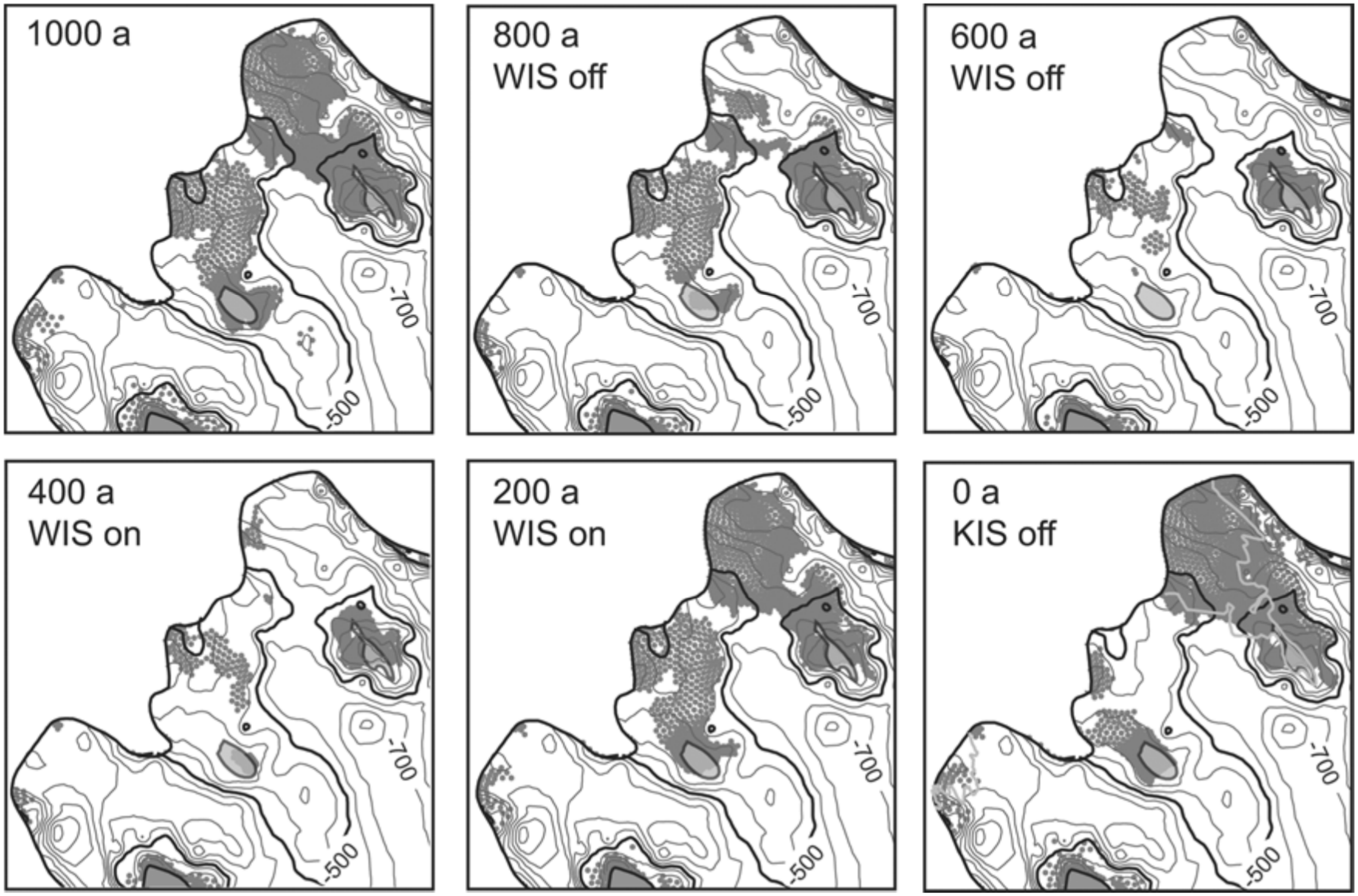
Rapid grounding line migration induced by ice stream internal variability

Alex Robel, Eli Tziperman
Harvard University

Christian Schoof
University of British Columbia

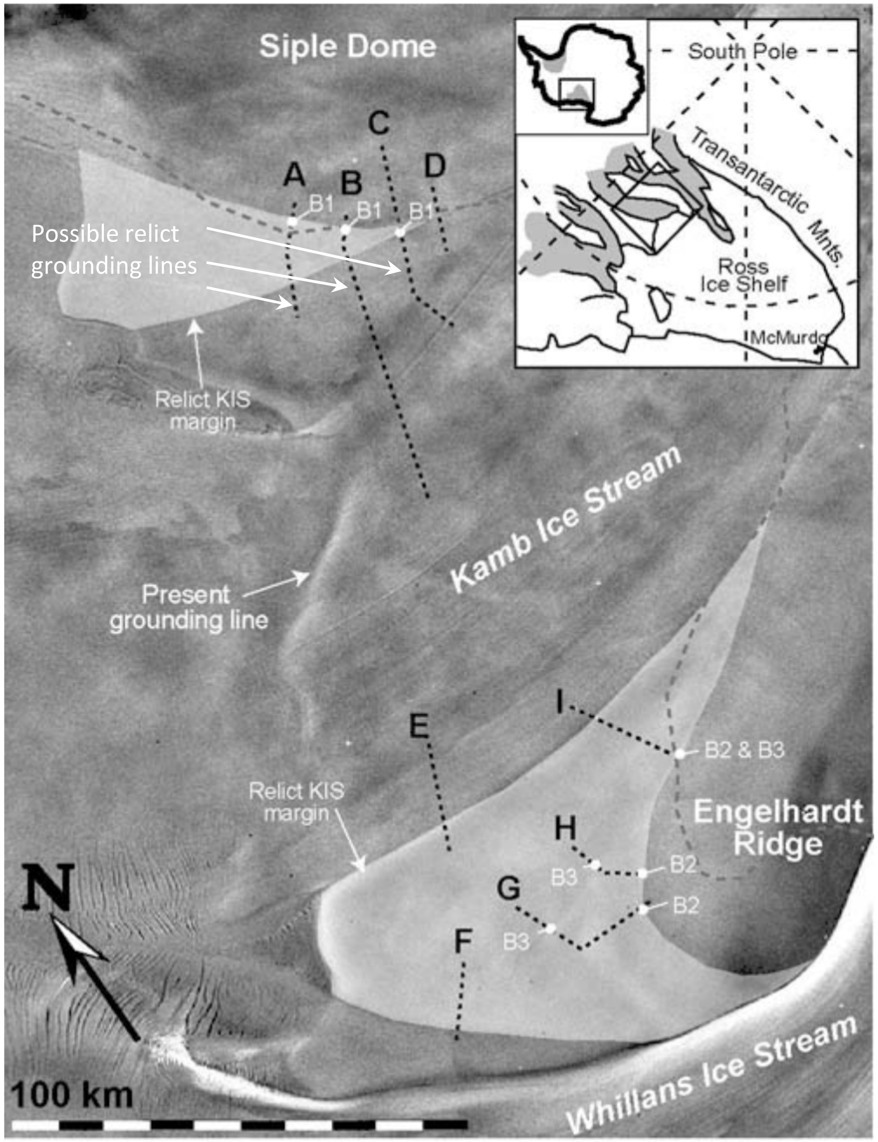
Ice stream variability



Hulbe & Fahnestock 2007

Ice streams exhibit strong variability on centennial/millennial time scales .

Ice stream grounding line variability



Catania et al. 2005

Evidence of relict grounding lines (Catania et al. 2005) and grounding zone wedges (Dowdeswell et al. 2008) from the Siple Coast indicate significant (100 km) grounding line variability in the present and past.

Central questions

1. What is the mechanism and spatial structure of internal ice stream variability

2. How is internal ice stream variability manifested at the grounding zone?

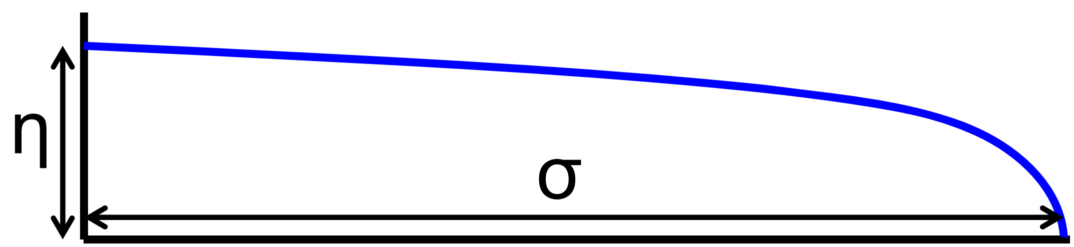
3. How is ice stream internal variability impacted by buttressing?

Ice Stream Model Details

- Flowline model with momentum equation:

$$\partial_x \tau_{xx} + G_s H \left|u\right|^{\frac{1}{n}-1} u + \tau_b = \tau_d$$

- Mass Continuity: $\partial_x u + \partial_z w = 0$
- τ_b set by undrained plastic bed model (Tulaczyk et al. 2000b) w/weak hydraulic diffusion.
- Streamwise x-coordinate scaled by grounding line position – mesh refined near GL.



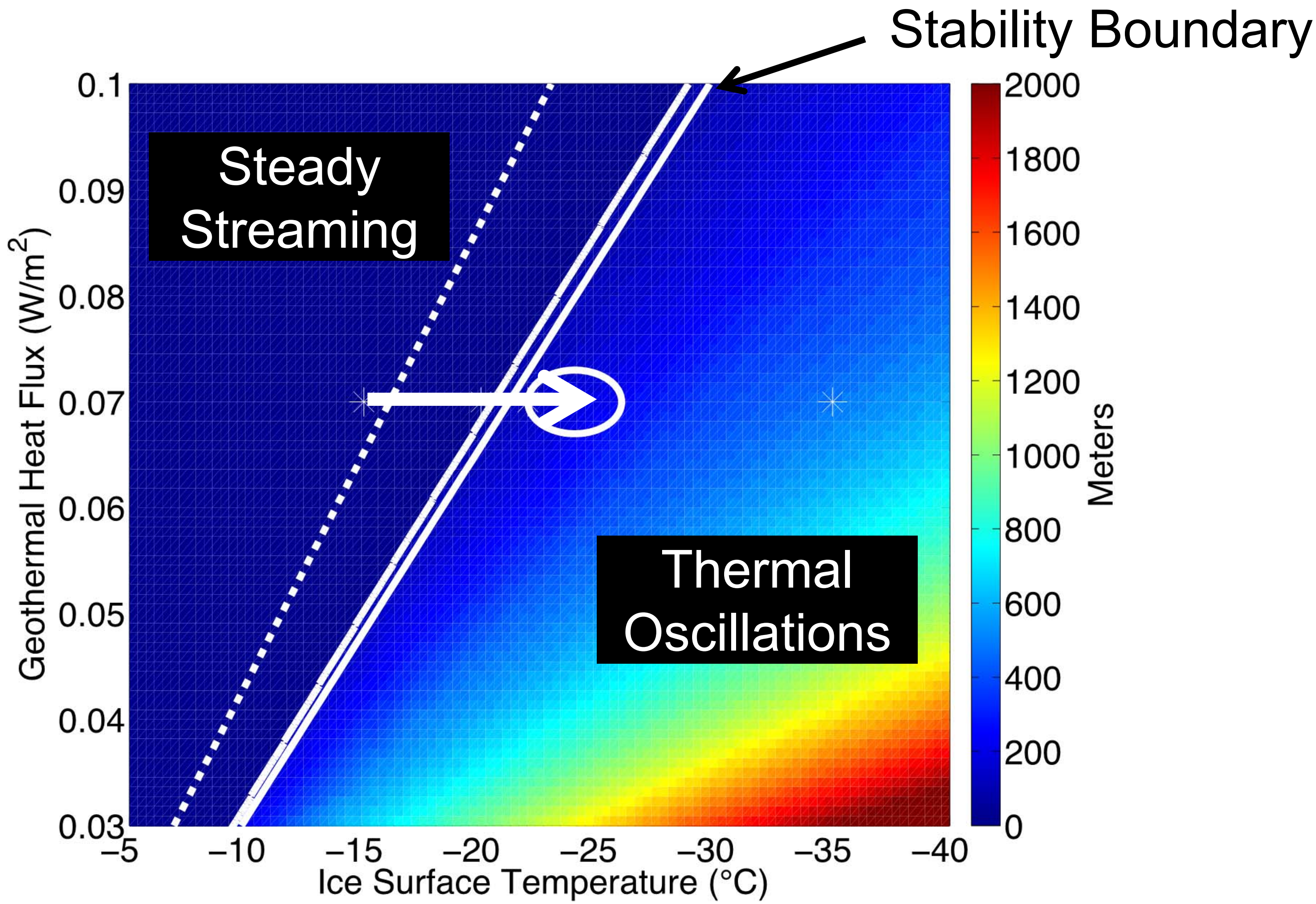
- Separated implicit solves on h/x_g, T, u
  - –Till water content solved explicitly to allow for ad-hoc freeze-on while enforcing energy conservation

Experiments

(Exp. 1) Transition from steady-streaming to thermal oscillations

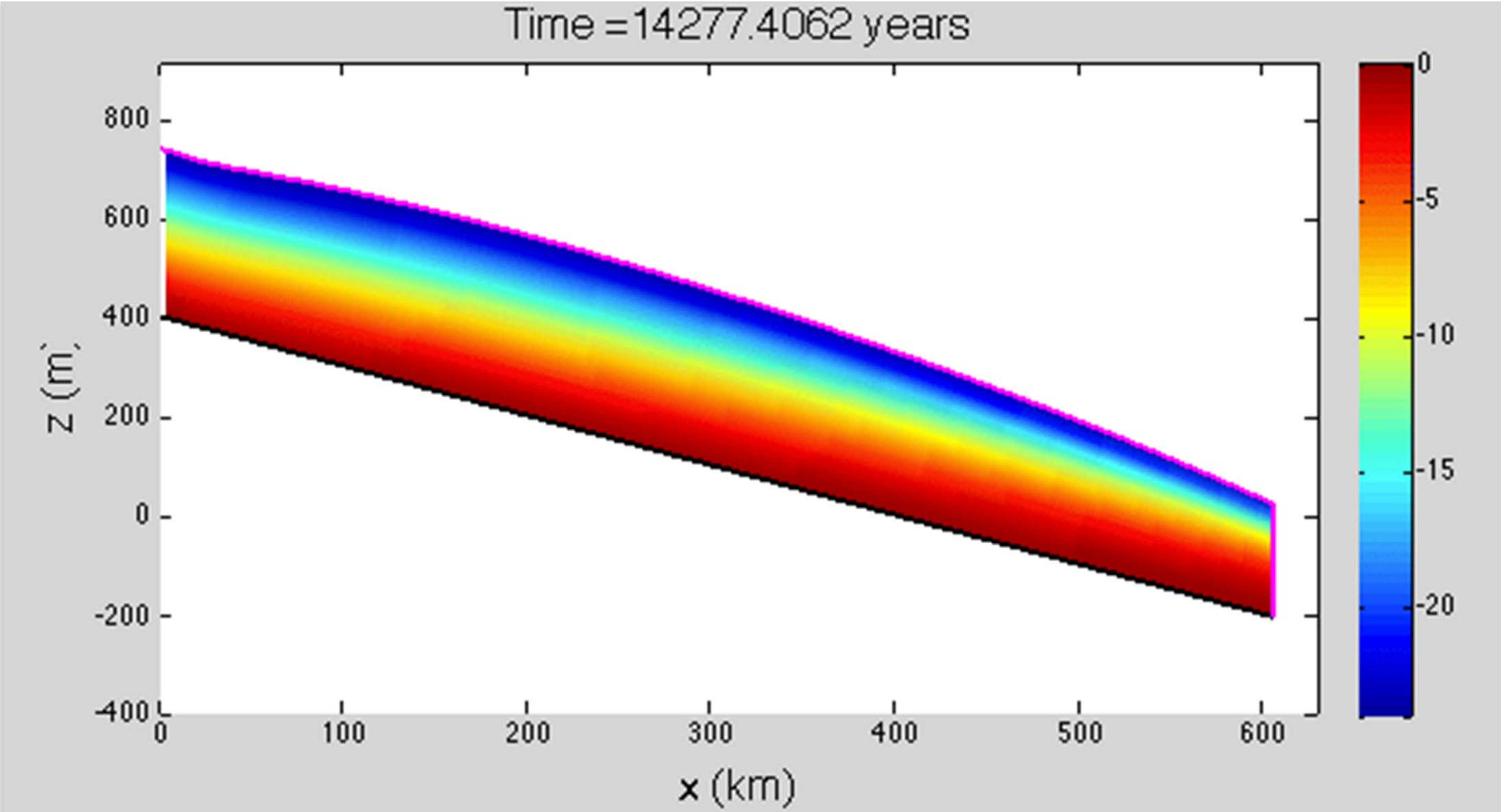
(Exp. 2) Removal of buttressing in oscillatory regime

Experiment Construction

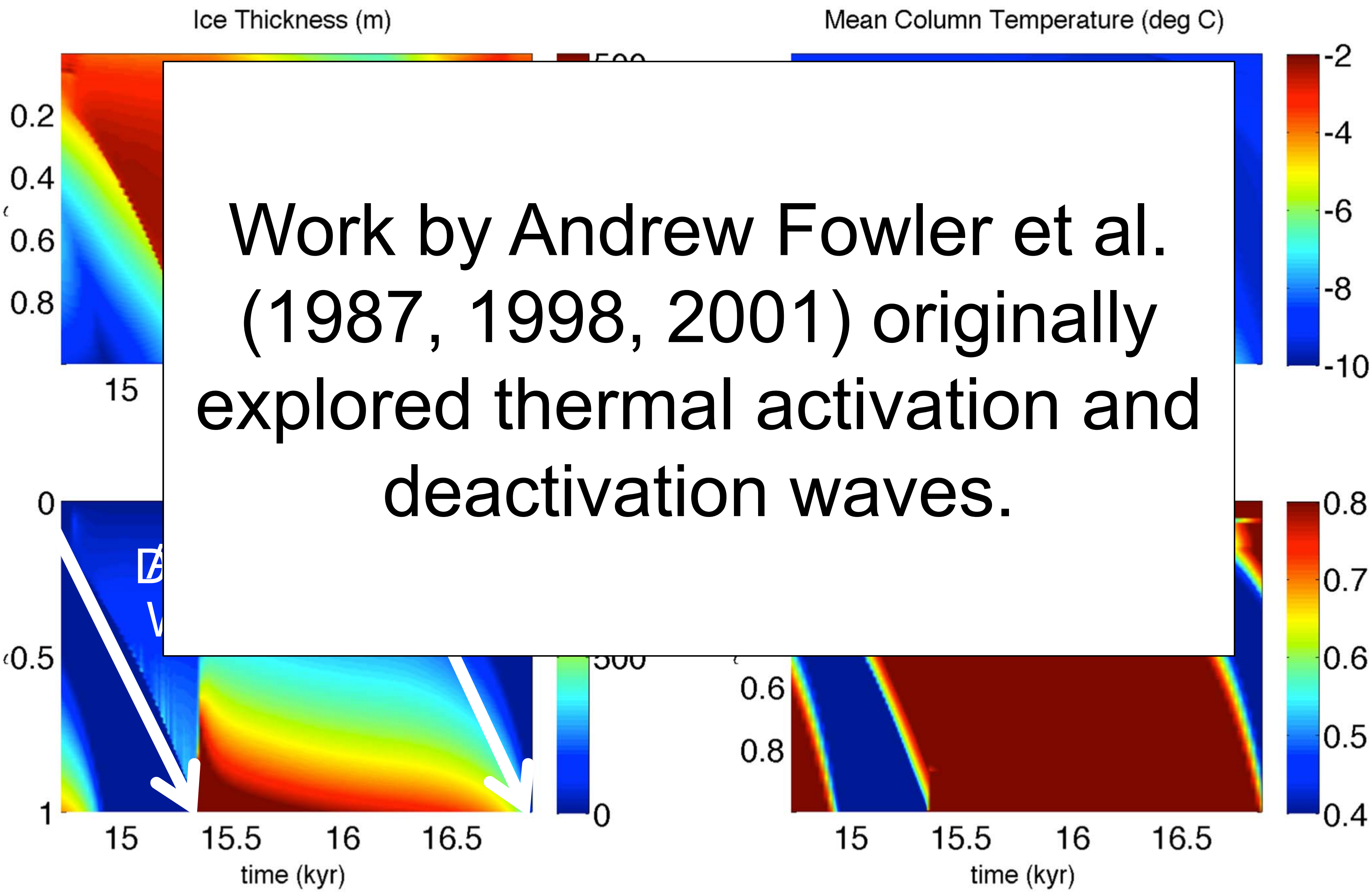


Robel et al., JGR, 2013

Ice Stream Thermal Oscillations



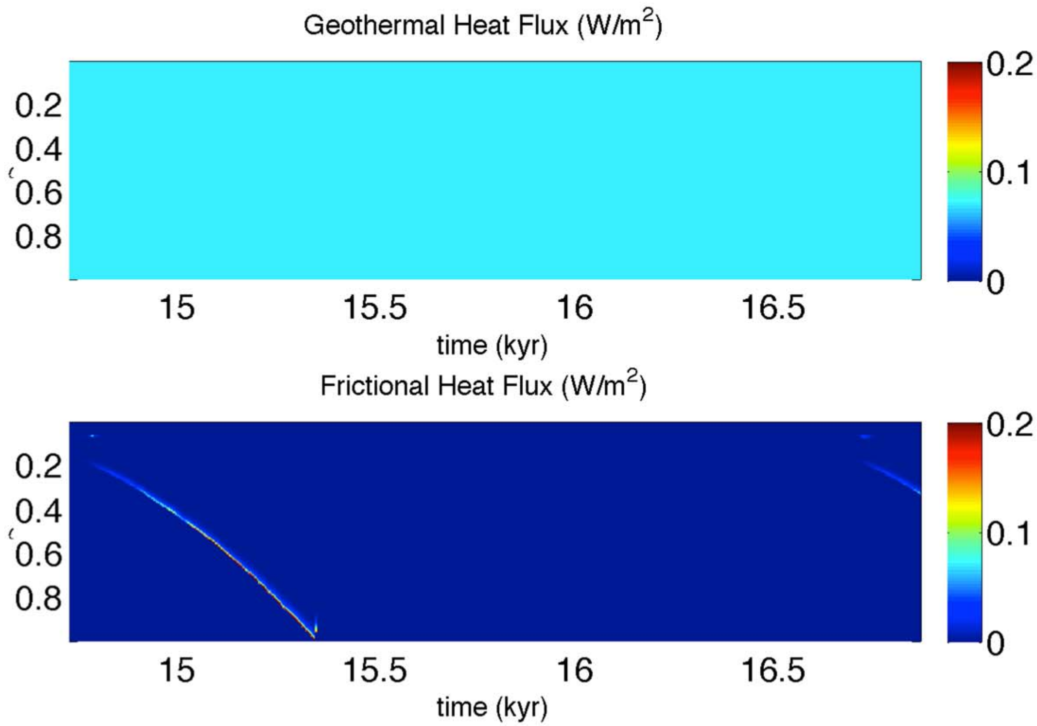
Activation/Deactivation Propagation



Work by Andrew Fowler et al. (1987, 1998, 2001) originally explored thermal activation and deactivation waves.

Activation Wave

Upstream basal heat budget becomes positive, MW produced, ice slides



Longitudinal stress diffuses momentum downstream at velocity convergence. Ice begins sliding.

Frictional heating occurs at newly sliding ice. Thick ice is advected downstream. MW produced.

Activation wave reaches GL

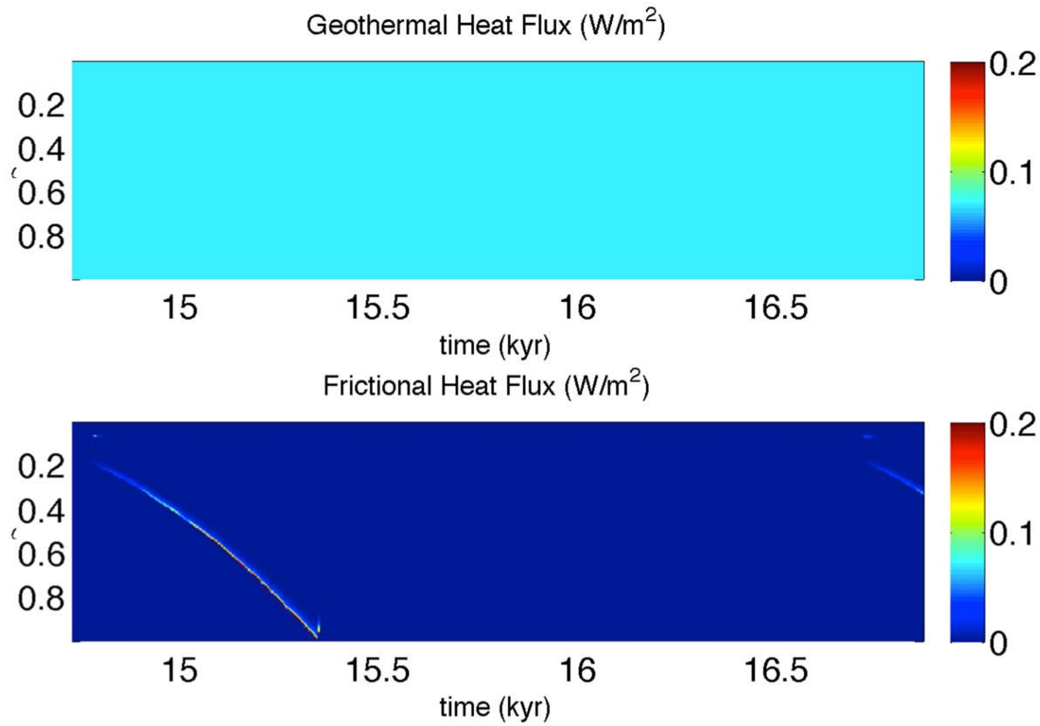
Bed is weak everywhere, ice stream transition to lateral shear support

Deactivation Wave

Upstream basal heat budget becomes negative, MW freezes-on

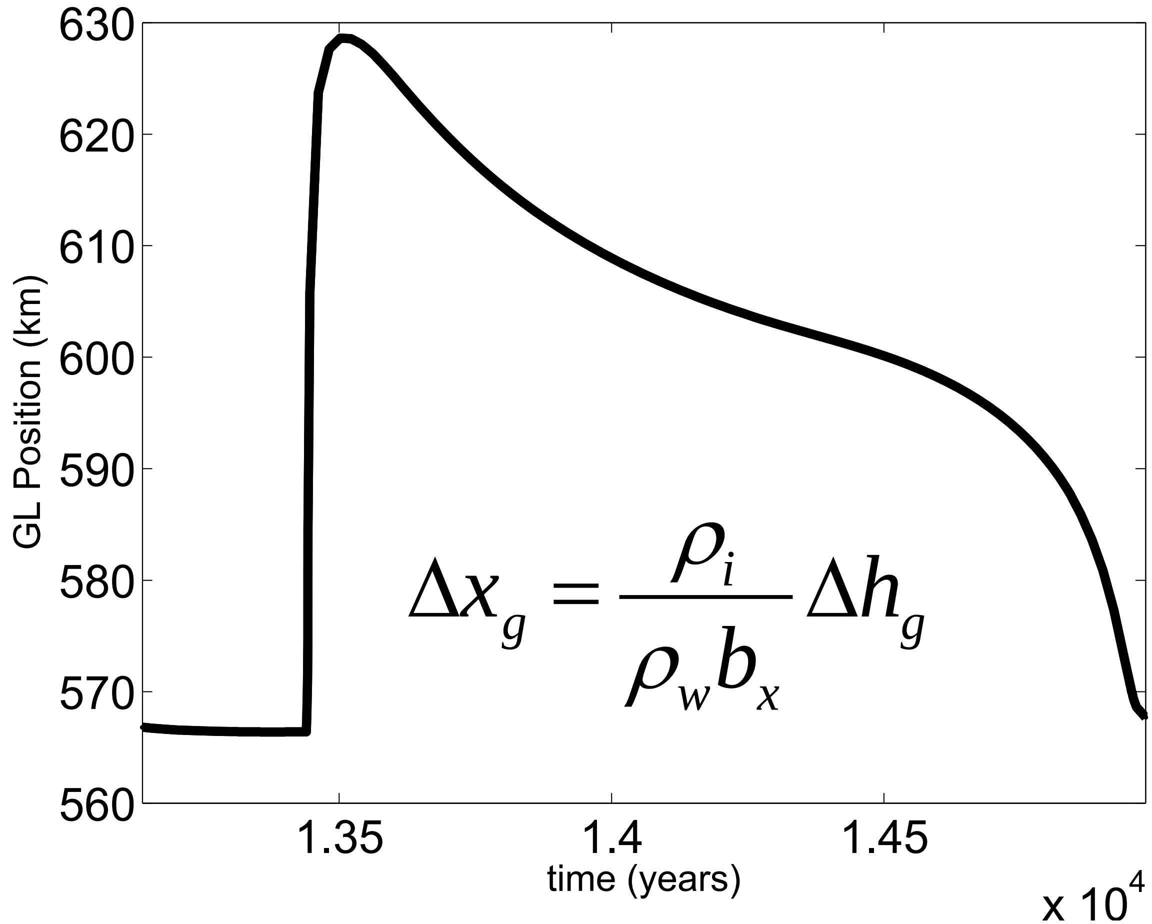
Velocity divergence downstream thins downstream ice

Basal temperature gradient downstream steepens, MW freezes-on



Bed is strong, supported by (relatively) strong driving stress

Grounding Line Migration



$$\Delta x_g = \frac{\rho_i}{\rho_w b_x} \Delta h_g$$

Note: this occurs on a linear, prograde bed

From simple model of Robel et al. 2013: $$\Delta h \sim REHF \sim \frac{k\Delta T}{G[h]}$$

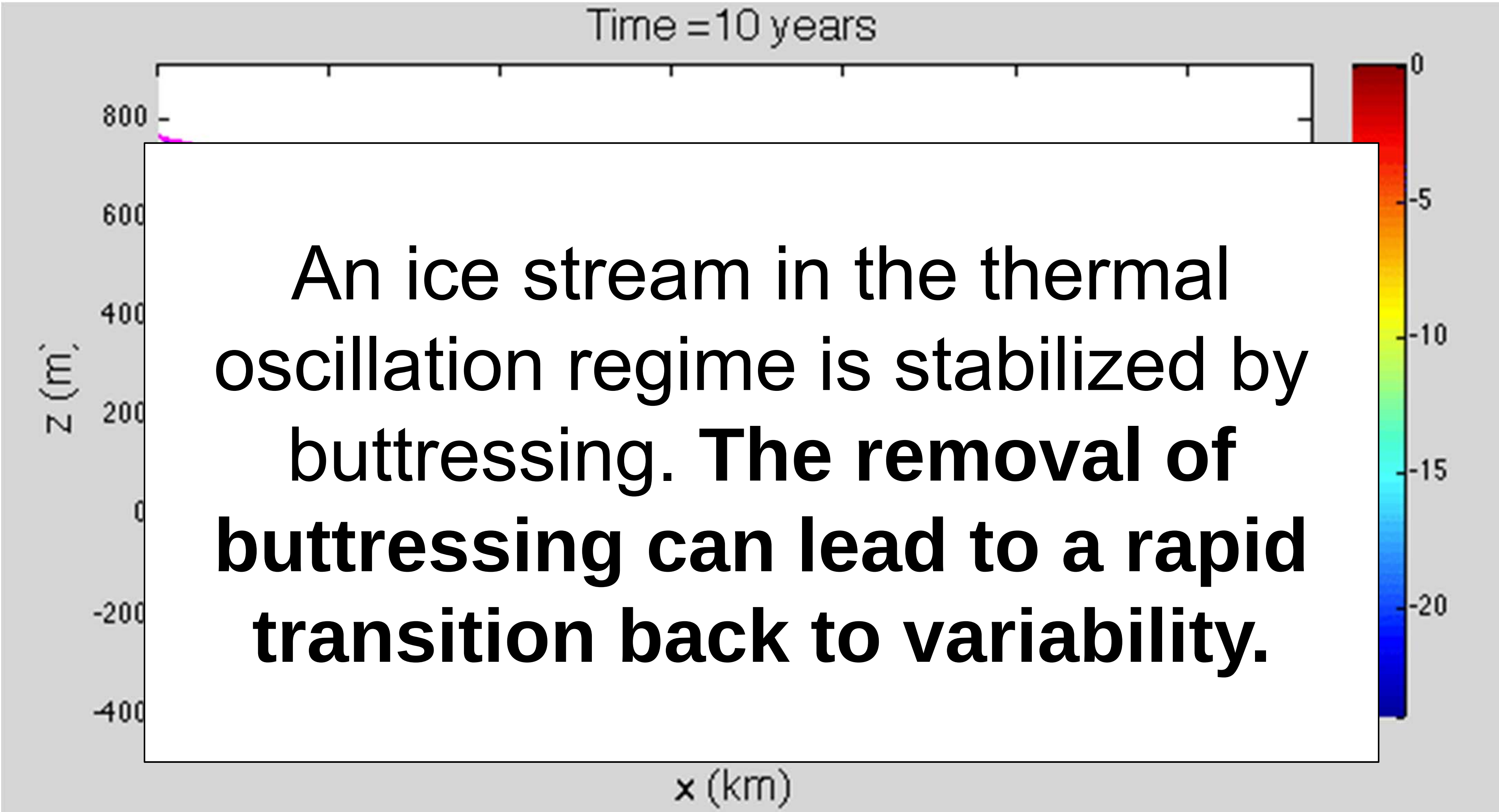
Buttressing parameterization

To investigate the how buttressing and its removal impact the steady-state, we parameterize at the GL stress condition:

$$\tau_{xx} = (1 - f)\frac{1}{2}\rho_i\left(1 - \frac{\rho_i}{\rho_w}\right)gh^2$$

Buttressing parameter

Buttress removal



An ice stream in the thermal oscillation regime is stabilized by buttressing. **The removal of buttressing can lead to a rapid transition back to variability.**

What we've learned

- Basal thermal oscillations cause stagnation and activation which propagate as waves.
- Activation at the grounding line can cause rapid grounding line migration (~km/yr).
- Deactivation can cause rapid migration (~100's m/yr).
- Buttressing can stabilize an ice stream that would otherwise exhibit internal variability.

robel@fas.harvard.edu

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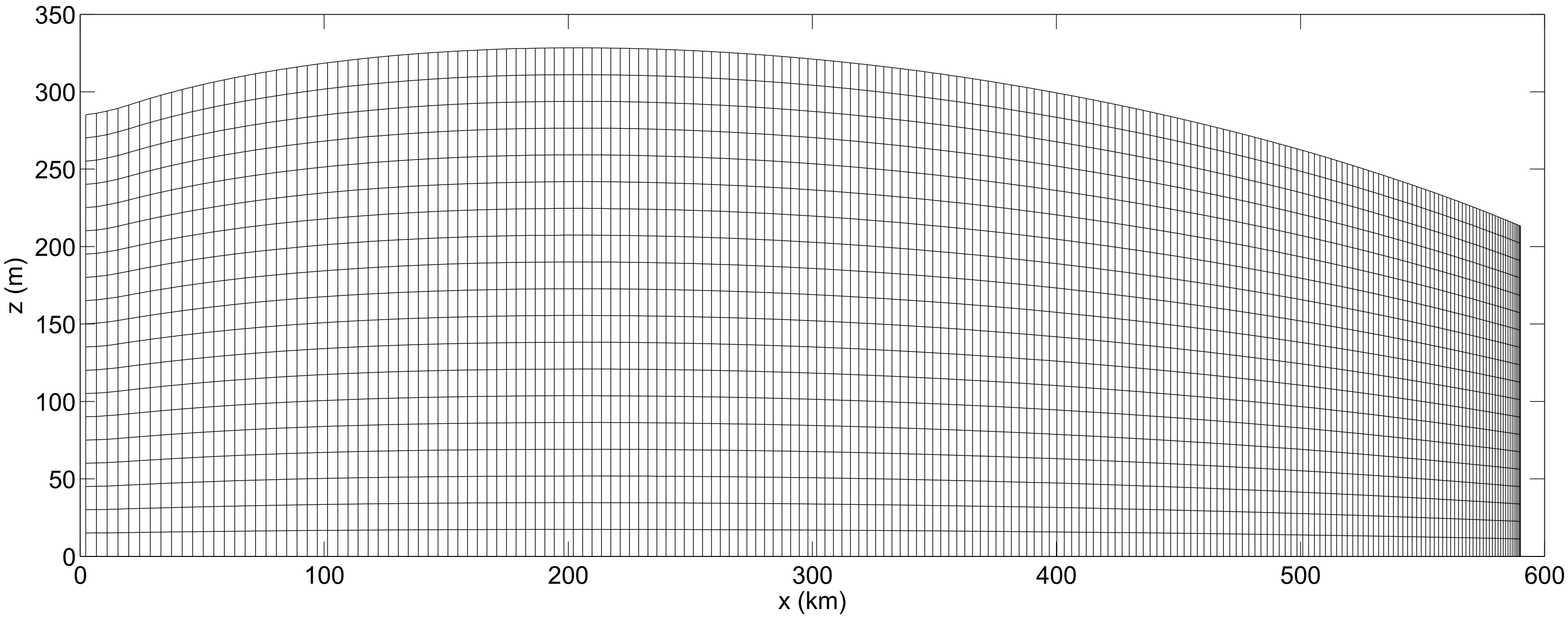
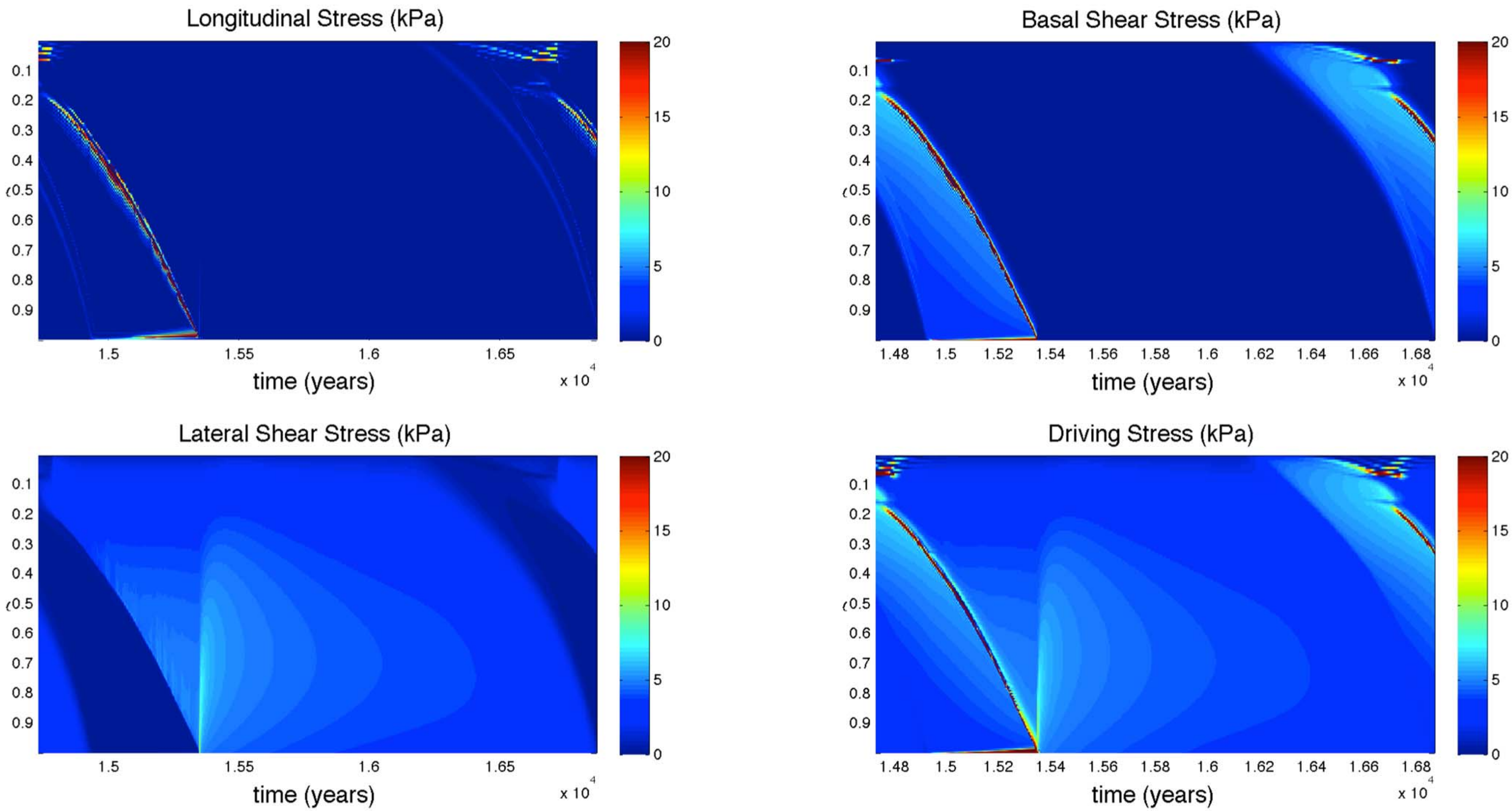
Supplements

Grid example





Longitudinal Stress (kPa)
Basal Shear Stress (kPa)
Lateral Shear Stress (kPa)
Driving Stress (kPa)
time (years)
x 10^4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.5
1.55
1.6
1.65
1.48
1.5
1.52
1.54
1.56
1.58
1.6
1.62
1.64
1.66
1.68
0
5
10
15
20