Ice rise and ice rumple dynamics, and the consequences for ice sheet evolution

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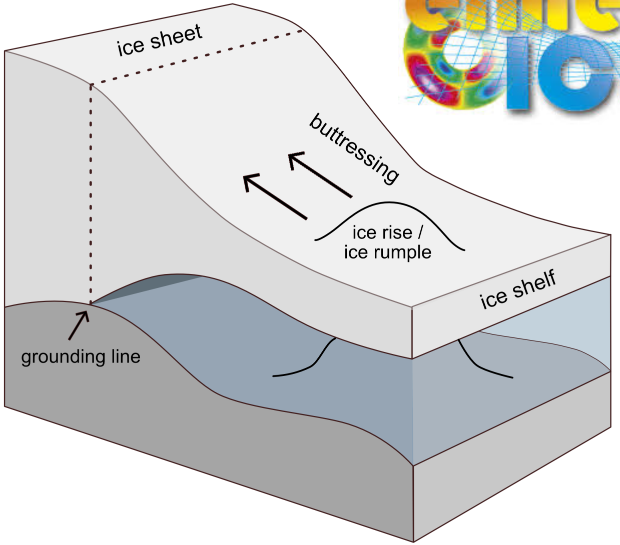

Max-Planck-Institut für Meteorologie

DFG-SCHWERPUNKTPROGRAMM 1158
ANTARKTIS FORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

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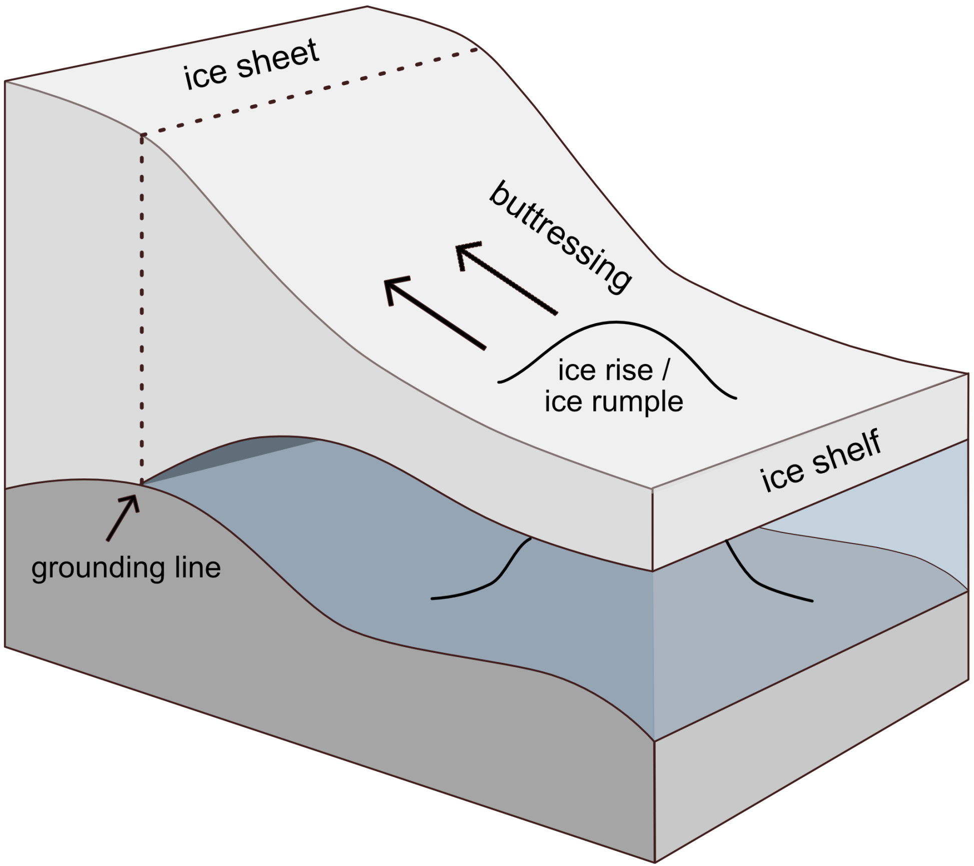
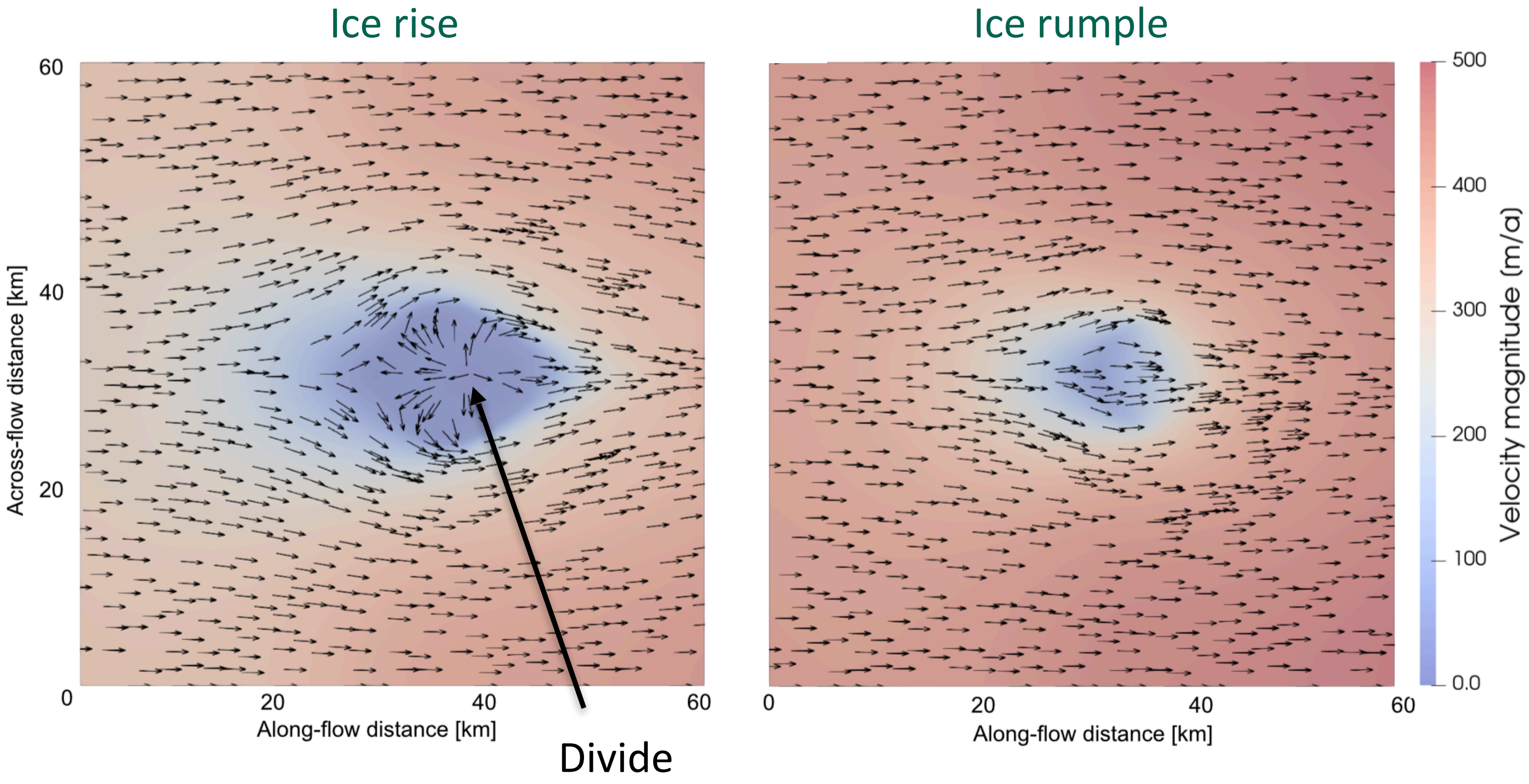
Research questions

- How does basal friction affect the geometry and dynamics of ice rises and ice rumples?
- How do ice rises and ice rumples respond to sea level variation?
- What are the consequences for ice shelf buttressing?

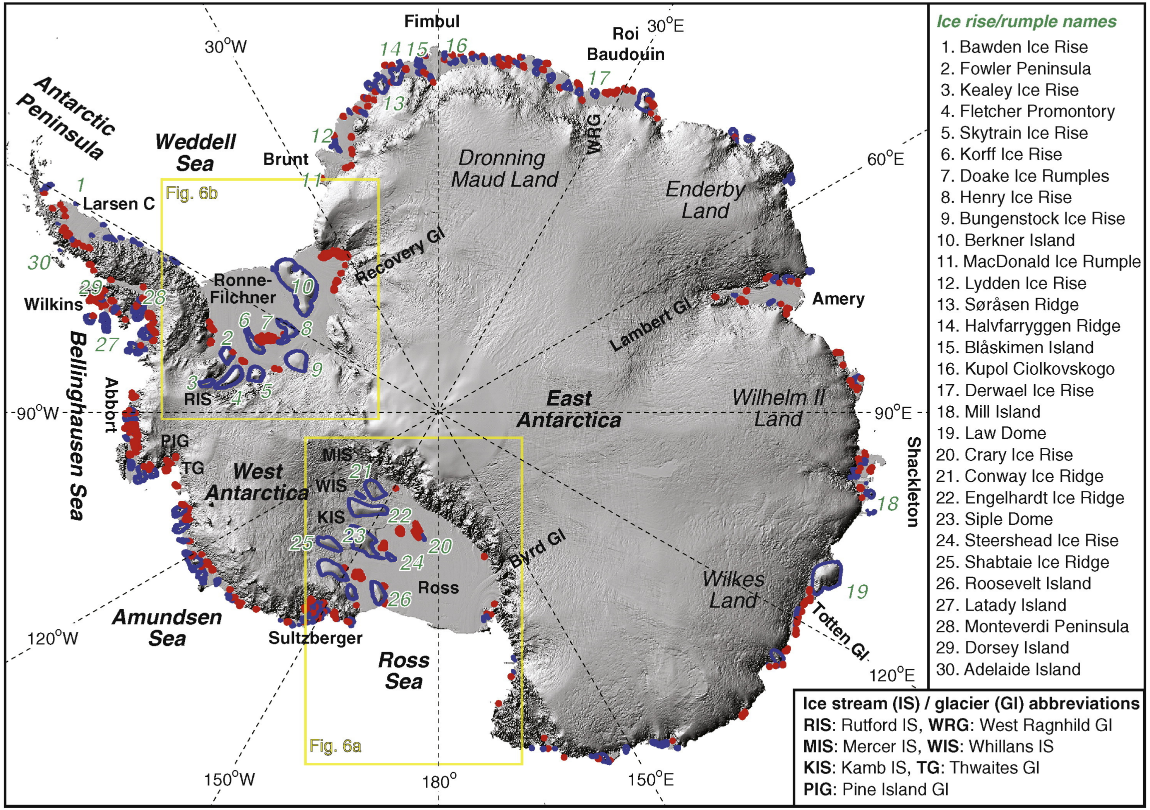
Ice shelf dynamics



Bird's eye view



Ice rises and ice rumples



— Ice rise
— Ice rumple

(Matsuoka et al., 2015)

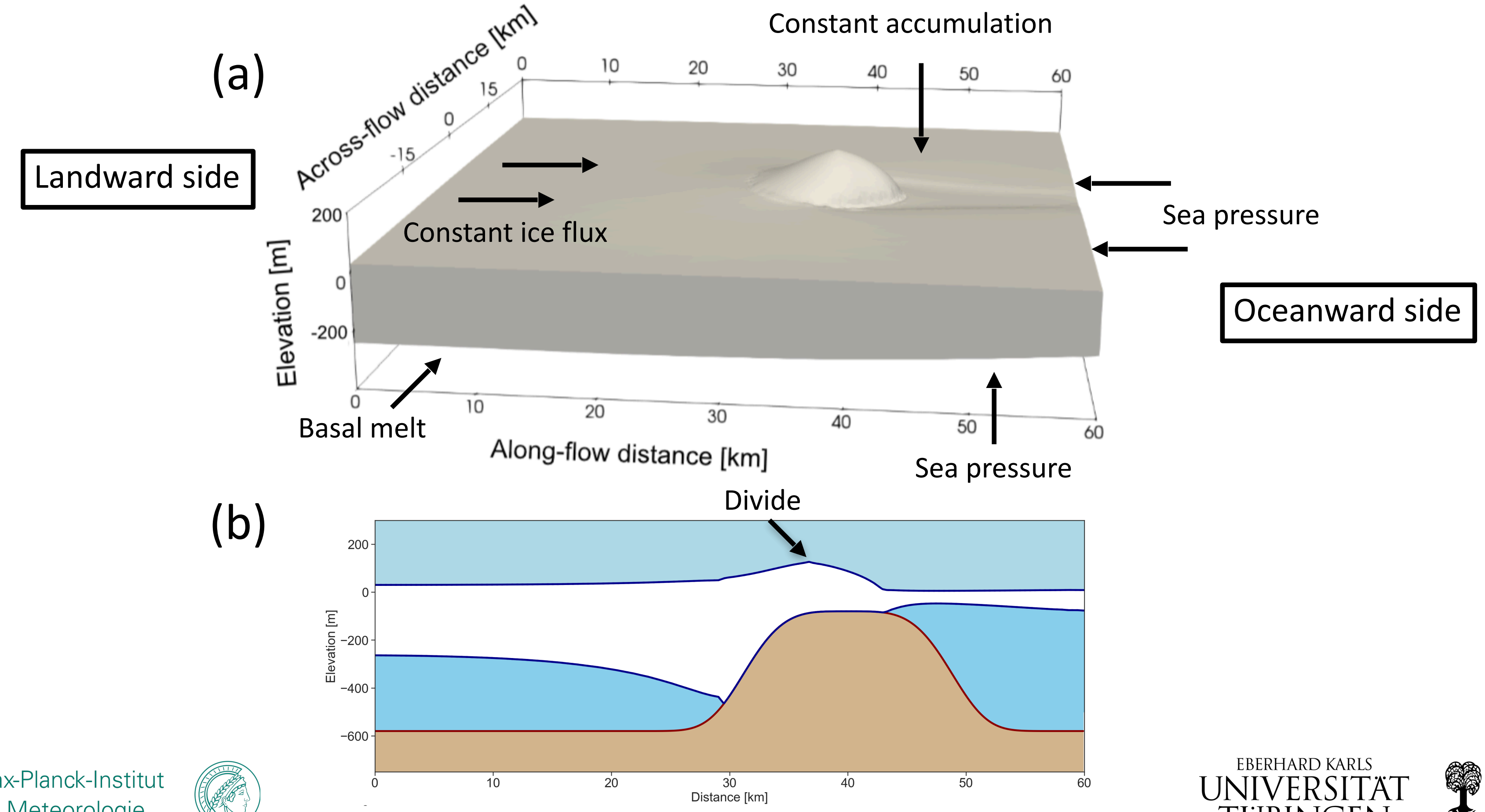
Ice rise / ice rumple model

- Finite element model Elmer/Ice (Gagliardini et al., 2013)
- Full Stokes equations
- Isothermal, isotropic, 3D ice flow model
- Non-linear Weertman-type friction law:

$$\boldsymbol{\tau}_b = C|\mathbf{u}_b|^{m-1}\boldsymbol{u}_b$$

Model setup

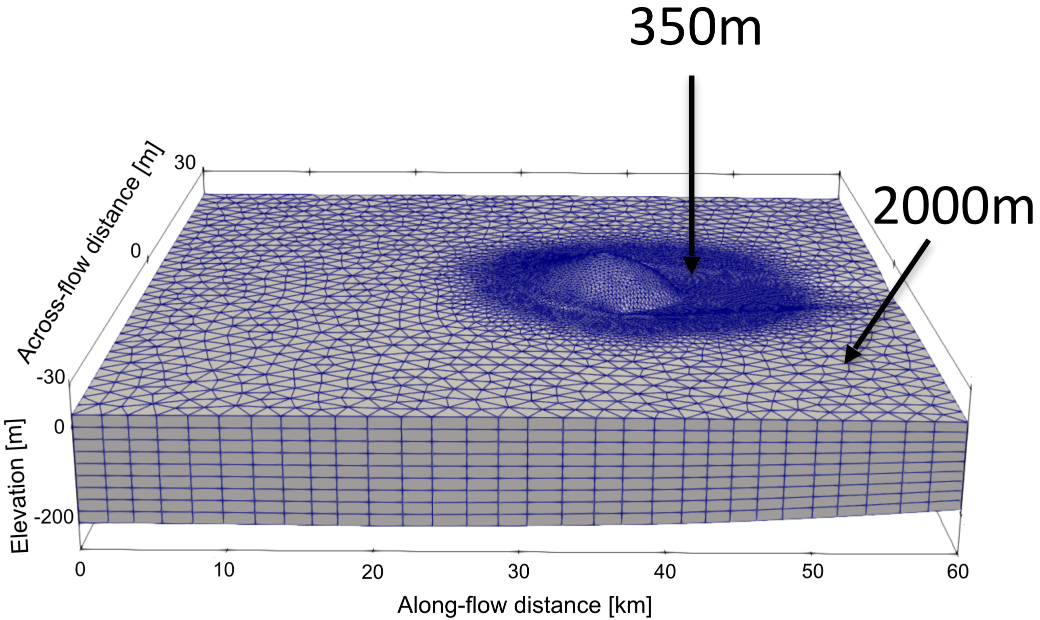
(a)



(b)

Mesh resolution

- Horizontally unstructured mesh
- High resolution to adequately resolve the grounding line
- 10 layer vertical extrusion



Steady state simulations

- Three simulations with various basal friction coefficients:
  - *Low*: C = 3.812 x 10^6 Pa $m^{-1/3}$ $s^{1/3}$
  - *Intermediate*: C = 7.624 x 10^6 Pa $m^{-1/3}$ $s^{1/3}$
  - *High*: C = 3.812 x 10^8 Pa $m^{-1/3}$ $s^{1/3}$

$$(\boldsymbol{\tau}_b = C|\mathbf{u}_b|^{m-1}\boldsymbol{u}_b)$$

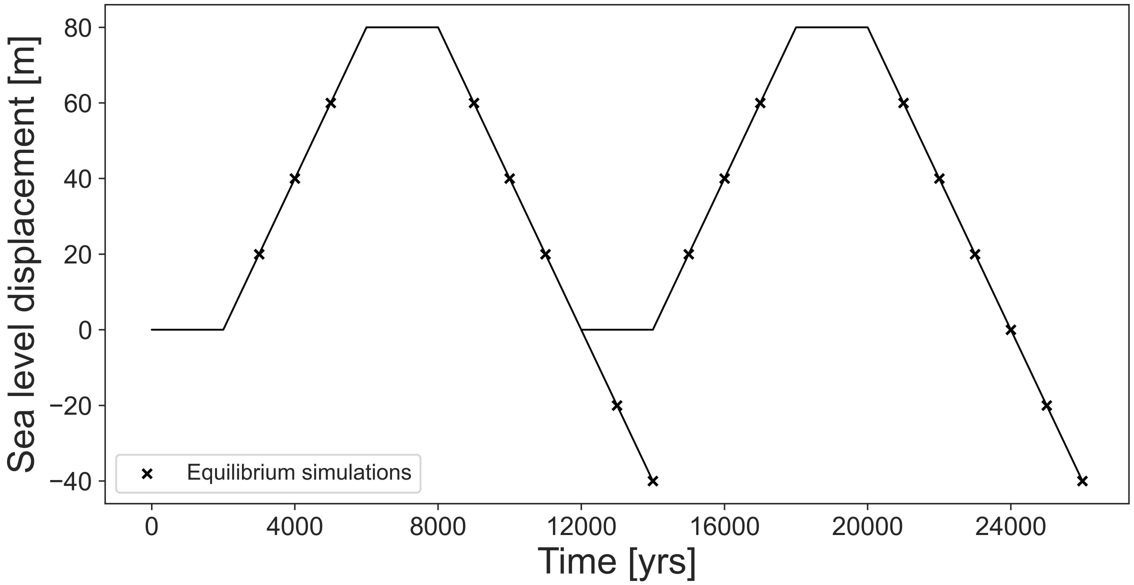
- Melt parameterisation:

$$\dot{a}_b = \begin{cases} 0, & \text{where ice is grounded, and} \\ \frac{1}{50} H^{\alpha} \tanh\left(\frac{|\mathbf{x}-\mathbf{x}_\mathbf{g}|}{100}\right), & \text{where ice is floating.} \end{cases}$$

- Grounding line definition: “First Floating”

Sea level variation

- Linear sea level perturbation.
- Periods of constant sea level to allow equilibration.



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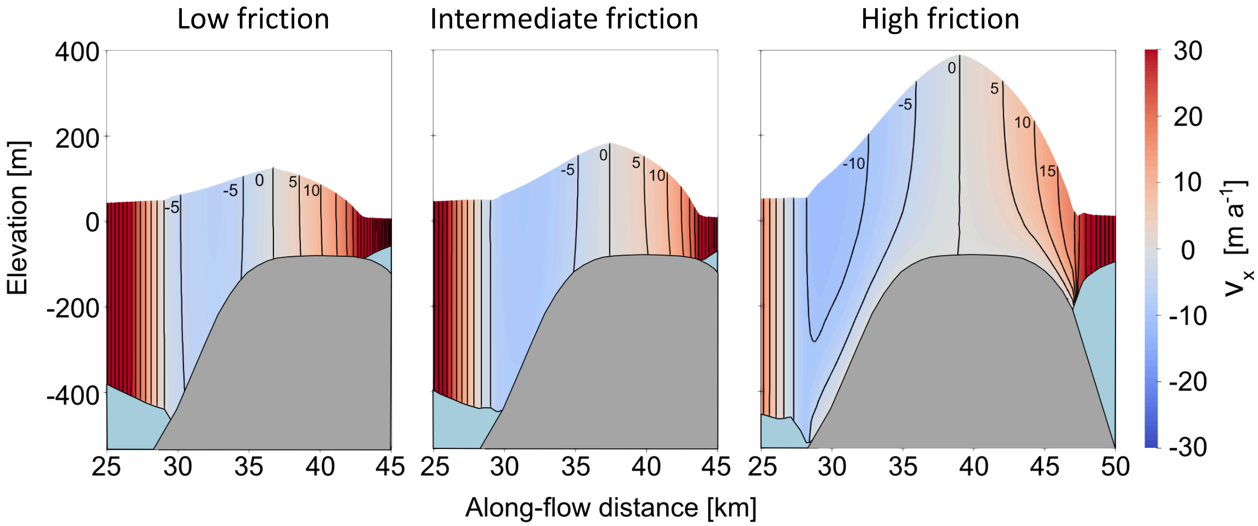
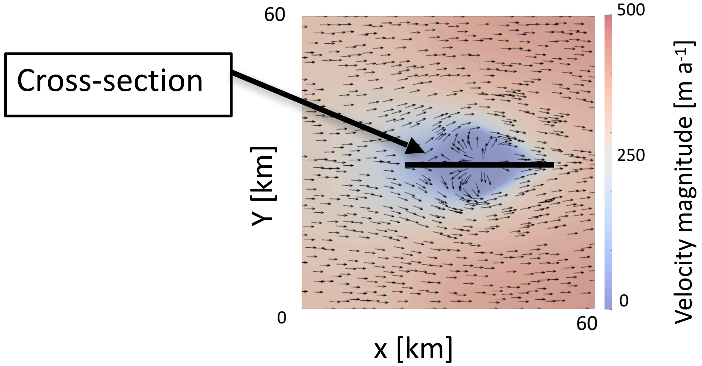
Steady state ice rise cross-sections





Full Stokes vs. SIA: Low friction

$$\mathbf{u} = \mathbf{u}_d + \mathbf{u}_b$$

$$\mathbf{u}_d(x, y, h) = -\frac{2A(\rho_i g)^n}{n+1} H^{n+1} |\nabla h|^{n-1} \nabla h$$

$$\mathbf{u}_b(x, y) = -C_b(\rho_i g H)^{p-q} |\nabla h|^{p-1} \nabla h$$

(Hutter, *Theoretical Glaciology*, 1983)

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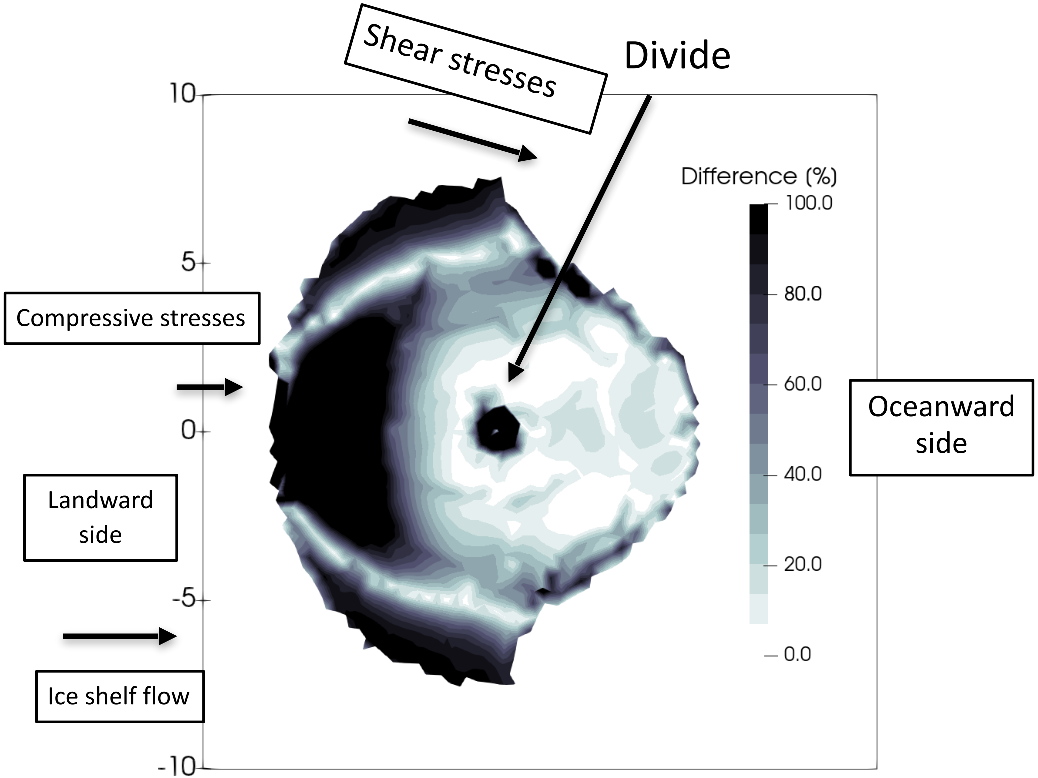
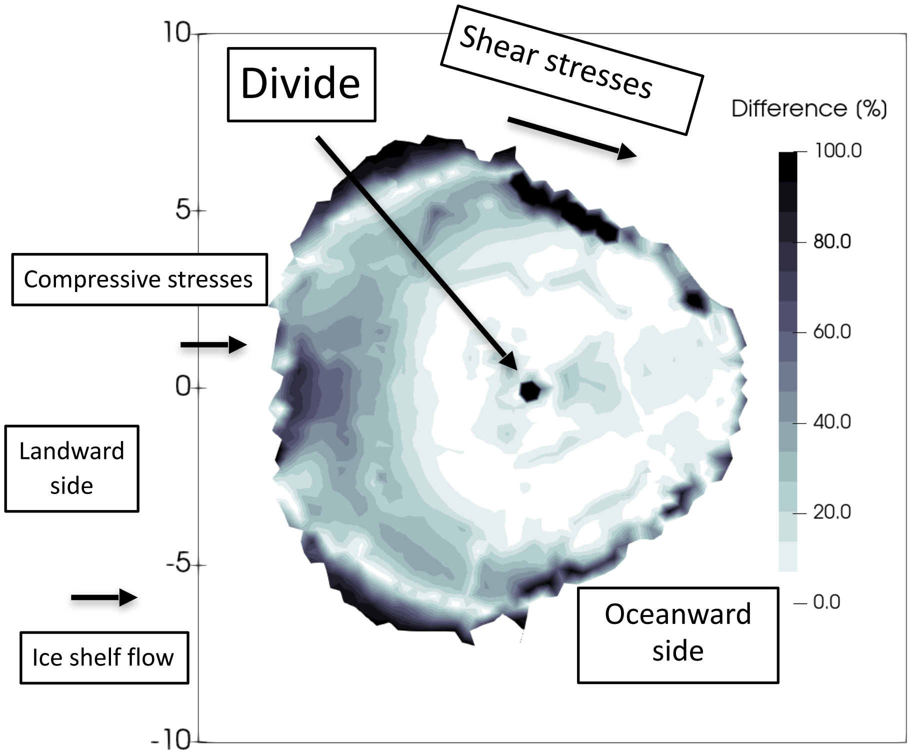
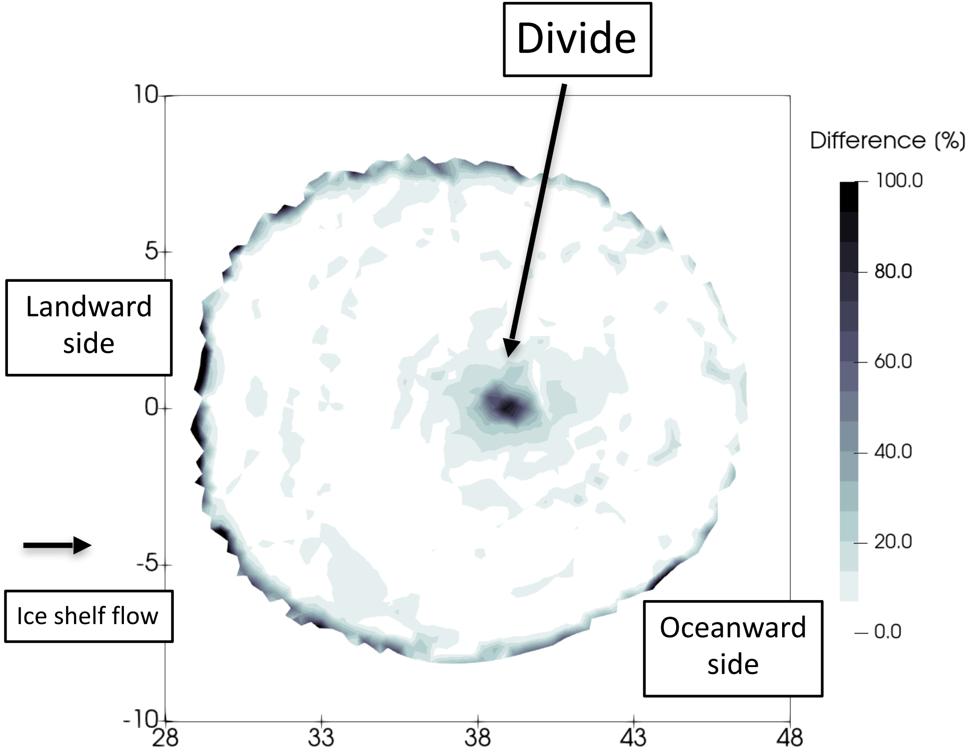
(Hutter, *Theoretical Glaciology*, 1983)



Full Stokes vs. SIA: Intermediate friction



Full Stokes vs. SIA: High friction



Research questions

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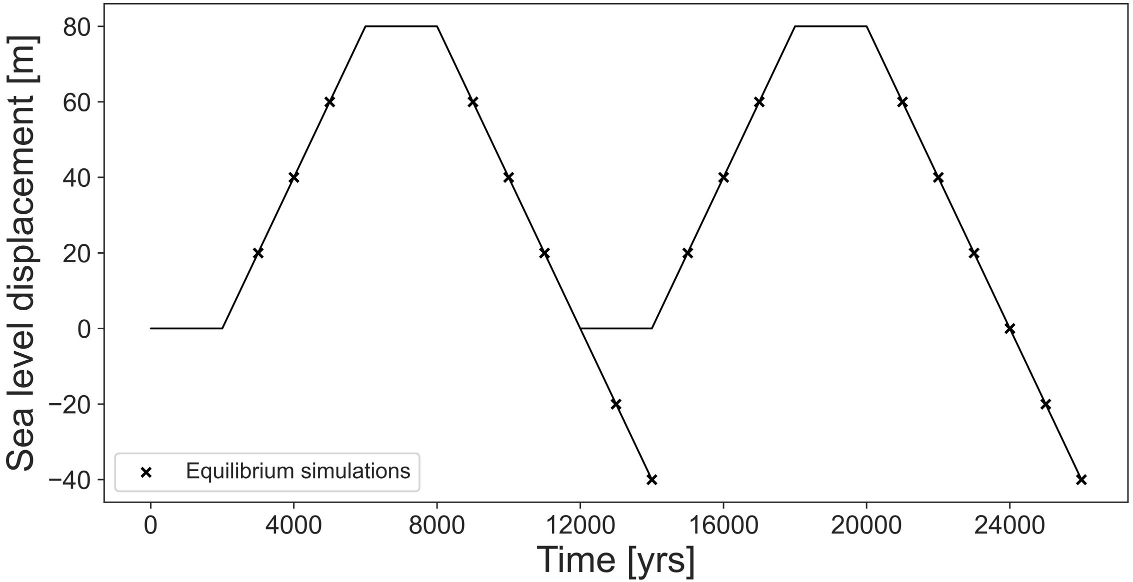
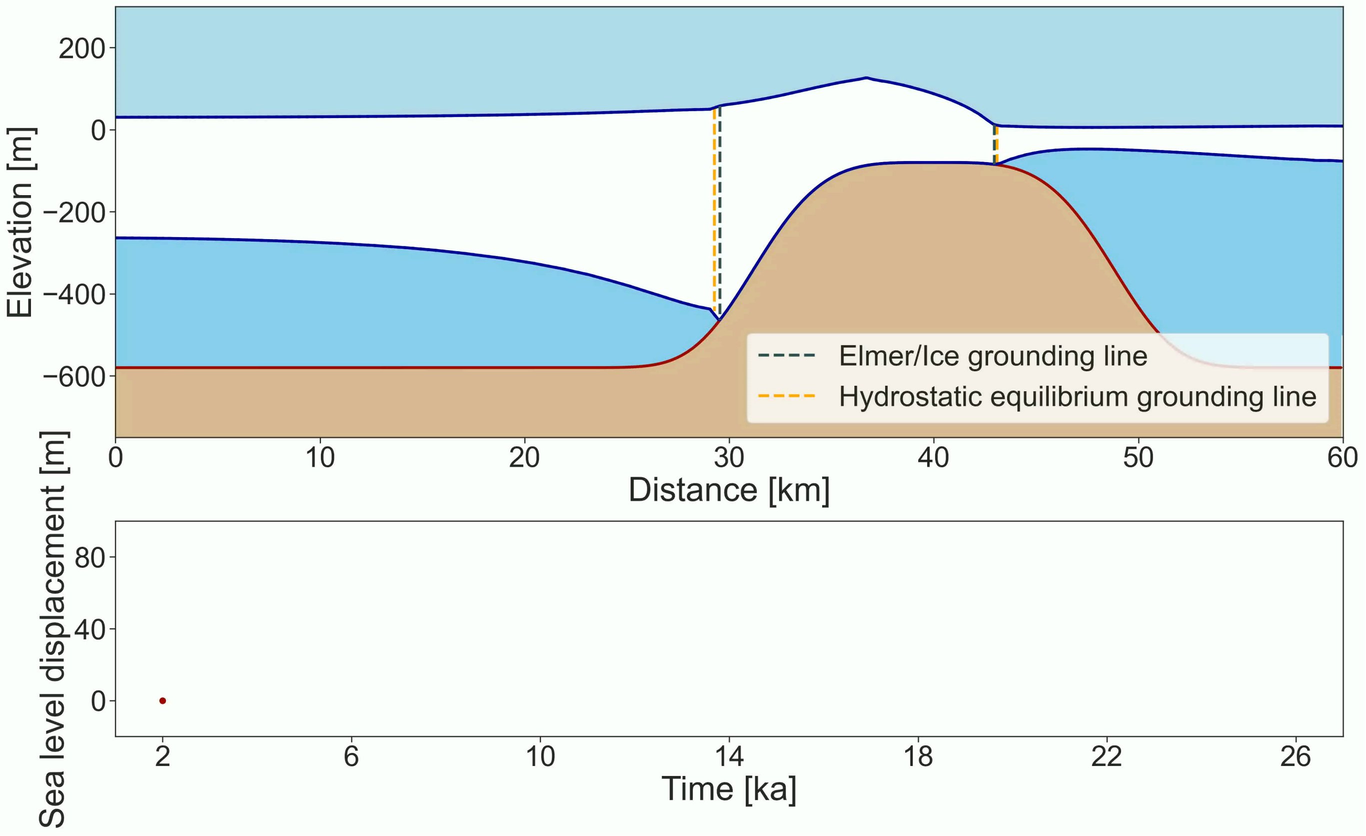
Sea level displacement cycles



First, we analyse the response to the first sea level cycle.

Response to sea level perturbation



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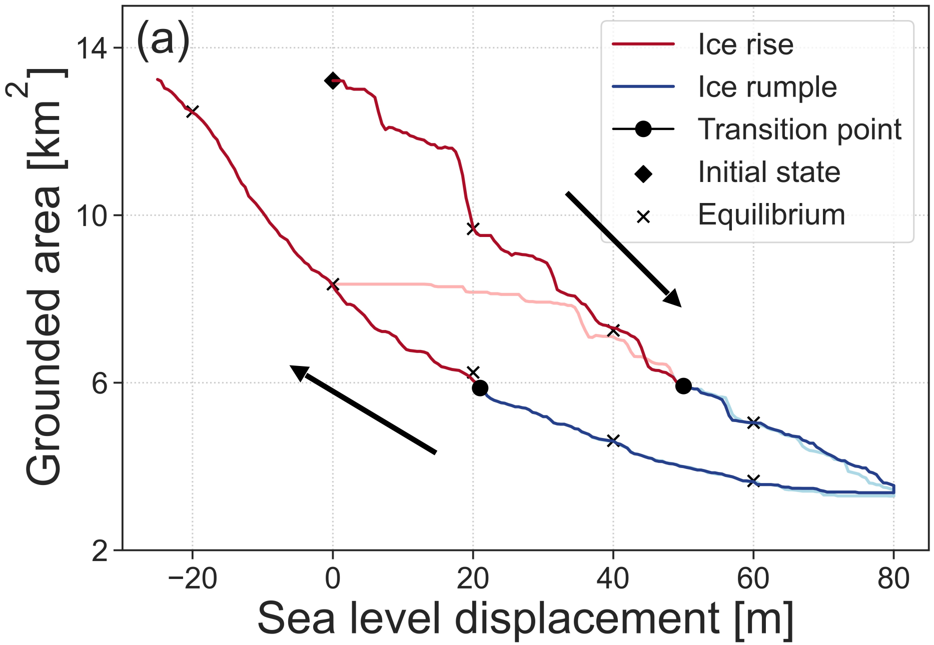
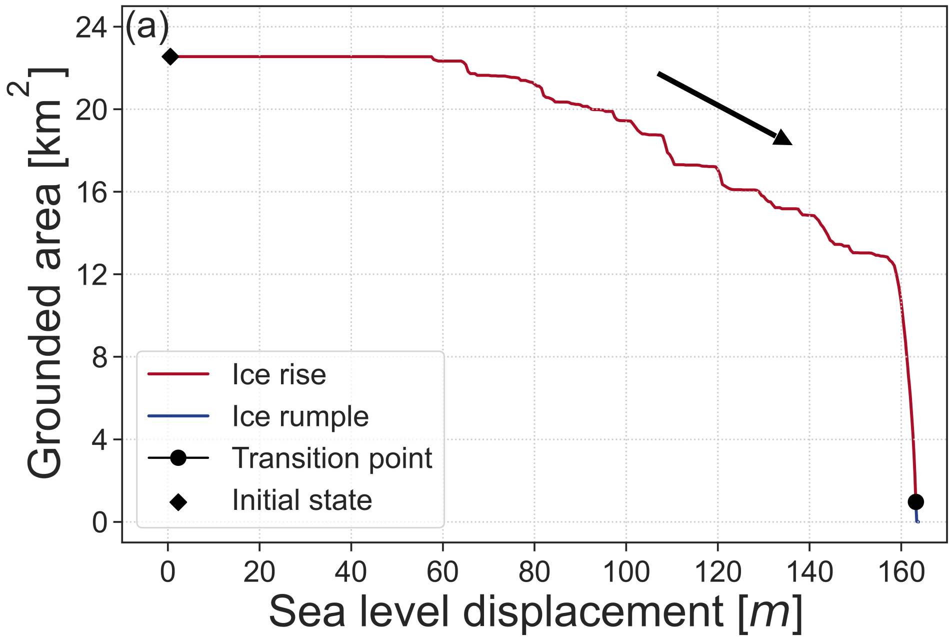
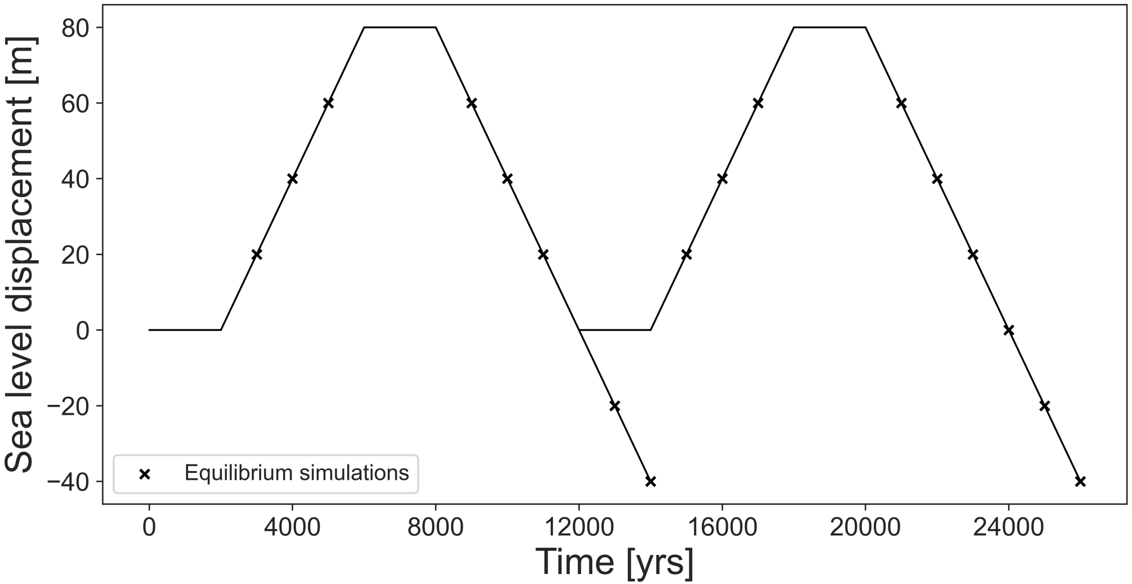
Hysteresis behaviour



Hysteresis behaviour: High Friction

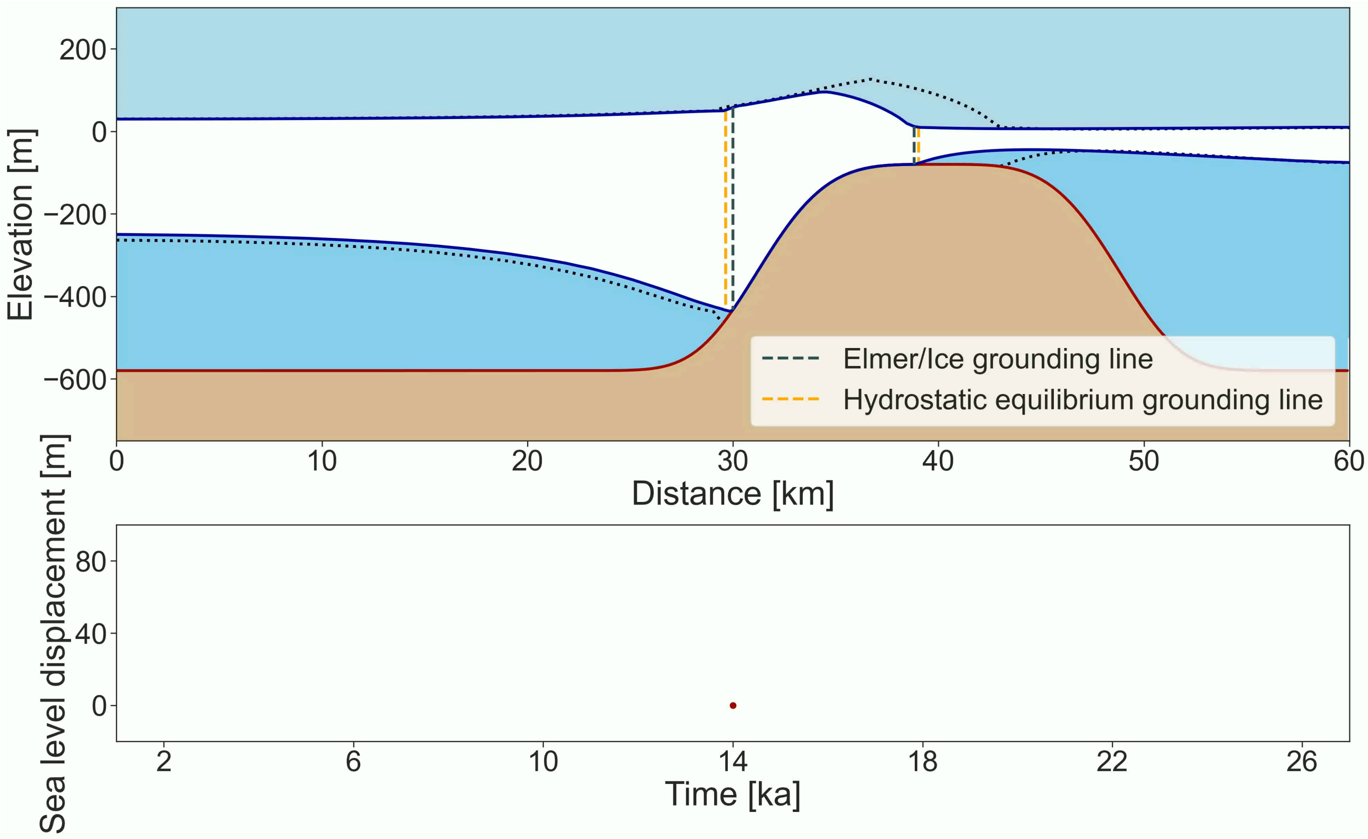


Sea level displacement cycles

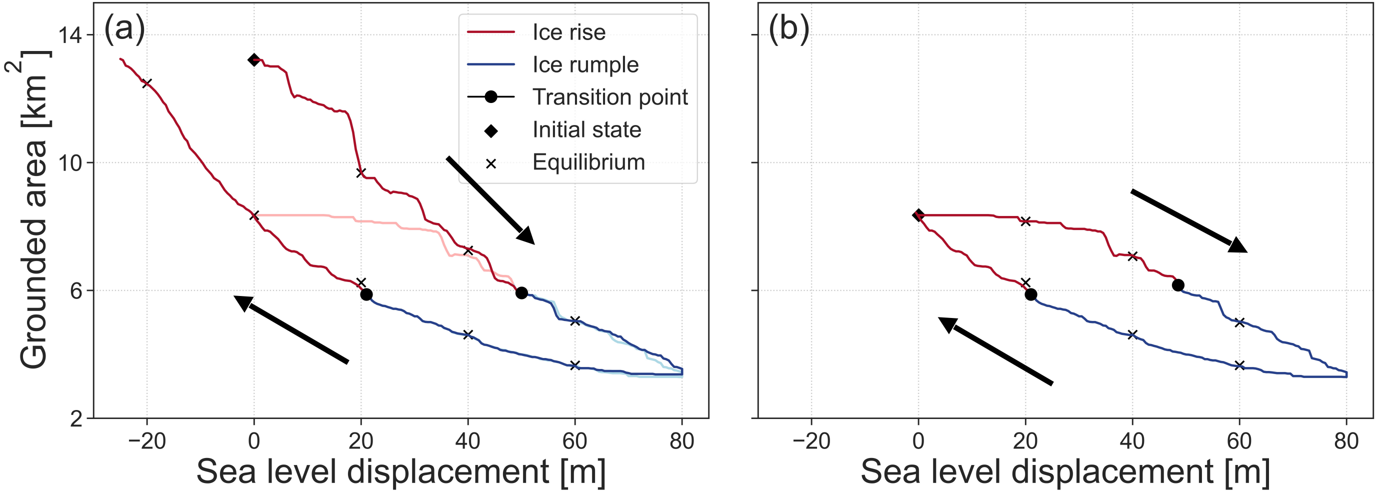


Secondly, we analyse the response to the second sea level cycle.

Response to sea level perturbation



Hysteresis response to sea level perturbation



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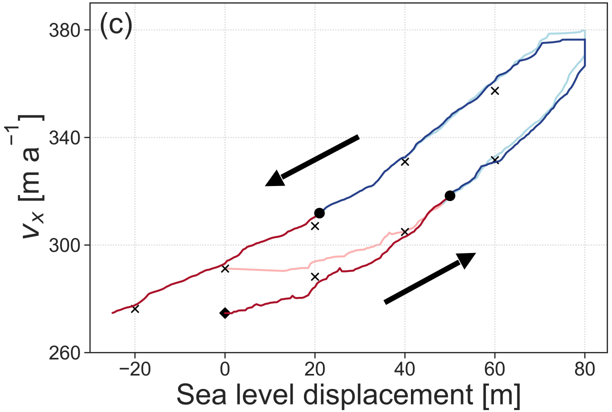
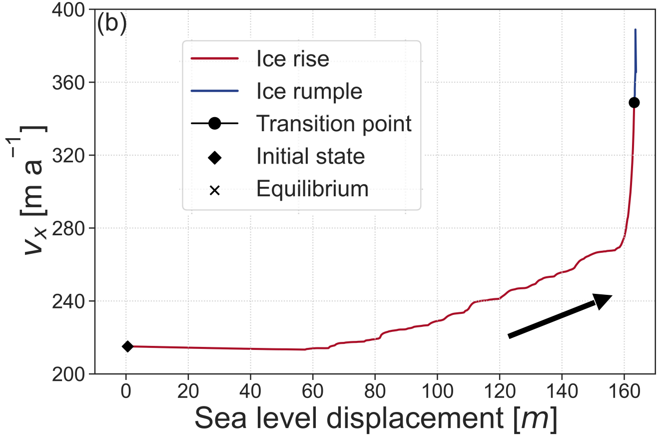
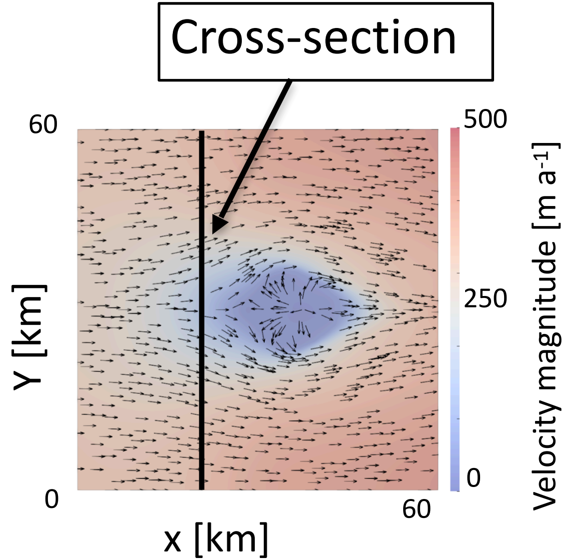
Hysteresis behaviour







Conclusions

- Ice rise evolution and transition is highly dependent on basal friction.
- Sea level perturbation causes hysteric and irreversible behaviour in the ice rise and the ice shelf.
- The ice geometry and flow regime is largely controlled by the grounded area.

Outlook

- Introduction of a continental grounding line.
- Quantifying the transient buttressing effect of ice rises.