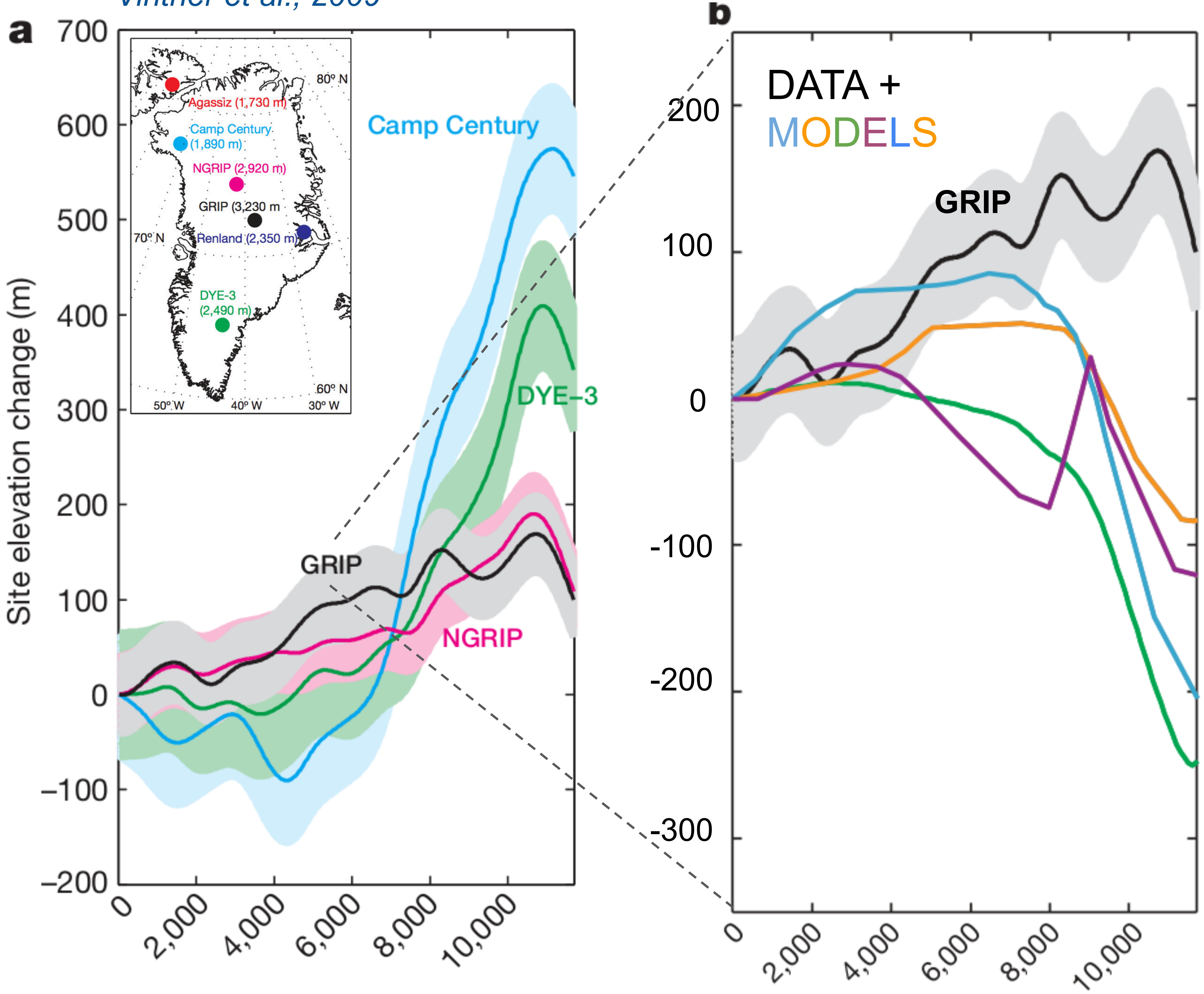
Holocene thinning in central Greenland controlled by the Northeast Greenland Ice Stream

Ilaria Tabone, Alexander Robinson, Jorge Alvarez-Solas and Marisa Montoya

mail to ilaria.tabone@fau.de

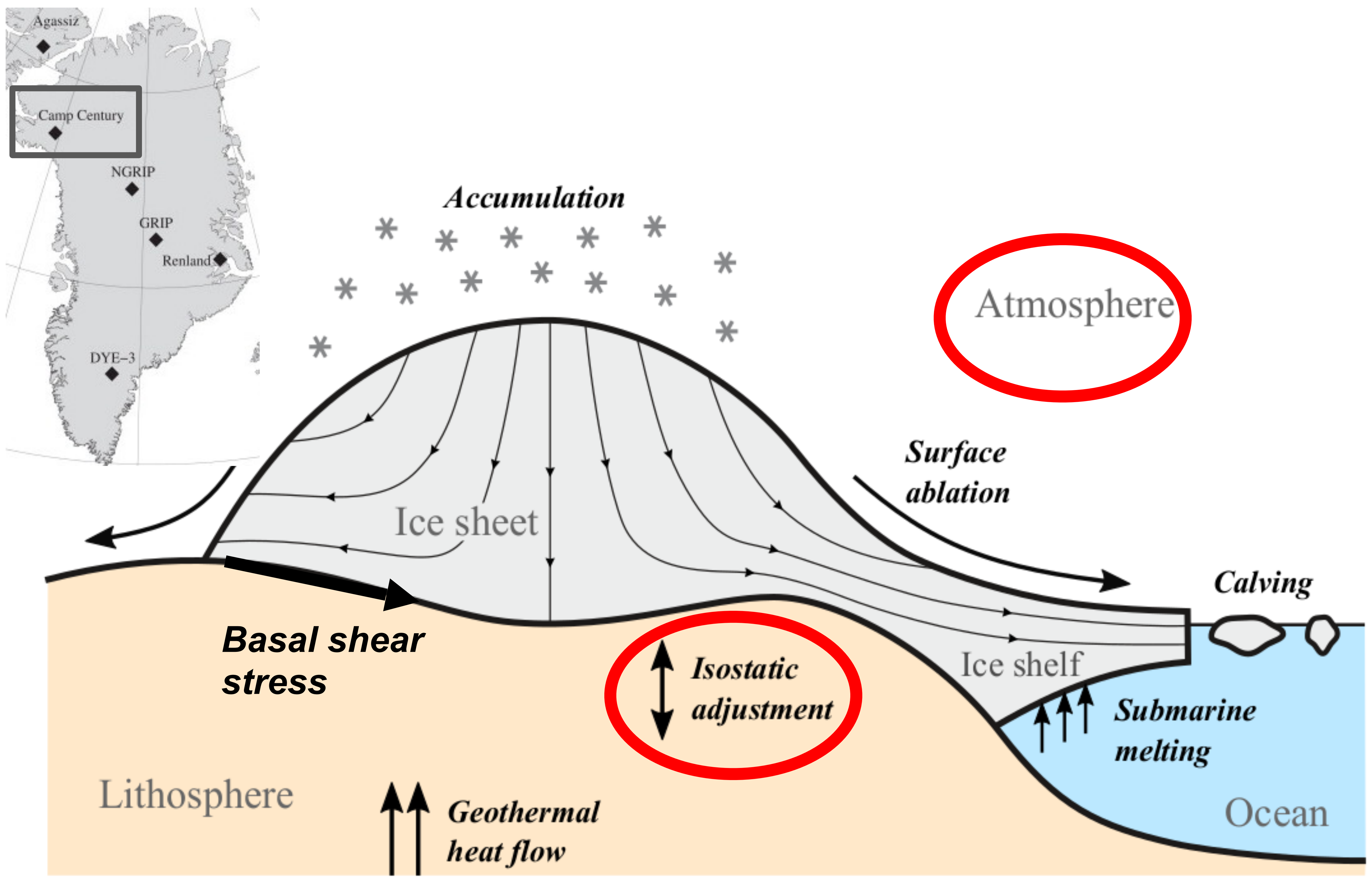
What we don’t understand: Greenland Holocene elevation change

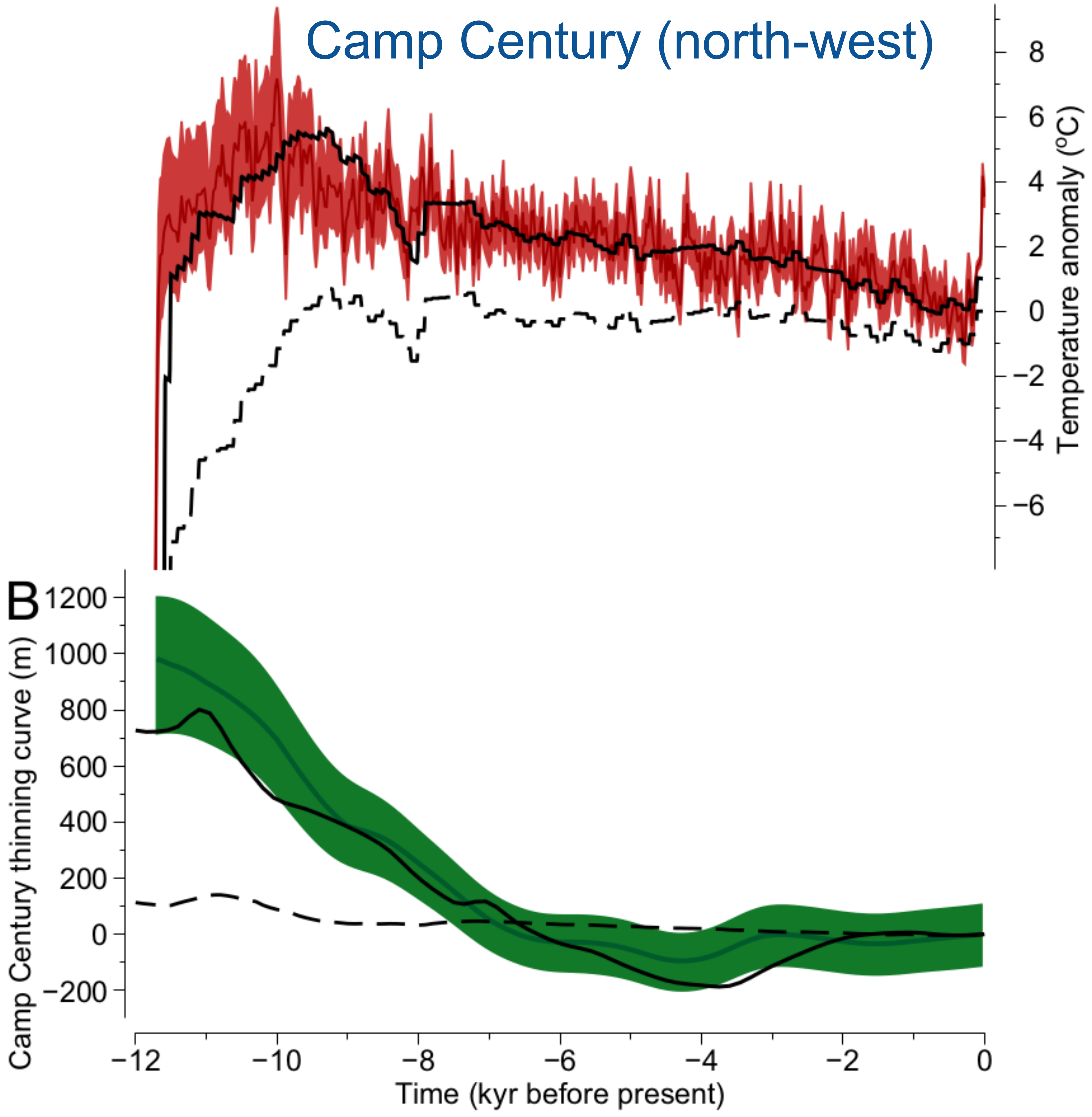
Vinther et al., 2009



- Summit Holocene elevation changes have been estimated from ice core analysis.
- Interestingly, 3D ice sheet models usually misrepresent such an impressive thinning.

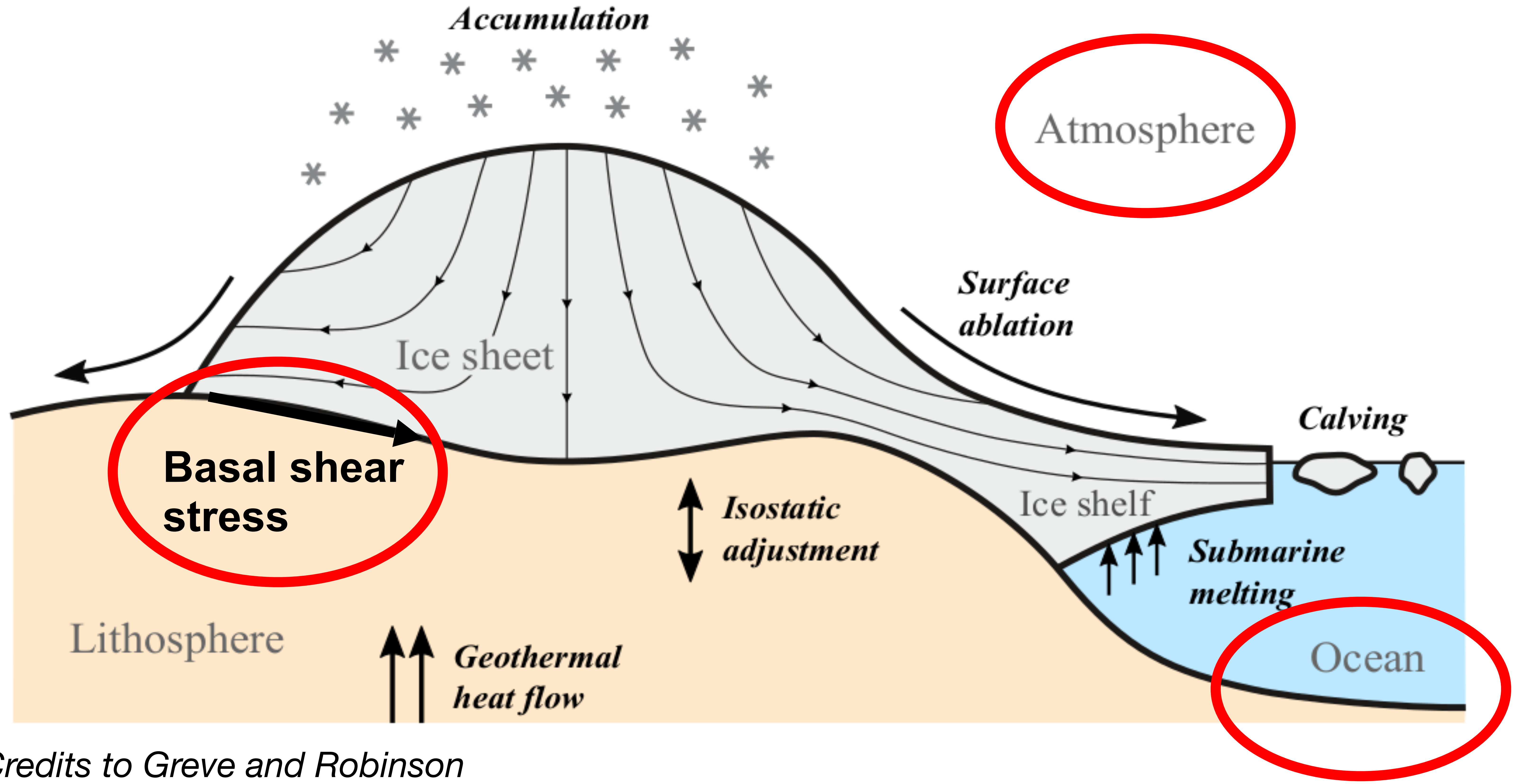
Previous attempts to reduce data-model discrepancy:
bedrock uplift and atmospheric forcing?





Ice thinning due to ***strong high Arctic*** climatic and isostatic effects. Not valid for other sites.

Data-model discrepancy…Towards a new approach



Credits to Greve and Robinson

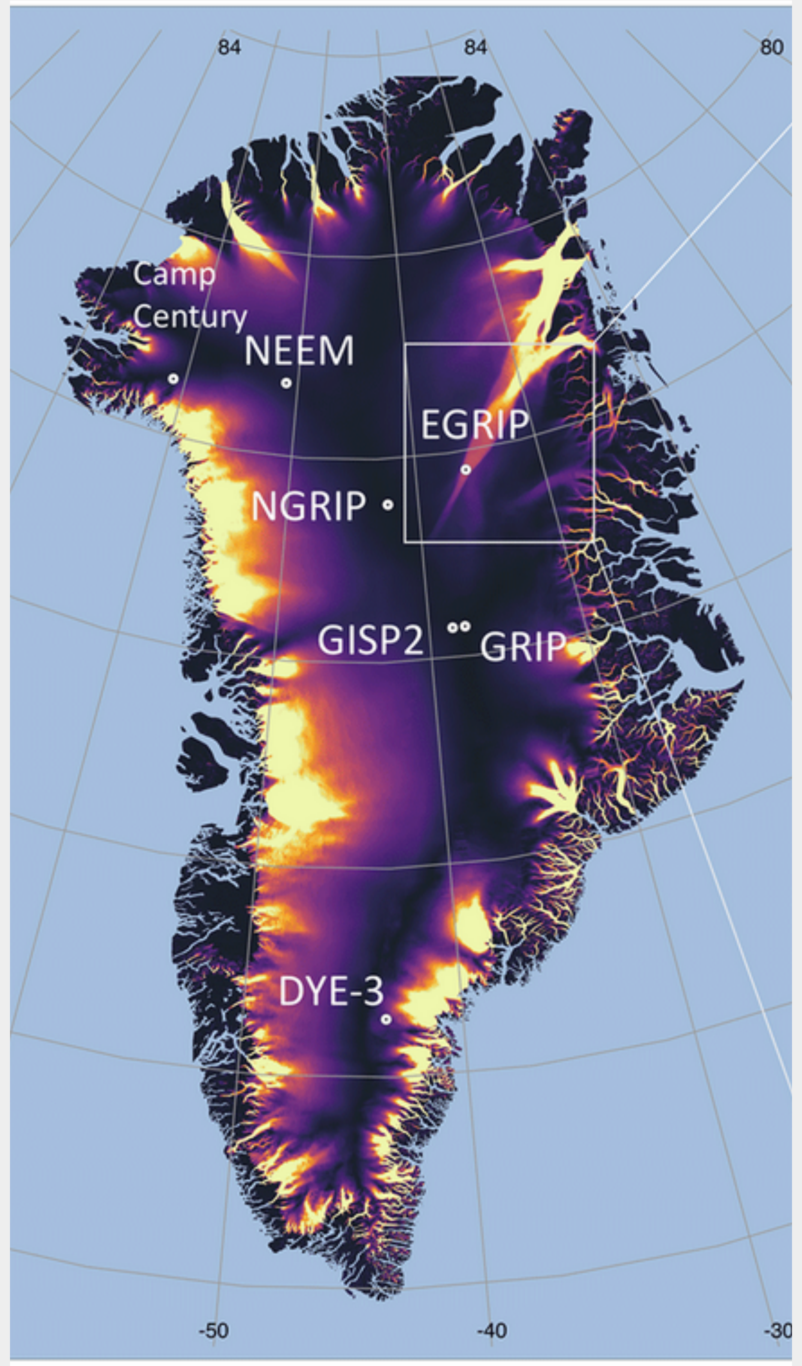
Can we reduce the NGRIP thinning mismatch by improving the climate forcing and the fast ice flow representation in a 3D ice sheet model?

Climate/ocean forcing?

Are modelled past surface Tatm, precip, Tocn used to force the model accurate?

Basal dynamics?

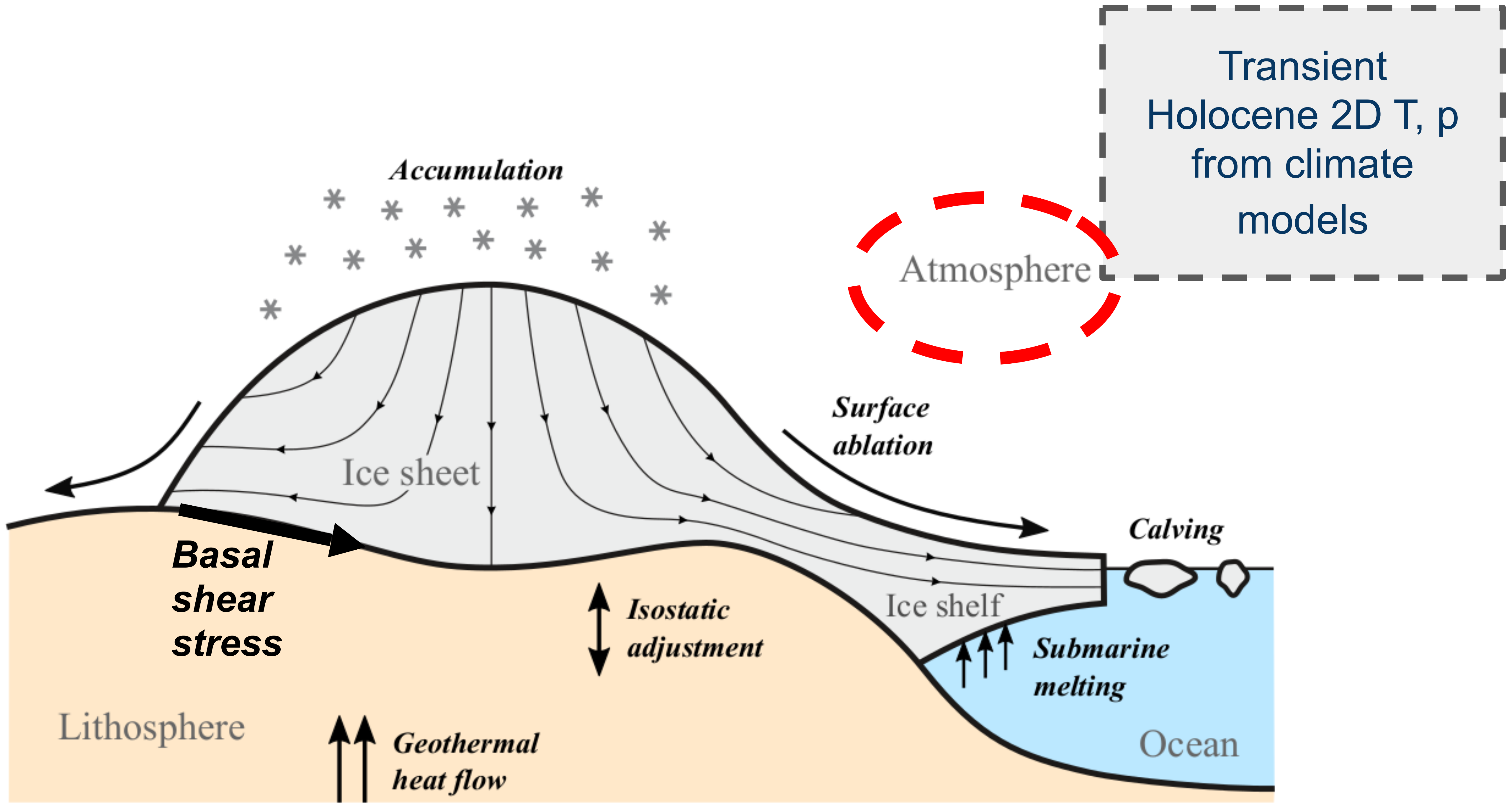
Basal conditions are poorly represented, especially in fast streaming areas (NEGIS) where basal sliding is higher

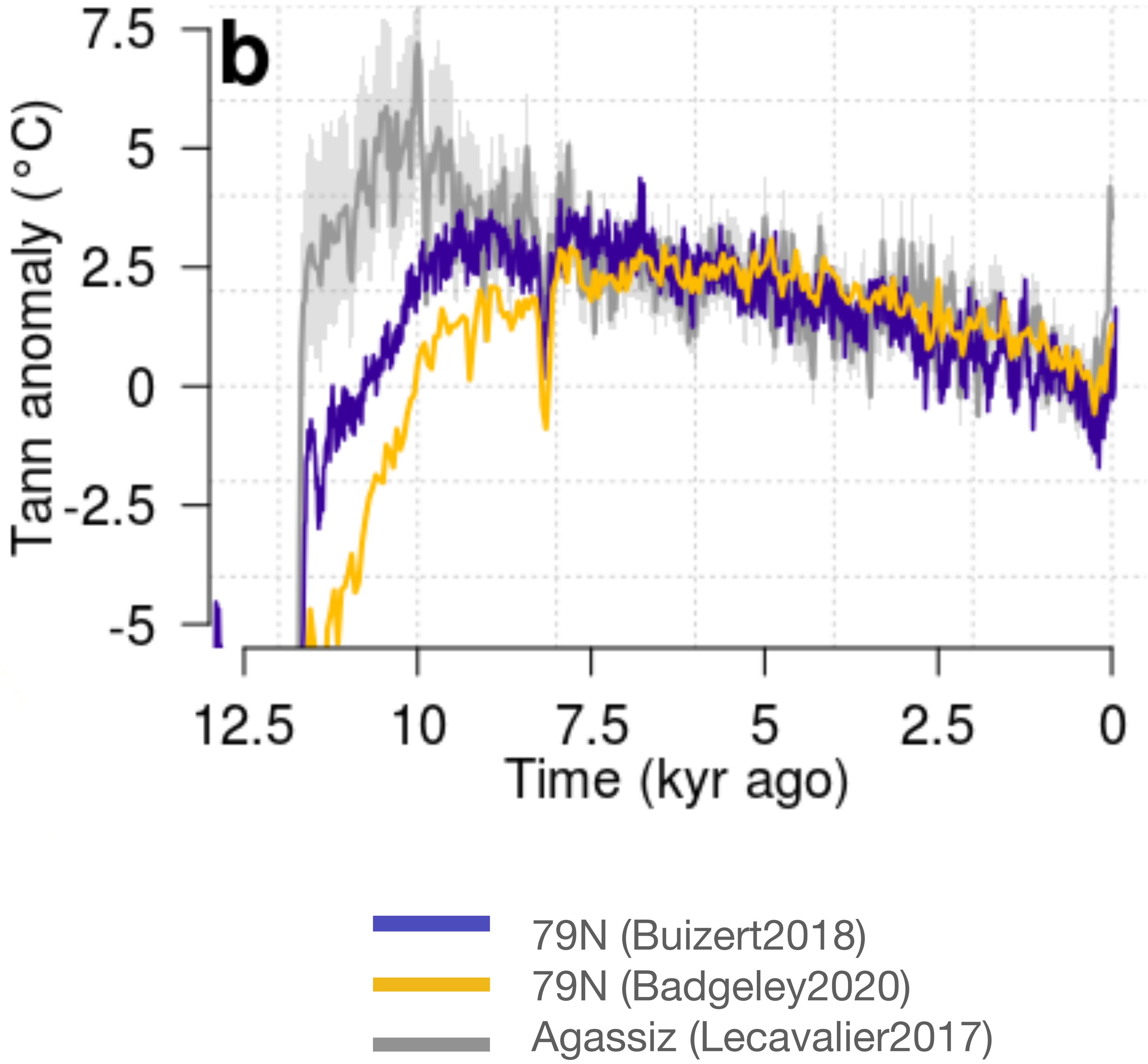


Methods: 3D ice-sheet model Yelmo

Model forcing

https://github.com/palma-ice/yelmo
Robinson et al., 2020





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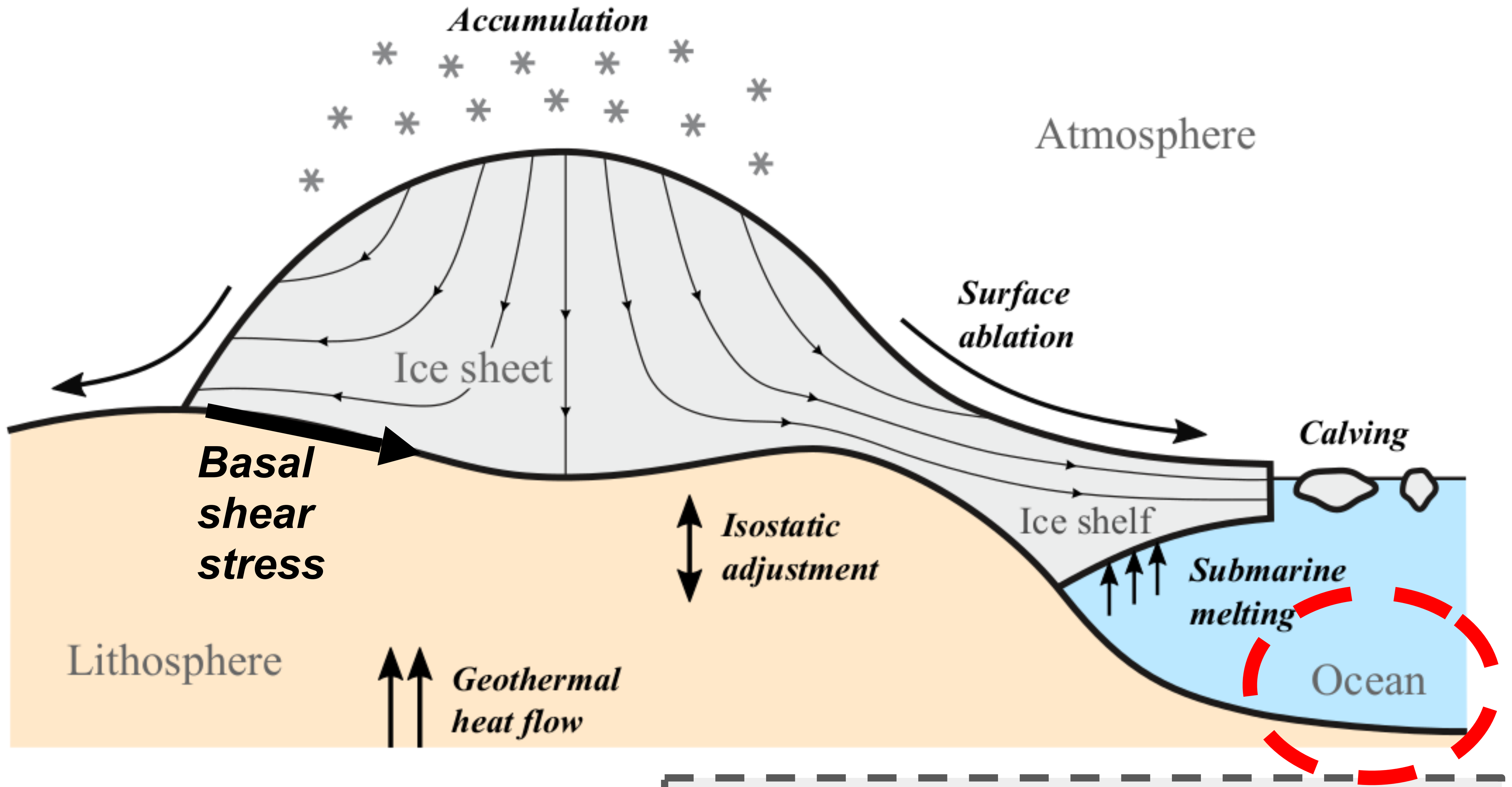
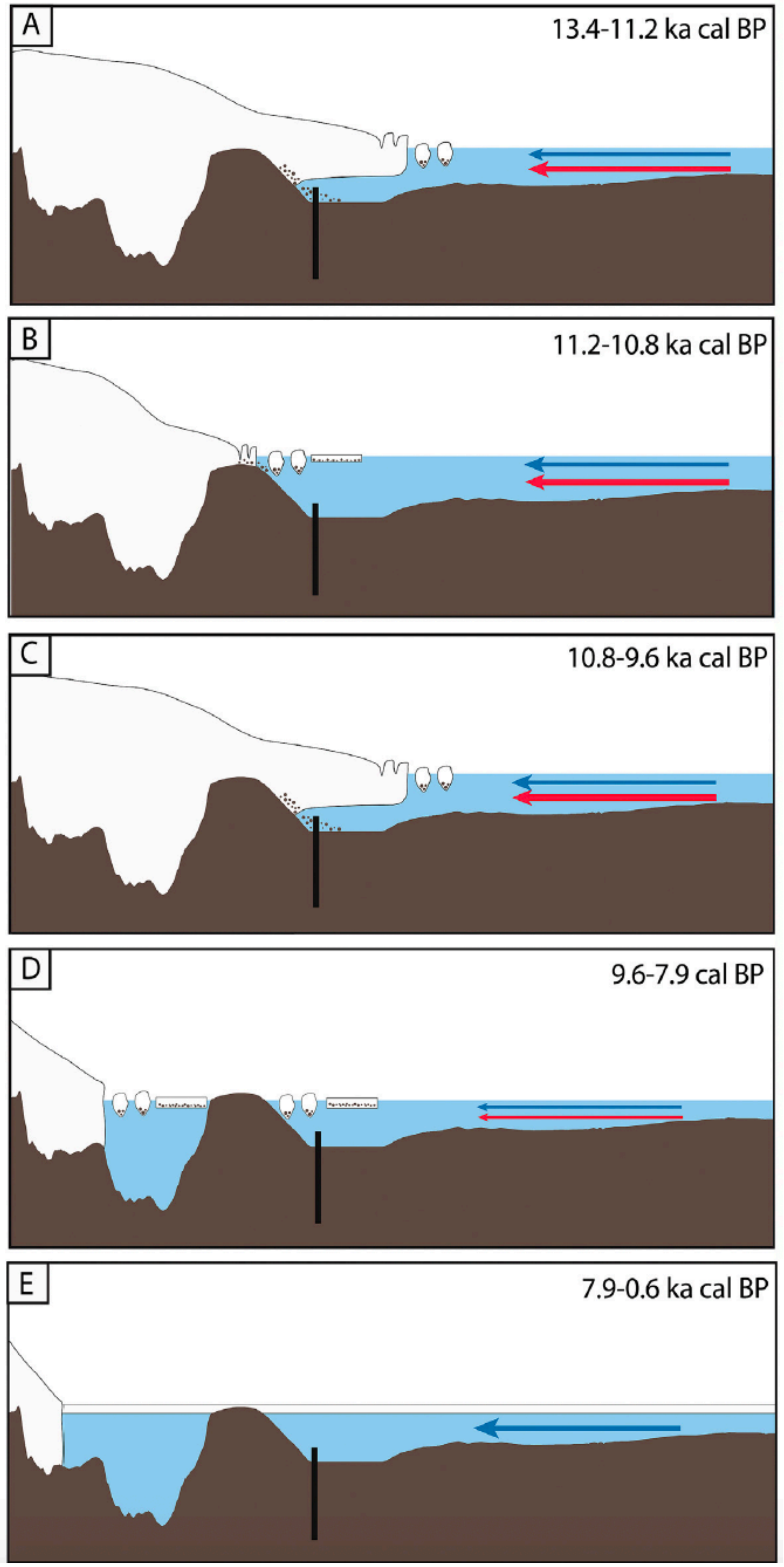
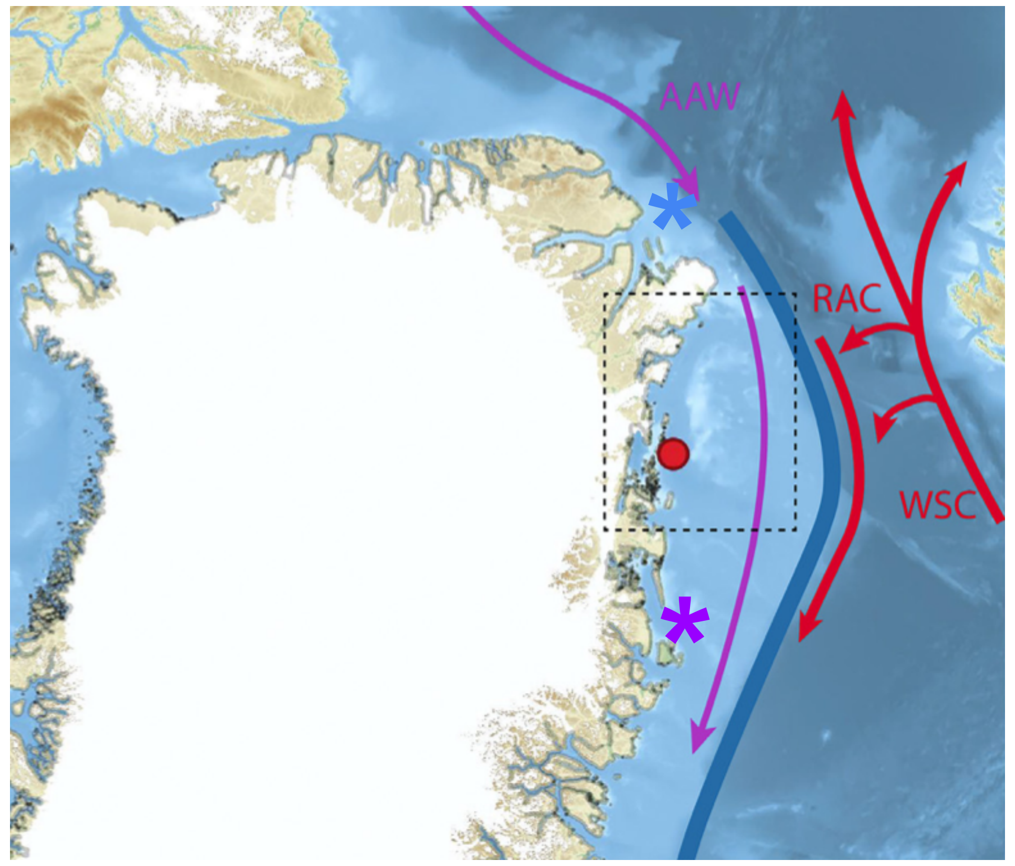
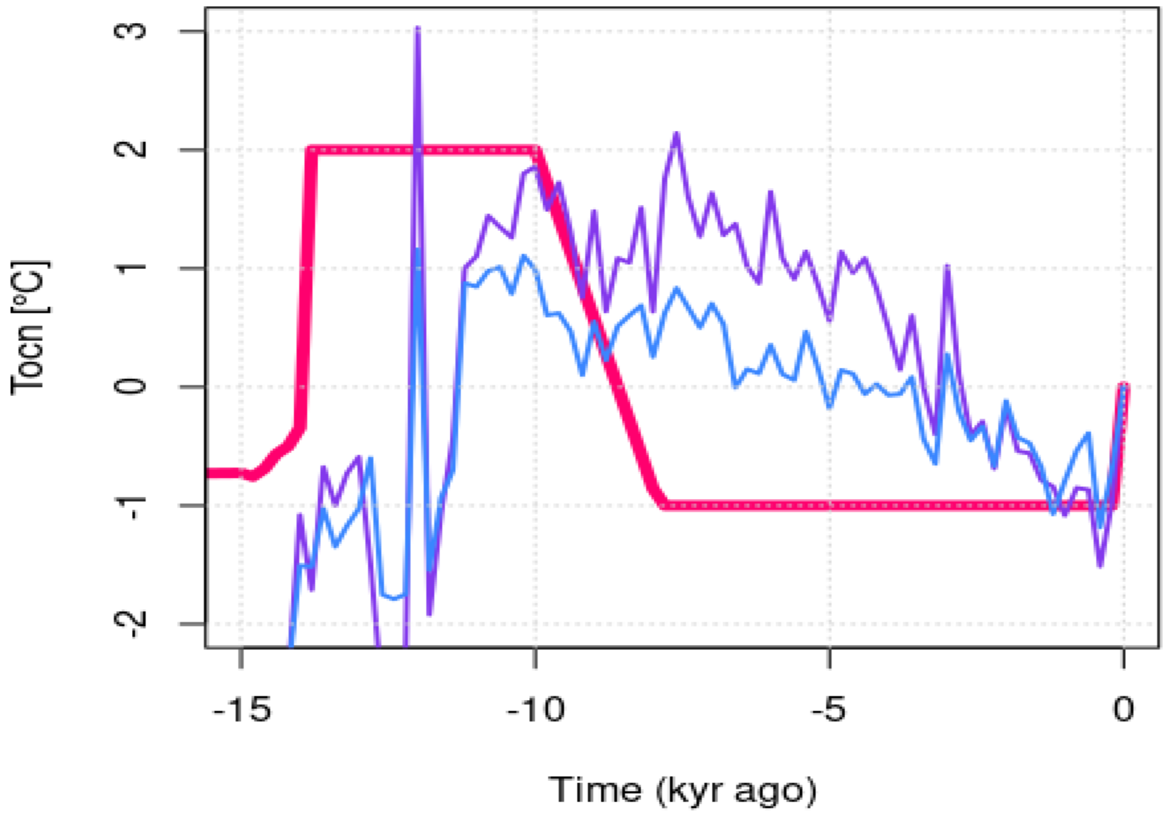


Transient Holocene 2D Tocn (Trace-21ka) corrected at the NE from marine sediment cores

Davies et al., 2022





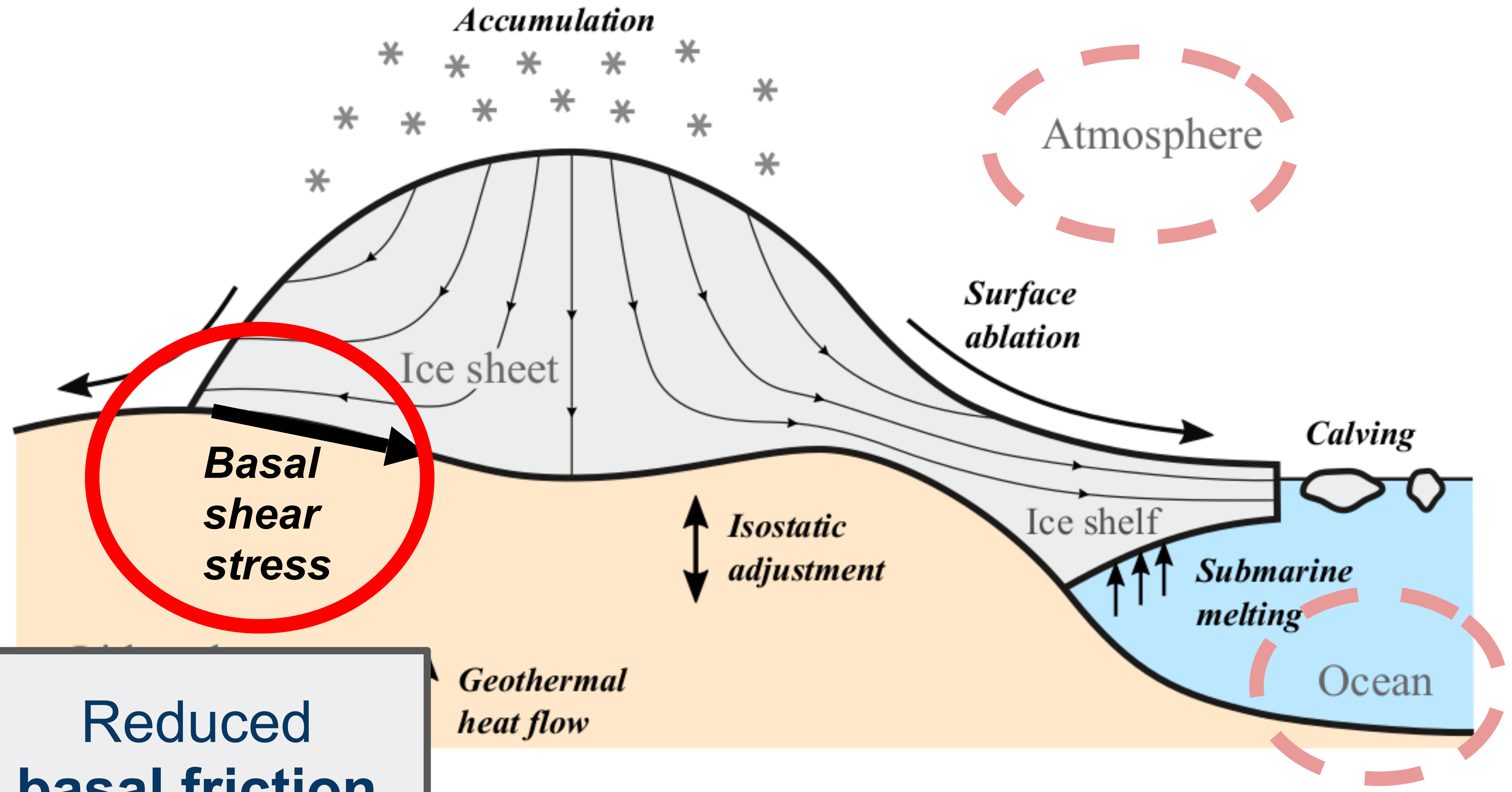


Submarine melting

$$B_m(t) = B_{ref} + \kappa \Delta T_{ocn}(t)$$

Methods: 3D ice-sheet model Yelmo

Model parameters



Reduced basal friction coefficient at the NEGIS

Other PERTURBED MODEL PARAMETERS

- calving rate
- lithospheric relaxation time
- ice flow enhancement factor
- effective pressure
- surface ablation
- ocean/ice heat flux exchanged

Regularized-power **basal friction** law

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

Friction coefficient scaled wrt bedrock elevation...

$$\lambda = \begin{cases} 1 & \text{if } z_b > z_1 \\ \max\left[\exp\left(\frac{z_b - z_1}{z_1 - z_0}\right), \lambda_{\min}\right] & \text{if } z_b < z_1 \end{cases}$$

... and coupled with basal water pressure

$$C_b = \lambda c_f N_{\text{eff}}$$

Effective pressure

$$N_{\text{eff}} = N_0 \left(\frac{\delta P_o}{N_0}\right)^s 10^{\left(\frac{e_0}{C_c}\right)(1-s)}$$

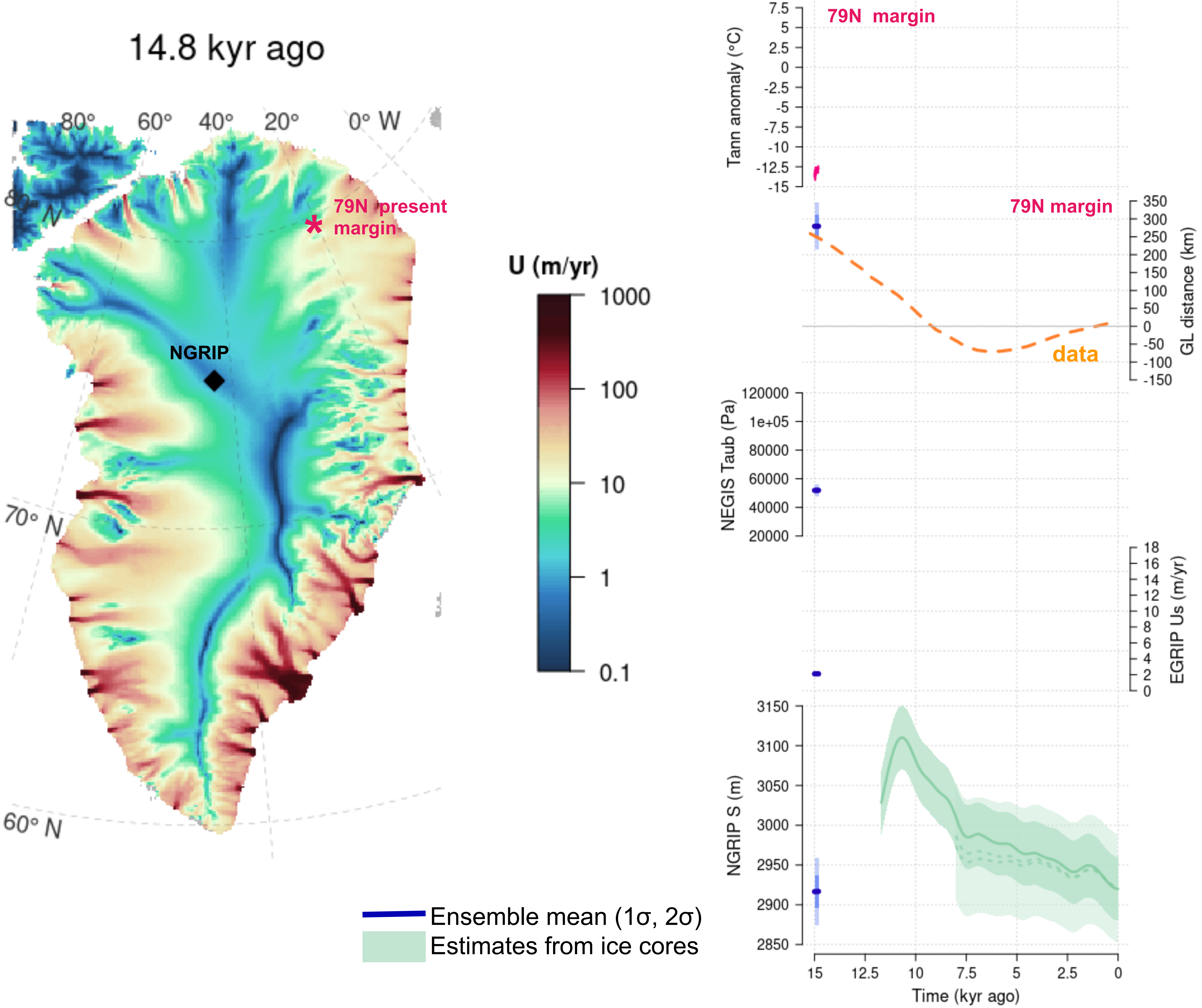
$$s = W_{\text{til}} / W_{\text{til}}^{\max} \qquad P_0 = \rho_i g H_{ice}$$

600 last-deglaciation runs (8 km)

evaluated against

PD area PD Hice PD U	NE deglaciation timings	Holocene surface thinning at NGRIP

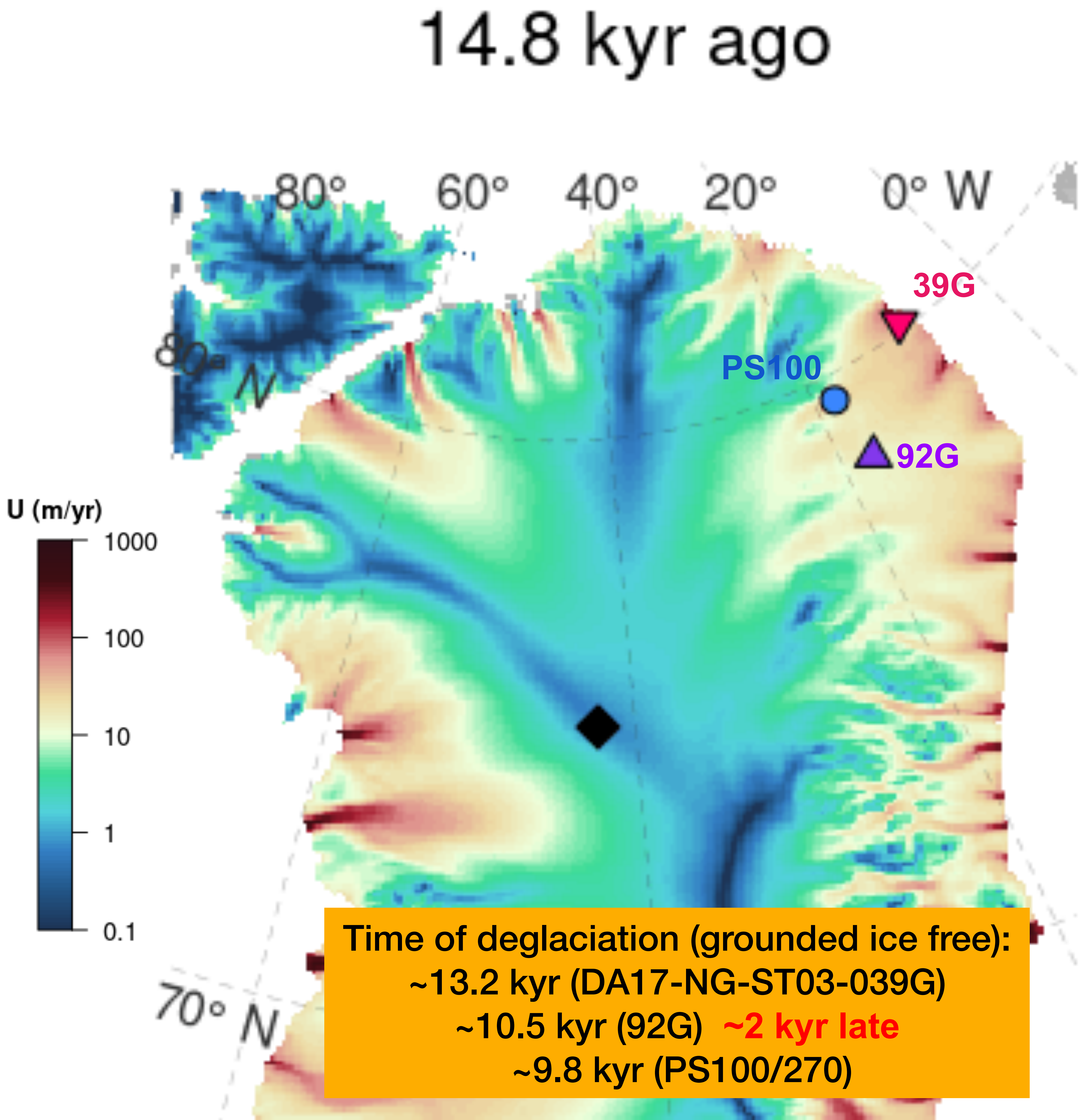
Results: NE Holocene retreat and implications in the NGRIP thinning



Tabone et al., in review

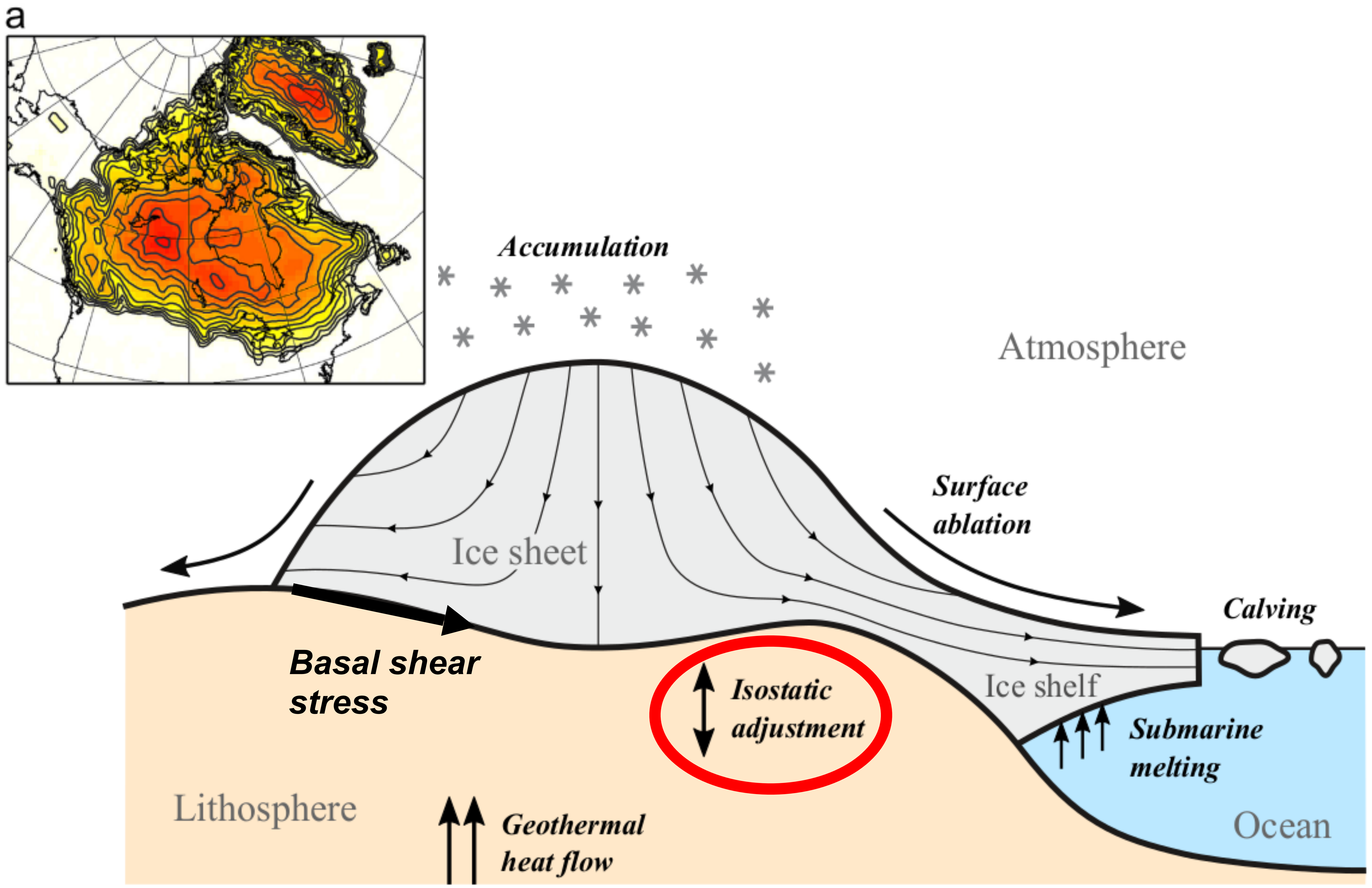
Take-home message

- **NGRIP Holocene surface thinning is partially explained by its dynamical response to the NE retreat (and NEGIS formation).**
- **NE high air and ocean temperatures trigger the early retreat of the NE sector**
- Our modelled **NE retreat follows fairly well the deglaciation timings** as suggested by 3 sediment cores.
- These results suggest that **the role of the NE basin** sector in shaping the summit Holocene thinning **has been underestimated** so far.

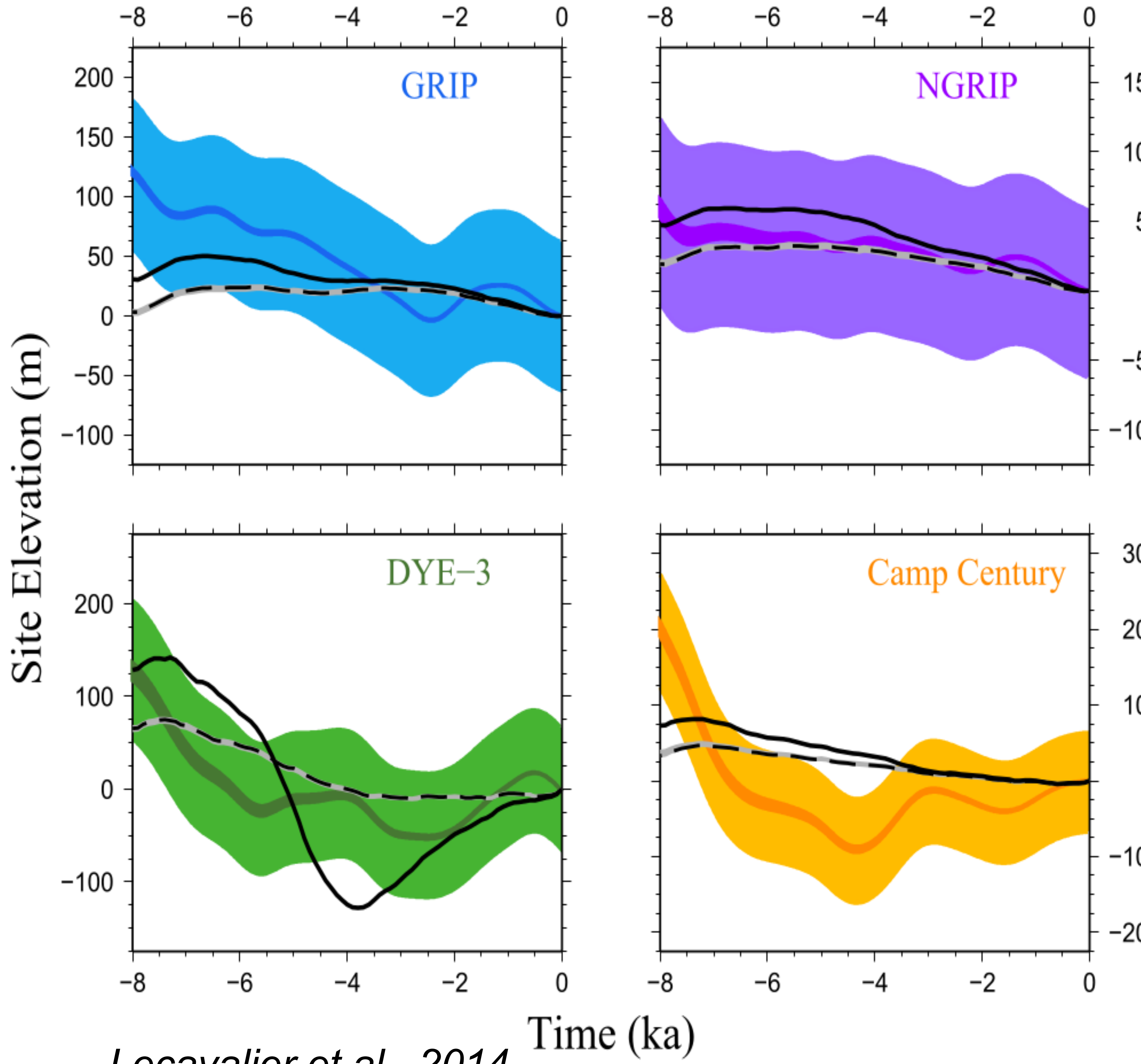


THANKS!

Previous attempts to reduce data-model discrepancy:
bedrock uplift?

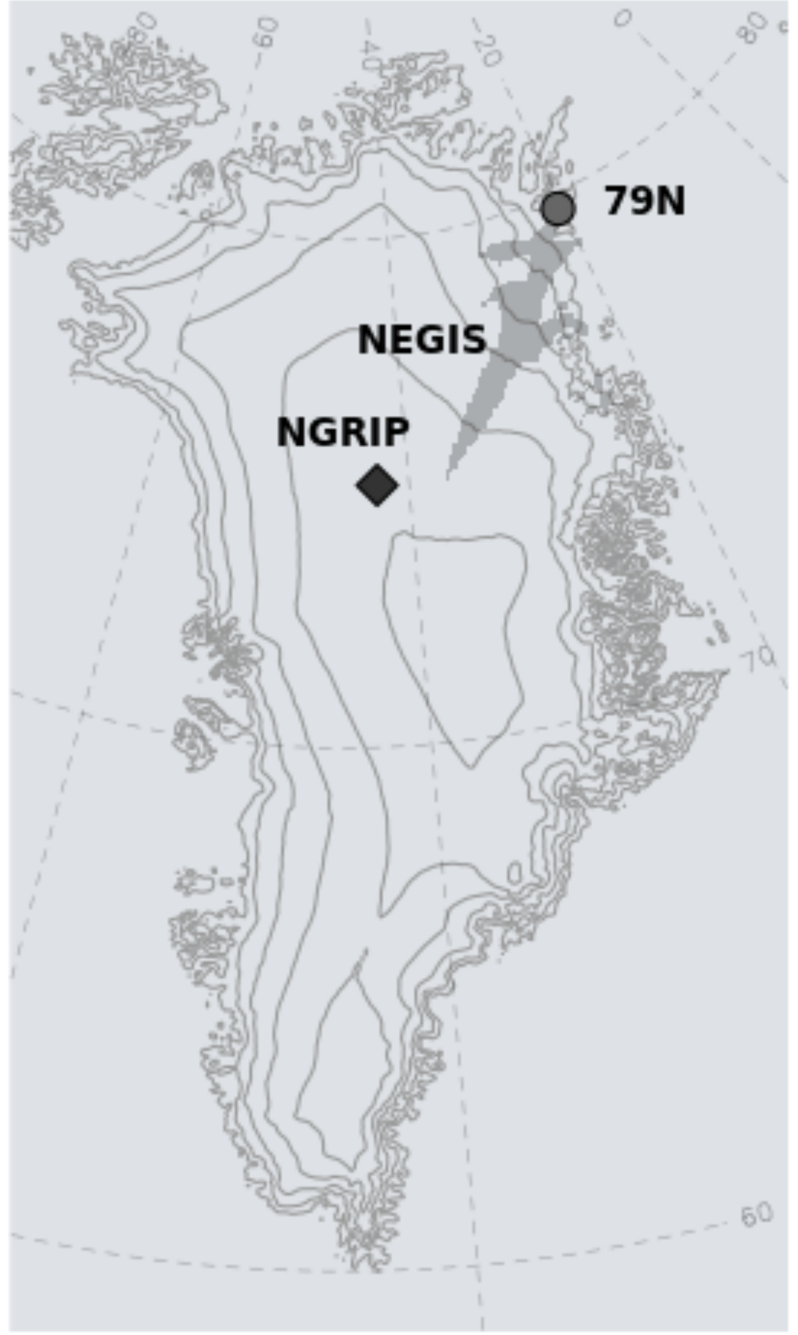


Credits to Greve and Robinson



Lecavalier et al., 2014

Perturbed model parameters



Enhancement factor

$$A(T') = E_f A_0 e^{-Q_a/RT'}$$

Basal friction

$$\boldsymbol{\tau}_\mathbf{b} = -C_\mathrm{b} \left(\frac{|\mathbf{u_b}|}{|\mathbf{u_b}| + u_0} \right)^q \frac{\mathbf{u_b}}{|\mathbf{u_b}|}$$

$$C_\mathrm{b} = \lambda c_\mathrm{f} N_\mathrm{eff}$$

At the NEGIS

$$\lambda = \begin{cases} 1 & \text{if } z_b > z_1 \\ \max\left[\exp\left(\frac{z_b - z_1}{z_1 - z_0}\right), \lambda_{\min}\right] & \text{if } z_b < z_1 \end{cases}$$

Calving rate

Kt

Von Mises stresses

Effective pressure

$$N_{eff} = N_0 \left(\frac{\delta P_0}{N_0} \right)^s 10^{\left(\frac{e_0}{C_c}\right)(1-s)}$$

$$s = W_\mathrm{til} / W_\mathrm{til}^\mathrm{max}$$

$$\frac{\partial W_\mathrm{til}}{\partial t} = -\frac{\rho}{\rho_w} \dot{b}_\mathrm{g} - C_\mathrm{d}$$

Surface ablation

$$M_\mathrm{s} = \frac{\Delta t}{\rho_\mathrm{w} L_\mathrm{m}} [\tau_\mathrm{a} (1 - \alpha_\mathrm{s}) S + c + \lambda T]$$

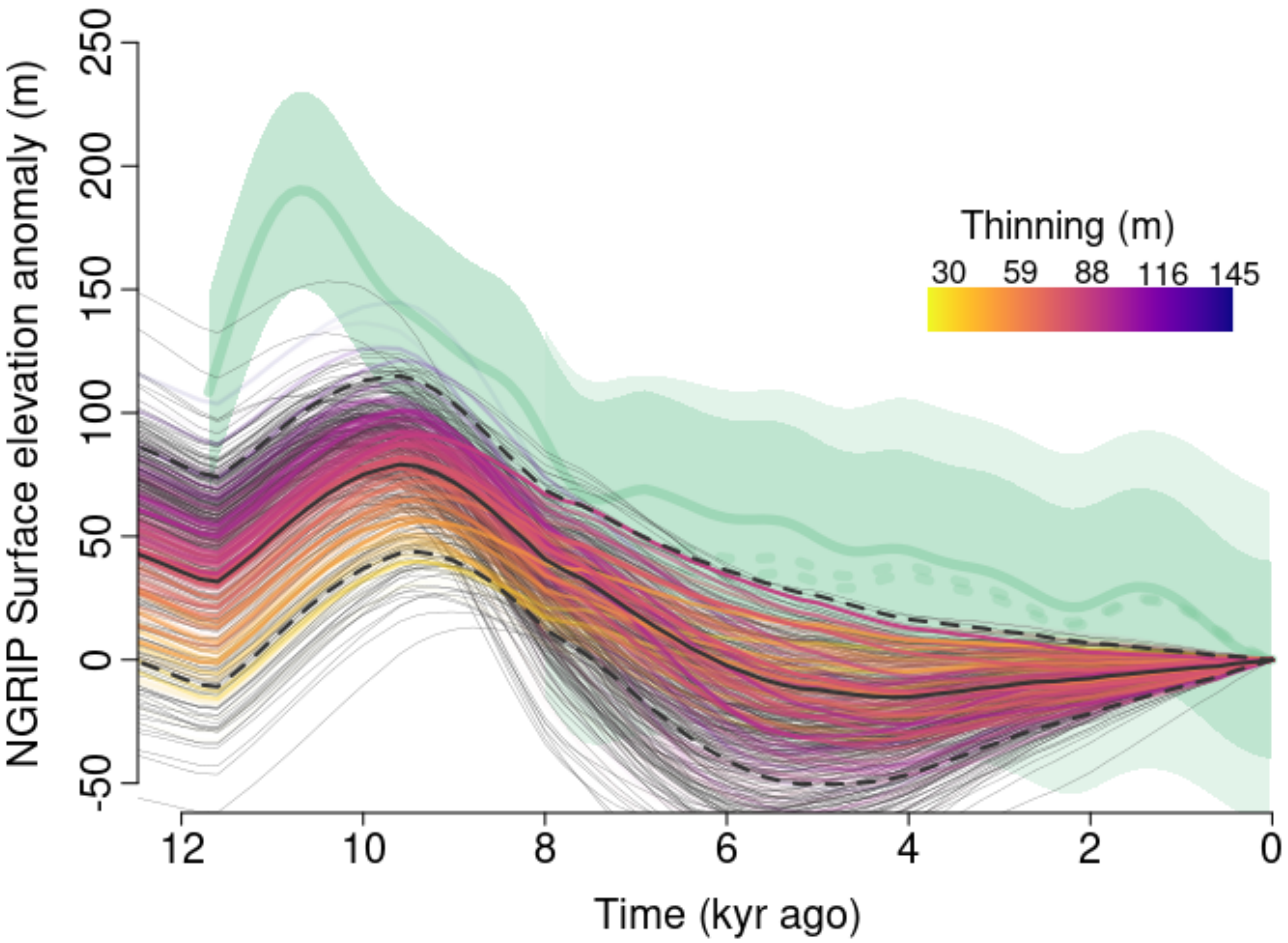
c=c_1+b(lat-lat_0)*

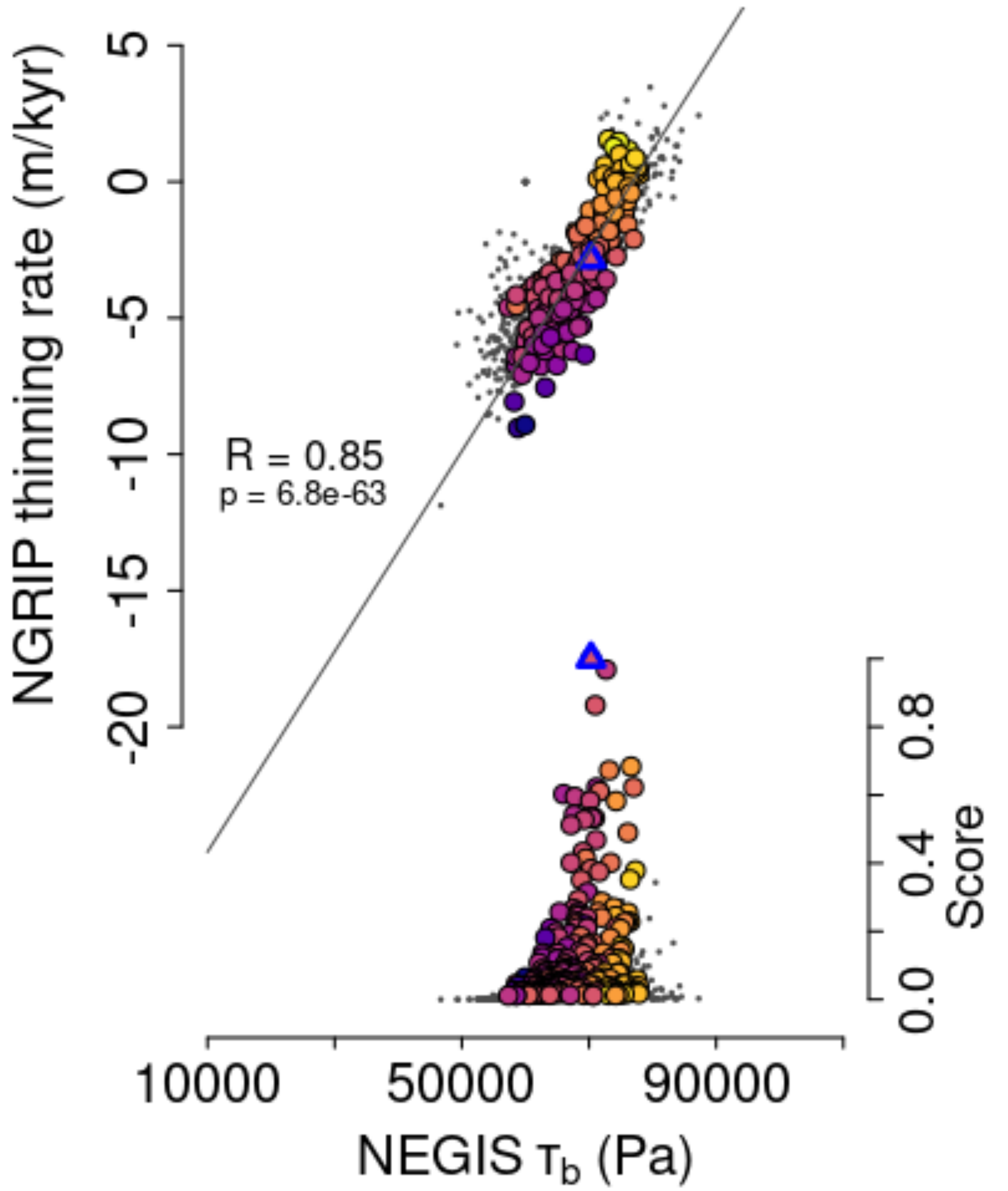
Isostasy

Lithosphere relaxation time tau

Subsurface melt

$$B_m(t) = B_{ref} + \kappa \Delta T_{ocn}(t)$$





$$S_{i,j} = \exp\left(-M_{i,j}/\mathrm{median}\left(M_{i,j} \quad \right)\right).$$

$$S_j = \prod_{i=1.} S_{i,j}.$$

Conclusions

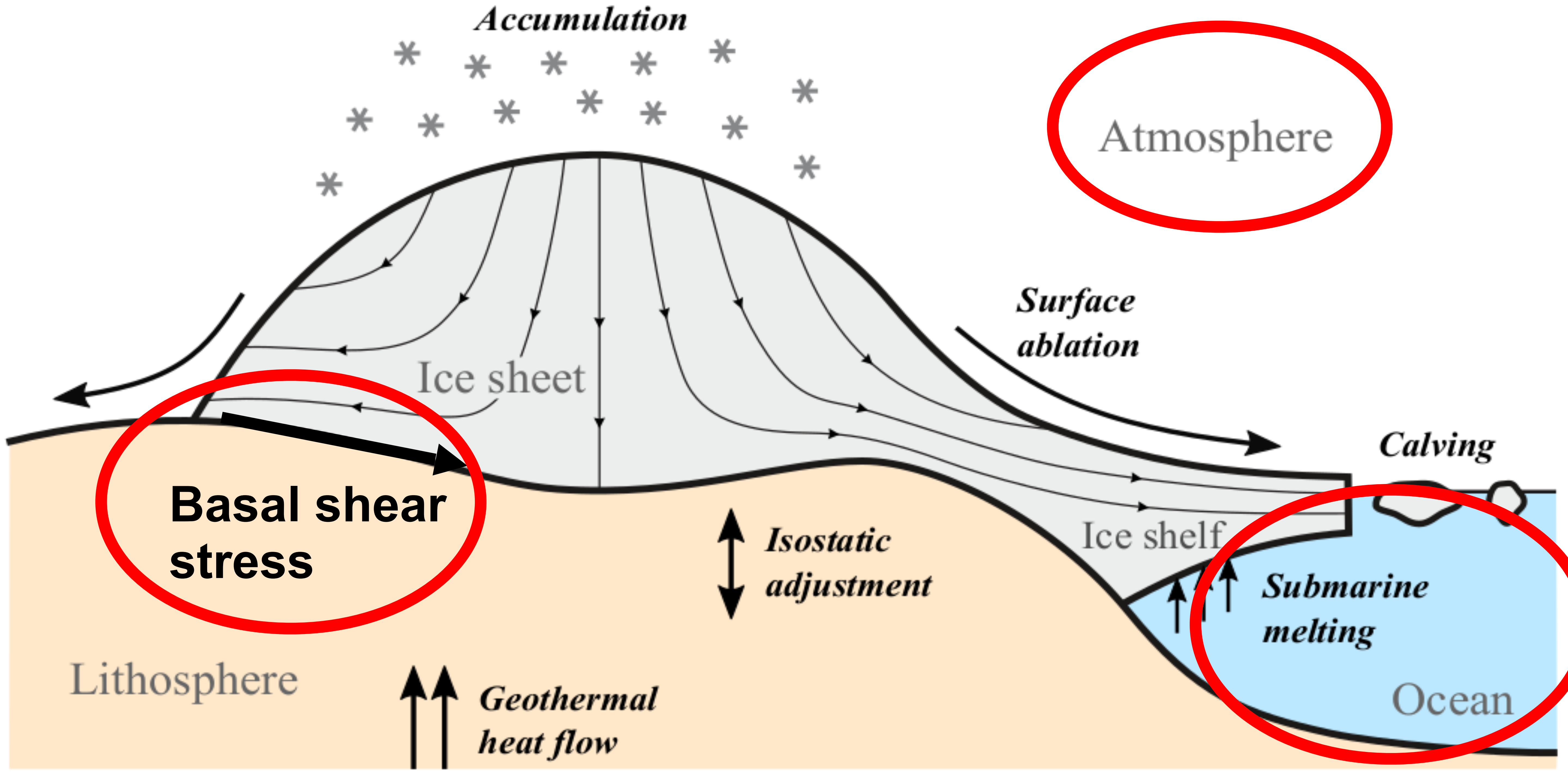
- **NGRIP Holocene thinning is driven by the formation and development of the nearby NEGIS**, which modulates the rate and the timing of the thinning through progressive fast flow inland penetration.

- **NE high temperatures trigger the early retreat of the NE sector**, defining the timing of the deglaciation. More Holocene transient climatologies are needed to accurately assess the heterogeneous deglaciation history across Greenland.

- These results suggest that **the role of the NE basin** sector in shaping the summit Holocene thinning **has been underestimated** so far. Summit thinning data-model mismatch could be partially related to the typical wrong model representation of the NEGIS (in terms of both dynamics and stream geometry).

Tabone et al., in review

Towards a new approach: basal sliding and atmospheric/oceanic forcings



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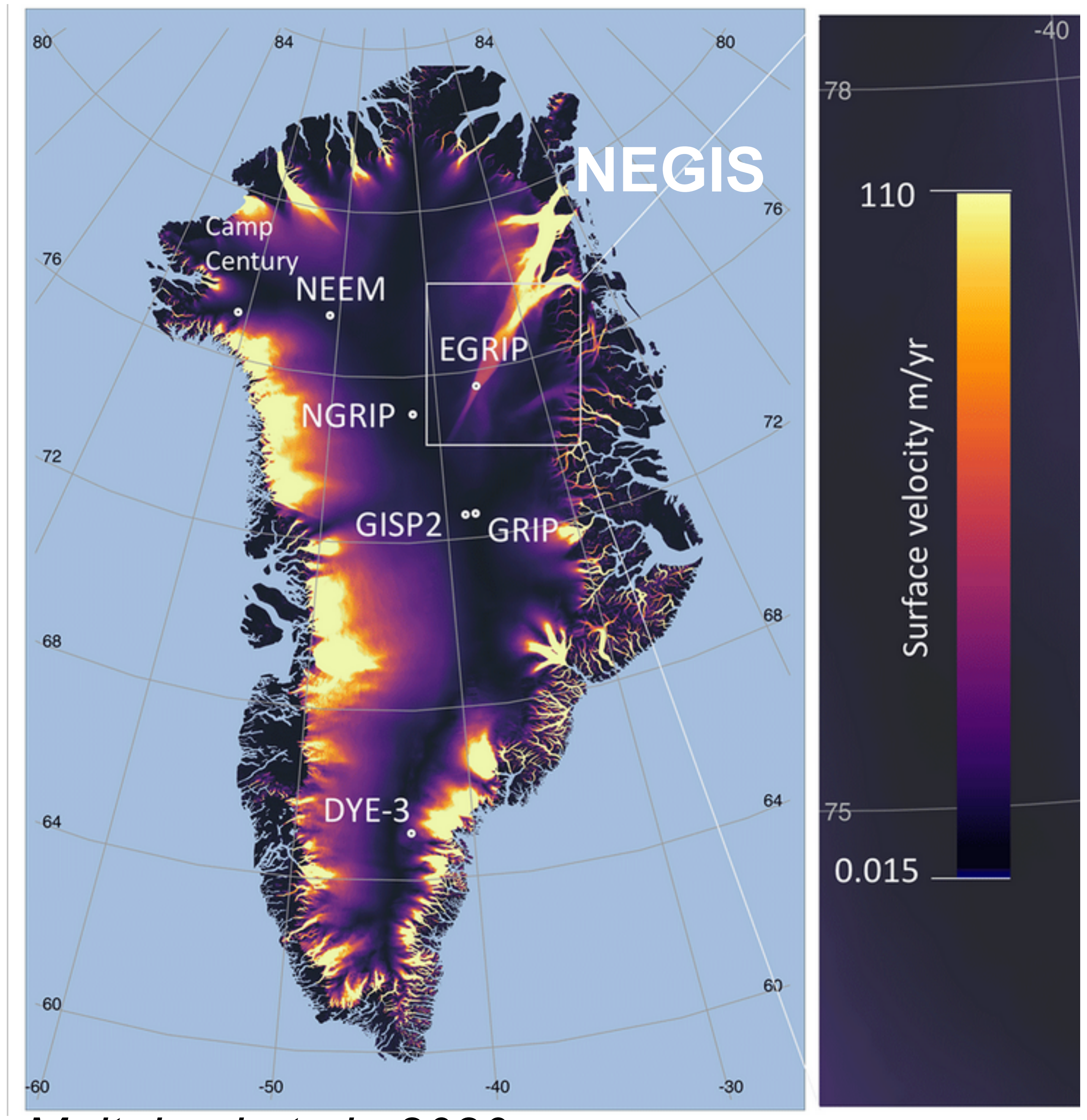

Mojtabavi et al., 2020

Can we reduce the NGRIP thinning mismatch by improving the climate/ocean forcing and the representation of fast flow in a 3D ice-sheet model?