Photo: POLENET

Neglected processes: the role of the solid earth in controlling ice sheet contributions to sea-level change

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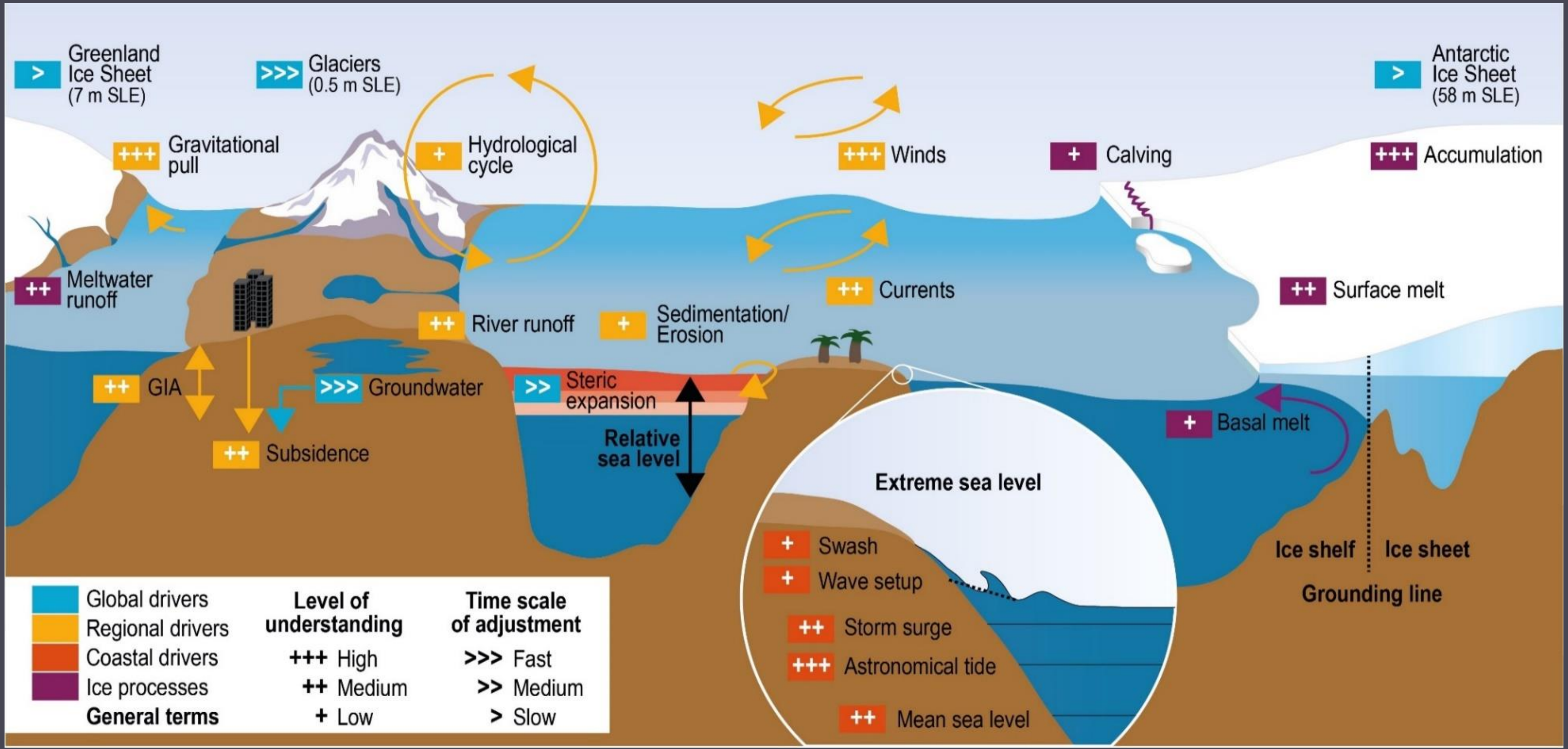
Motivation



Large ice sheets exert a primary control on long-term sea-level change

This talk will focus on the role of the solid earth in controlling rates of ice sheet change, and hence sea-level change

- Oppenheimer et al. (2020)

Take home message

We don't fully understand the strength of the feedbacks between ice sheet dynamics and solid earth deformation, but we do know that understanding 3D variations in earth rheology matter

(also see Jacky Austermann's talk)

Why important…?

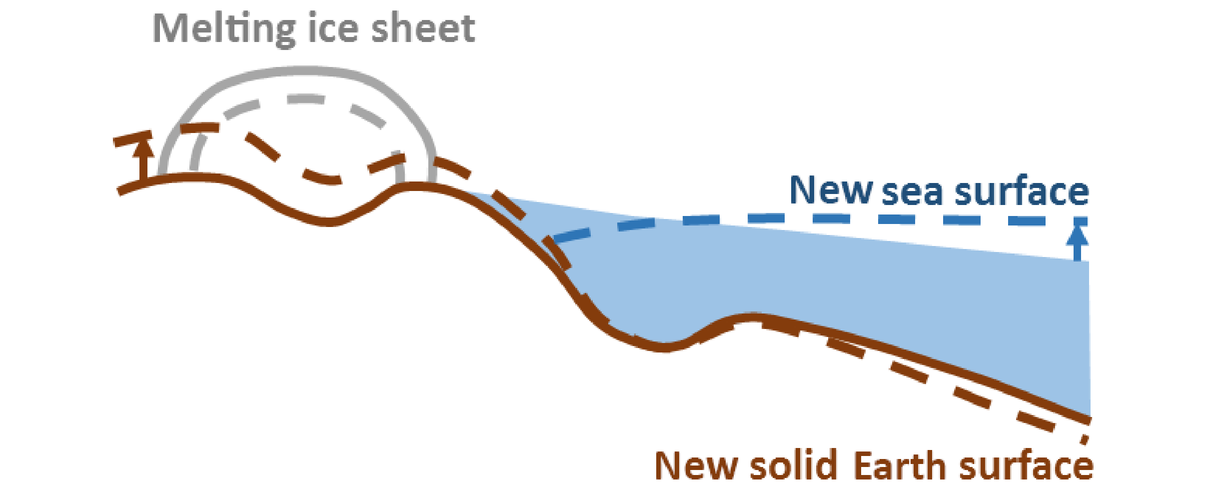
…to understand the role of solid earth in controlling ice sheet dynamics?

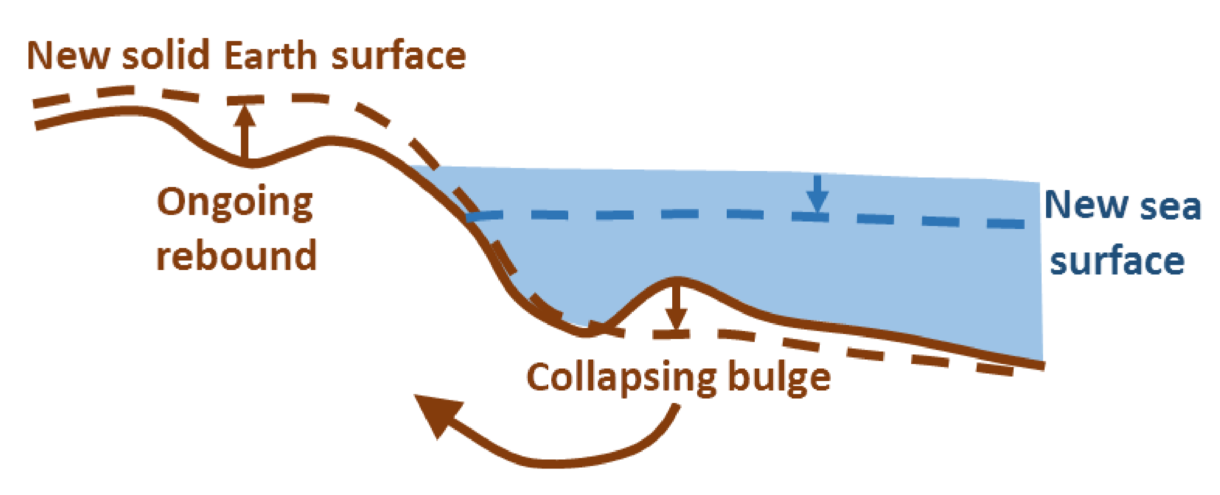
- increasingly complex processes are included in models that are used to predict future change
- such models are calibrated based on their ability to reproduce observations of past change
- if feedbacks are not correctly represented, or data misinterpreted, then models will be biased

Talk structure

- Key concepts
- Recent advances
- Open questions

Key concepts: glacial isostatic adjustment (GIA)

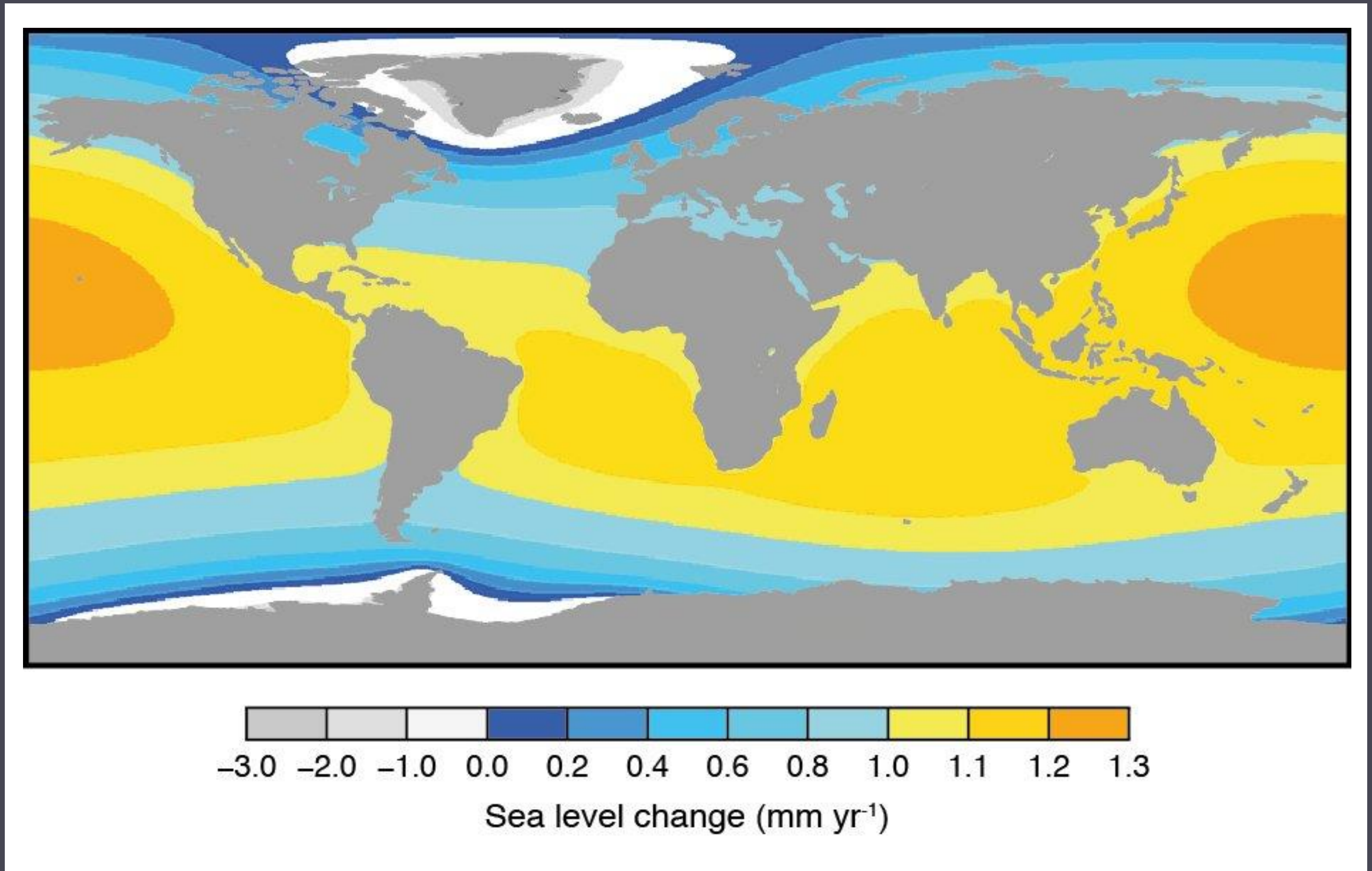




- Elastic response
  - instantaneous deformation of solid earth
  - instantaneous change in ocean volume
  - instantaneous change in shape of geoid
- Viscous response
  - time-decaying earth deformation
  - no change in ocean volume
  - Instantaneous change in shape of geoid

Whitehouse (2018)

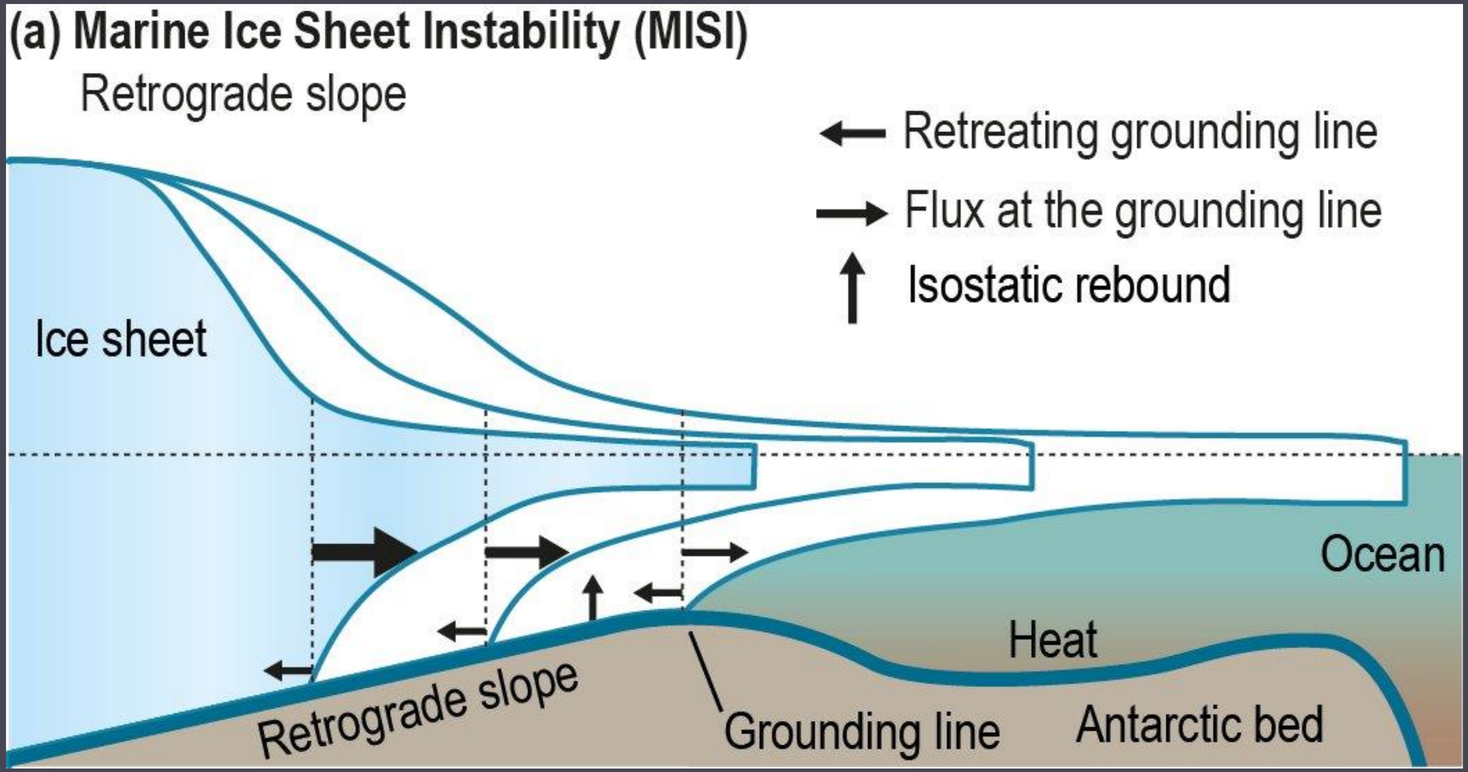
Key concepts: sea-level fingerprint



- Sea-level change due to WAIS and Greenland ice loss
- Reality is more complex
  - other ice masses
  - 3D earth rheology (e.g. Hay et al. 2017; Bartholet et al., ESDD, 2020)
- Need global distribution of observations
- <u>Caveat</u>: other factors cause sea-level change

- Church et al., IPCC AR5 (2013)

Key concepts: marine ice sheet instability (MISI)

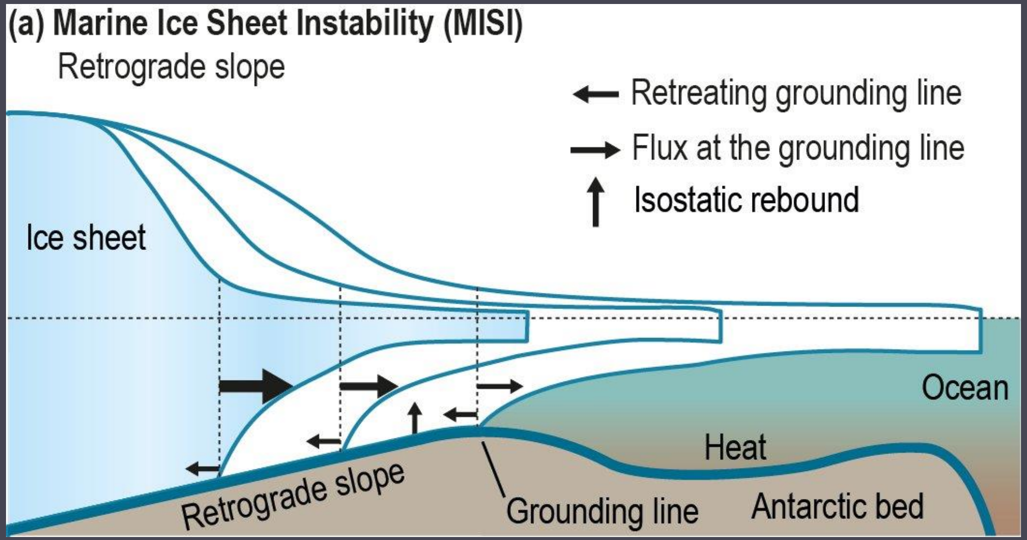


- Flux across grounding line depends on ice thickness at the grounding line
- On a retrograde bed, grounding line retreat triggers increased ice loss
- <u>Note</u>: models often assume constant sea level

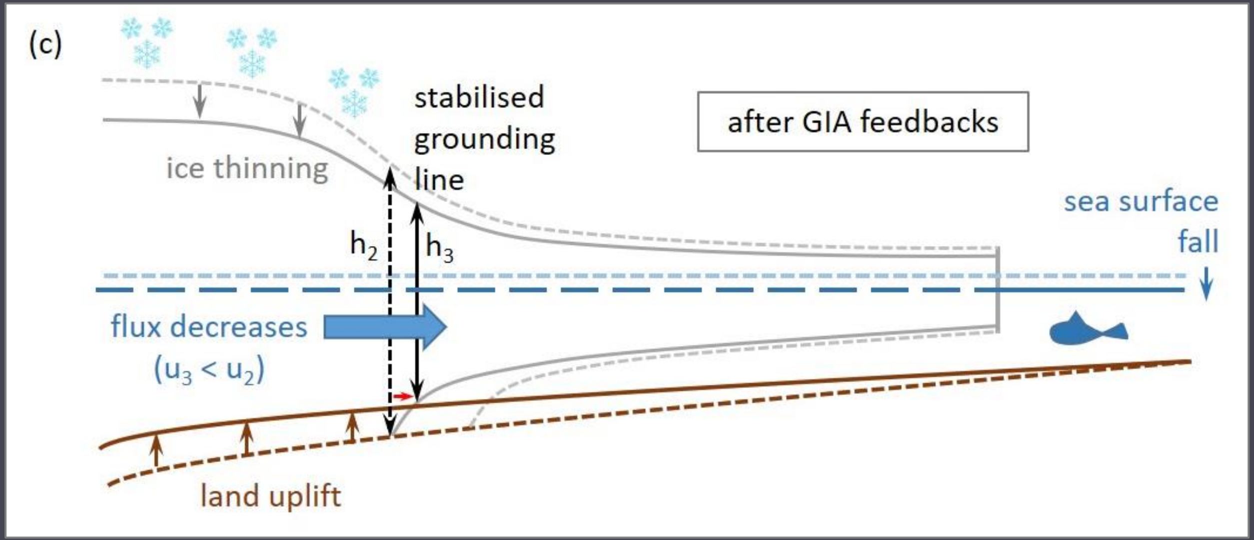
Talk structure

- Key concepts
  - GIA
  - sea-level fingerprint
  - MISI
- Recent advances
- Open questions

Recent advances: stabilizing effect of GIA



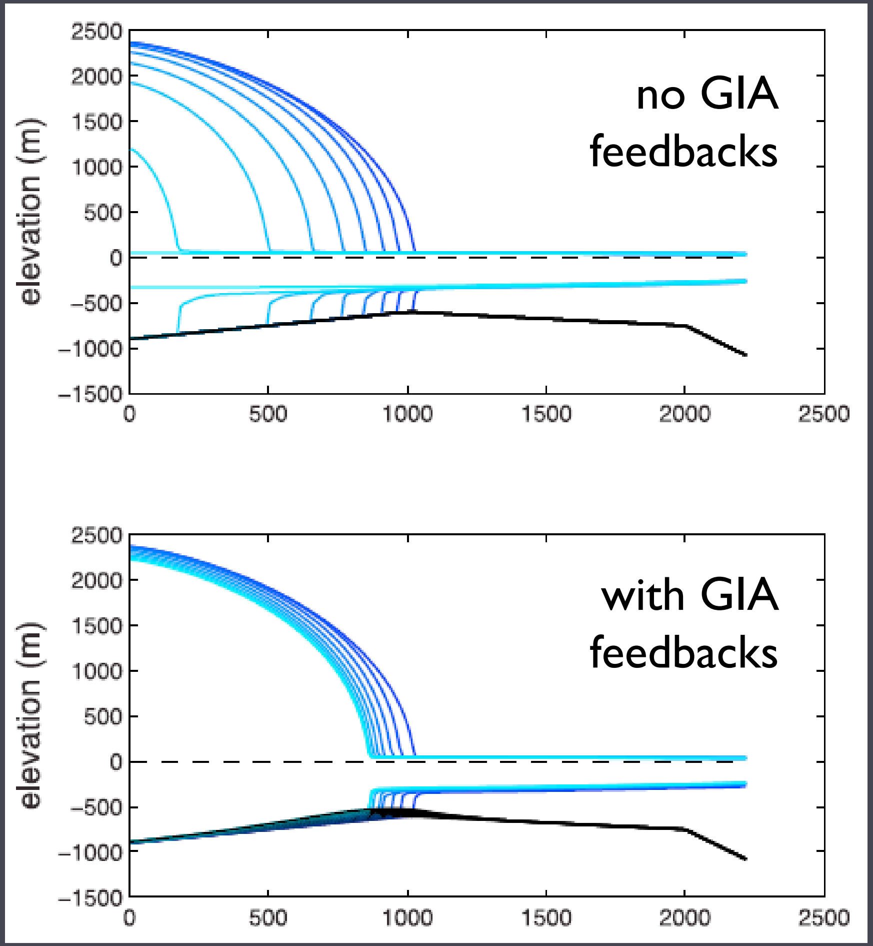
Meredith et al. (2020)



Whitehouse et al. (2019)

- Ice mass loss triggers: (i) bed uplift, and (ii) local sea surface fall
- Near-field decrease in water depth acts to stabilize the grounding line position
- The rate and spatial pattern of bed uplift depends on earth rheology

Recent advances: stabilizing effect of GIA



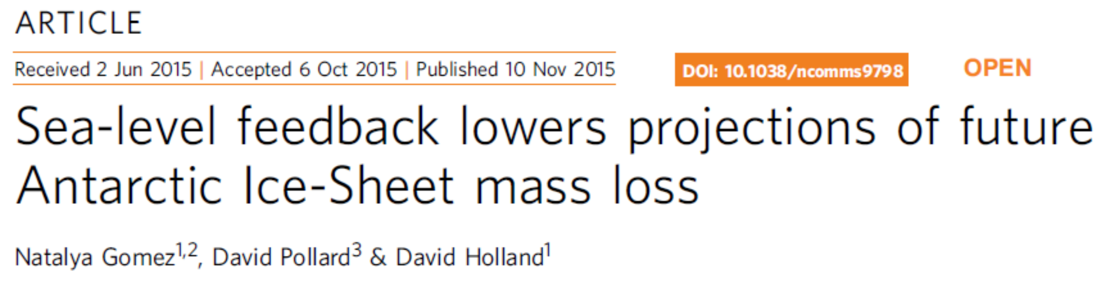
Gomez et al. (2012)

de Boer et al. (2014)

- Damps the rate of grounding line retreat (or advance)
- Reduces the magnitude of glacial-interglacial variability

Recent advances: importance of mantle viscosity

- Model predictions demonstrate that GIA can play a role in reducing rates of future ice loss <u>if mantle viscosity is low enough</u>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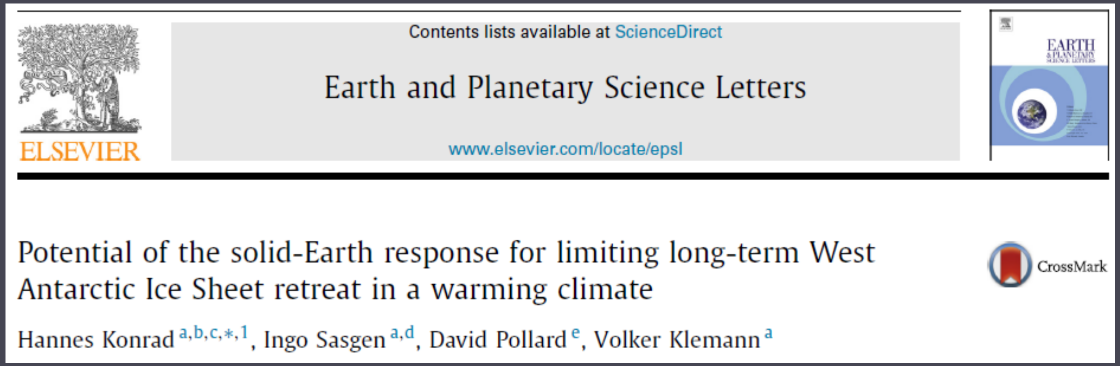
Sea-level feedback lowers projections of future Antarctic Ice-Sheet mass loss

Natalya Gomez[1,2], David Pollard[3] & David Holland[1]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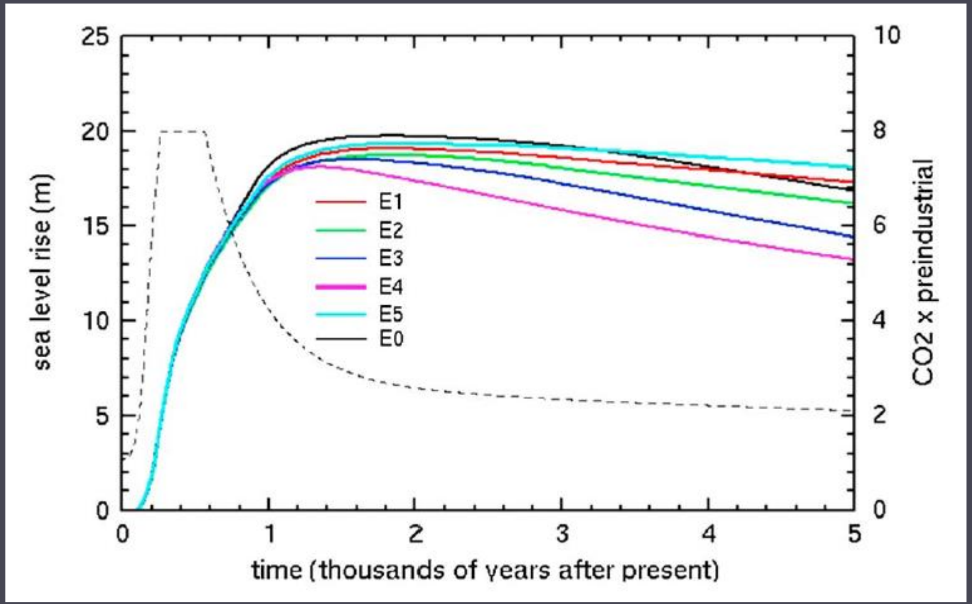
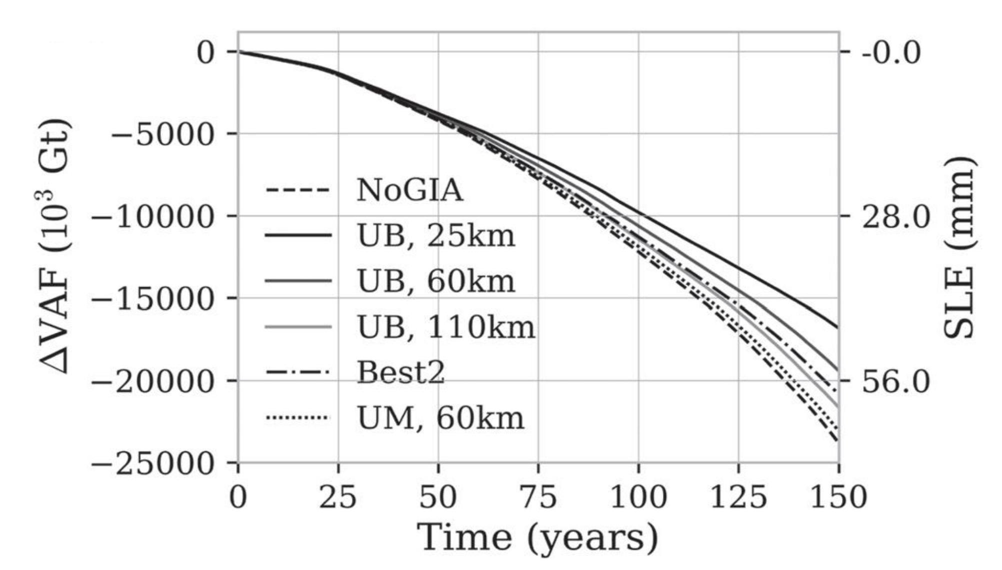
Potential of the solid-Earth response for limiting long-term West Antarctic Ice Sheet retreat in a warming climate

Hannes Konrad[a,b,c,*,1], Ingo Sasgen[a,d], David Pollard[e], Volker Klemann[a]

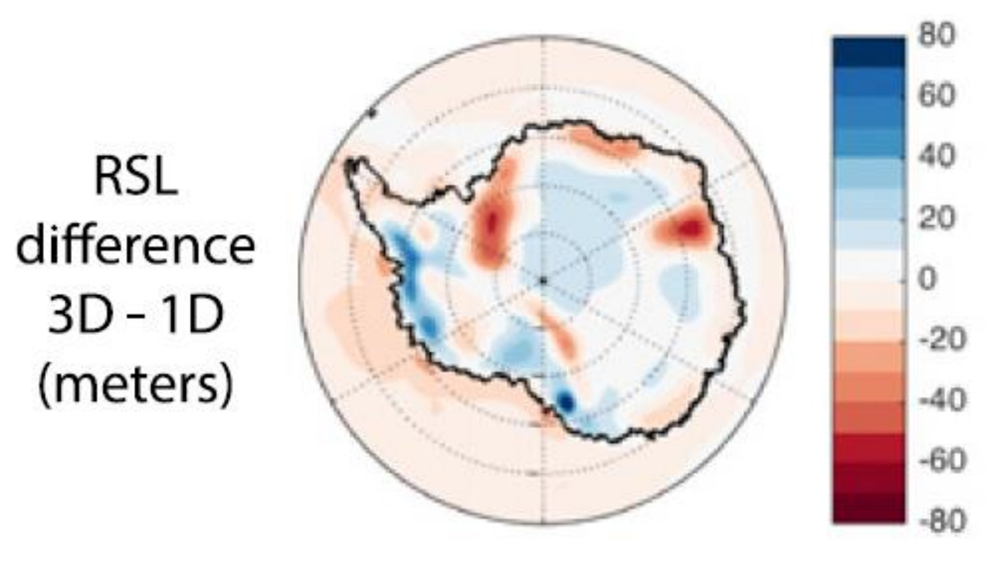


Pollard et al. (2017)

Recent advances: importance of mantle viscosity



Kachuck et al. (2020)



Gomez et al. (2018)

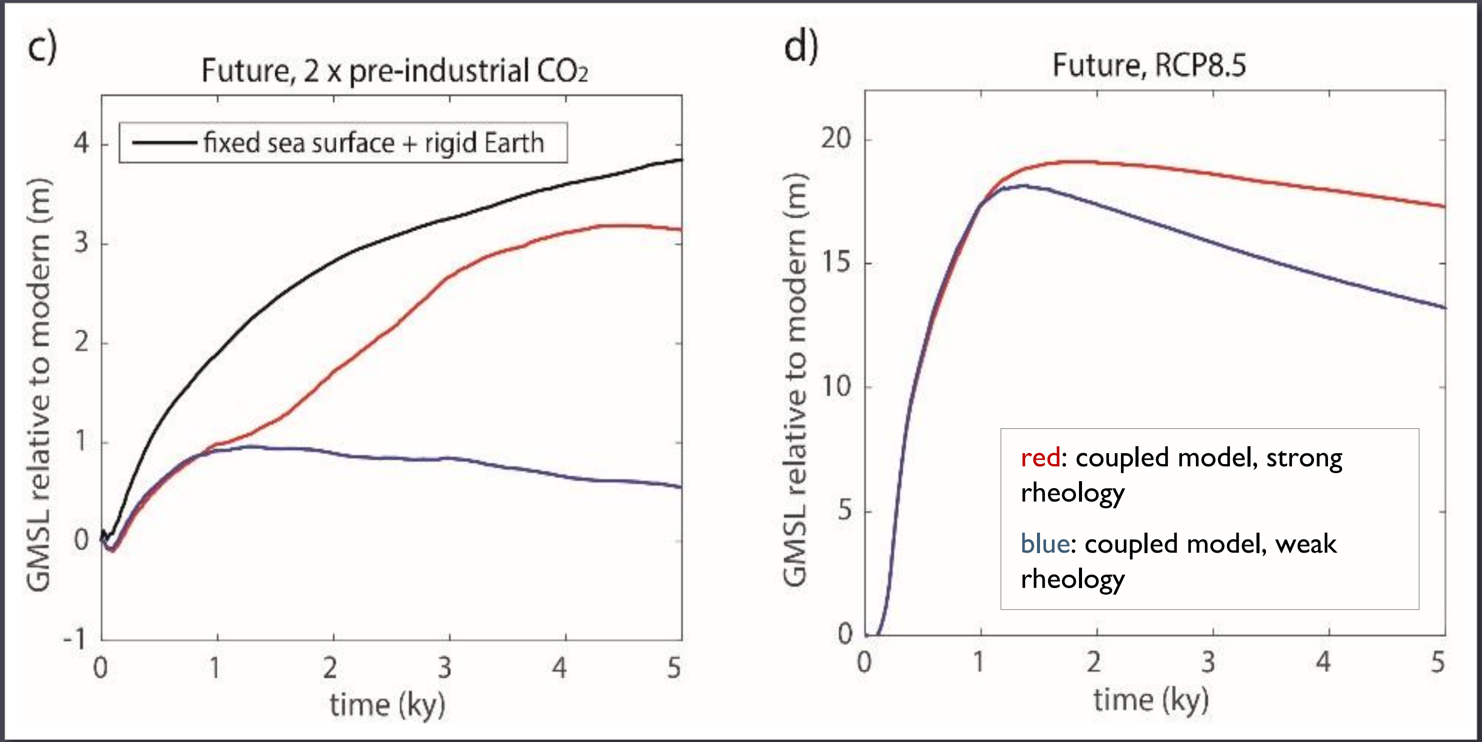
- Pine Island Glacier: delayed ice loss with more realistic earth model (see also Powell et al., 2020)
- differences in grounding line forcing at 15 ka BP due to inclusion of 3D variations in earth rheology

Talk structure

- Key concepts
  - GIA
  - sea-level fingerprint
  - MISI
- Recent advances
  - GIA stabilization
  - role of mantle viscosity
- Open questions

Open questions: I

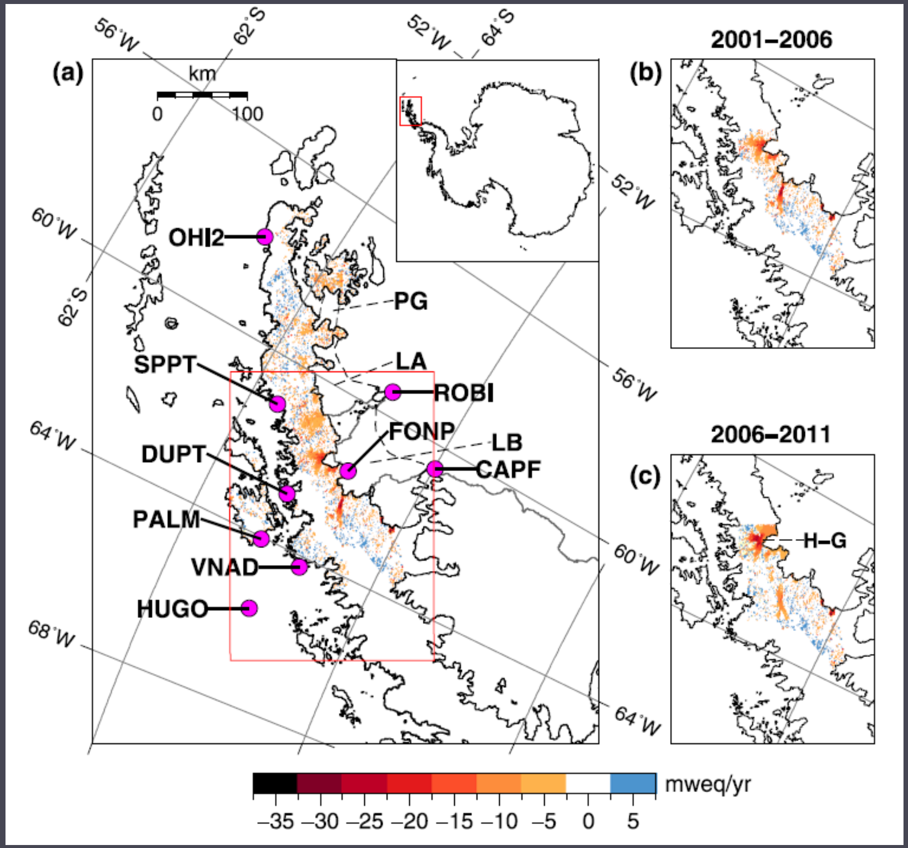
- what is the strength of the feedback between earth deformation and ice sheet dynamics?



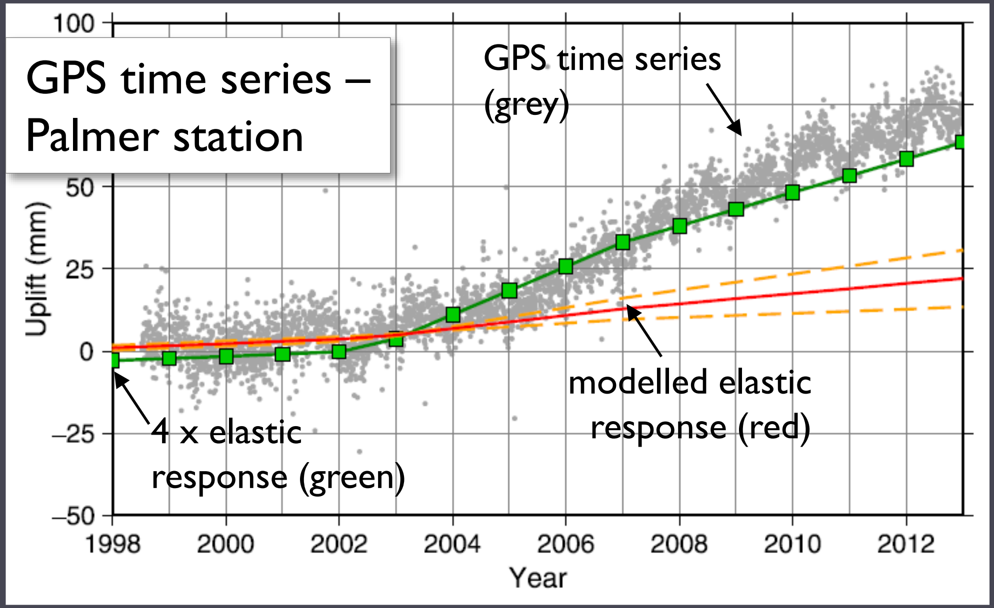
- Whitehouse et al. (2019)

Open questions: 2

- how do we map out earth rheology?



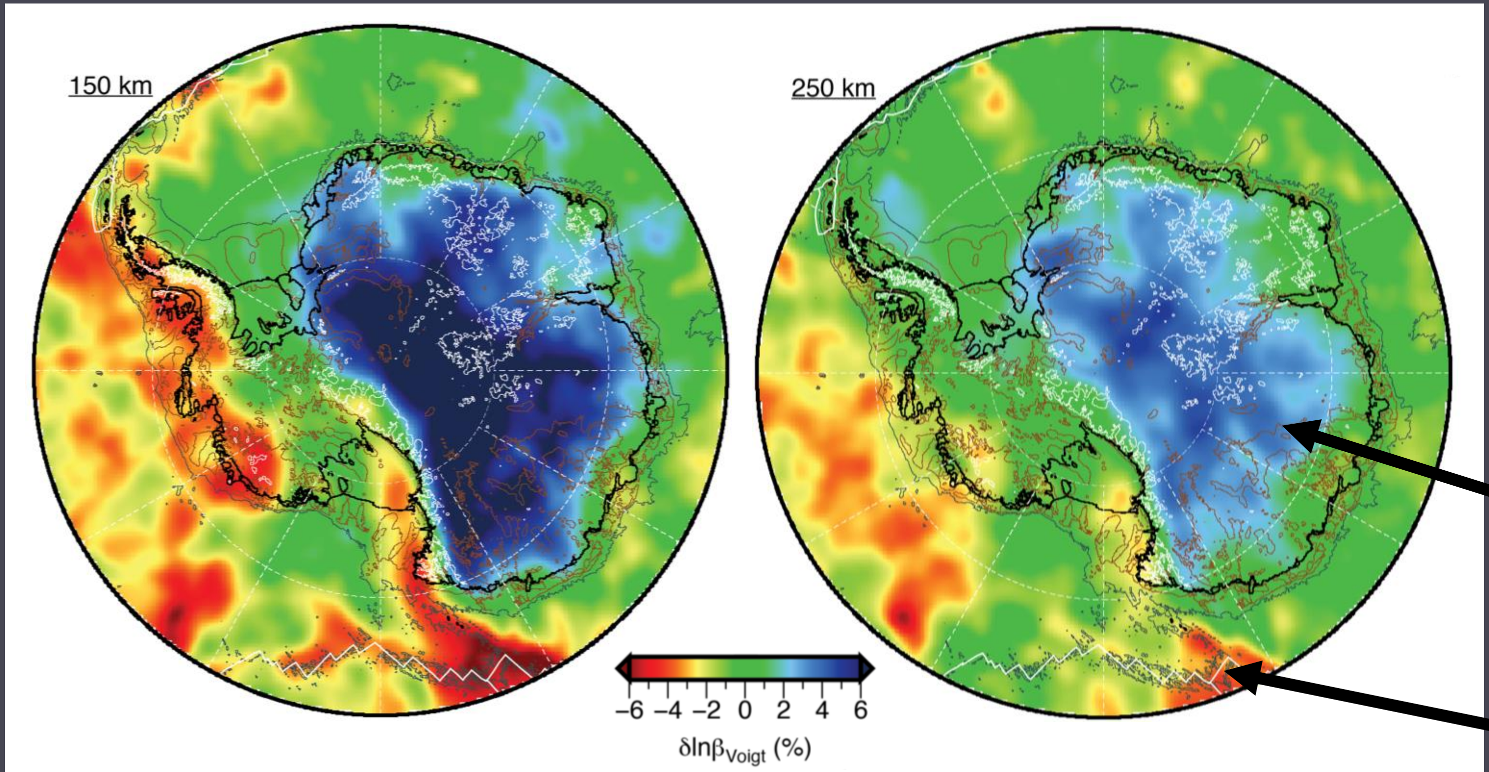
Method one: if we know surface forcing (left) and earth response (right), we can make inferences about earth properties



- Nield et al. (2014) : see also Wolstencroft et al. (2015), Zhao et al. (2017), Barletta et al. (2018), Samrat et al. (2020)

Open questions: 2

- how do we map out earth rheology?



Method two: seismic velocity perturbations can be used to map out mantle temperature and hence viscosity

blue = faster ⇒ denser ⇒ colder ⇒ higher viscosity

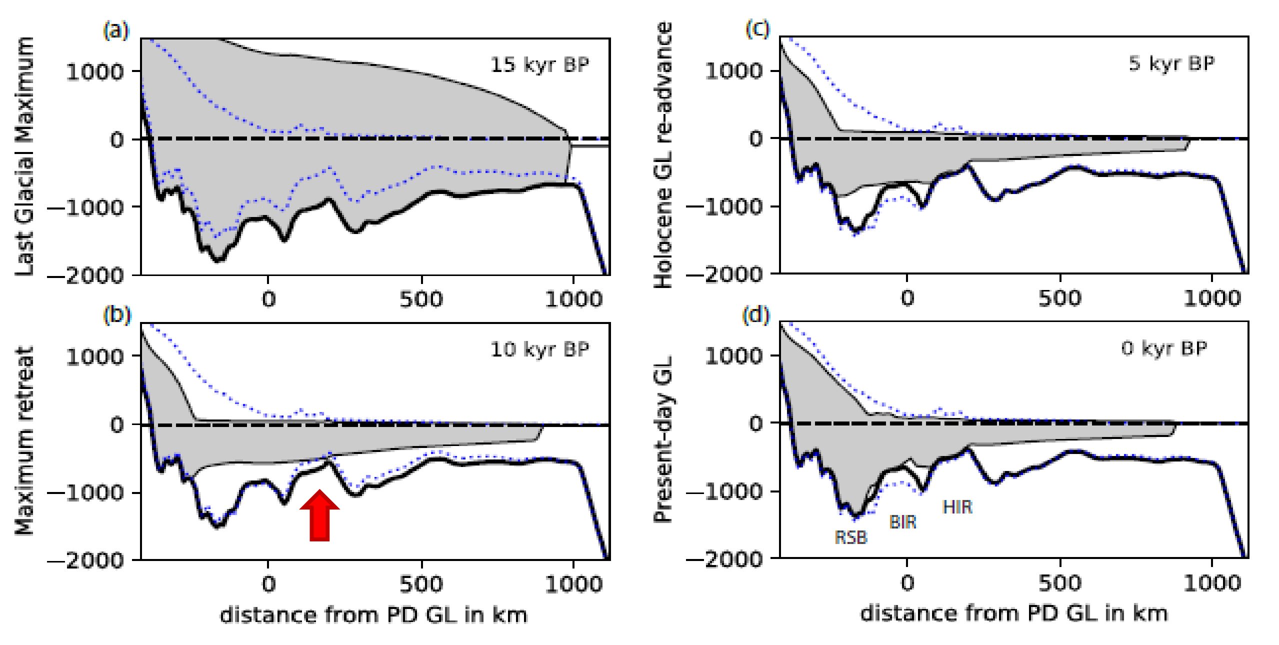
red = slower ⇒ less dense ⇒ hotter ⇒ lower viscosity

- Lloyd et al. (2019)

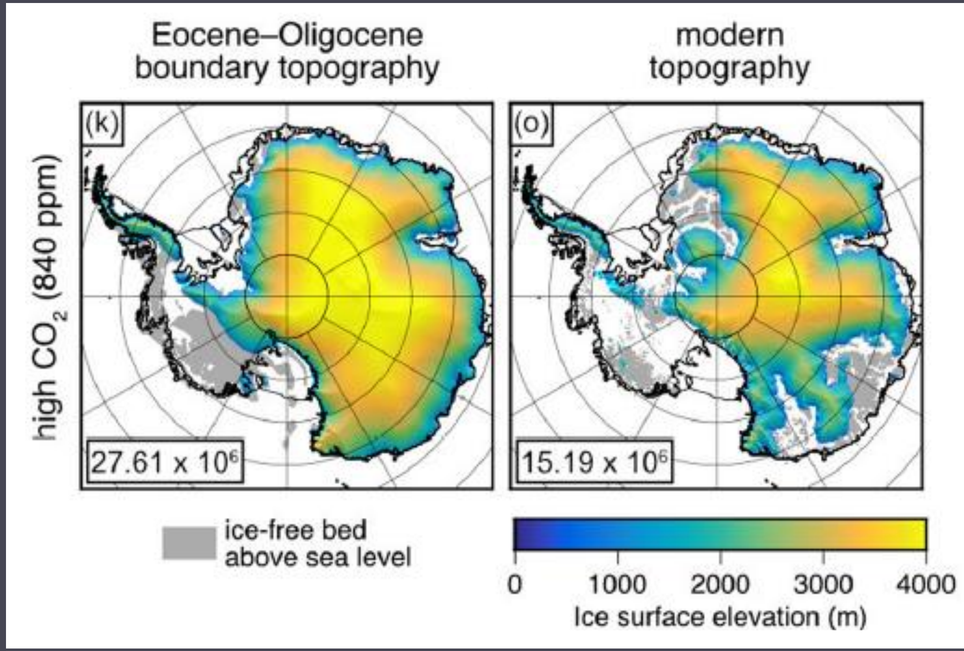
Open questions: 3

- what role has earth deformation played in controlling past ice sheet change?

Last deglaciation



Long-term ice sheet sensitivity



Kingslake et al. (2018)

Paxman et al. (2020)

Approaches to tackling these questions

- Observations
  - of surface deformation
  - of sub-ice/ocean deformation
  - that reflect past deformation

- Modelling
  - data inversion
  - coupled modelling

- Robust treatment of uncertainties
  - in data and modelling
  - we have moved beyond the goal of seeking a single ‘right answer’

Summary

- Sea-level change regulates ice sheet dynamics, which affects sea level
  - the details depend on earth rheology
- Need to account for feedbacks between ice sheets – earth – ocean:
  - within process-based models
  - or when interpreting data/using data to tune models
- Need to map out spatially variable earth rheology, implications for:
  - global ice sheet reconstructions, tuned to fit sea-level data assuming 1D earth profile
  - spatial pattern of contemporary vertical land motion due to GIA
  - future ice sheet change

need to understand the <u>strength of the feedbacks</u> between ice sheet dynamics and solid earth deformation; this depends on <u>3D variations in earth rheology</u>