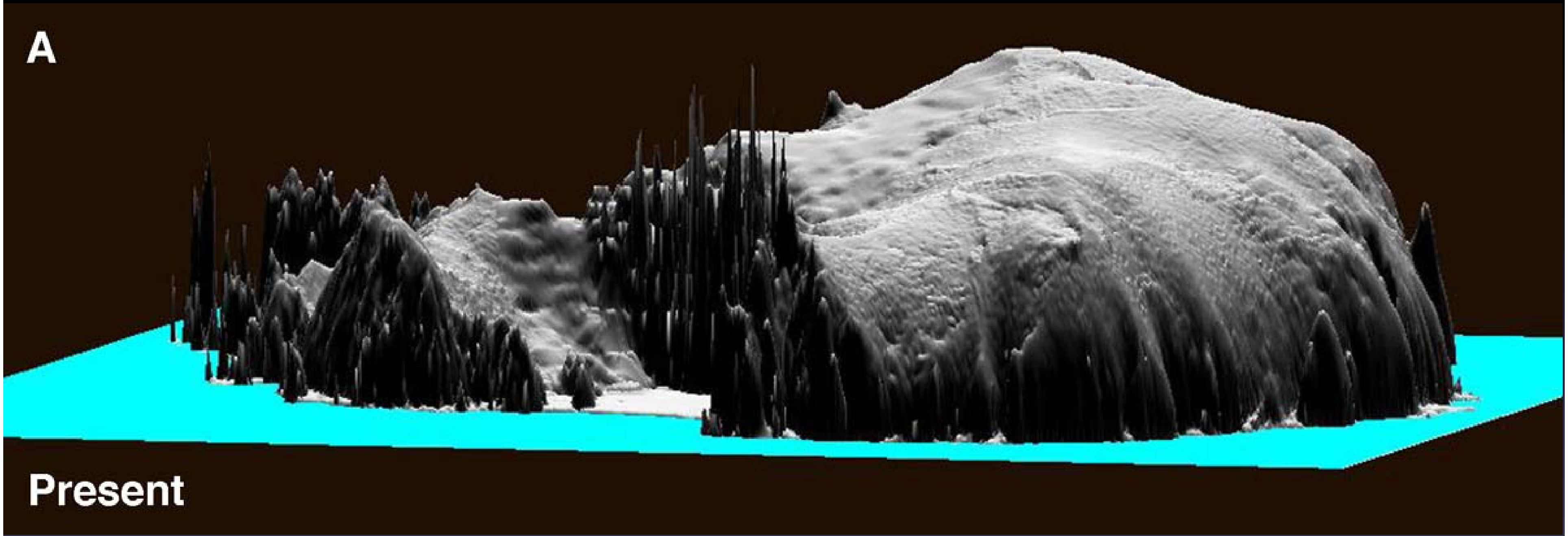
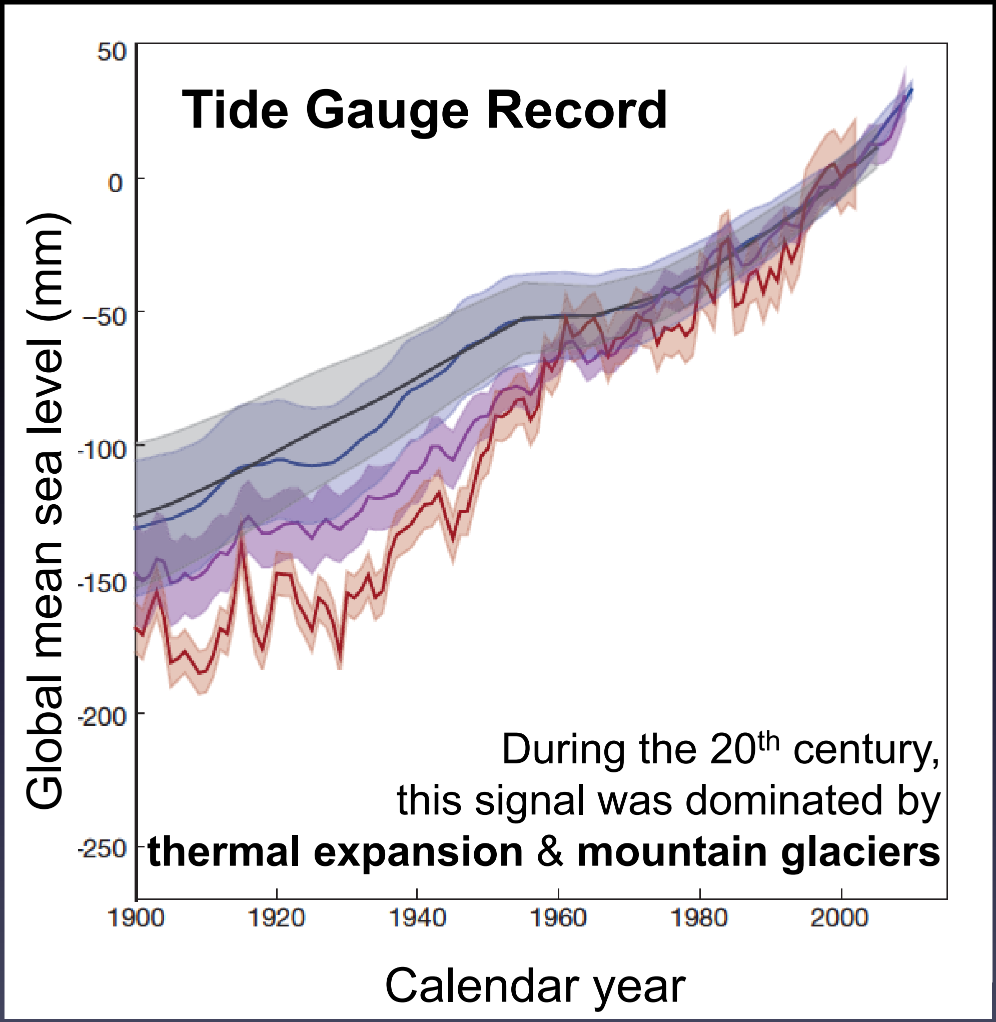
New perspectives on “old” data: What the earth’s past tells us about future sea-level rise



Bindschadler, *Science*, 1998

Andrea Dutton
Department of Geological Sciences
University of Florida

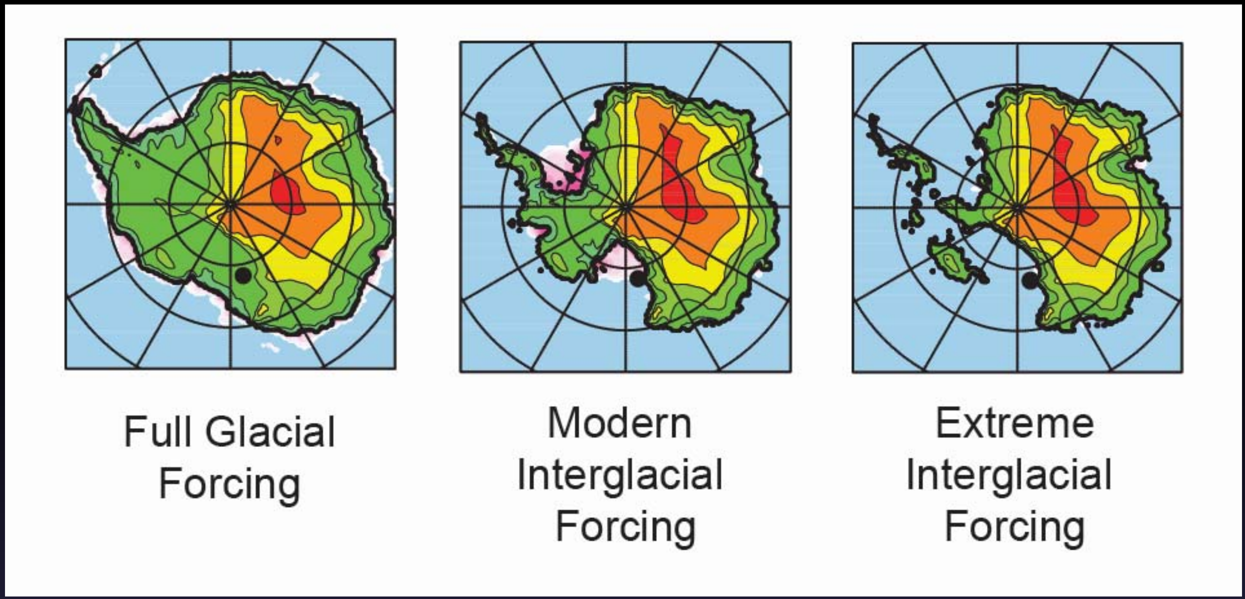
Historical record of sea-level rise



Hay et al. (2015) *Nature*

- Mass loss from the polar ice sheets is expected to exceed other contributions to GMSL rise under future warming.
- Retreat and/or collapse of polar ice sheets during past warm periods can inform future projections of ice sheet response and sea-level rise.

Fundamental Questions

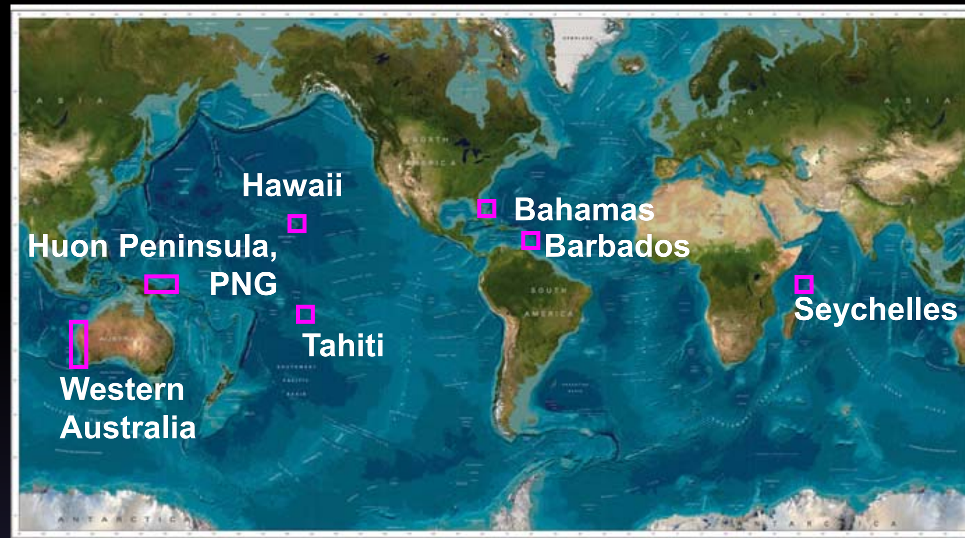


Pollard & DeConto (2009) *Nature*

- **Did one or more sectors of the Antarctic ice sheet collapse during the Last Interglacial (LIG)?**
- **If so, when (and how quickly) did this contribution occur?**

Fossil Corals Record Past Position of Sea Level

Location of some important fossil coral reefs that are used to reconstruct sea level history →



Map modified from the GEBCO world map, http://www.gebco.net

Corals live near the sea surface & can be dated by measuring U & Th isotopes

Last Interglacial Fossil Reef (+3.5m)
Western Australia

Last Interglacial Field Sites

Location of field sites with fossil coral reefs that we are actively researching to reconstruct: →

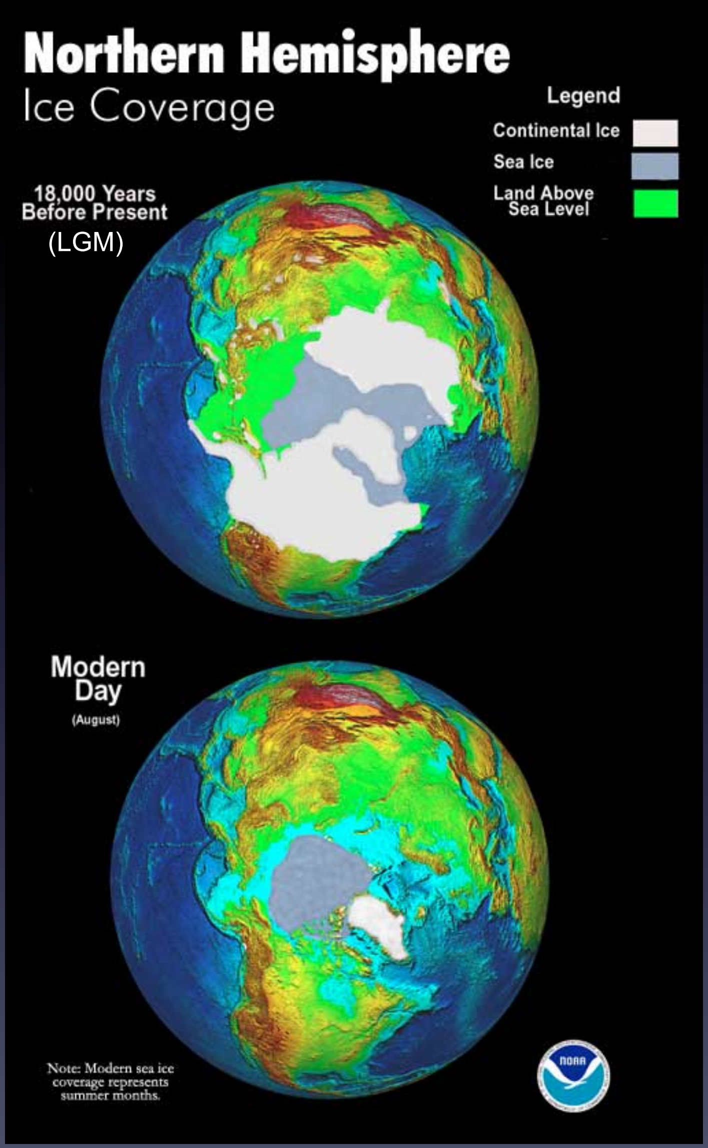
(1) Peak sea level

Seychelles & Australia

(2) Rapid jumps or oscillations in sea level during the interglacial

all sites

(1) Glacial isostatic adjustment (GIA)



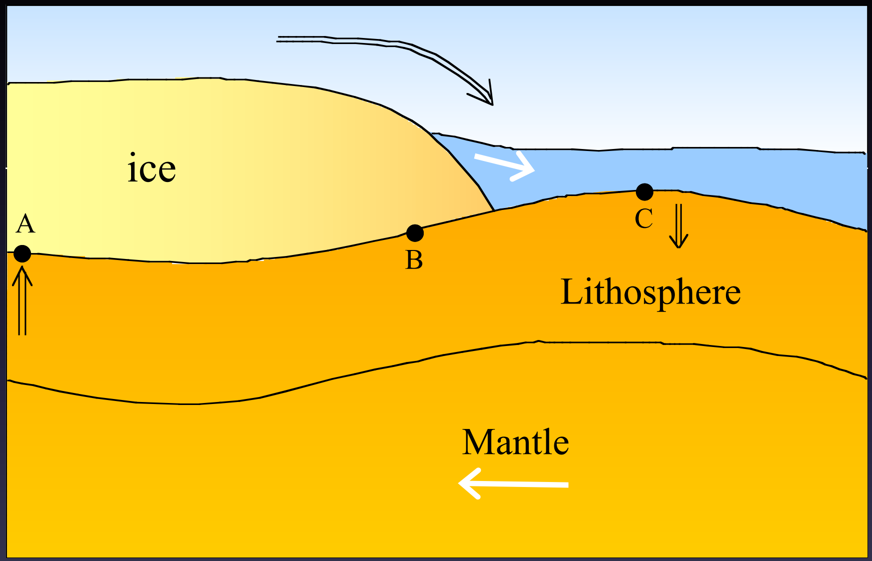
Processes that contribute to the sea level signal on glacial-interglacial timescales

(1) The "eustatic" sea level (GMSL) signal that is a function of the mass-transfer between the ice sheets and the oceans

(2) The response of the solid Earth and gravity field to this mass exchange (GIA).

What is Glacial Isostatic Adjustment (GIA)?

Perturbations to the Earth's gravity field and solid surface that cause the total (observable) sea-level change to depart from the global mean sea level curve



- Solid Earth deformation
- Gravitational component
- Rotational component

Eustatic sea level (GMSL) is not a directly measurable quantity and so must be estimated by subtracting a model-derived estimate of non-eustatic contributions from observations. ***…refer to Milne & Mitrovica (2008) QSR***

Sea-level rise due to polar ice-sheet mass loss during past warm periods

Andrea Dutton, Anders Carlson, Antony Long, Glenn Milne, Peter Clark, Rob DeConto, Ben Horton, Stefan Rahmstorf, Maureen Raymo

PALSEA 2

Dutton et al. (2015) *Science*, 349, doi:10.1126/science.aaa4019

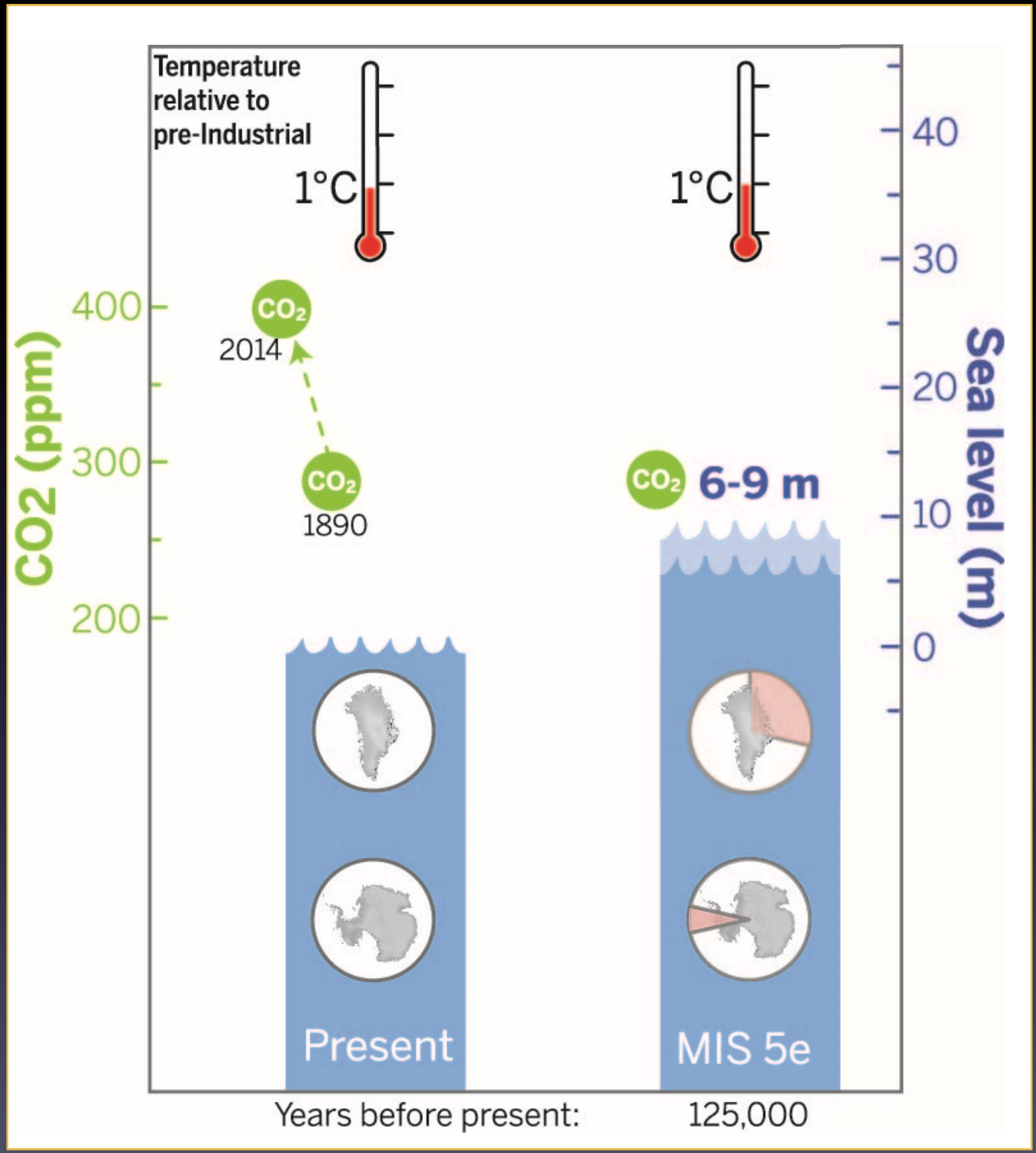
Focus of PALSEA 2

To understand the **magnitudes, rates & sources** of sea-level rise during past warm periods

PAGES PAST GLOBAL CHANGES

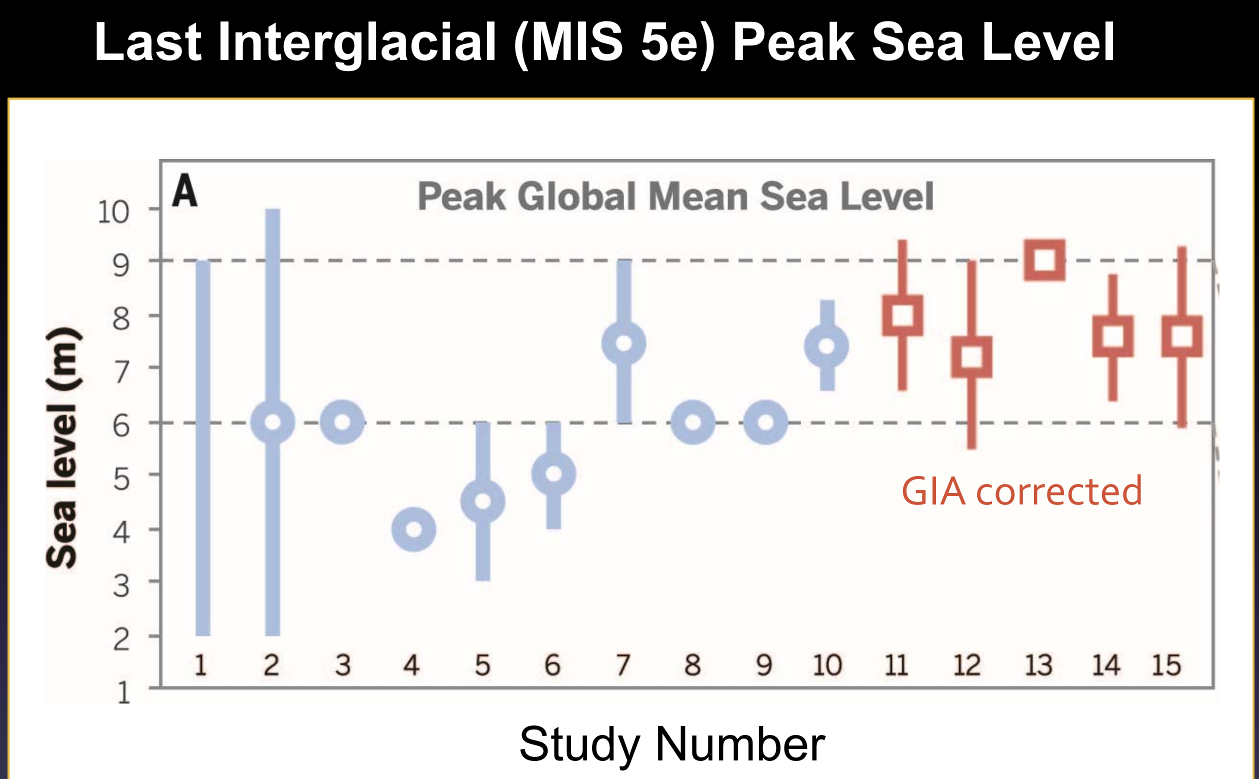
INQUA International Union for Quaternary Research

Conclusions for Last Interglacial period (~125,000 yrs ago)



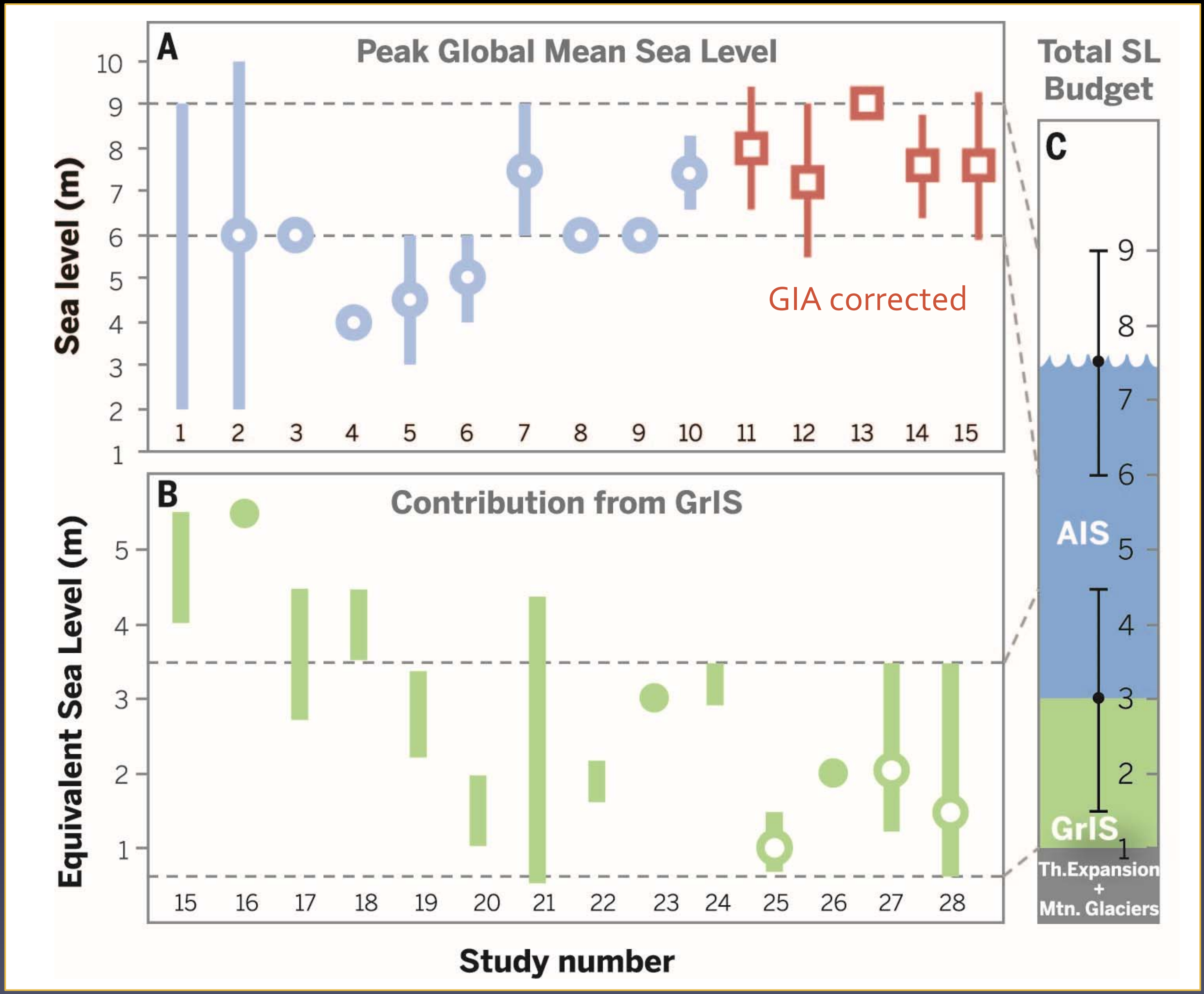
Dutton et al. (2015) *Science*

Magnitude of peak sea-level rise during Last Interglacial



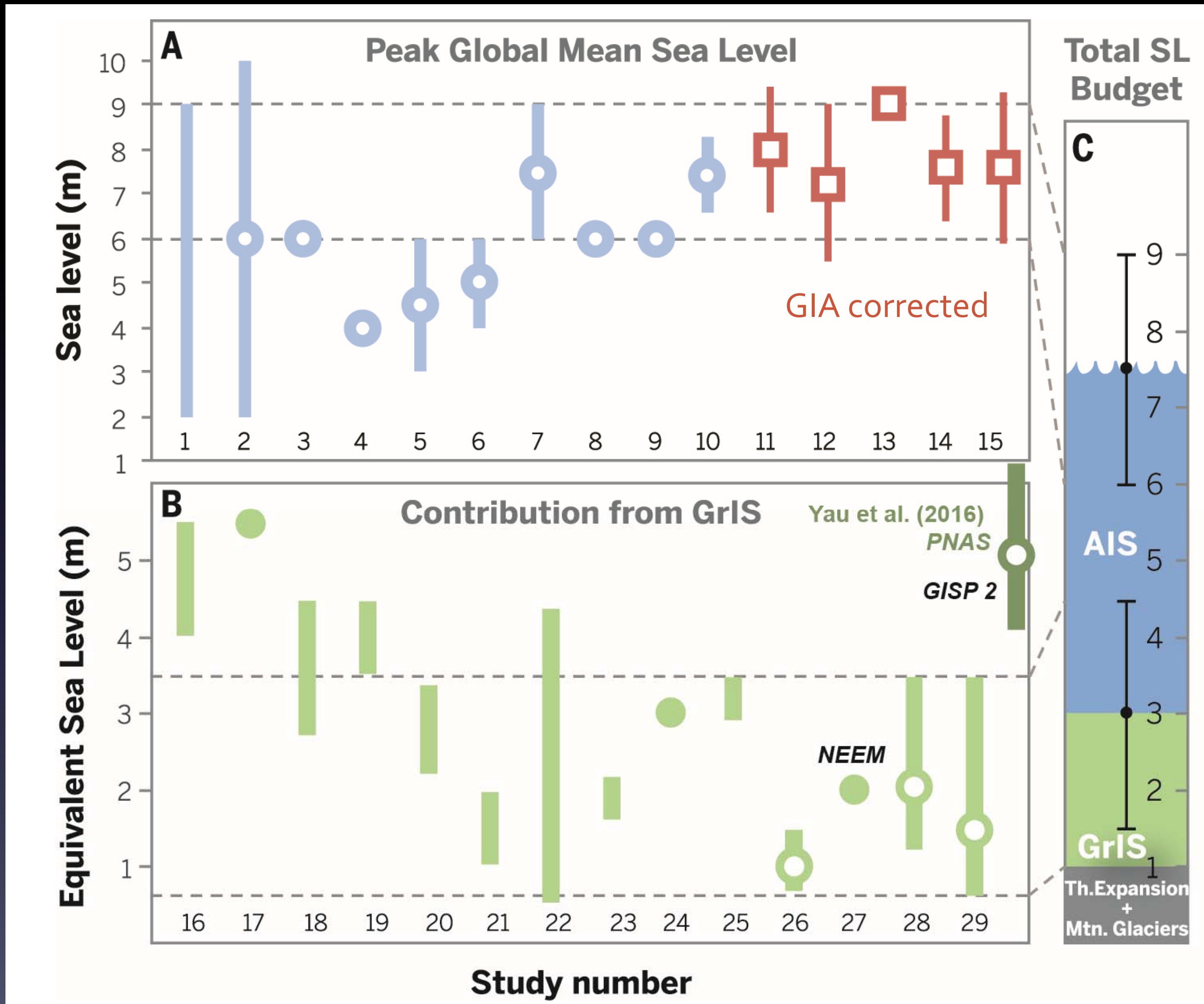
Modified from Dutton et al. (2015) *Science*

Last Interglacial Peak Sea Level: Magnitude and Budget



Modified from Dutton et al. (2015) *Science*

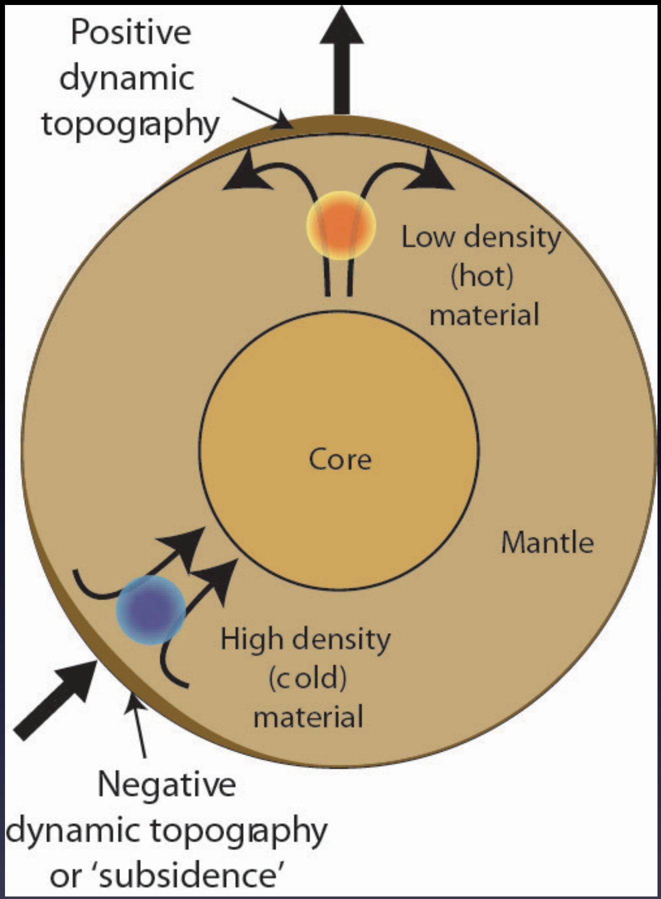
Last Interglacial Peak Sea Level: Magnitude and Budget



Dynamic topography

- Mantle flow drives significant vertical motions of the crust across the entire surface of the planet

- A significant proportion of Earth's topography results from the viscous stresses created by flow within the underlying mantle, rather than by the moving plates

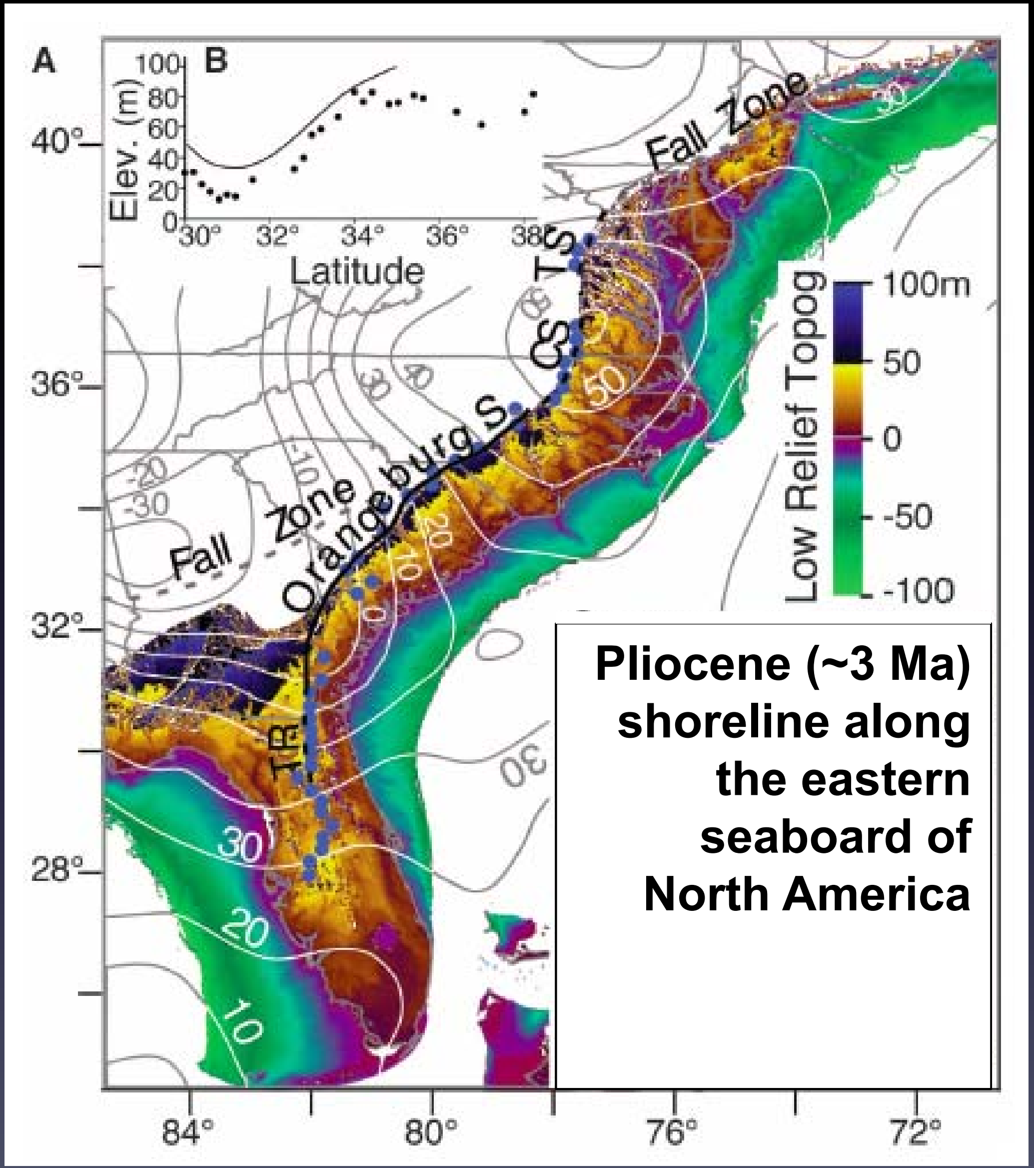


Braun (2010) *Nature Geoscience*

Dynamic topography

- Dynamic topography is capable of inducing 10s of meters of vertical motion over several million years.

- Easily could induce a few meters of change on the 100,000 year timescale.



Rowley et al. (2013) *Science*

Dynamic topography and the Last Interglacial (LIG)

Work done in collaboration with Alessandro Forte (UF)

- To what extent is dynamic topography important to consider in reconstructions of Last Interglacial sea levels?
  - Potential magnitude of vertical motion?
  - What is the spatial variability in this signal?

Australia

- Can dynamic topography help to reconcile existing differences between far-field, tectonically stable sites that have been GIA-corrected?

Dynamic Topography Conclusions

- Magnitude of surface elevation change due to dynamic topography can easily be on the order of several meters since the Last Interglacial period.

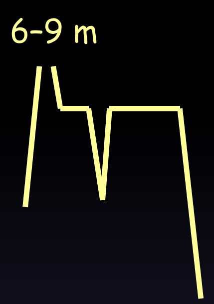
- Dynamic topography has been previously thought to only significantly affect RSL estimates on longer timescales but needs to be considered on shorter timescales.

Interpretation of Antarctic Contribution?

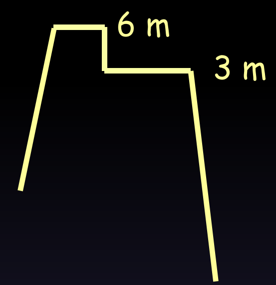
- At a first pass, dynamic topography could increase our uncertainty about peak sea level and hence the magnitude of Antarctic contribution. *However*, our preliminary results suggest that some of the key far-field sites are consistently predicted to have subsided due to dynamic topography since the LIG, meaning that our reconstructions have potentially underestimated peak sea levels by ~1 to 3 m.

Evidence for Antarctic contribution to LIG highstand

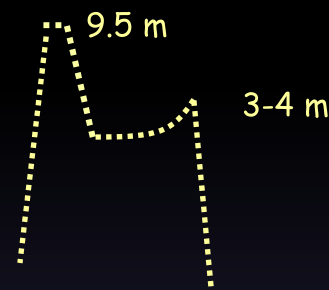
A late, rapid peak?



Global analysis
Hearty et al. (2007) *QSR*



Yucatan
Blanchon et al. (2009) *Nature*



Western Australia
O'Leary et al. (2013) *Nature Geosci.*

- Published interpretations of a late, rapid peak (~118 to 121 ka) at several sites has led to a hypothesis that the West Antarctic ice sheet collapsed at the end of the Last Interglacial.

- Consideration of local GIA, tectonics, sedimentary, and geochronological evidence leads us to conclude that there is no robust evidence for a late, rapid peak in GMSL but that there was an ephemeral fall followed by a rapid rise earlier in the interglacial (~125-126 ka).

Work done in collaboration with J. Webster and G. Eberli

Antarctic contribution @125-126 ka?

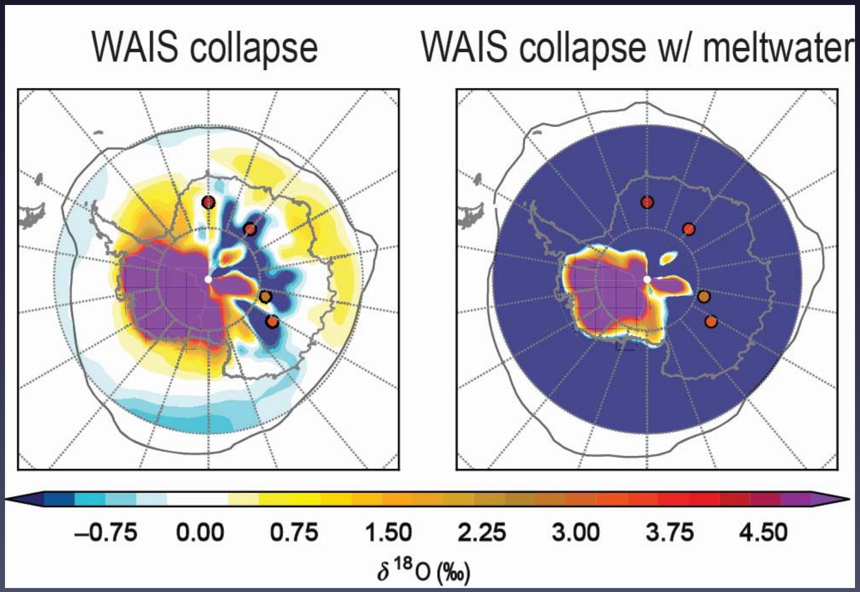
- There is evidence globally that supports a rapid change in sea level at ~125-126 ka, here termed the mid-LIG sea level oscillation.

- Distinct unconformities observed in fossil reefs, evidence of exposure, erosional surfaces and/or regression at numerous sites.

Antarctic contribution @125-126 ka?

Holloway et al. (2016) *Nature Communications*

"Our results strongly support the conclusion that the WAIS was present at 128 ka…we suggest that a large sea ice retreat best explains the early isotope maximum and a subsequent retreat of the WAIS, and sea ice build-up could provide an explanation for the observed pattern of isotope anomalies following the LIG maximum."



Holloway et al. (2016) *Nature Communications*

Fundamental Questions

- **Did one or more sectors of the Antarctic ice sheet collapse during the Last Interglacial (LIG)?**

Our best estimates of GMSL that account for GIA processes fall in the range of 6-9 m above present. Based on our present understanding of Greenland ice sheet mass loss, this would seem to require some contribution from Antarctica.

Quantification of the effects of dynamic topography is critical to this conclusion. There remains considerable uncertainty in the dynamic topography calculations, hence this casts uncertainty on estimates of peak sea level from observational records in coastal regions.

The answer to this question is still open to debate.

Fundamental Questions

- **If so, when (and how quickly) did this contribution occur?**

The timing of potential Antarctic contribution is still debated. Far-field records from coral reefs indicate potential for rapid sea-level rise very early (at or before the onset of the highstand at ~129 ka) or in the middle of the highstand (~125-126 ka), but not at the end.

→ **The answer to this question is still open to debate.**

There is a clear and present need for near-field evidence that can shed light on the answers to these questions.