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Hysteresis and orbital pacing of the early Cenozoic Antarctic ice sheet

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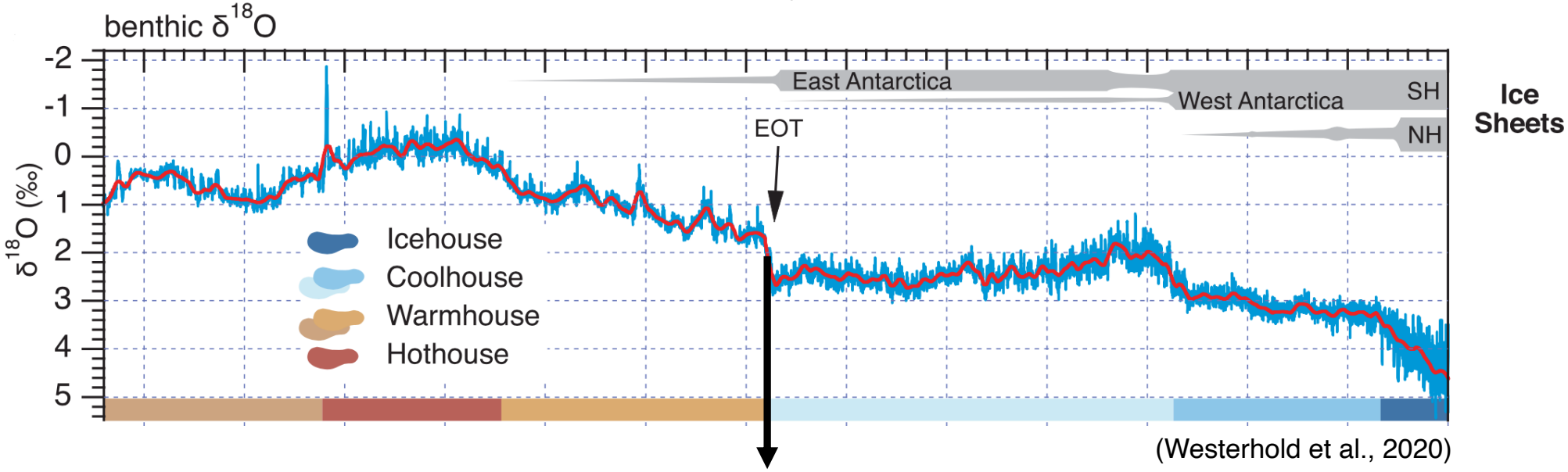
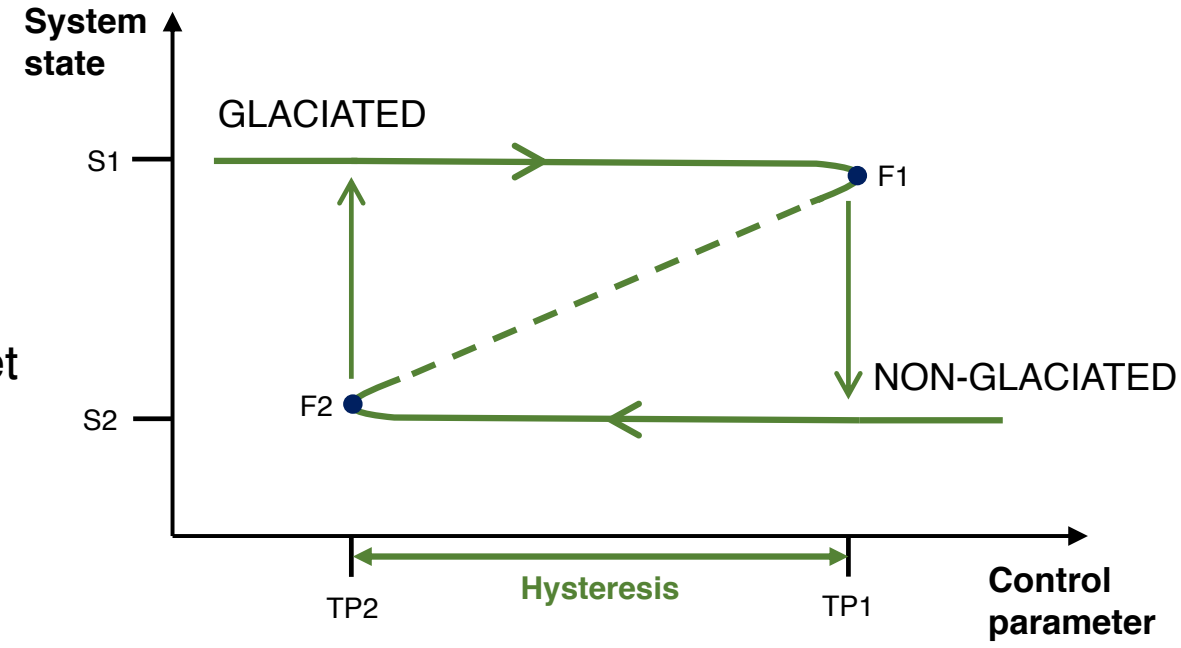
Introduction



- Antarctic ice sheet growth at EOT ~34 Ma ago
  - → Large excursion in the benthic $\delta^{18}O$ record
  - → Offshore ice-rafted debris
  - → Drop in global sea level (~50 m)
- Ephemeral late Eocene ice sheet growth (Van Breedam et al., 2022, EPSL)
- Hysteresis effect of ice sheets: state dependency on the initial conditions



Method: emulator for coupling ice sheets and atmosphere

Previous

Asynchronous coupling (e.g. DeConto and Pollard, 2003)

- Run a GCM for a few decades
- Run an ISM for a few kyr

Previous

GCM look-up table (e.g. Ladant et al., 2014; Berends et al., 2018)

- Perform a number of GCM runs (including the end members)
- Interpolate the climate to intermediate states

This study

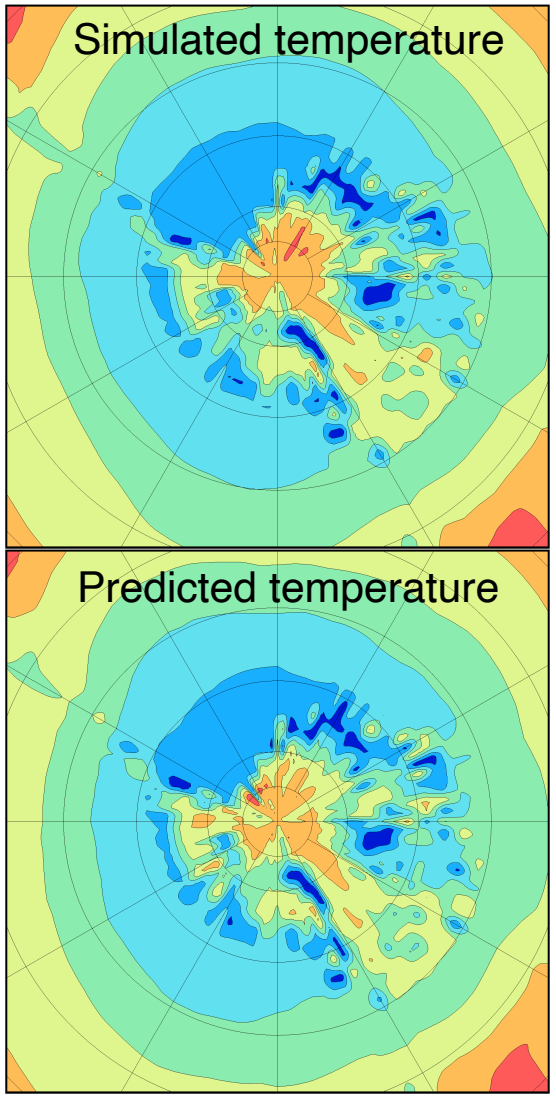
Gaussian process emulator: CLISEMv1.0 (Van Breedam et al., 2021, GMD)

- Emulate temperature and precipitation fields based on many preliminary climate model runs (100 in this case)

Coupling:

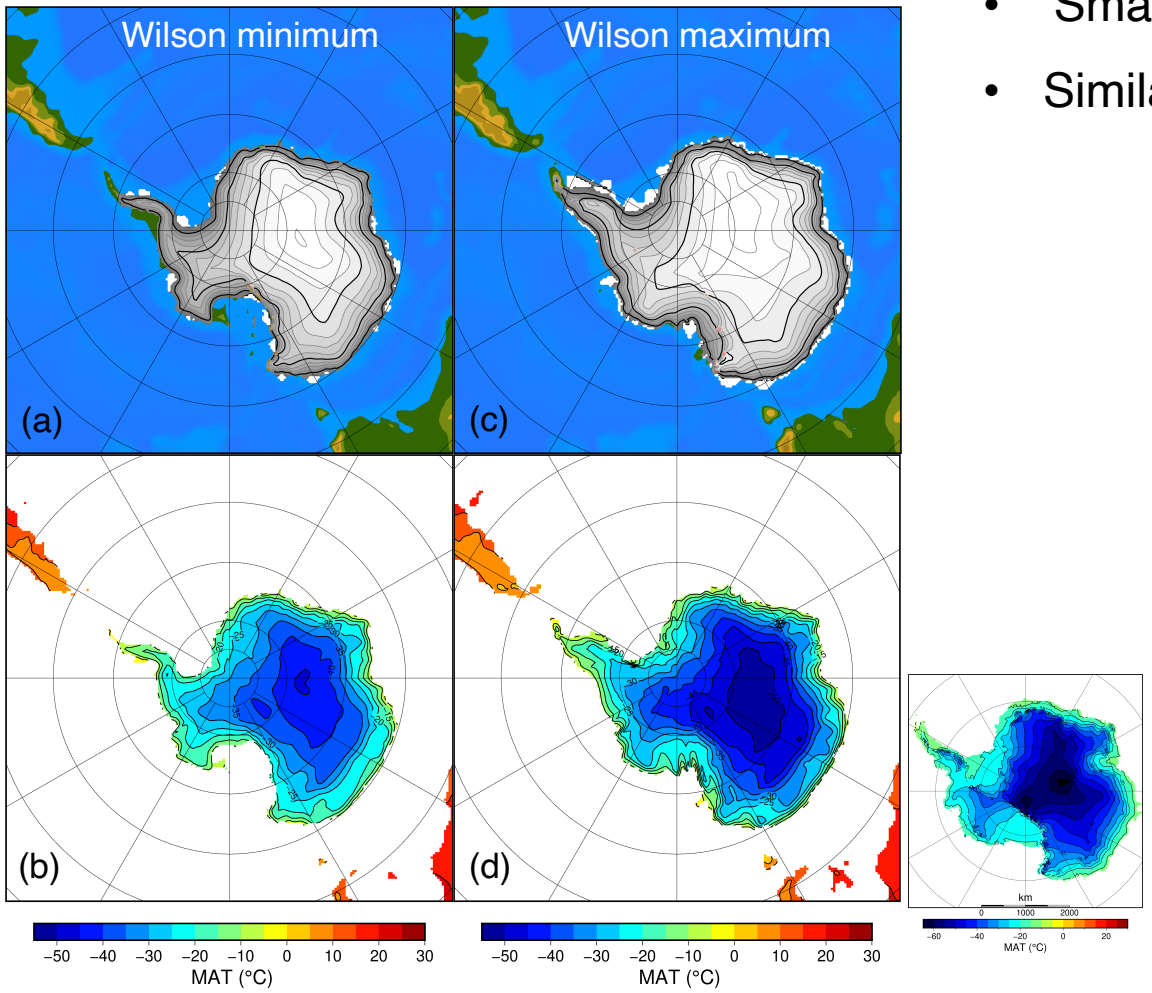
- Run the ISM from an initial GCM state
- Update ice volume and pass it to the emulator
- Calculate the climate based on the ice volume, the orbital parameters and the CO_2 value

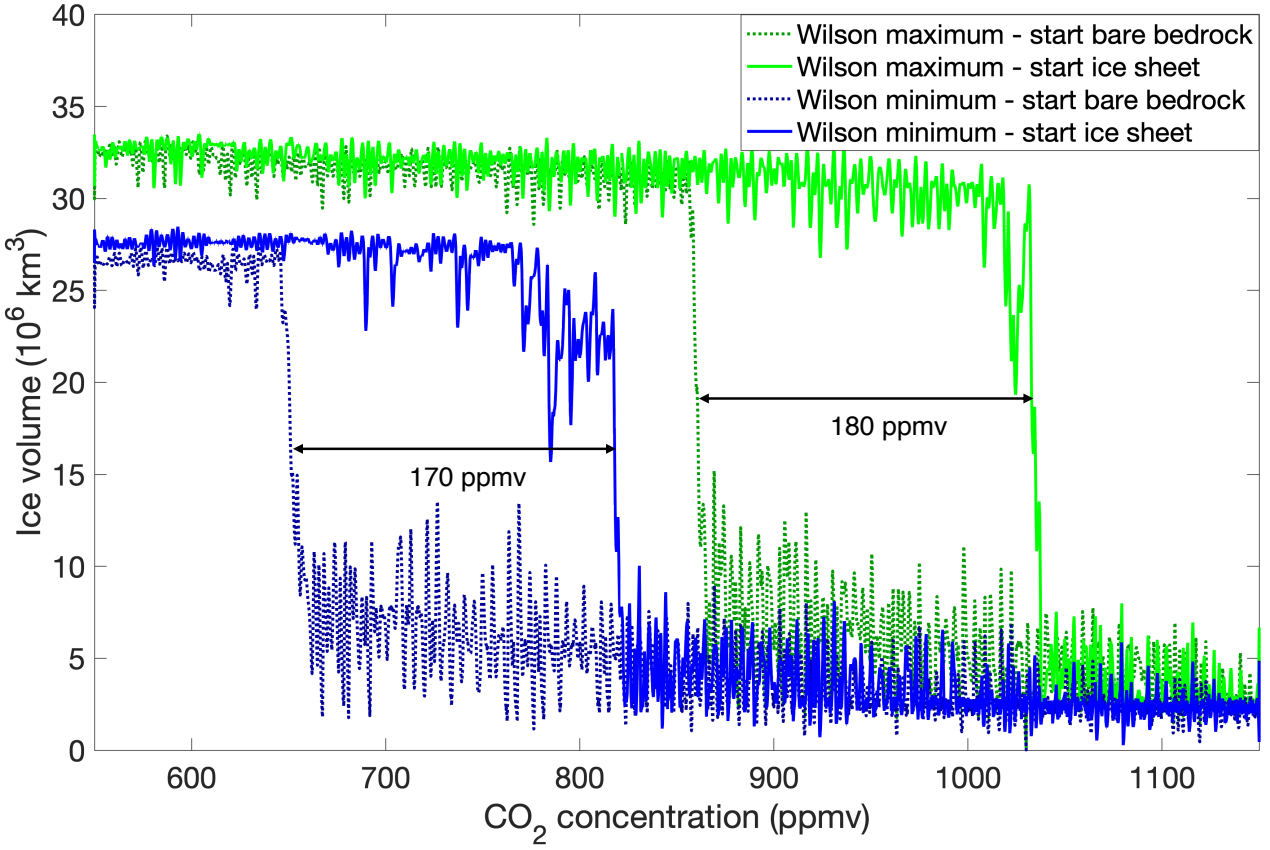
CLIMATE= F($e \sin \tilde{\omega}$, $e \cos \tilde{\omega}$, ε, CO_2, ice volume)



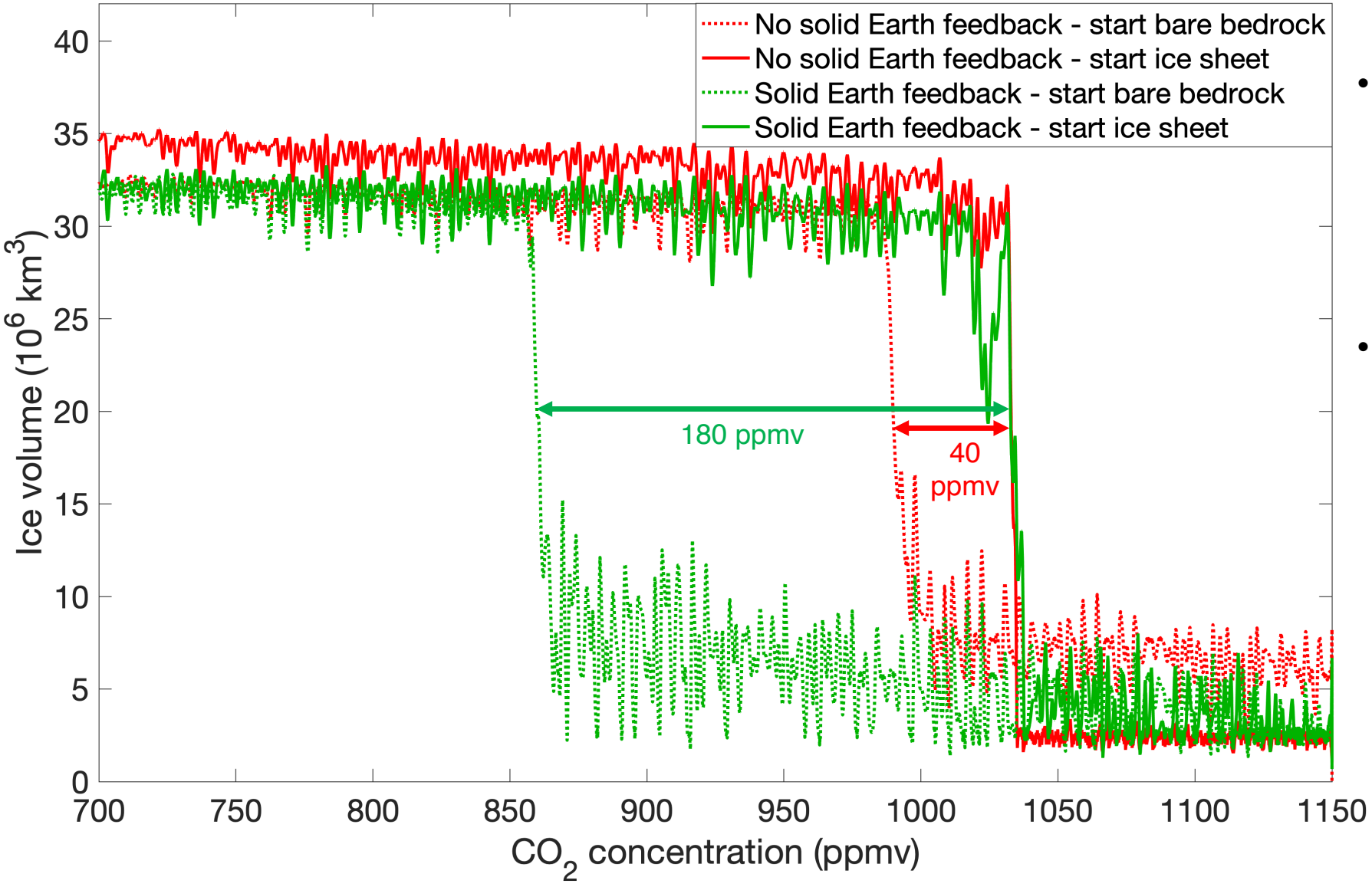
Ice sheet hysteresis: bedrock topography sets thresholds

- Minimum and maximum bedrock elevation reconstructions
- ‘Small’ and ’large’ continental-scale ice sheet
- Similar magnitude of the hysteresis effect





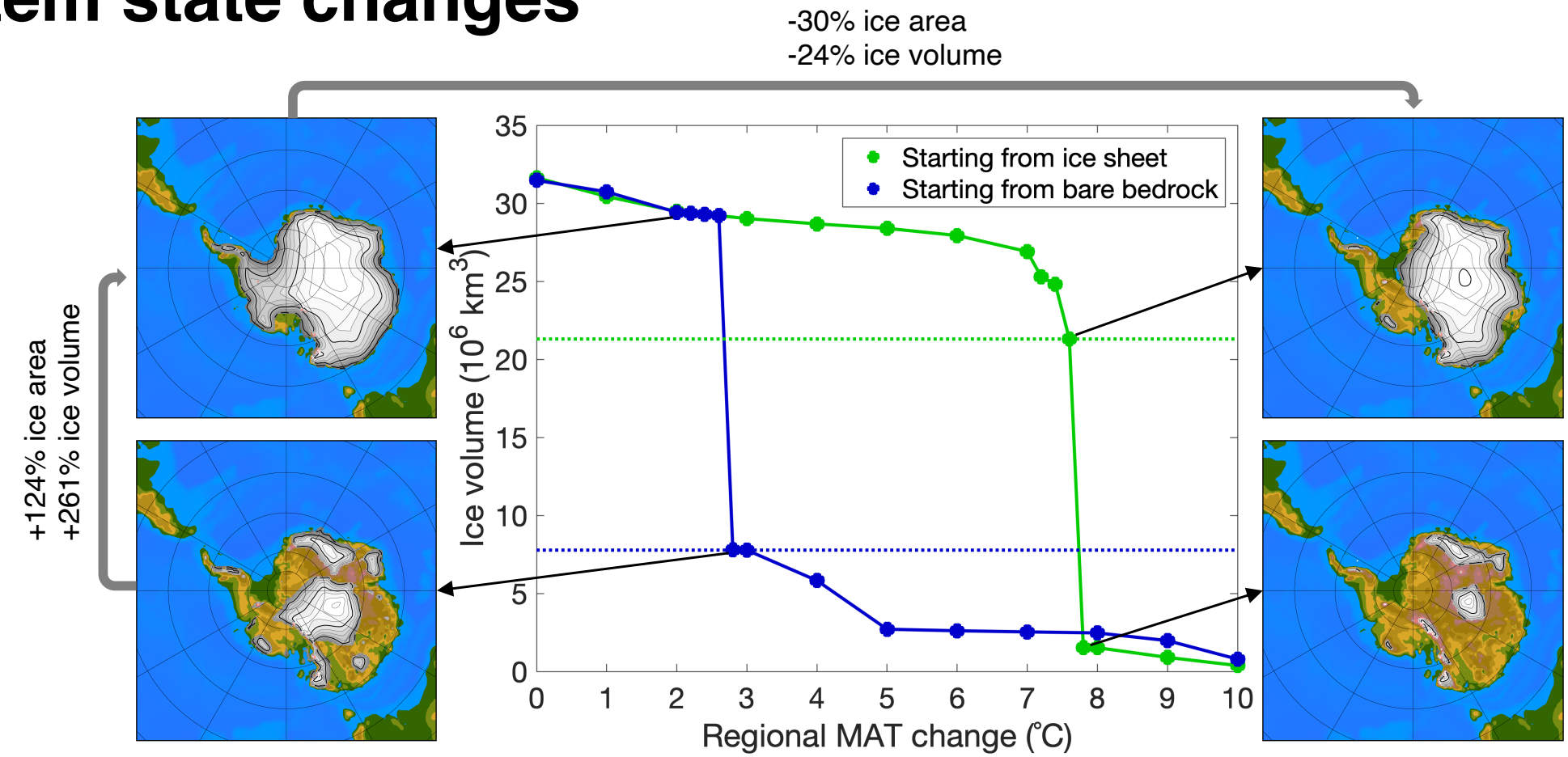
Ice sheet hysteresis: isostasy largely enhances hysteresis



- Bedrock is being depressed as the ice sheet builds-up
  → Strong influence on the CO_2 threshold to glaciation

- CO_2 threshold to deglaciation is similar
  → Strong influence on the magnitude of the hysteresis effect

Ice sheet hysteresis: albedo feedback enhances rapid system state changes



- Early Cenozoic bedrock topography – pre-industrial forcing
- Very sharp ice volume decline when the ice sheet shrinks with about 1/3 of its area
- Very sharp ice volume increase when the Antarctic continent is ice-covered for about 1/3 of the total area

Conclusions

- Investigate the thresholds (tipping points) to Antarctic ice sheet growth and decline

	GLACIATION	DEGLACIATION
TOPOGRAPHY	• Higher bedrock enhances glaciation	• Higher topography (high bedrock) delays deglaciation
ISOSTASY	• Delays glaciation	• Very limited effect on deglaciation
ALBEDO	• Enhances glaciation • Effective when ice covers ~30% of the total area	• Enhances deglaciation • Effective when ice area has decreased with ~30%