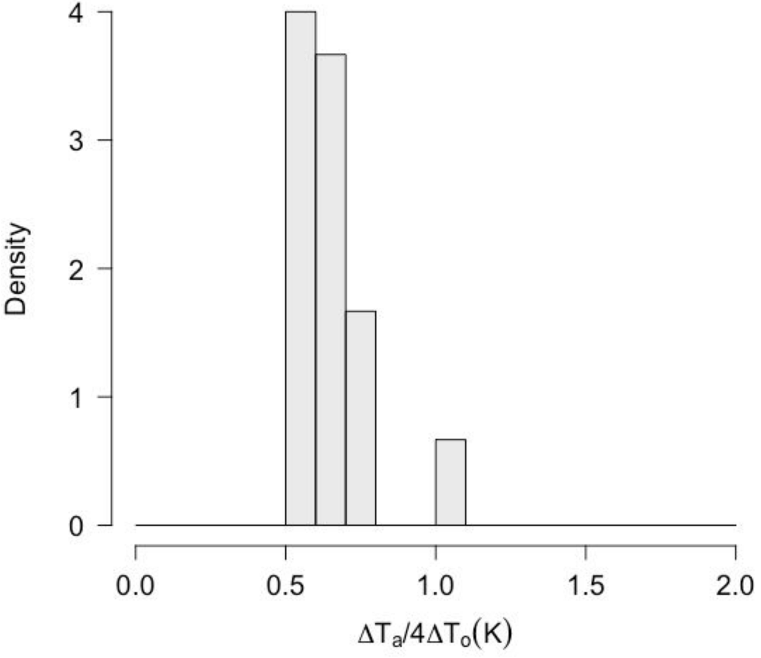
Dark grey: selected ensemble.

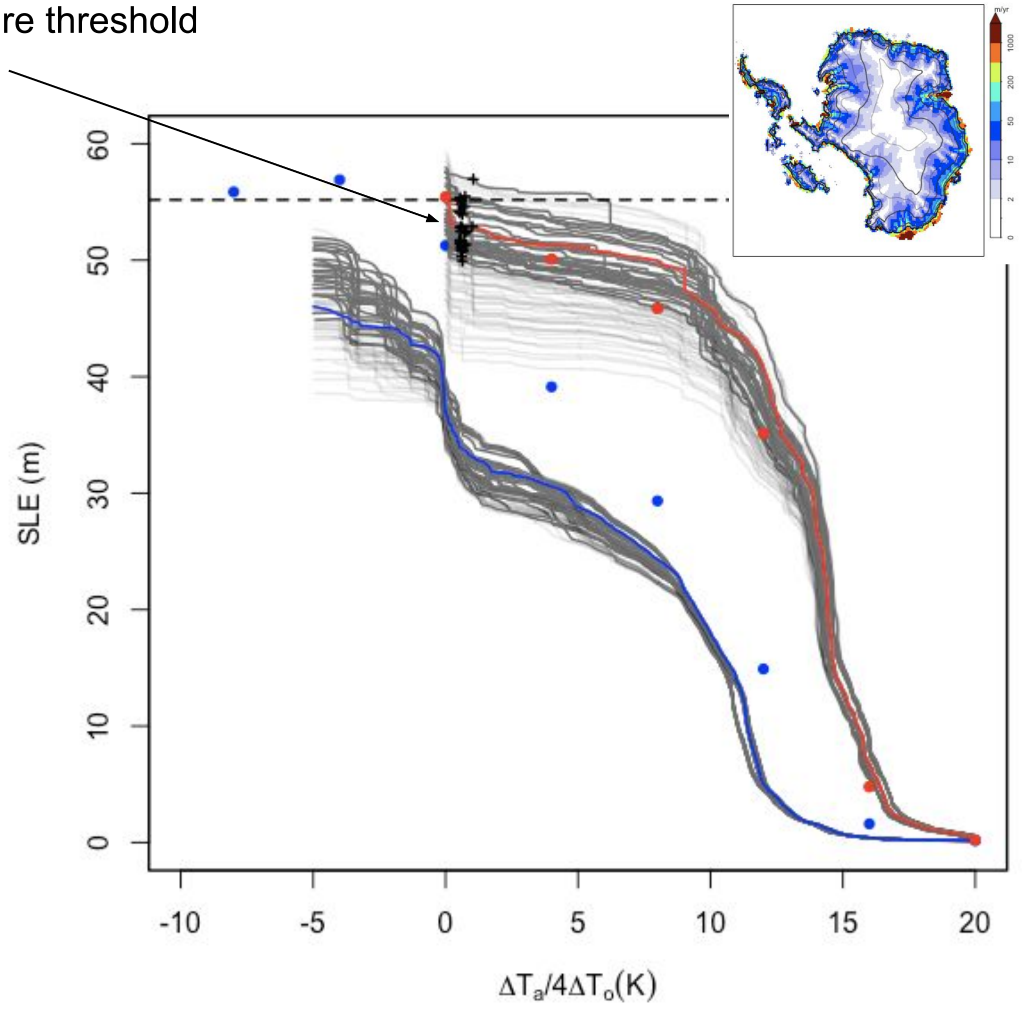
Red, blue lines: best cases for increasing and decreasing temperature forcing, respectively.

Hysteresis width reduced in steady-state control runs with constant forcing starting from present (red dots) and zero-ice initial conditions (blue dots).

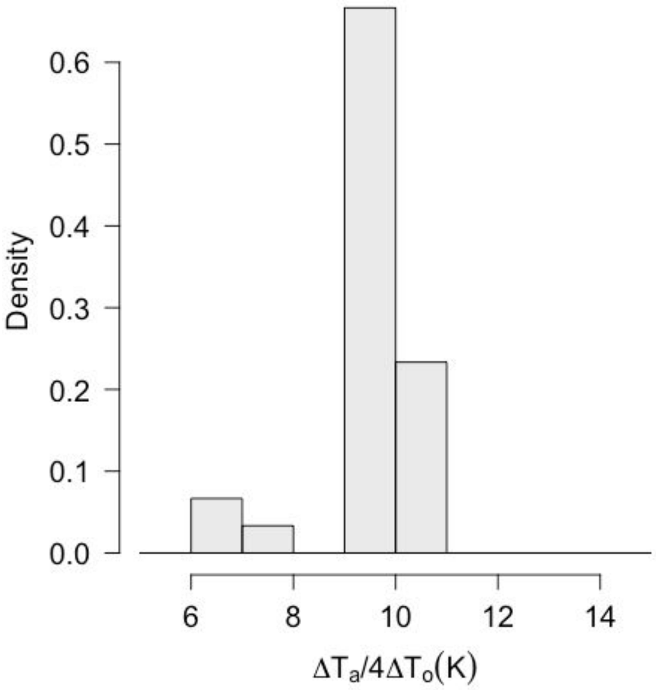


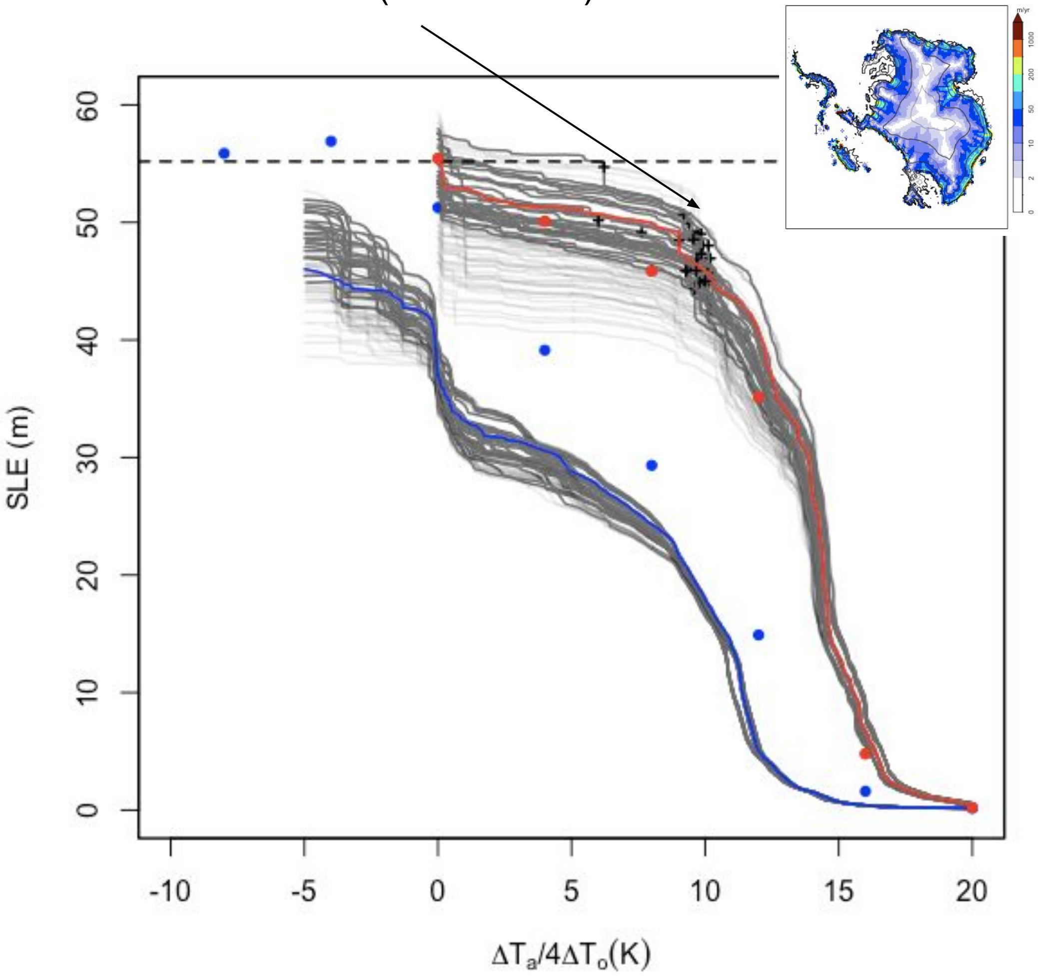
Ice volume hysteresis | WAIS collapse temperature threshold



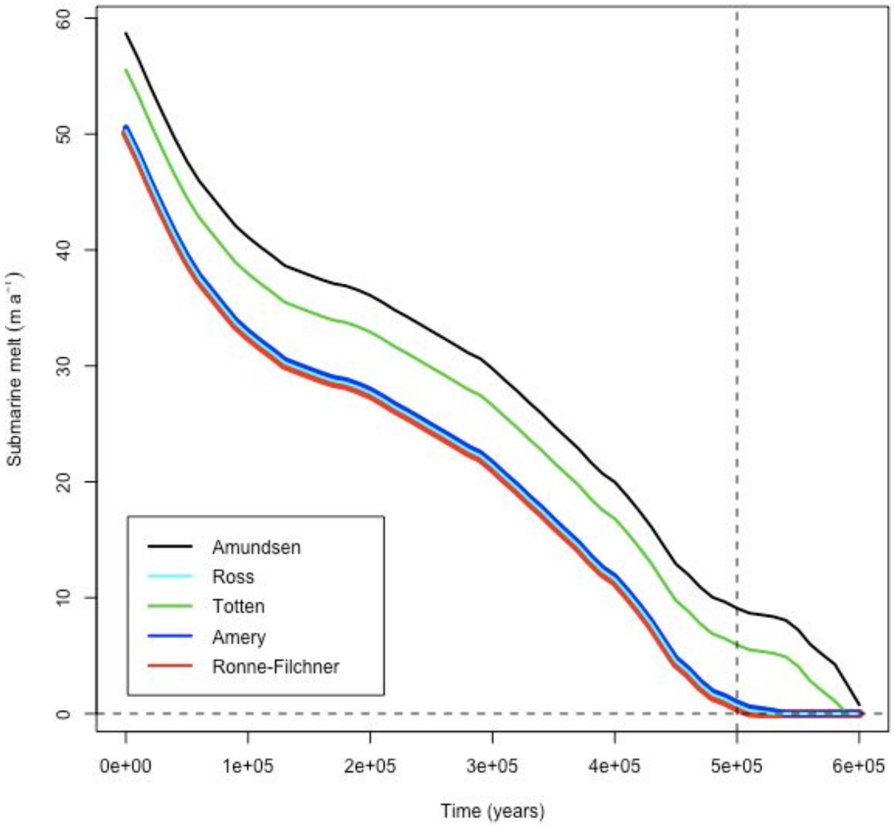


Ice volume hysteresis | Threshold for accelerated ice-volume decrease (> 100 m K^{-1})





Reason for jump at ΔT = 0: basal melting reduces to zero in many basins



Conclusions

The AIS volume shows hysteresis with respect to temperature forcing. Steady-state runs suggests slightly smaller width of hysteresis - possibly linked to forcing rate in transient runs.

The temperature threshold for WAIS collapse is much lower than previously thought (regional warming of 0.5-1.05 K) but could depend on oceanic forcing parameters (e.g., here the heat exchange coefficient is 10 m a^{-1} K^{-1}).

Regional warming of 6-11 K leads to accelerated AIS mass loss.

AIS ice volume and distribution do not recover to present-day values after forcing reversal.