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integrated climate impact research
at the Potsdam Institute.

Idealized simulations: Shear-margin melt causes stronger transient ice discharge than ice-stream melt

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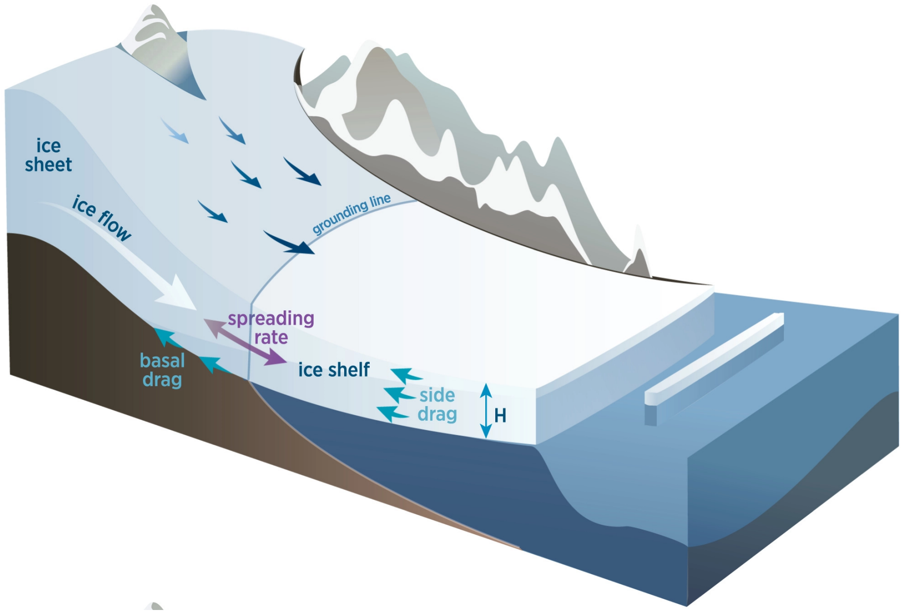
DFG-SCHWERPUNKTPROGRAMM 1158
ANTARKTISFORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

EGU General Assembly 2022 | Session CR 4.3 | 25 May 2022

Leibniz Association

Motivation

Gudmundsson et al., GRL (2019)



- Virtually all of **Antarctica's sea level contribution** comes from **increased discharge of ice** into ocean

- Discharge is regulated by floating **ice shelves** that **buttress the upstream grounded outlet glaciers**

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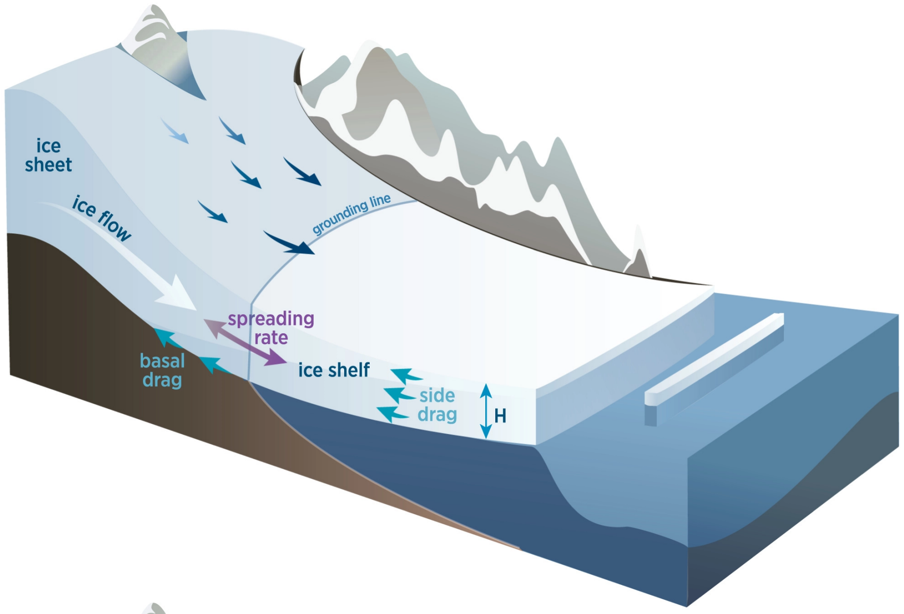
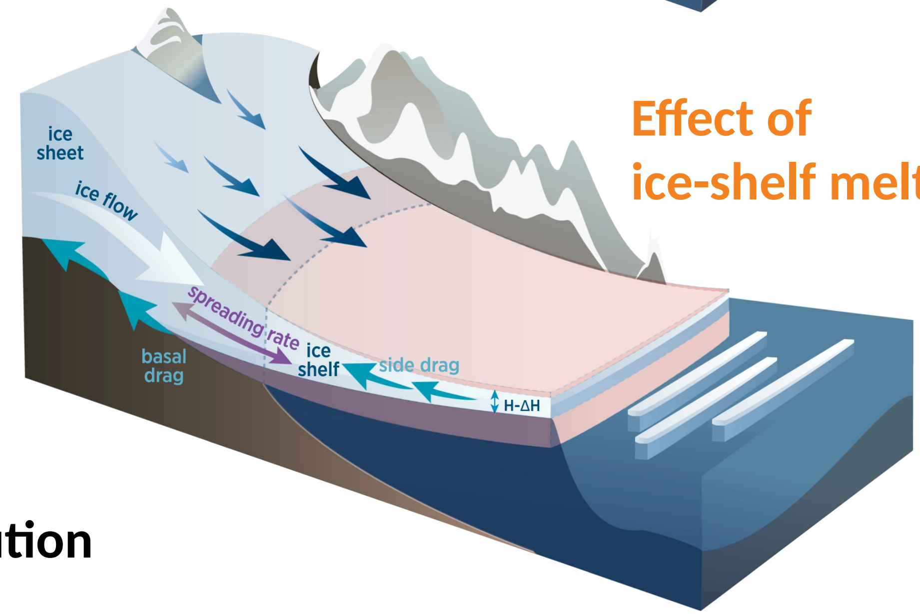
- Virtually all of **Antarctica's sea level contribution** comes from **increased discharge of ice** into ocean

- Discharge is regulated by floating **ice shelves** that **buttress the upstream grounded outlet glaciers**

- **Increased basal melting**
  → ice-shelf thinning
  → buttressing reduction
  → increased ice discharge

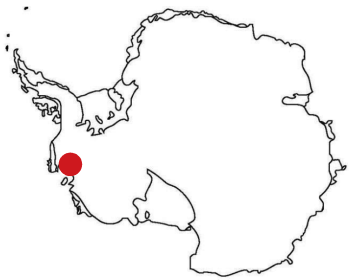




Effect of ice-shelf melting

→ Basal melting key driver of Antarctica's sea level contribution

Motivation

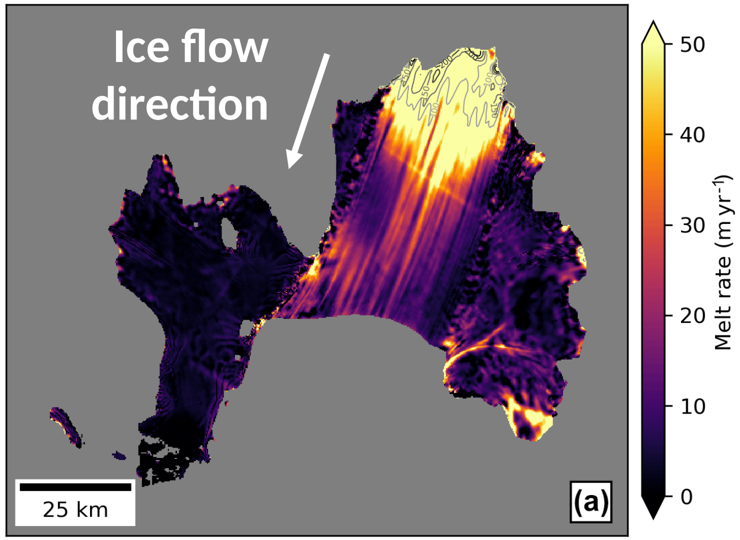


- Basal ice-shelf melting typically strongest close to central grounding line (thick ice, fast **ice stream**)

- Existence of **along-flow melt channels** with relatively warm water (persistent polynias at ice-shelf front)

Pine Island Ice Shelf

Basal melt



Shean et al., The Cryosphere (2019)

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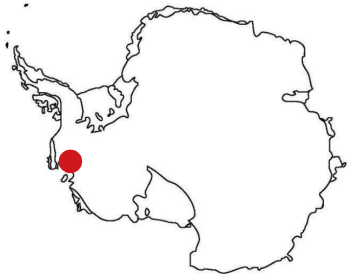

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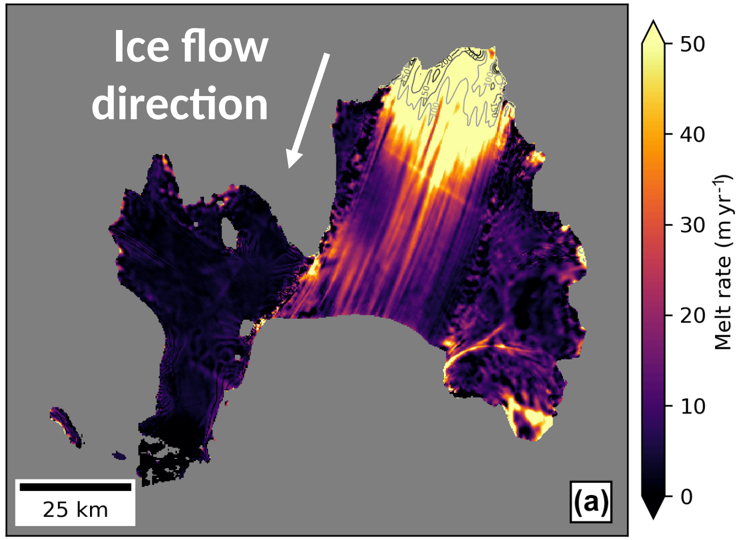

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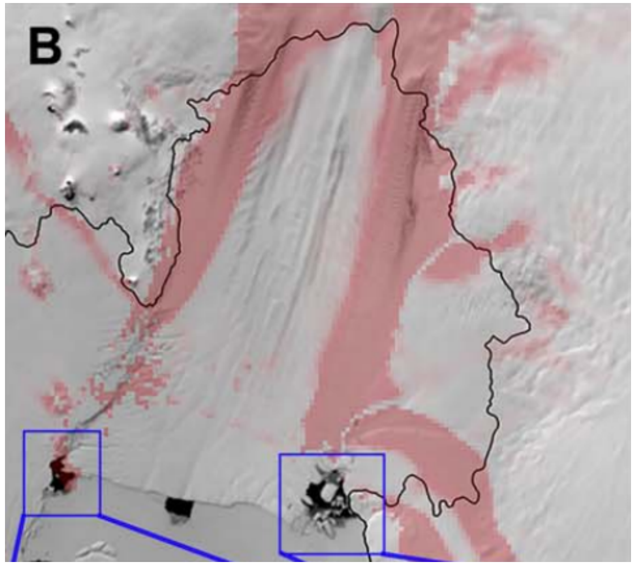
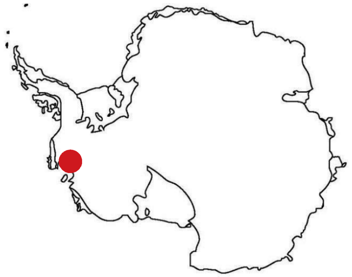
Shear margins



Alley et al., Science Advances (2019)

Motivation



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Here we compare sensitivity of ice discharge to ice-stream vs. shear-margin melting

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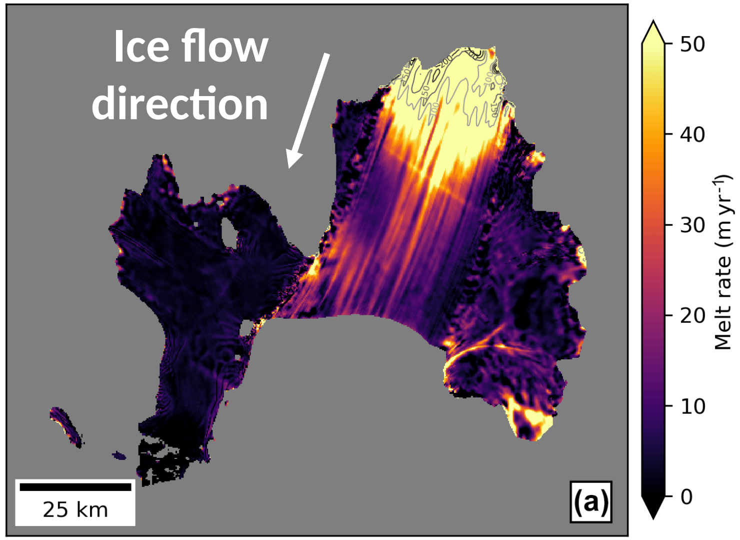
Basal melt



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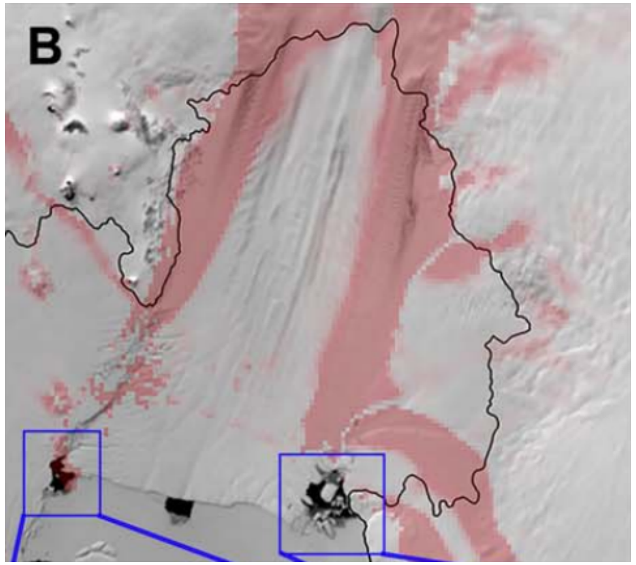

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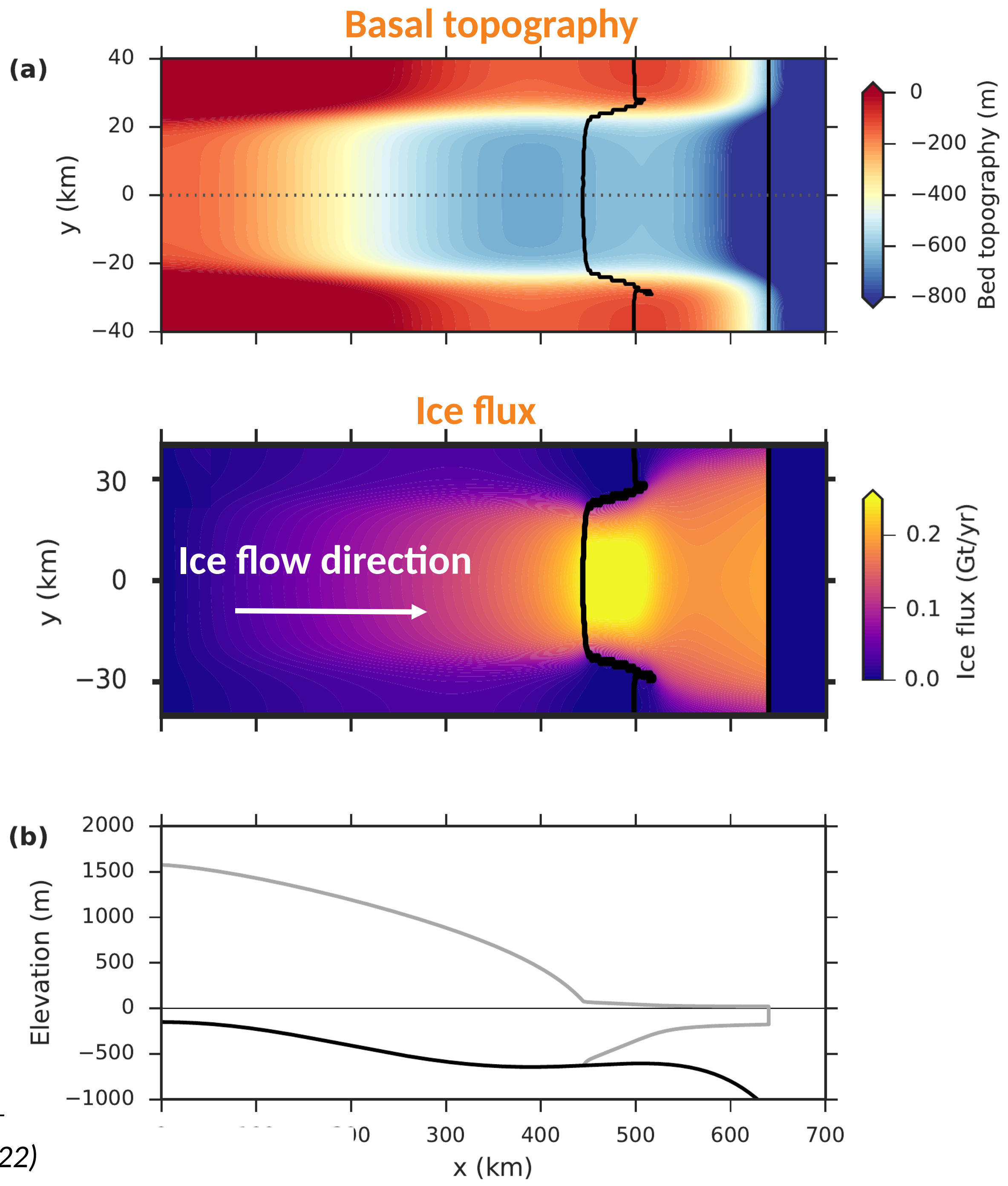
Experiments

- **Numerical simulations** with Parallel Ice Sheet Model (**PISM**)
- **Idealized setup** (MISMIP+) of **strongly buttressed, Antarctic-type outlet glacier** that streams through a topographic confinement; run into steady state on 1-km resolution



Feldmann et al., The Cryosphere (2022)

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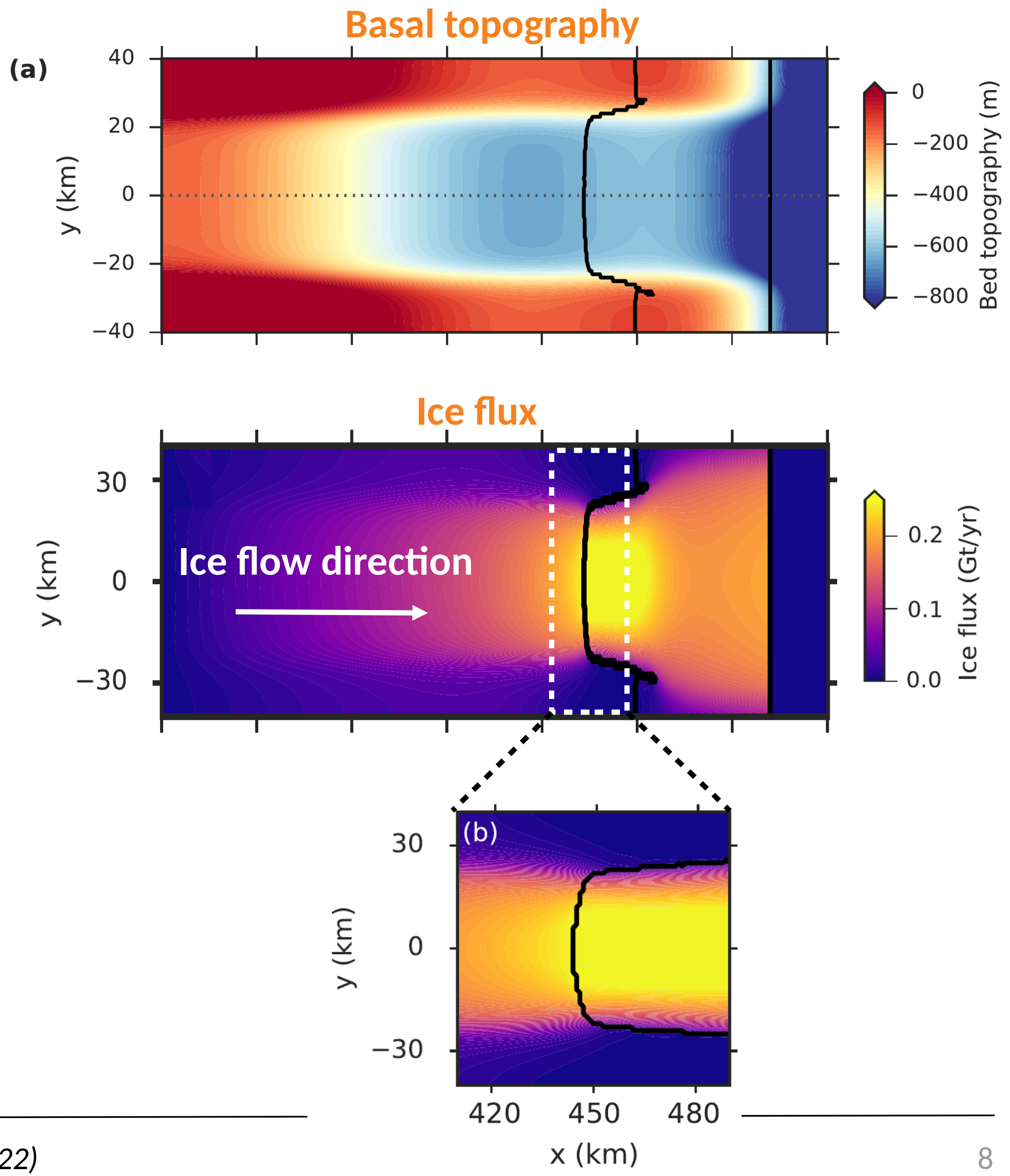
- **Numerical simulations** with Parallel Ice Sheet Model (**PISM**)
- **Idealized setup** (MISMIP+) of **strongly buttressed, Antarctic-type outlet glacier** that streams through a topographic confinement; run into steady state on 1-km resolution
- **Several simplifying assumptions** (shallow shelf approximation, isothermal ice, no damage/fractures, fixed calving front)
- **Relevant physics are captured** (emergence of buttressing, fast ice streaming, shear margins)



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- **Ice-shelf melt perturbations** applied to

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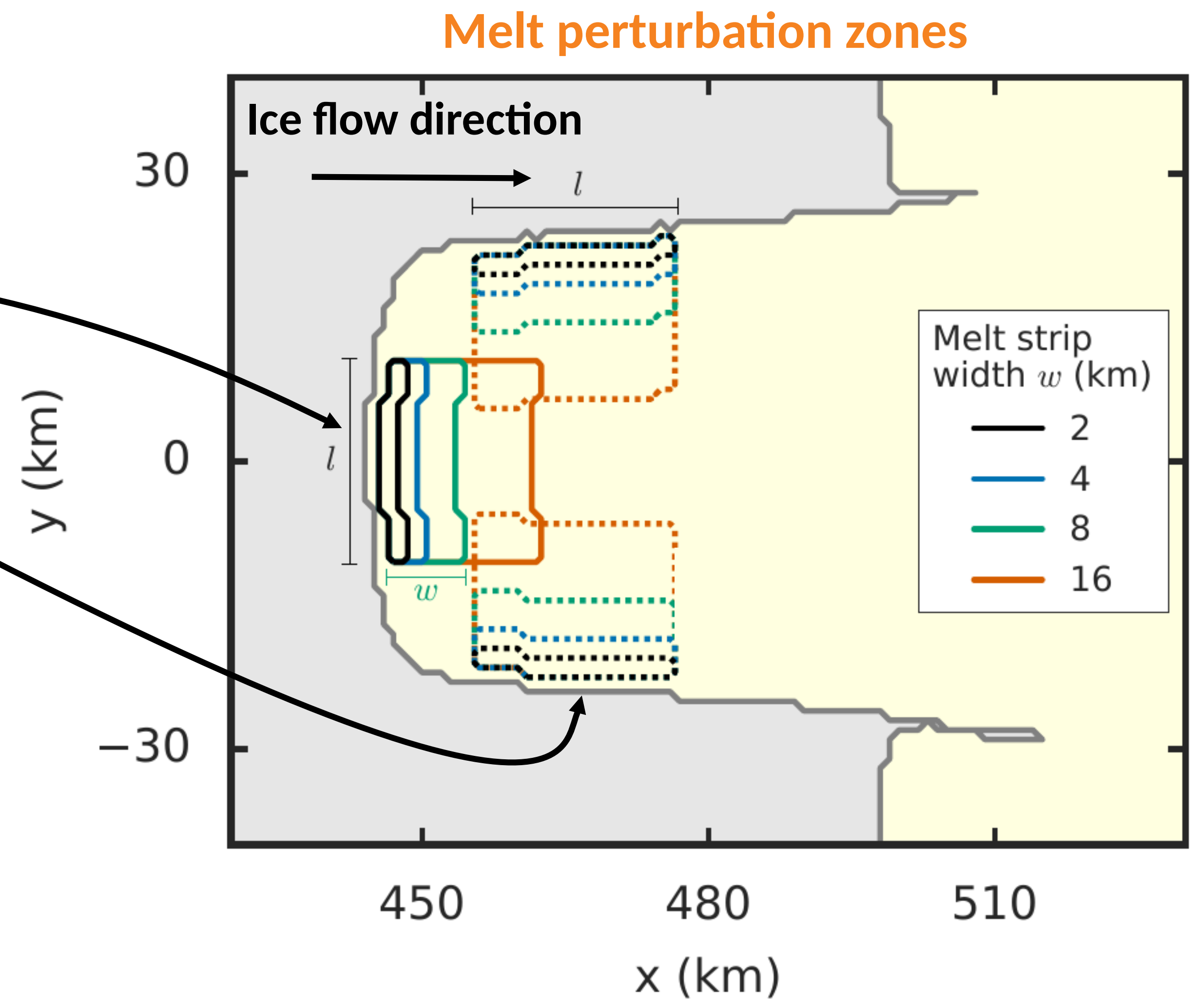
- Variation of melt-strip width (2 – 16 km) and melt rate (0.5 – 2 Gt/yr)

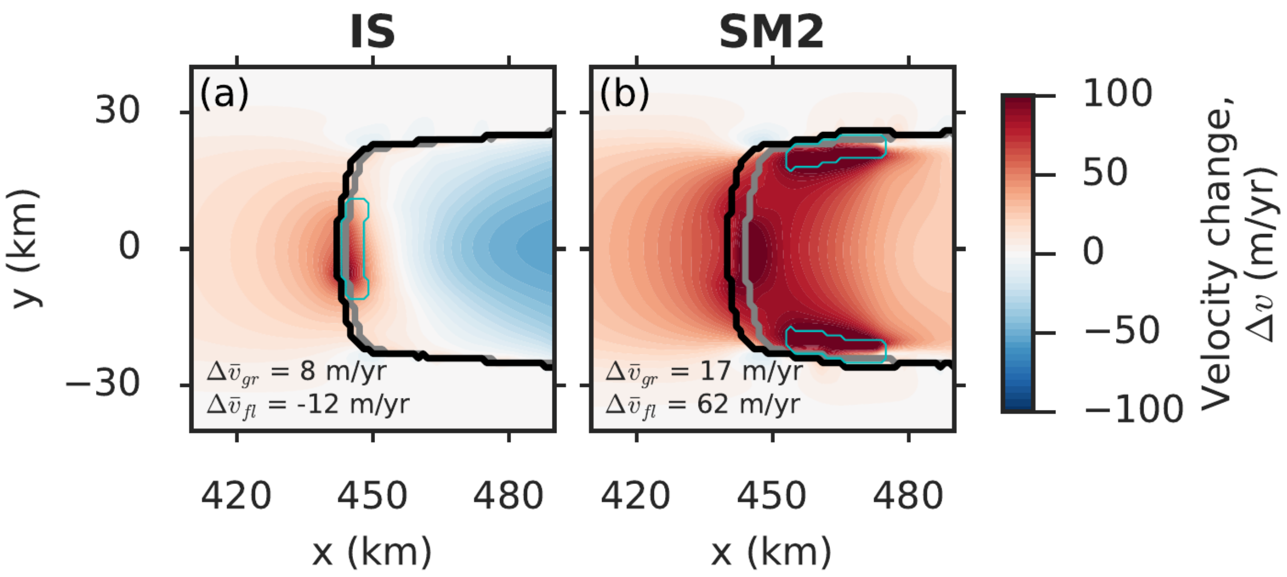


Feldmann et al., The Cryosphere (2022)

Results

- **General response:**
  Thinning, speed-up, retreat, increase in ice discharge

Ice speed-up after 100 yr



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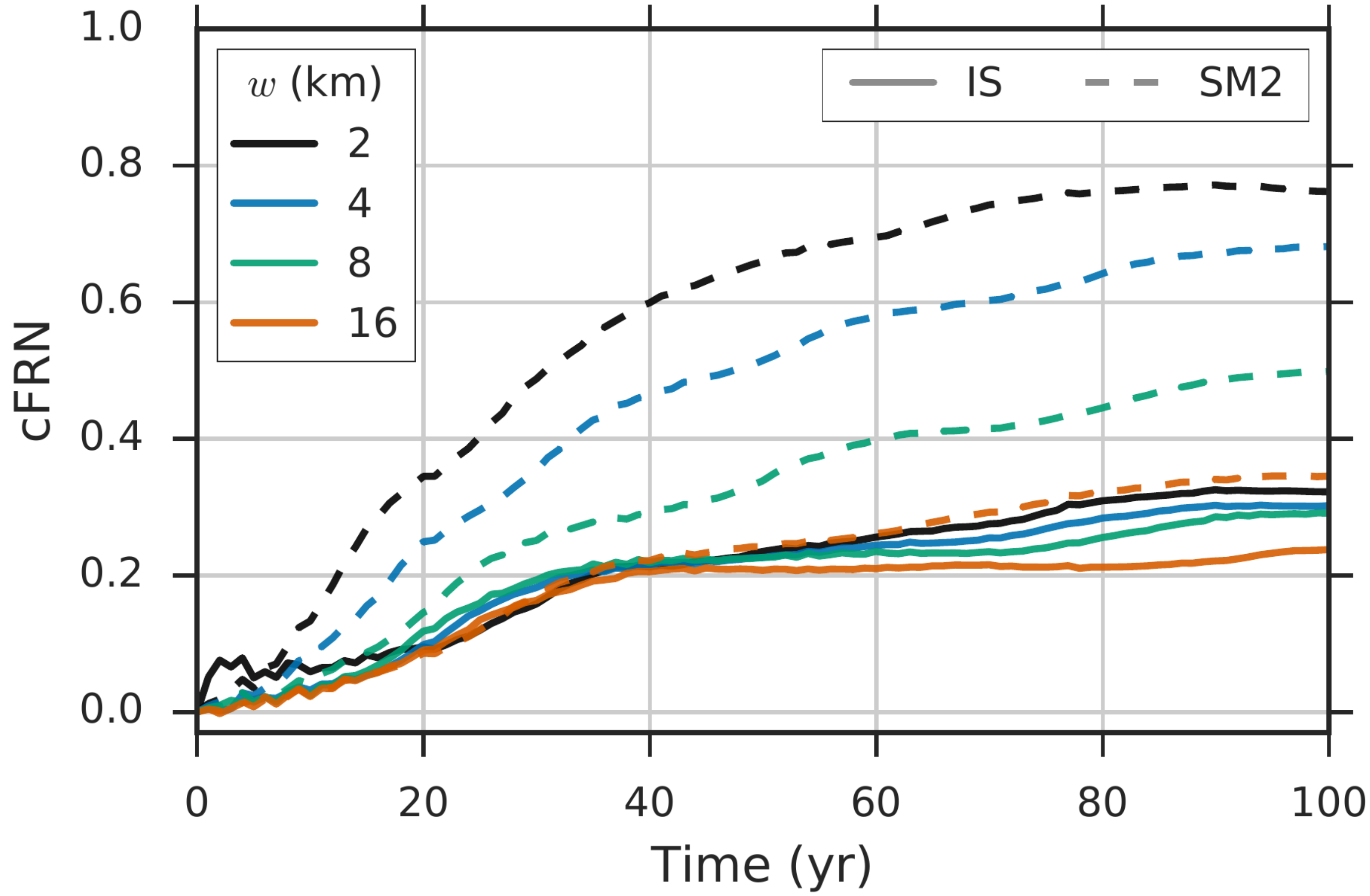

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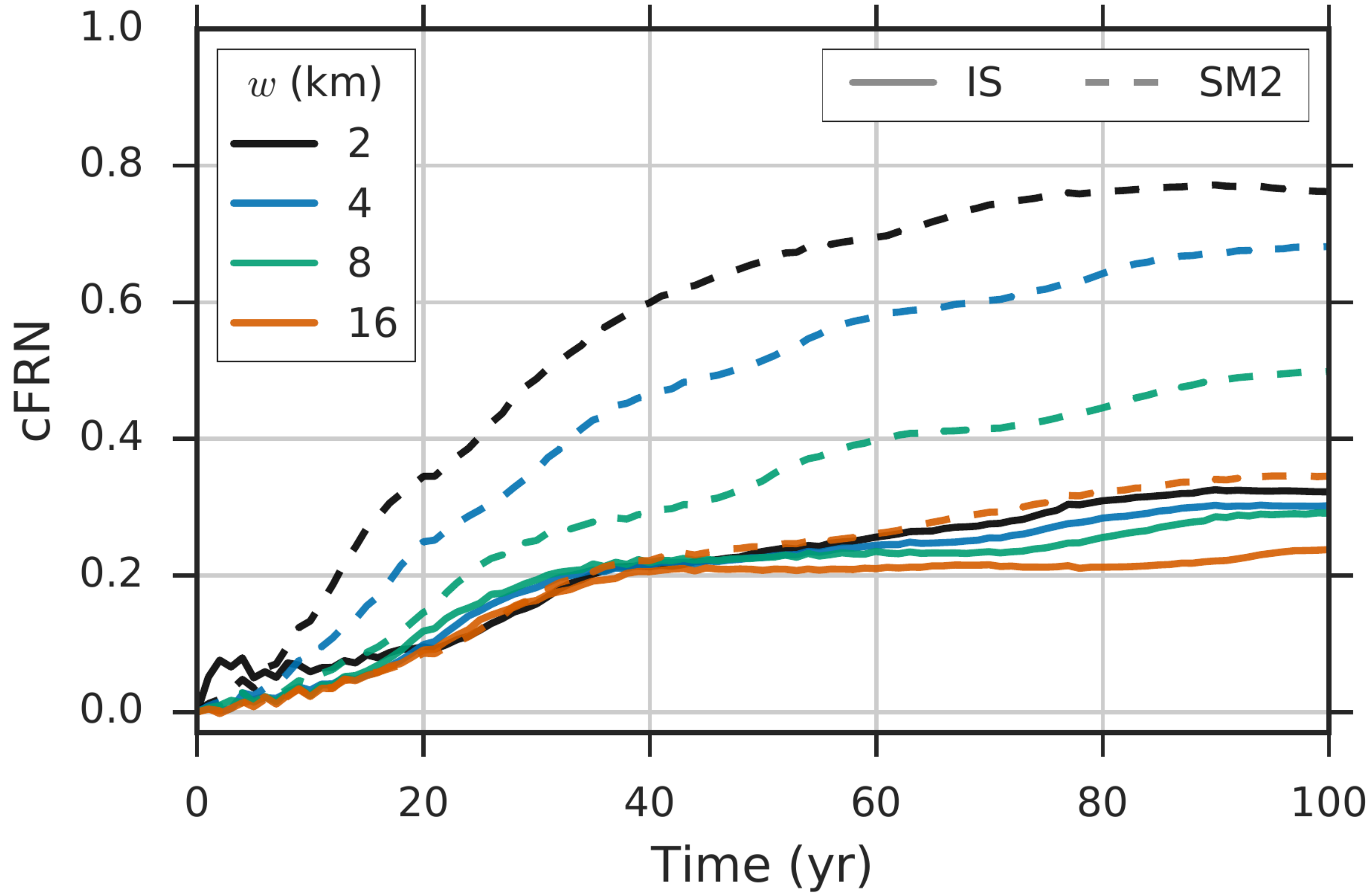

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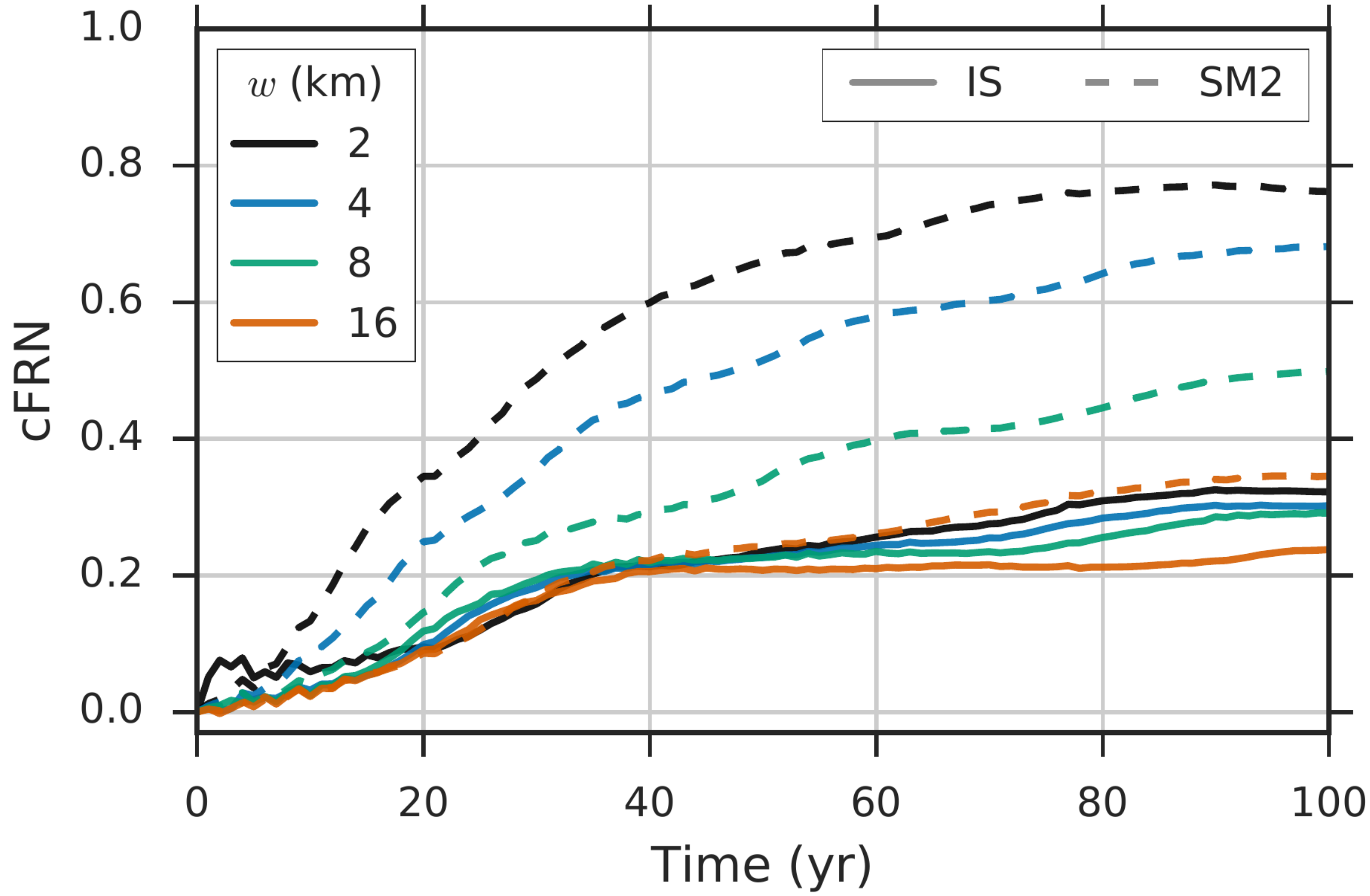
Results

- **General response:**
  Thinning, speed-up, retreat, increase in ice discharge

- **Stronger response** for **stronger perturbation** and **higher concentration** of melting close **to grounding line**

- **Shear-margin melt:**
  Long-term response up to 2.5 times stronger

Cumulative flux response number

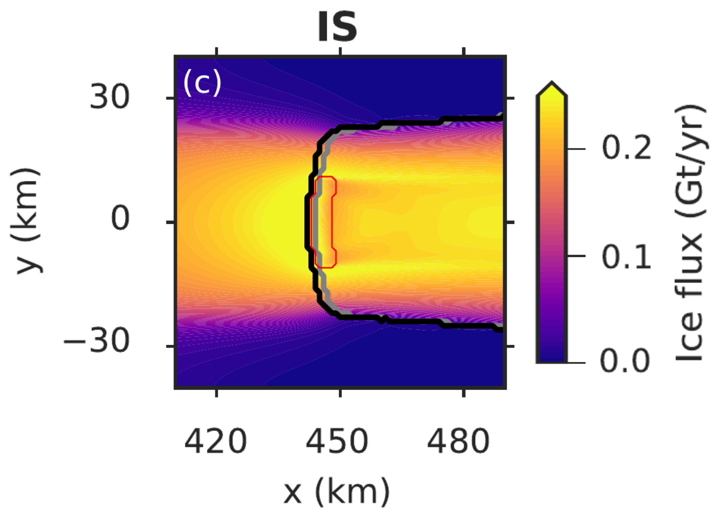


Feldmann et al., The Cryosphere (2022)

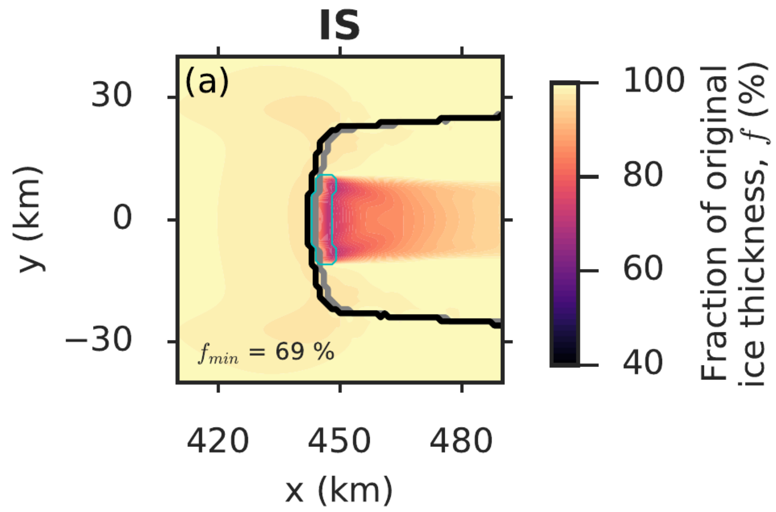
Underlying mechanism

- **Ice-stream melt (IS):**
  Fast advection through ice-stream center
  → **spreads thinning** into less buttressing-relevant regions
  → **weaker response**

Ice flux after 100 yr



Ice thinning after 100 yr



Feldmann et al., The Cryosphere (2022)

Underlying mechanism

- **<u>Ice-stream melt (IS):</u>**
  Fast advection through ice-stream center
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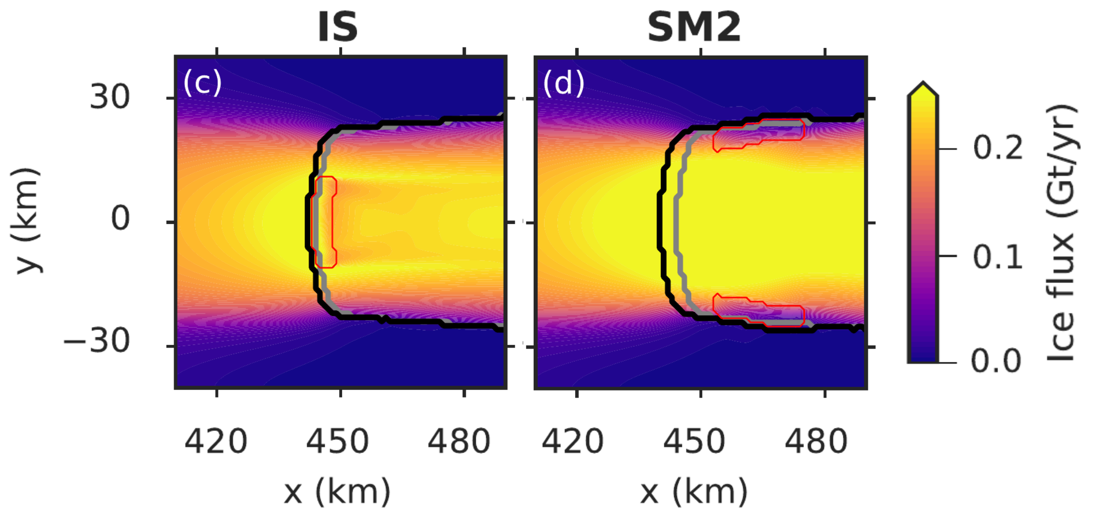
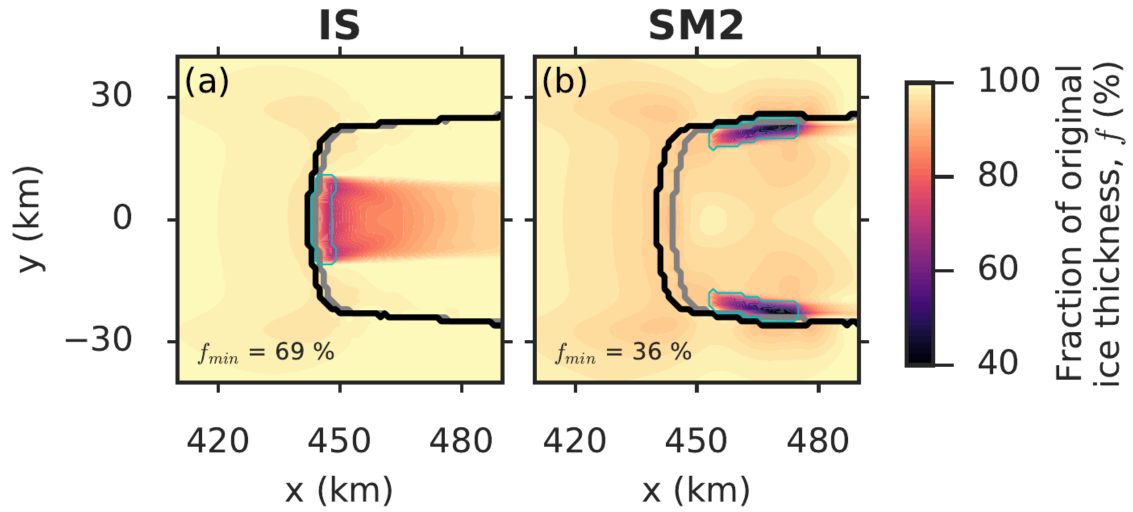
  → **weaker response**

- **<u>Shear-margin melt (SM):</u>**
  Weak advection in shear margins
  → **thinning very concentrated** in buttressing relevant region
  → **stronger response**

Ice flux after 100 yr



Ice thinning after 100 yr



Feldmann et al., The Cryosphere (2022)

Summary & conclusion

Paper just published:
https://doi.org/10.5194/tc-16-1927-2022

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- **Idealized simulations of strongly buttressed, Antarctic-type outlet glacier** to investigate transient response to basal ice-shelf melting in shear margins (compared to ice-stream center)

- Simulations only account for **purely thinning-induced buttressing reduction** (no shear-margin weakening due to heating/damage)

- **Long-term response much stronger for shear-margin melt**

- Mechanism: **Relatively weak advection in ice-shelf shear margins** promotes localized thinning and stronger buttressing reduction, stronger sea-level response → shear-margin melt much more “effective”

  → Observations of **continued melting/thinning beneath Antarctic ice-shelf shear zones should receive special attention**!

  → **Mechanism might gain importance with increasing basal melt rates** under future global warming

Experiments

- **Ice-shelf melt perturbations** applied to

  1) Central **ice stream** region (**IS**)

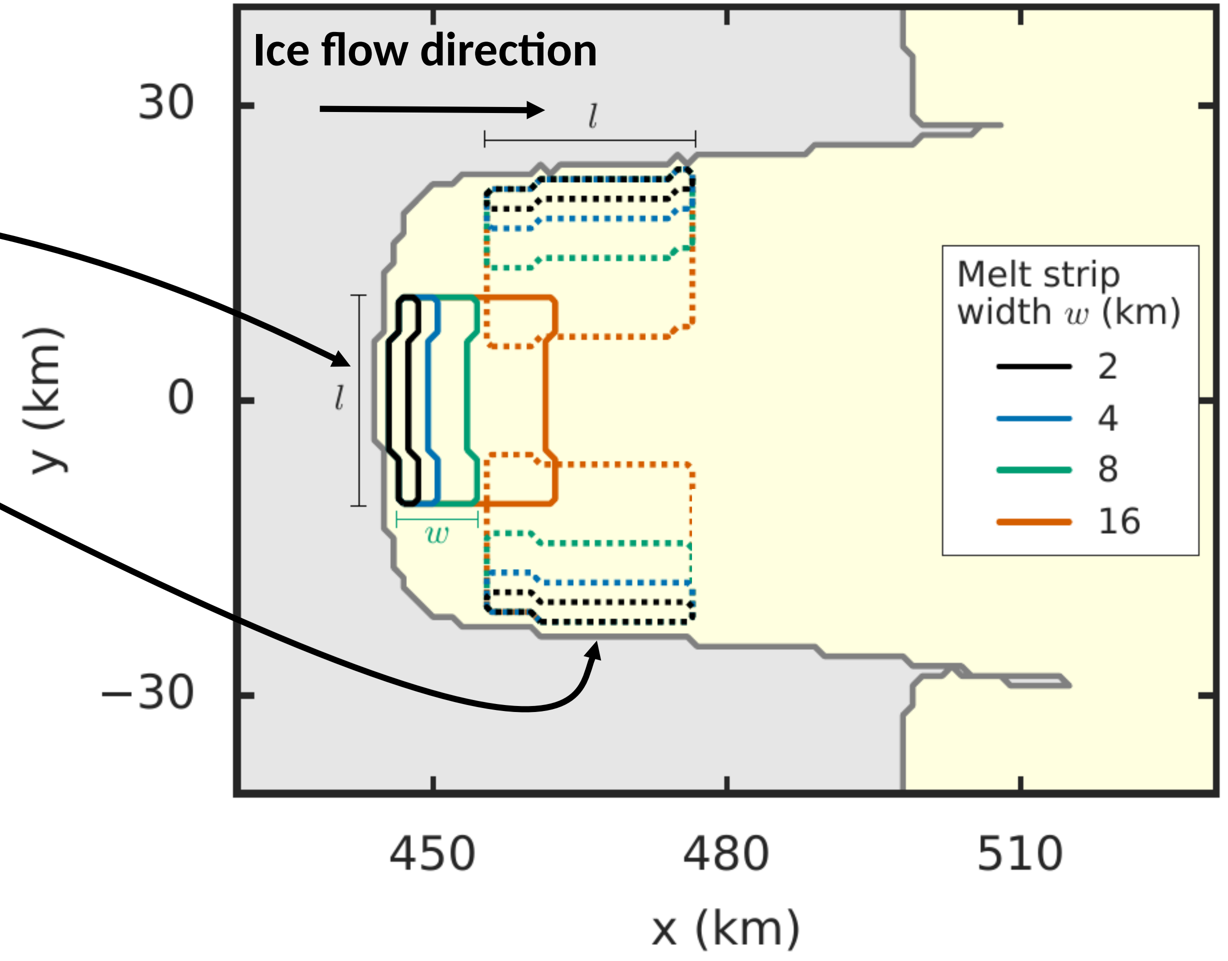
  2) Lateral **shear margins** (**SM**)

- Variation of melt-strip width (2 – 16 km) and melt rate (0.5 – 2 Gt/yr)

- Measure for sensitivity to perturbations: **Cumulative flux response number (cFRN)**

cFRN = $\frac{\text{Change in ice discharge (cumulative)}}{\text{Perturbation rate (cumulative)}}$

Melt perturbation zones



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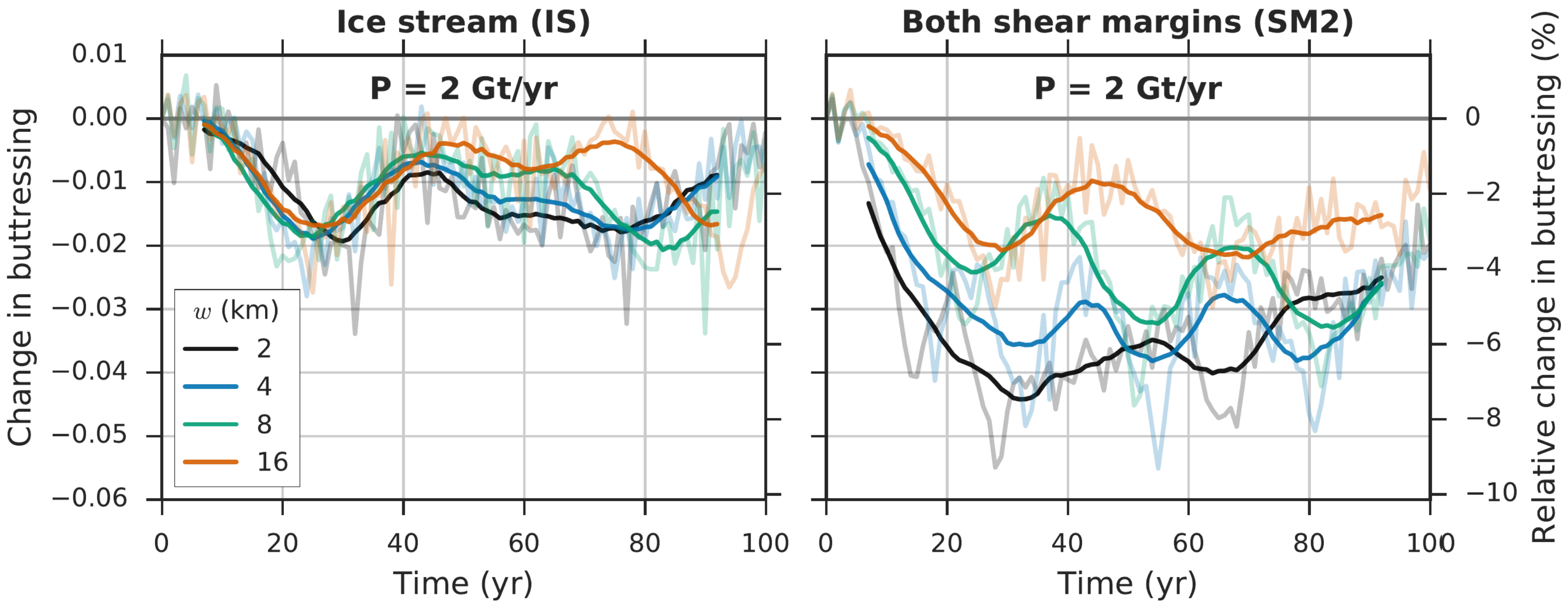
Buttressing response



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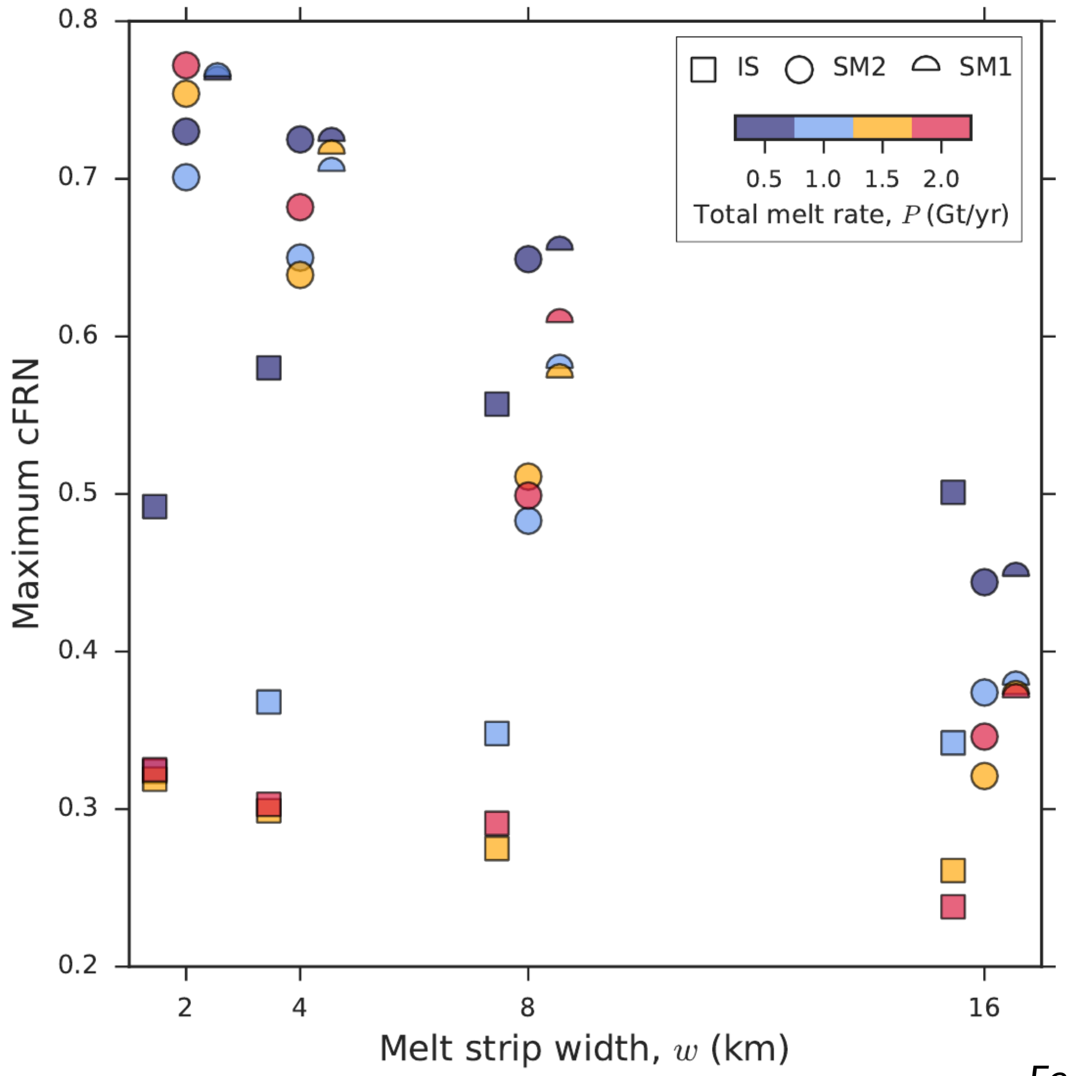
Maximum cFRN



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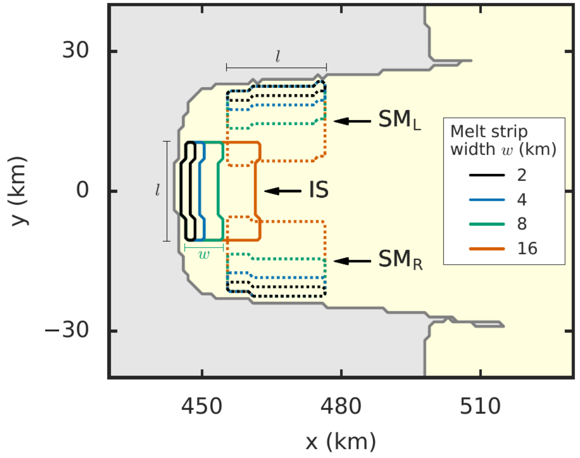
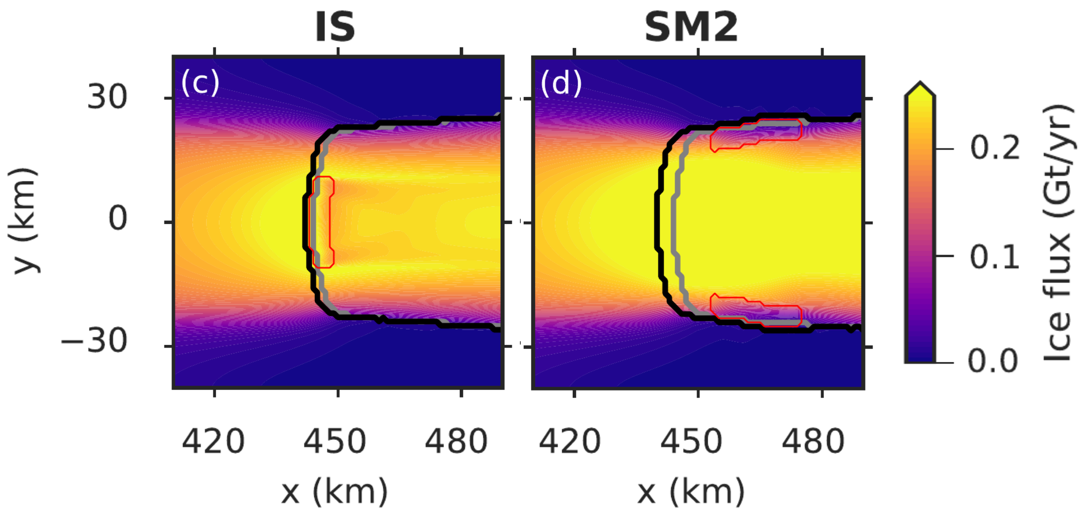
Ice speed-up



Ice flux after 100 yr



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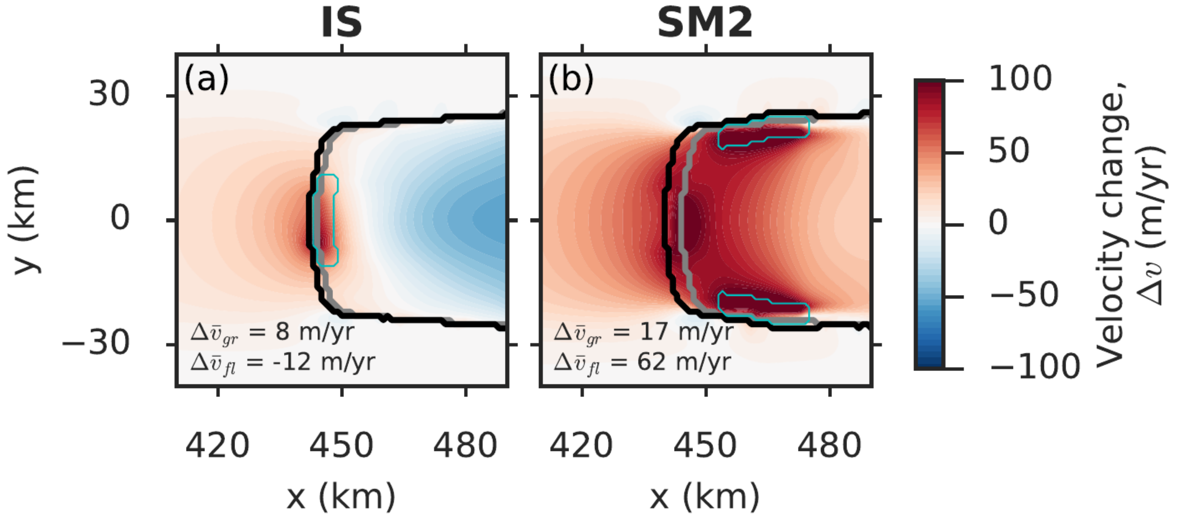

Feldmann et al., *The Cryosphere* (2022)