Excess ice loads prior to the Last Glacial Maximum in the Indian Ocean sector of East Antarctica derived from sea-level observations and GIA modeling

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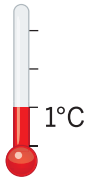
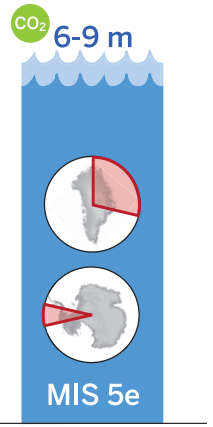
Introduction: sea-level change since the Last Interglacial

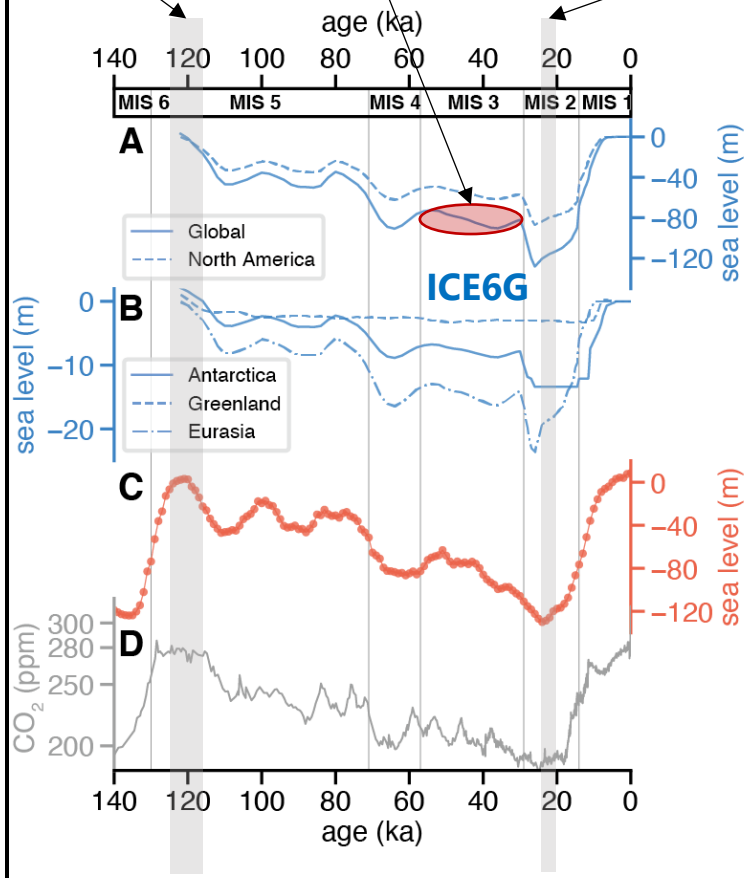
LIG
+6–9 m
Dutton et al., 2015



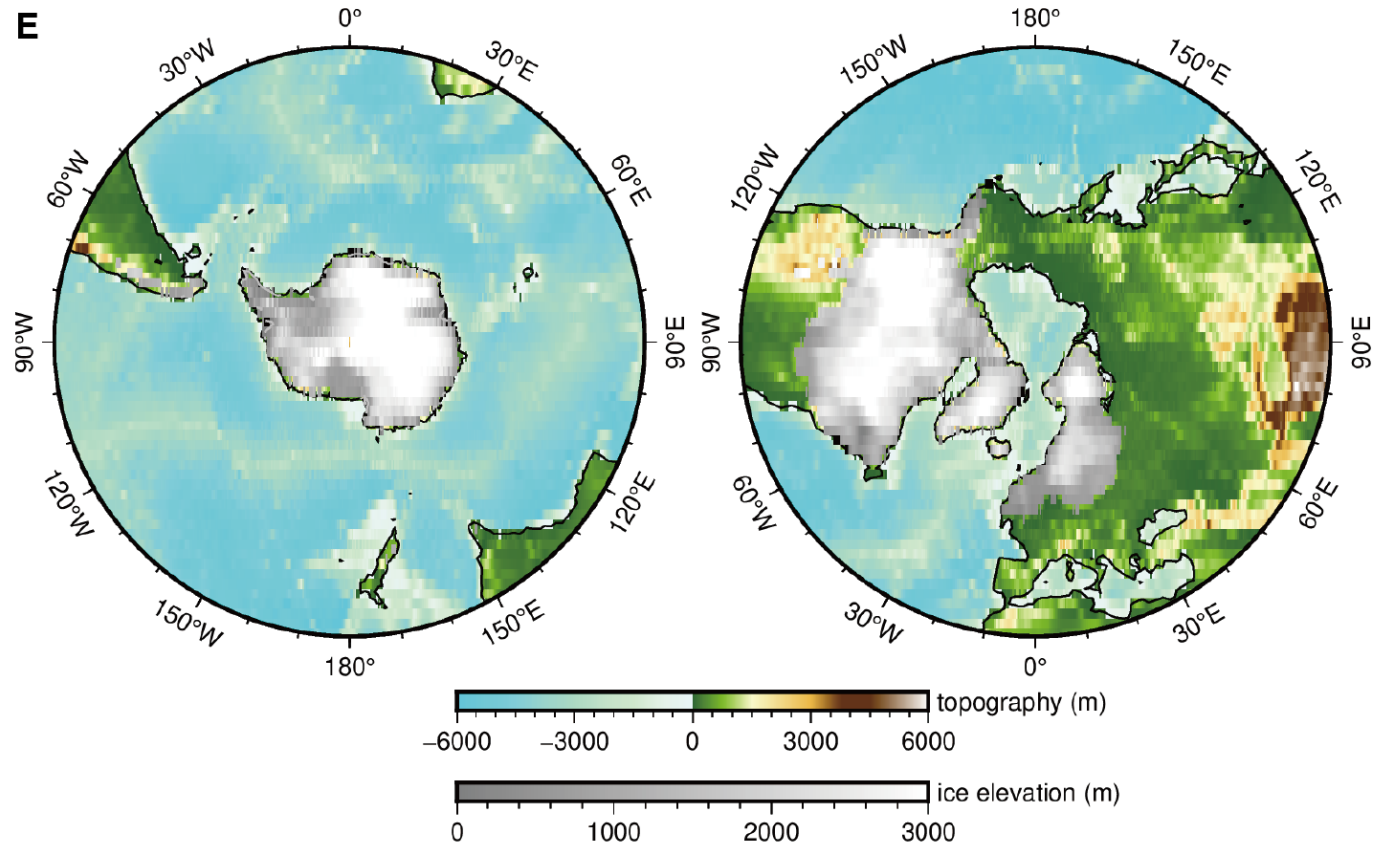


125,000

MIS 3
~ -80 m
Peltier et al., 2015

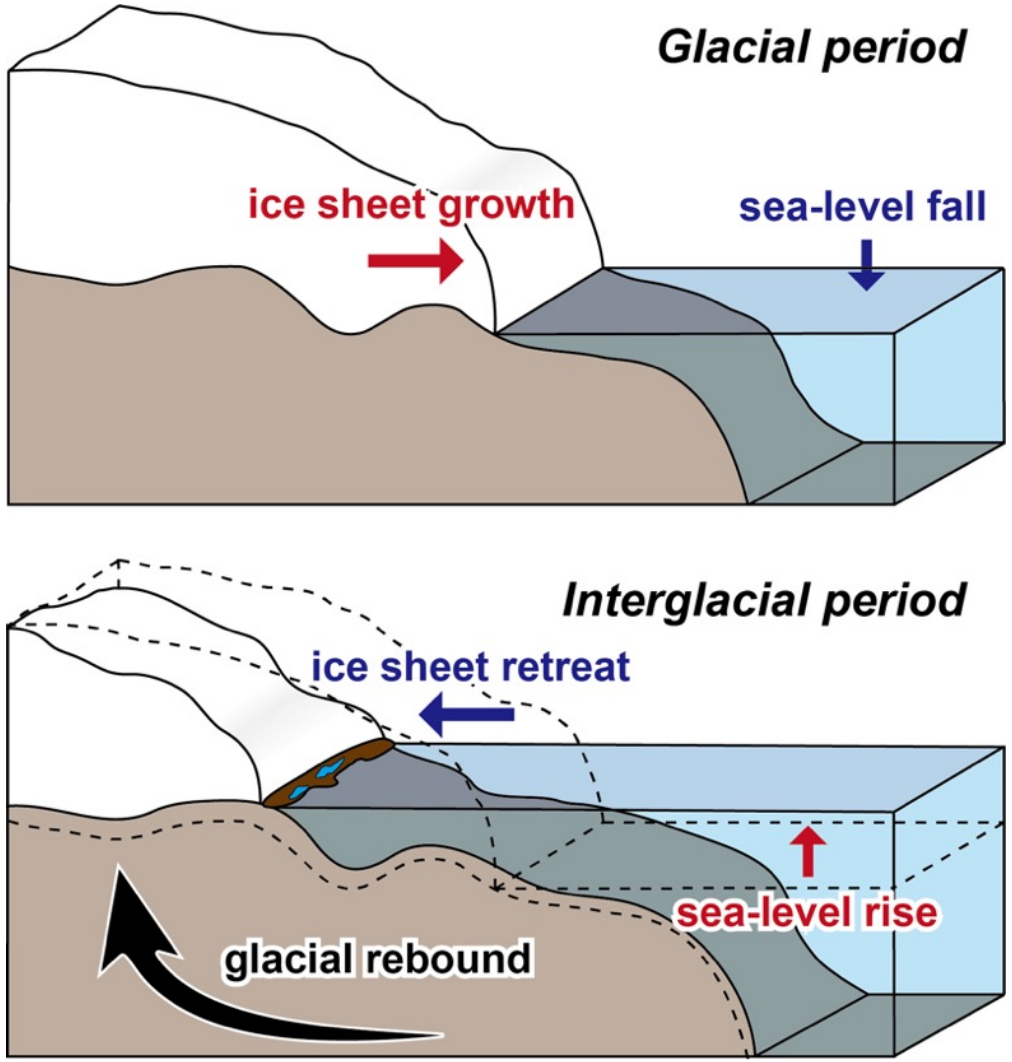


LGM
~ -130 m
Peltier et al., 2015



Data from Argus et al., 2014; Bereiter et al., 2014; Grant et al., 2014; Peltier et al., 2015; Spratt and Lisiecki, 2016

Introduction: Glacial Isostatic Adjustment



Suganuma et al., 2020

Main input of GIA modeling

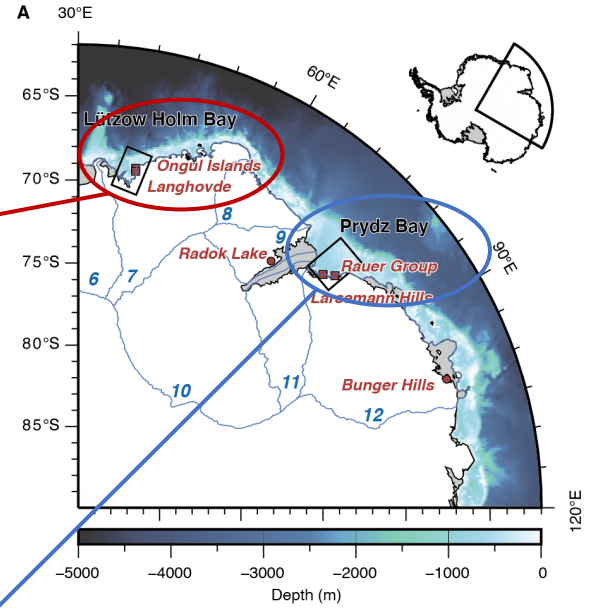
- Earth parameter (Lithosphere thickness, Upper mantle viscosity, Lower Mantle viscosity)
- Ice loading history

Relative sea level *Glacial isostasy* *Hydro isostasy*

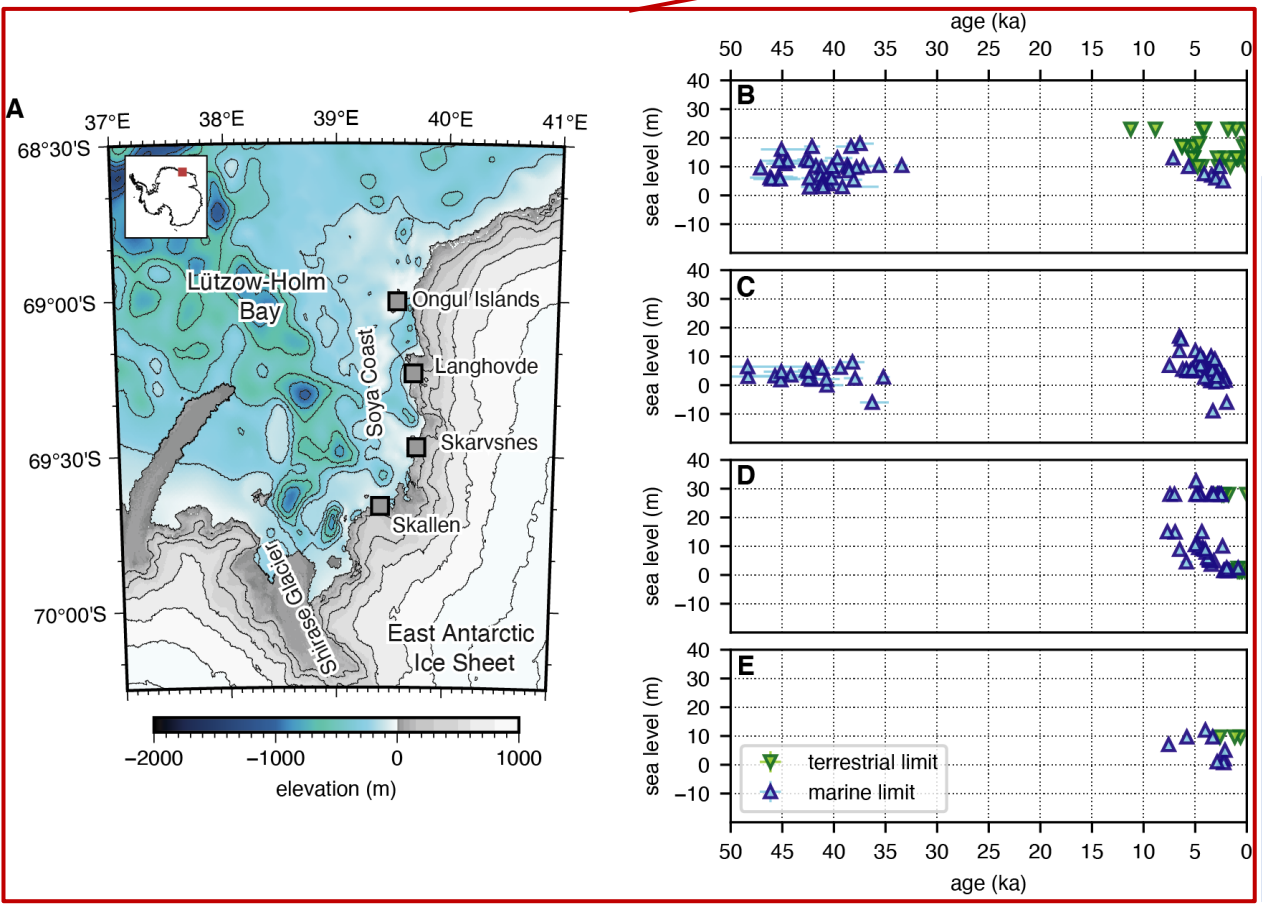
$$\Delta\zeta_{rsl}(\phi,t) = \Delta\zeta_{esl}(t) + \delta\zeta_{ice}^{iso}(\phi,t) + \delta\zeta_{water}^{iso}(\phi,t)$$

Ice loading history

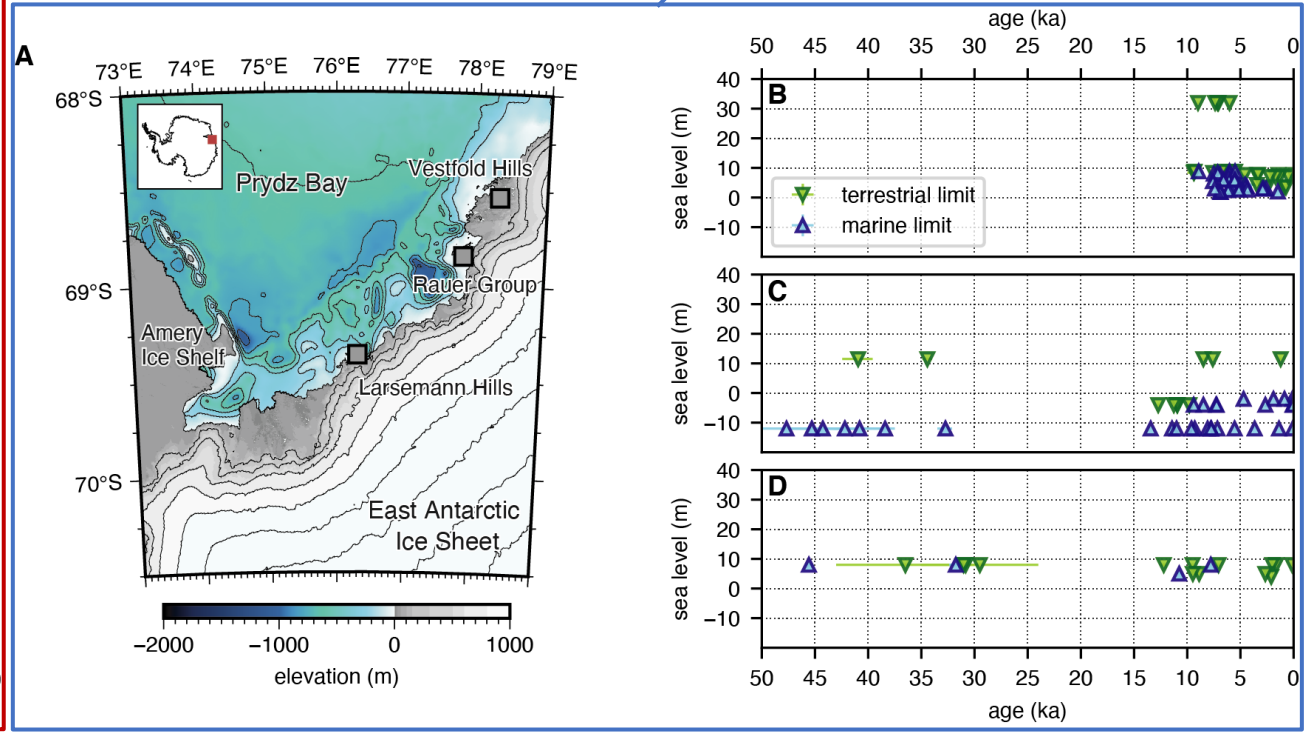
Sea-level observations in Indian Ocean sector of East Antarctica



Lützow-Holm Bay

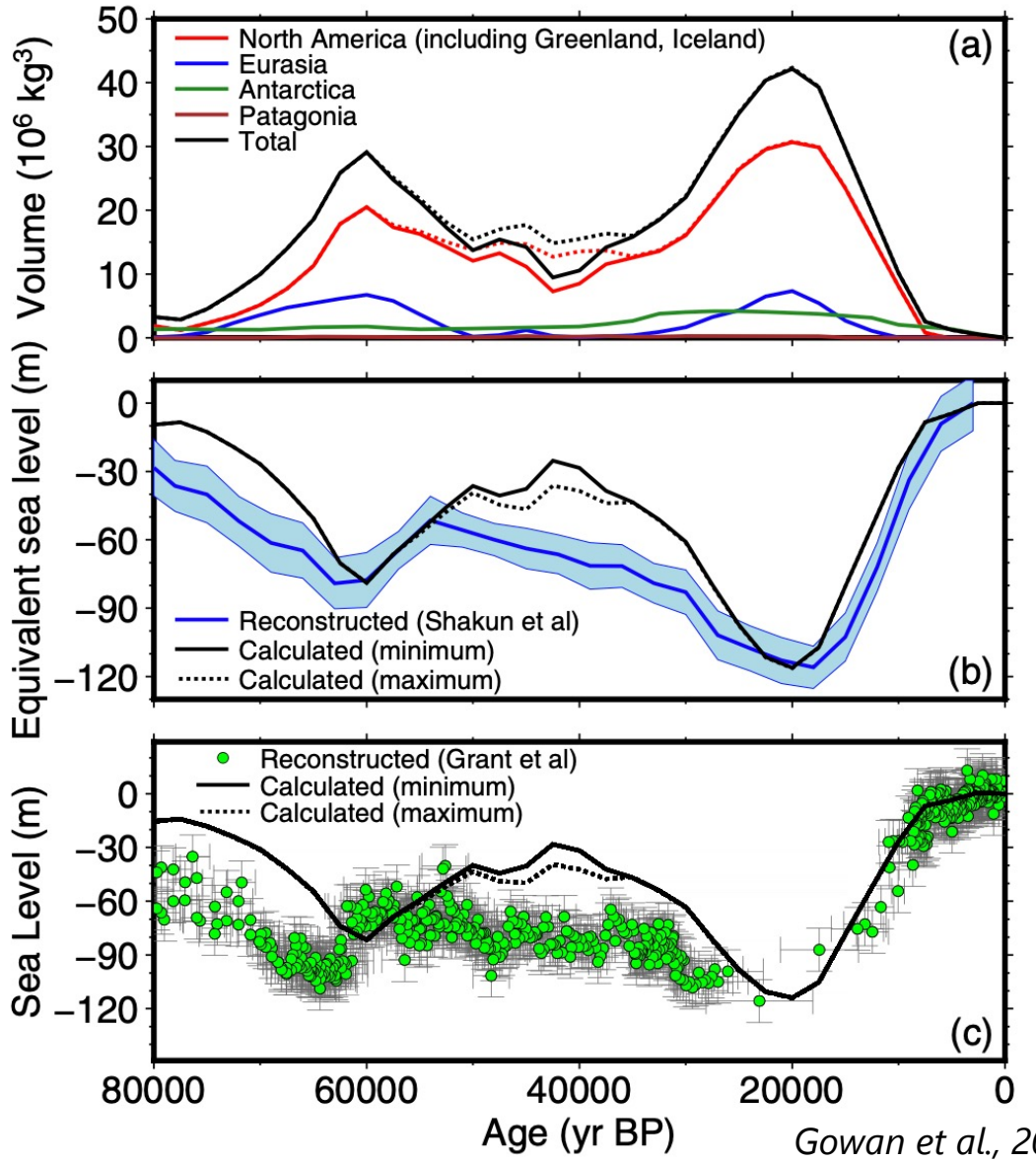


Prydz Bay



Topography data from GEBCO2020

Global sea-level change during glacial period



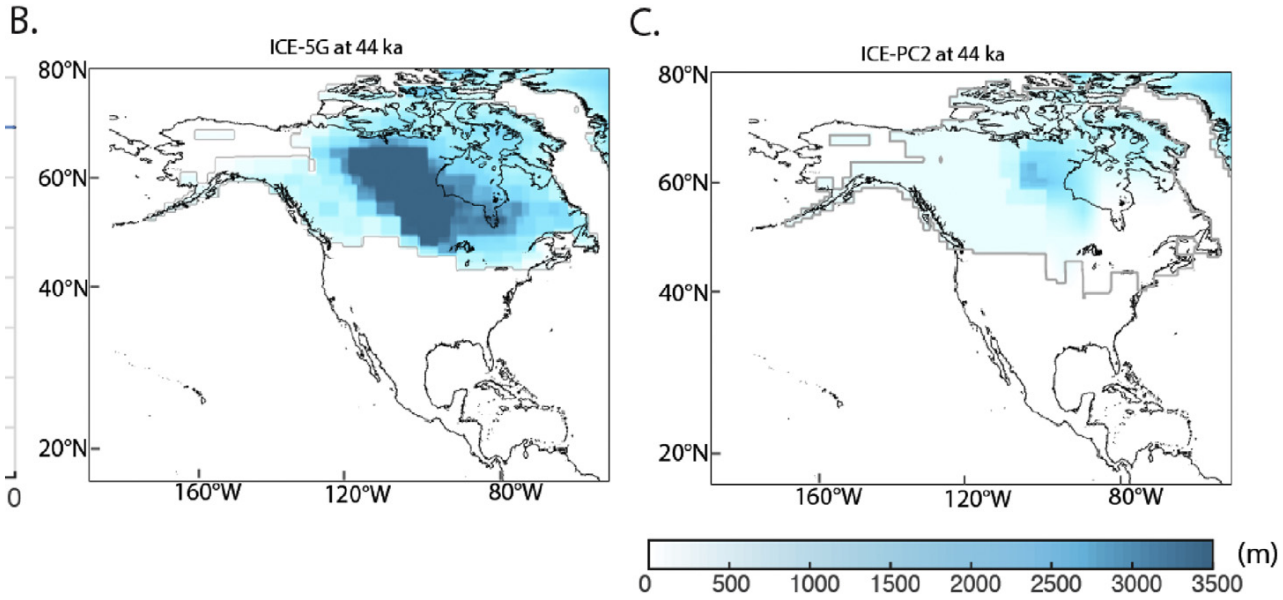
Gowan et al., 2021

"Small" North American Ice sheet during MIS 3.

Dalton et al., 2016, 2019; Pico et al., 2017,2018

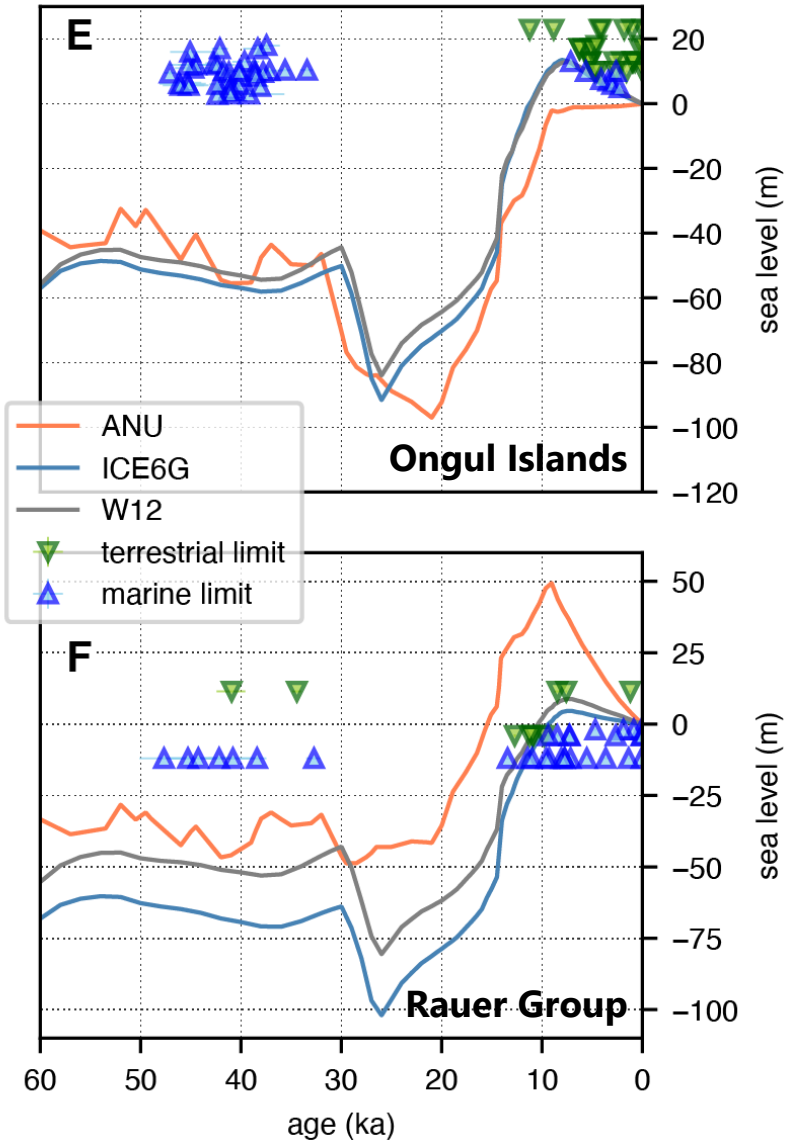
-> "High" global sea level (up to 30 m)

Gowan et al., 2021



Pico et al., 2018

Objective: Reconstruction of AIS changes during Glacial period



GIA modeling cannot explain MIS 3 sea-level observations.

What is the main cause of this discrepancy?

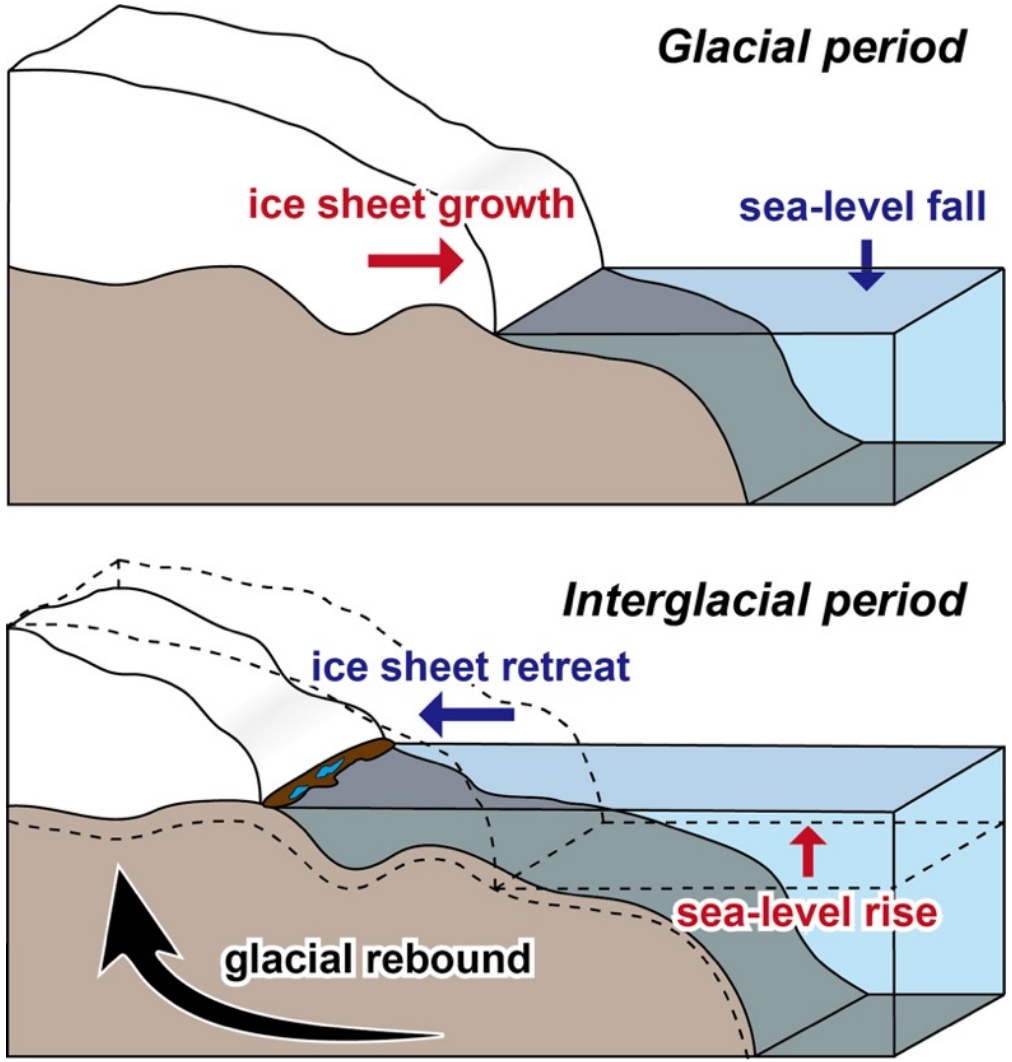
1. Earth parameter of GIA modeling.
2. Small North American Ice Sheet.
3. The timing of Antarctic Ice Sheet growth.
4. The growth timing and maximum volume of Antarctic Ice Sheet.

GIA modeling

Ice loading history

- ANU (Lambeck et al., 2002,2014)
- W12 (Whitehouse et al., 2012)

Methods: Glacial Isostatic Adjustment

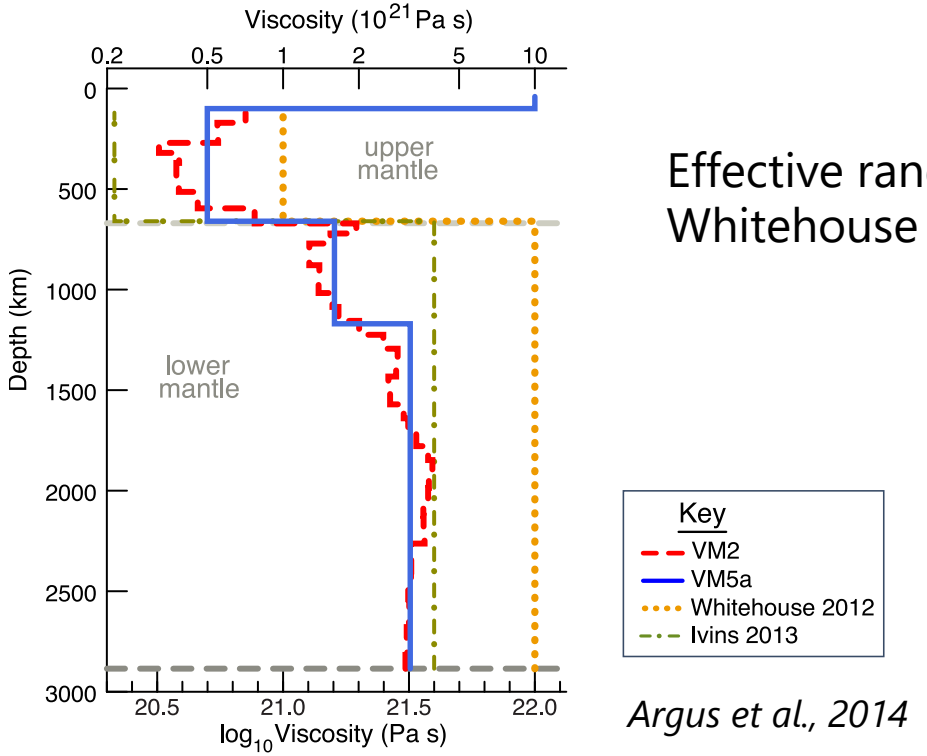


Suganuma et al., 2020

Relative sea level *Glacial isostasy* *Hydro isostasy*

$$\Delta\zeta_{rsl}(\phi,t) = \Delta\zeta_{esl}(t) + \delta\zeta^{iso}_{ice}(\phi,t) + \delta\zeta^{iso}_{water}(\phi,t)$$

Ice loading history

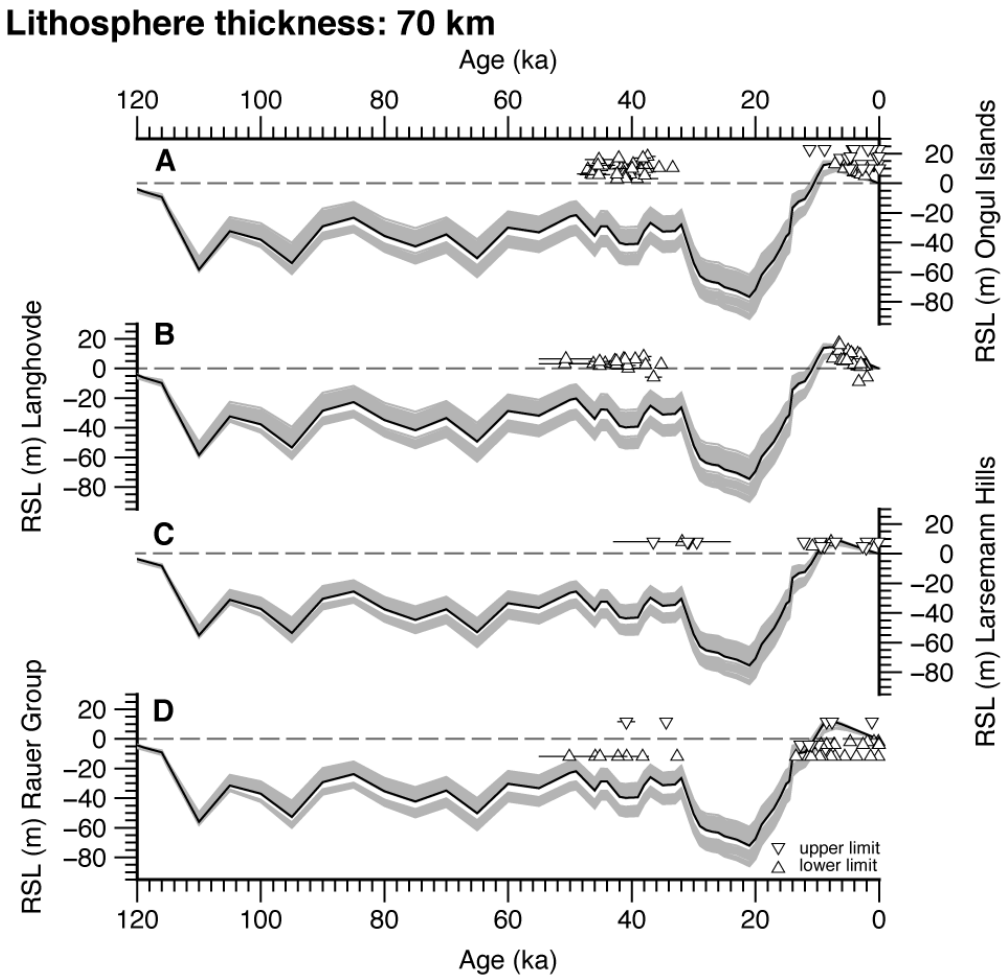


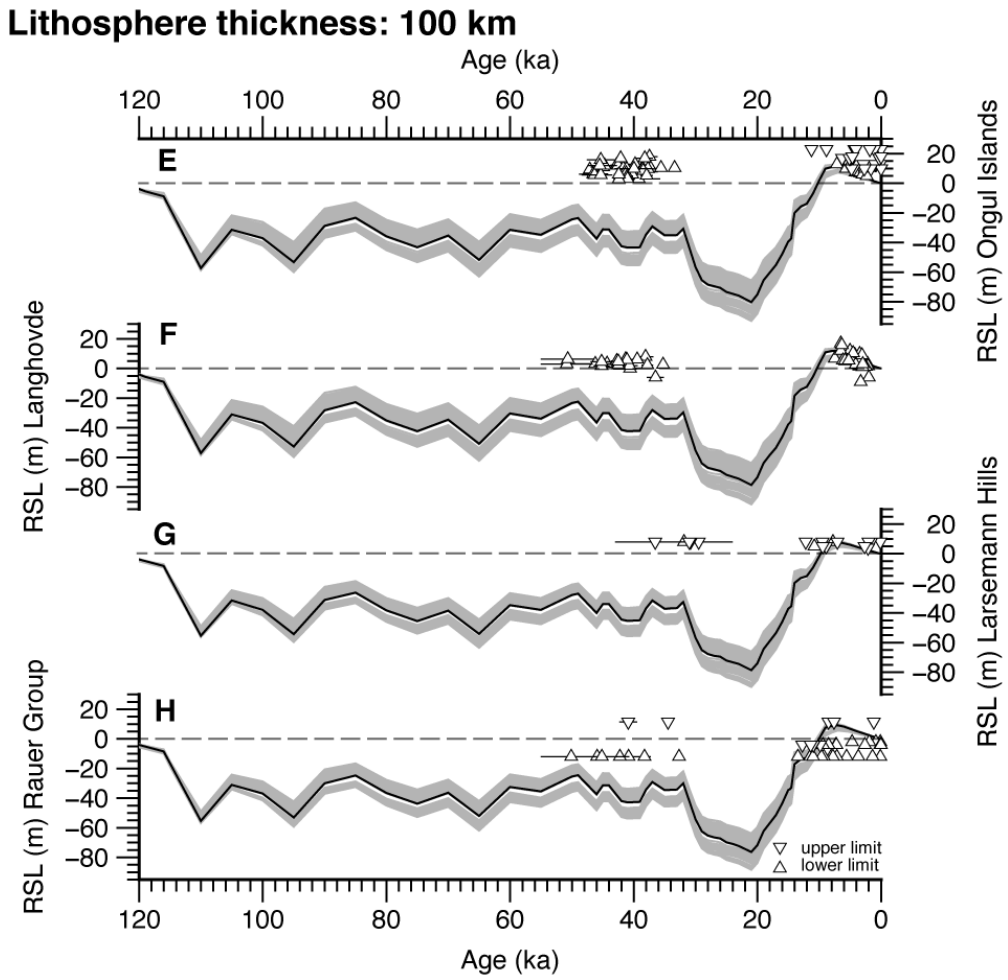
Argus et al., 2014

Effective range is from Whitehouse et al. (2012).

Results and Discussion: the effect of Earth parameter

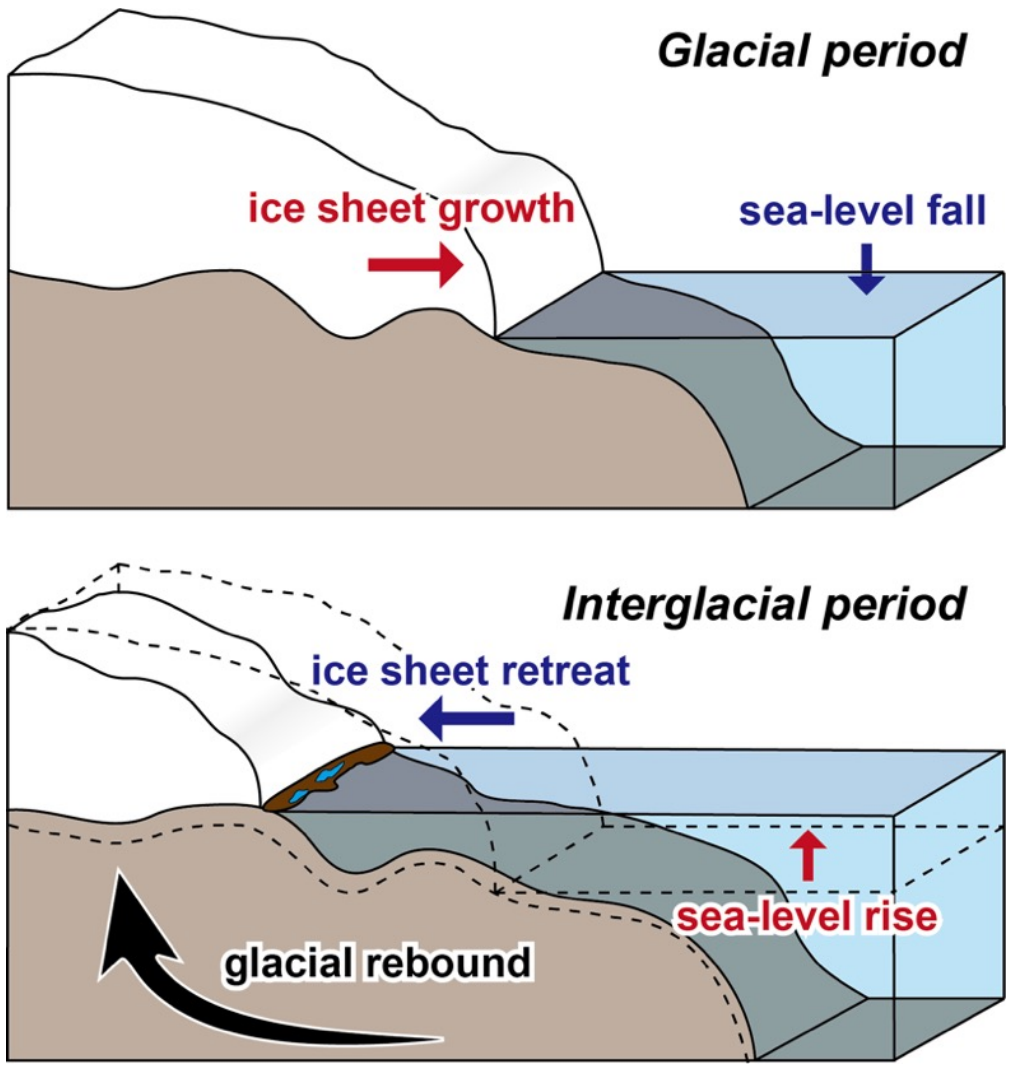
Effective range of Earth parameter is insufficient to explain MIS 3 sea-level observations





Ishiwa et al., 2021

Methods: Glacial Isostatic Adjustment



Suganuma et al., 2020

Relative sea level *Glacial isostasy* *Hydro isostasy*

$$\Delta\zeta_{rsl}(\phi,t) = \Delta\zeta_{esl}(t) + \delta\zeta_{ice}^{iso}(\phi,t) + \delta\zeta_{water}^{iso}(\phi,t)$$

Ice loading history

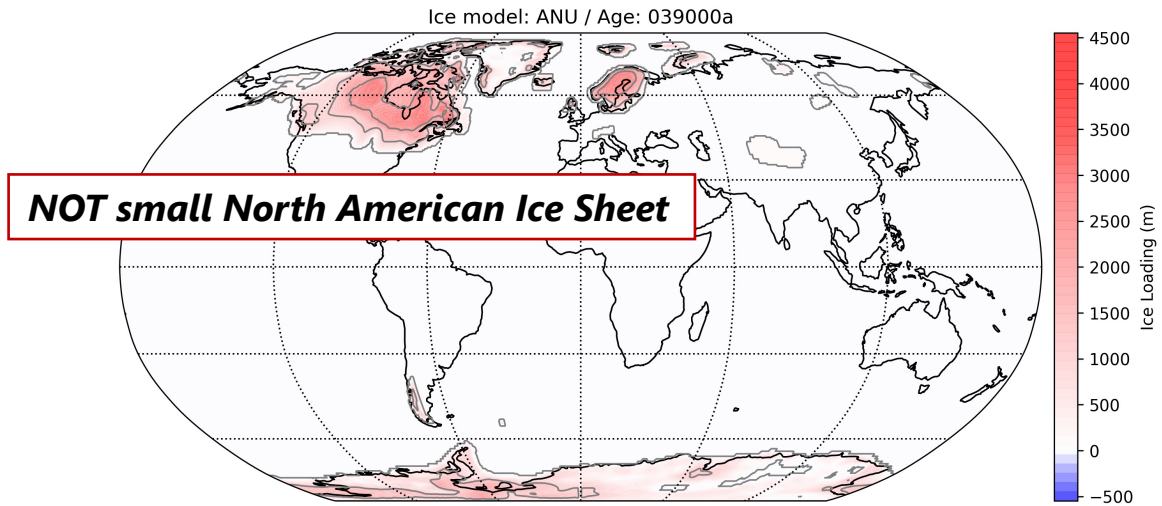
Ice loading history

Antarctica

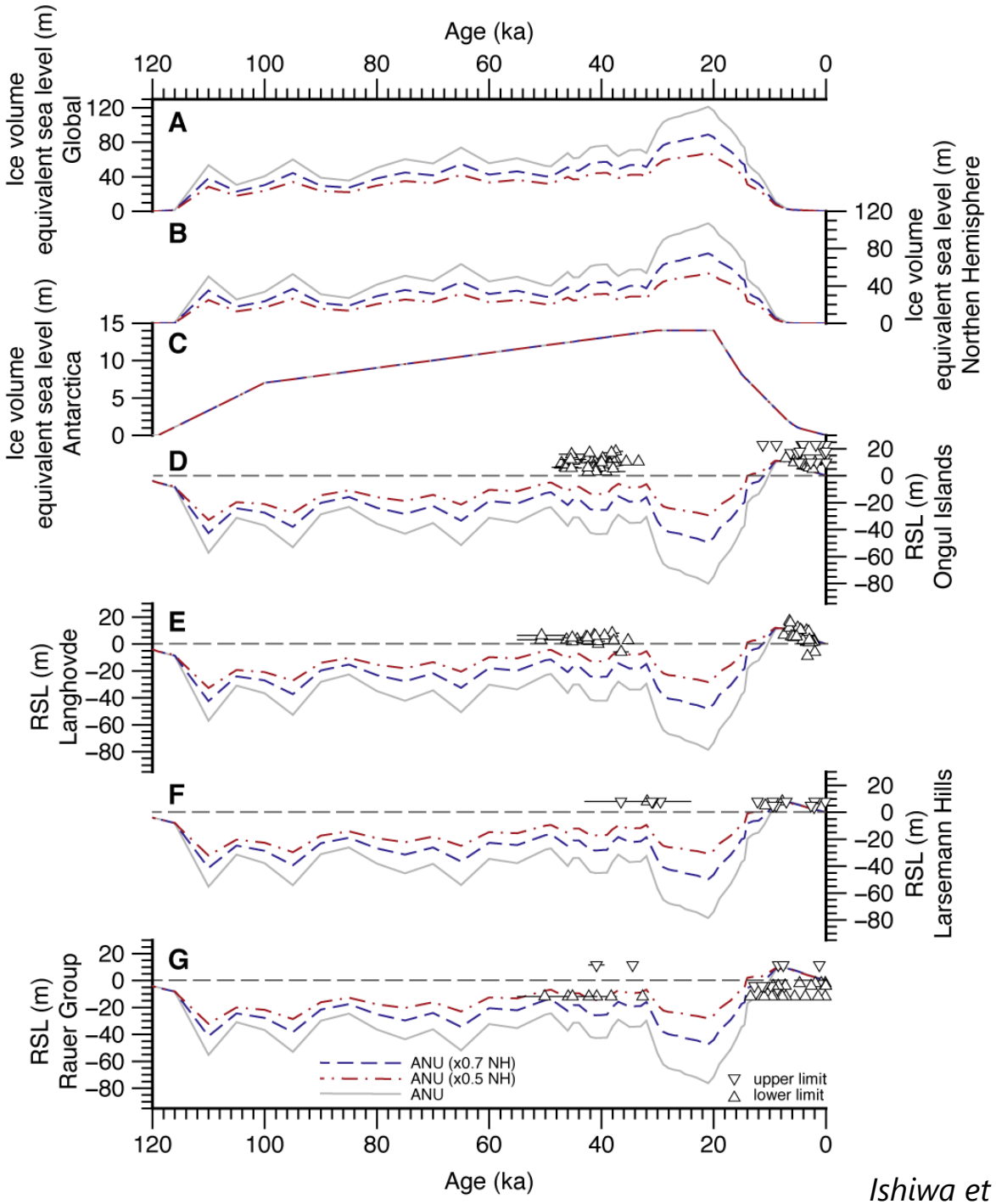
- W12 (Whitehouse et al., 2012)

Except for Antarctica

- ANU (Lambeck et al., 2002,2014)



Results and Discussion: the effect of North hemisphere ice sheet



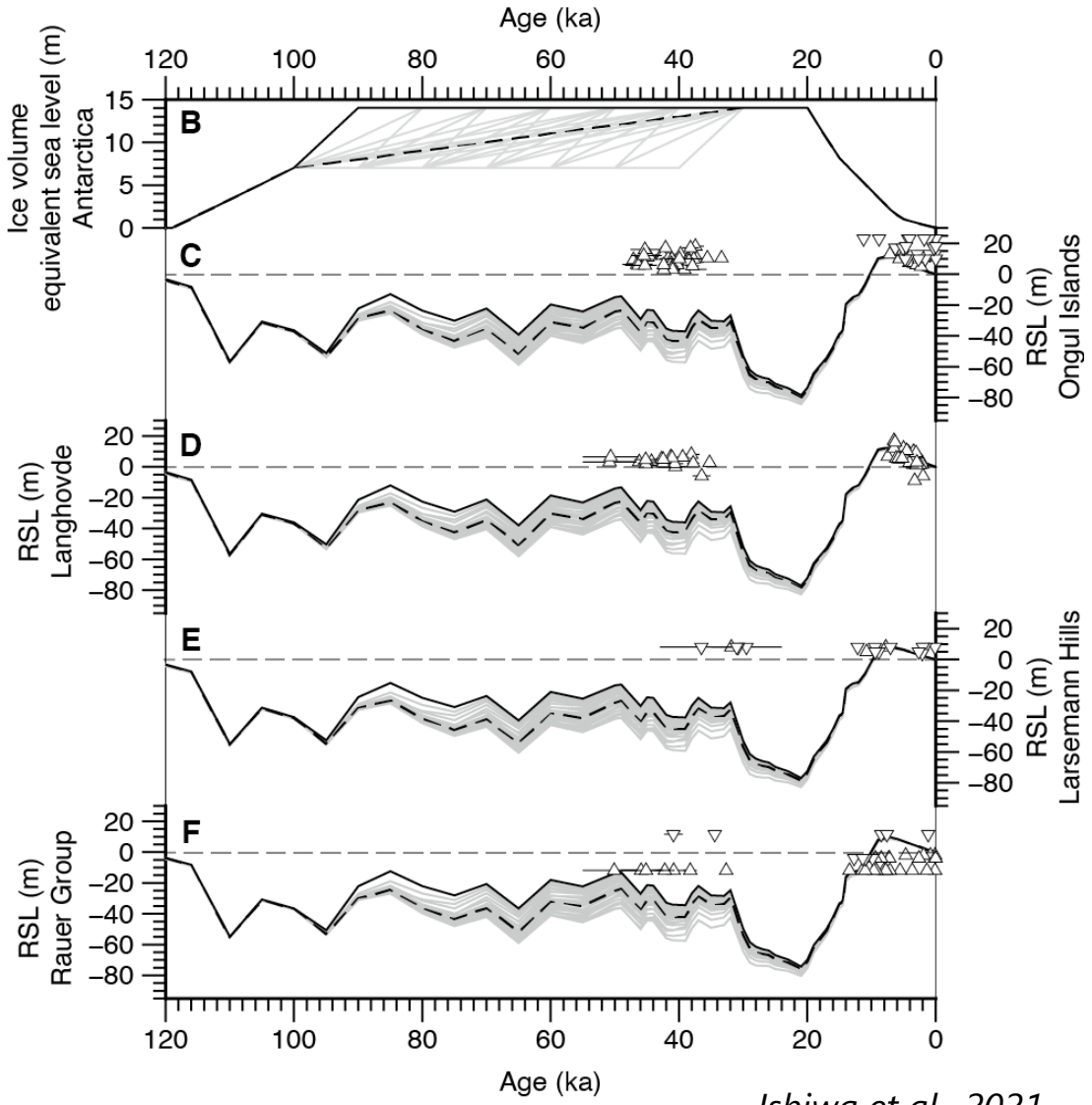
Ishiwa et al., 2021

1. Earth parameter of GIA modeling.
2. **Small North American Ice Sheet.**
3. The timing of Antarctic Ice Sheet growth.
4. The growth timing and maximum volume of Antarctic Ice Sheet.

Small North American ice sheet is not effective.

Antarctic Ice Sheet history should be revised.

Results and Discussion: the timing of AIS growth



Ishiwa et al., 2021

1. Earth parameter of GIA modeling.
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3. **The timing of Antarctic Ice Sheet growth.**
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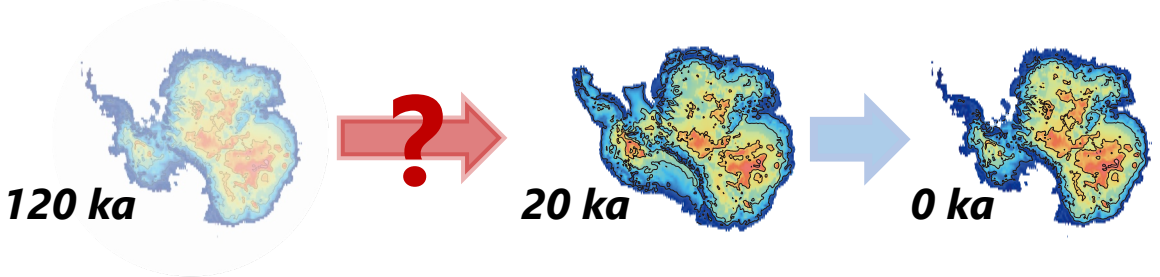
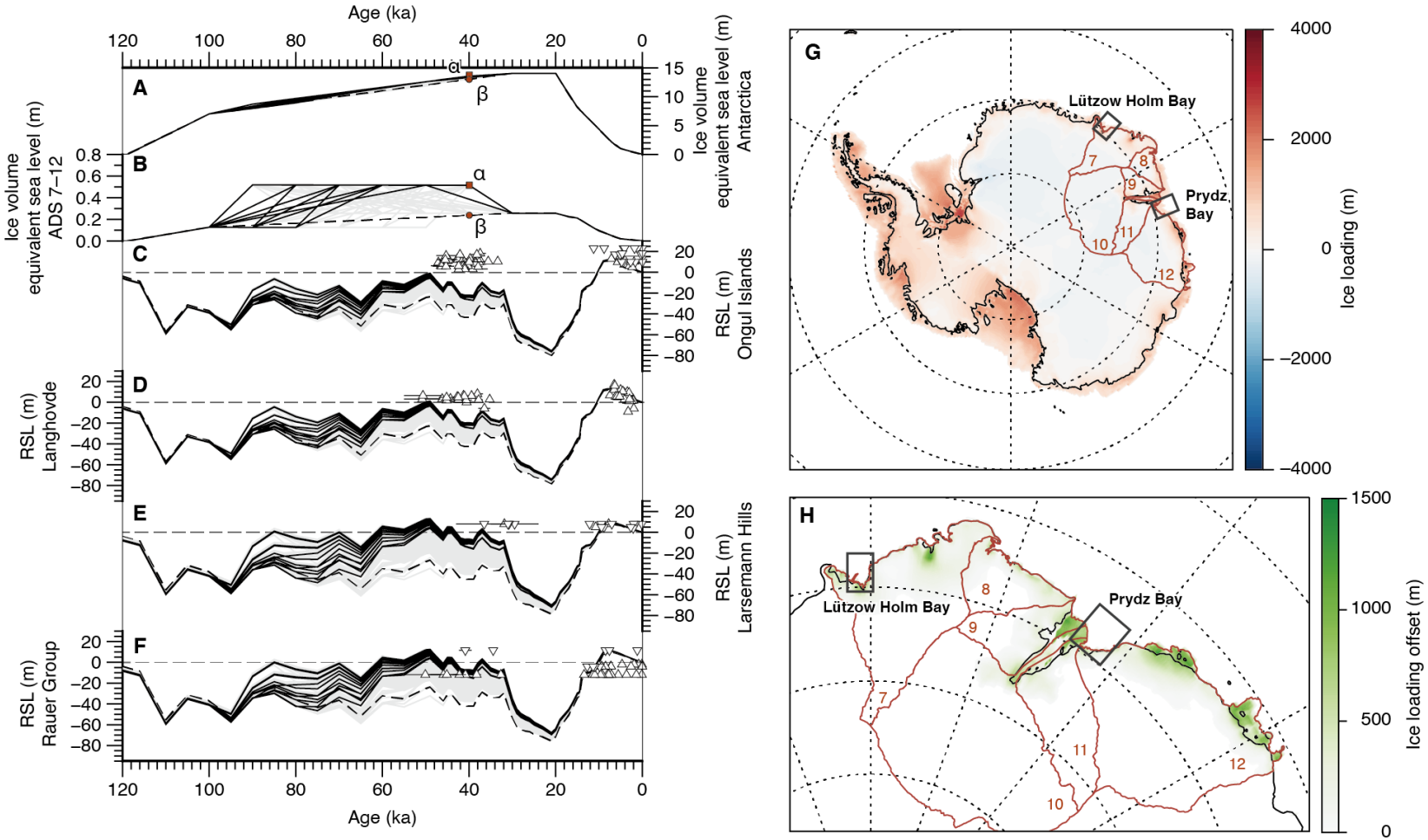


The timing of Antarctic Ice Sheet growth is insufficient to explain MIS 3 sea-level observations.

Results and Discussion: the maximum volume of AIS

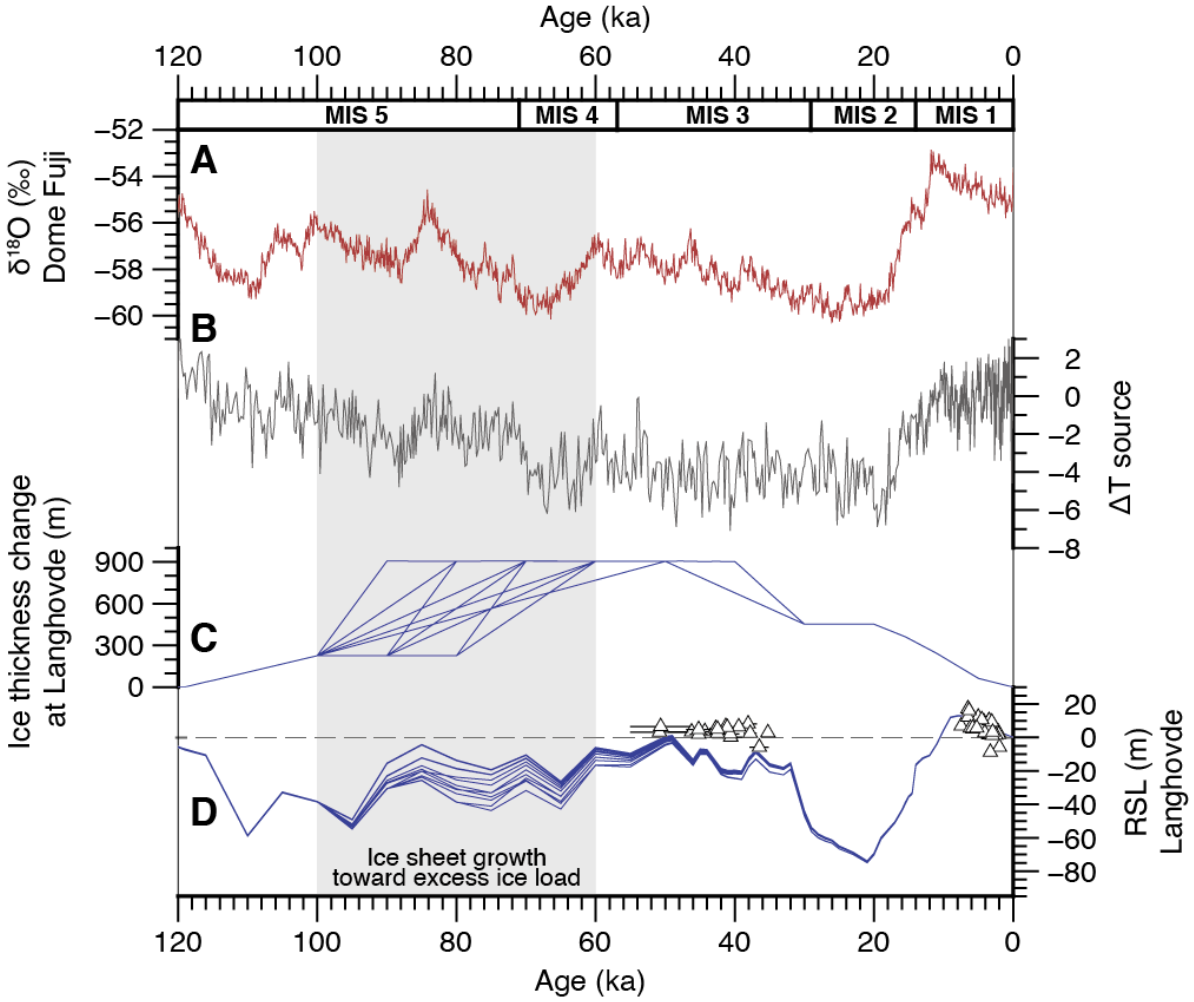


Ishiwa et al., 2021

1. Earth parameter of GIA modeling.
2. Small North American Ice Sheet.
3. The timing of Antarctic Ice Sheet growth.
4. **The growth timing and maximum volume of Antarctic Ice Sheet.**

Excess ice load is key to explain sea-level highstands during MIS 3.

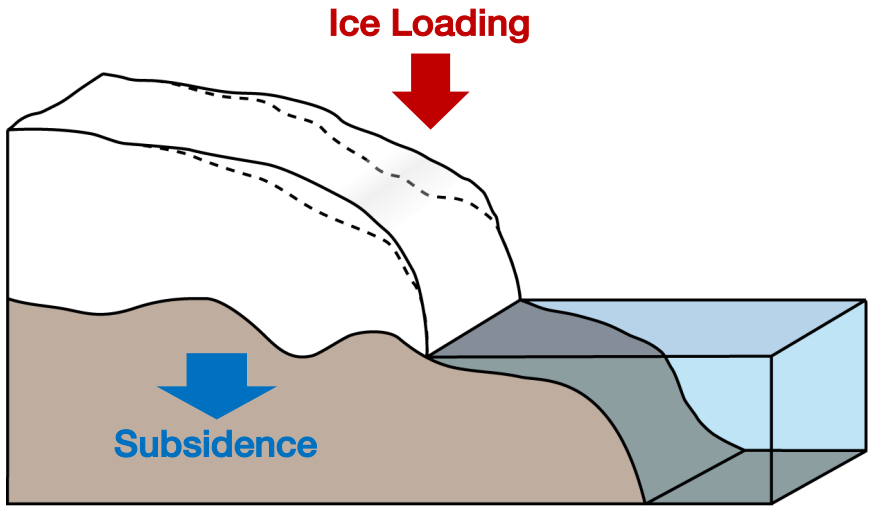
Discussion: East Antarctic Ice Sheet change during glacial period



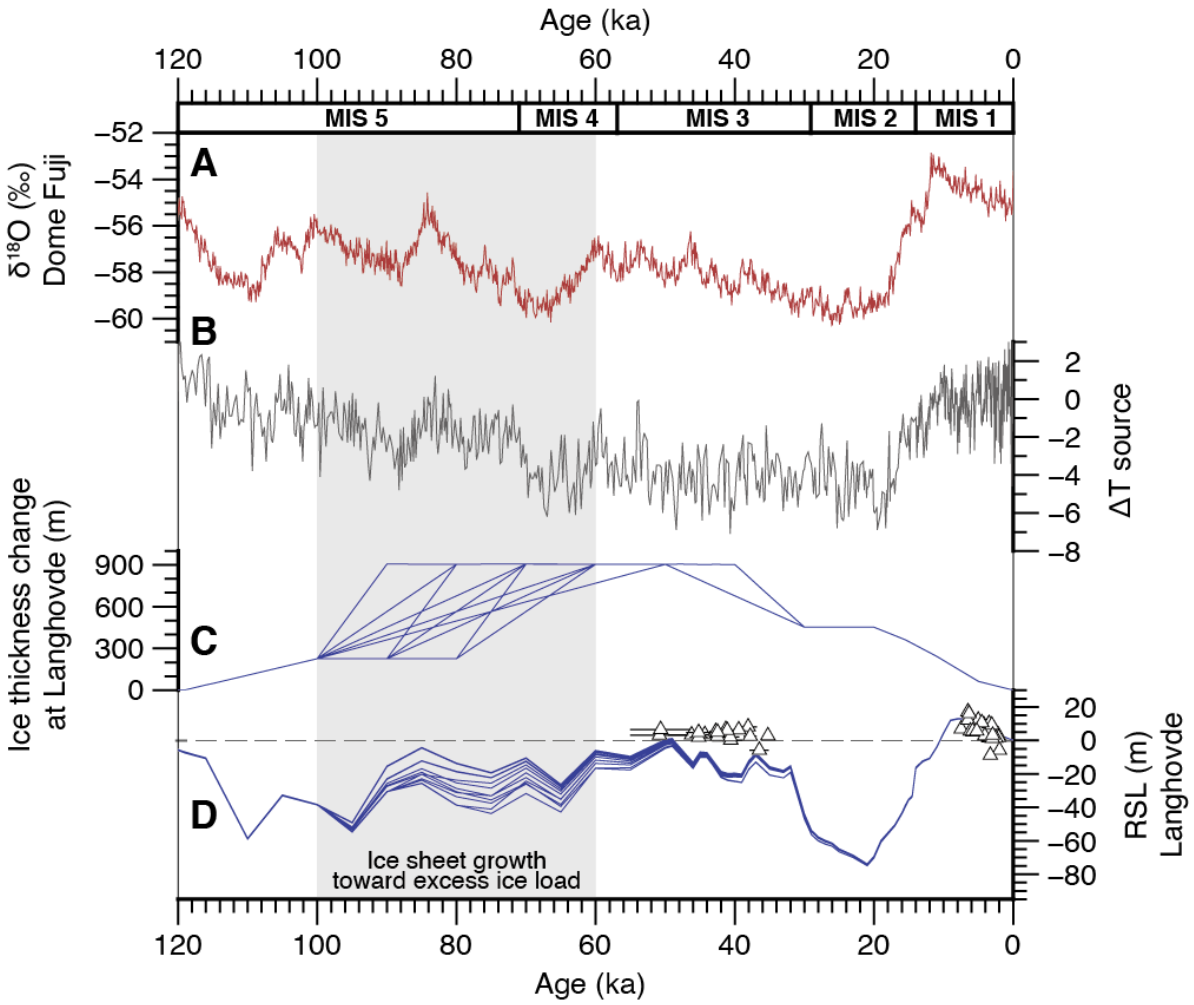
Ishiwa et al., 2021

- Excess ice load before MIS 3
  -> GIA-induced predictions fit the observations.

- The fluctuation of warming and cooling periods in the Southern Ocean and Antarctica caused excess ice load.
  - Warming: enhanced precipitation
  - Cooling: reduced ice loss in coastal area



Conclusion



Ishiwa et al., 2021

- There is an offset between observations and GIA-induced predictions around 40,000 years ago (MIS 3: Marine Isotope Stage 3) in the Indian Ocean sector of East Antarctica.
- "Small" North American Ice Sheet is insufficient to explain MIS 3 sea-level observations.
- Excess ice loading (not only the timing of growth but also the maximum ice load) before the LGM should be needed to explain the MIS 3 sea-level observations in East Antarctica.

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https://doi.org/10.1130/G48830.1

Manuscript received 17 January 2021
Revised manuscript received 10 April 2021
Manuscript accepted 13 April 2021

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