Empirical Constraints on Future Sea Level Rise: Sea Level and Ice Sheet Dynamics During Warm Interglacial Periods

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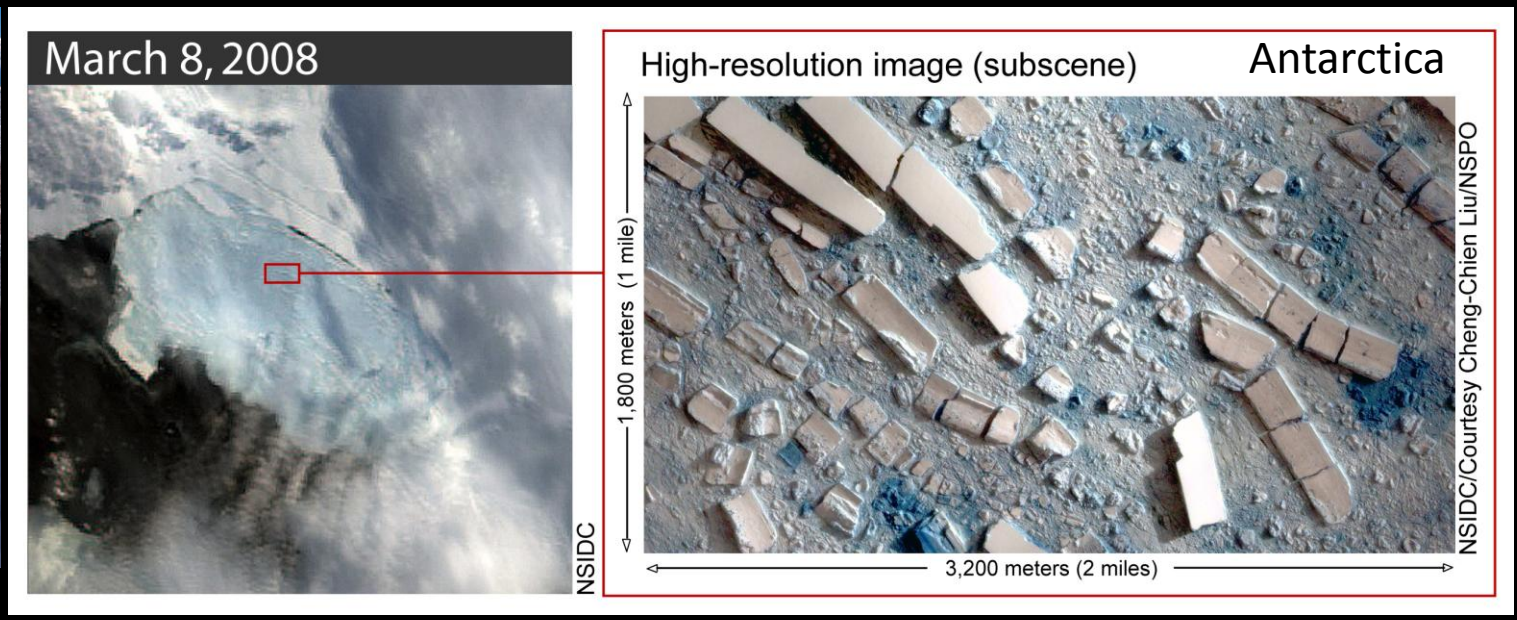
↑ Meltwater from the Greenland Ice Sheet



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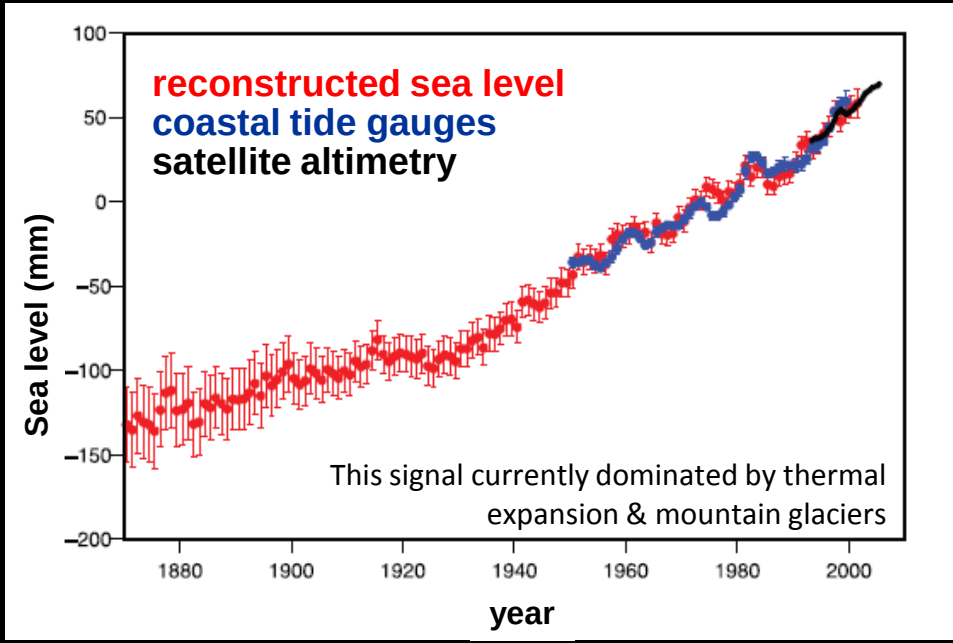
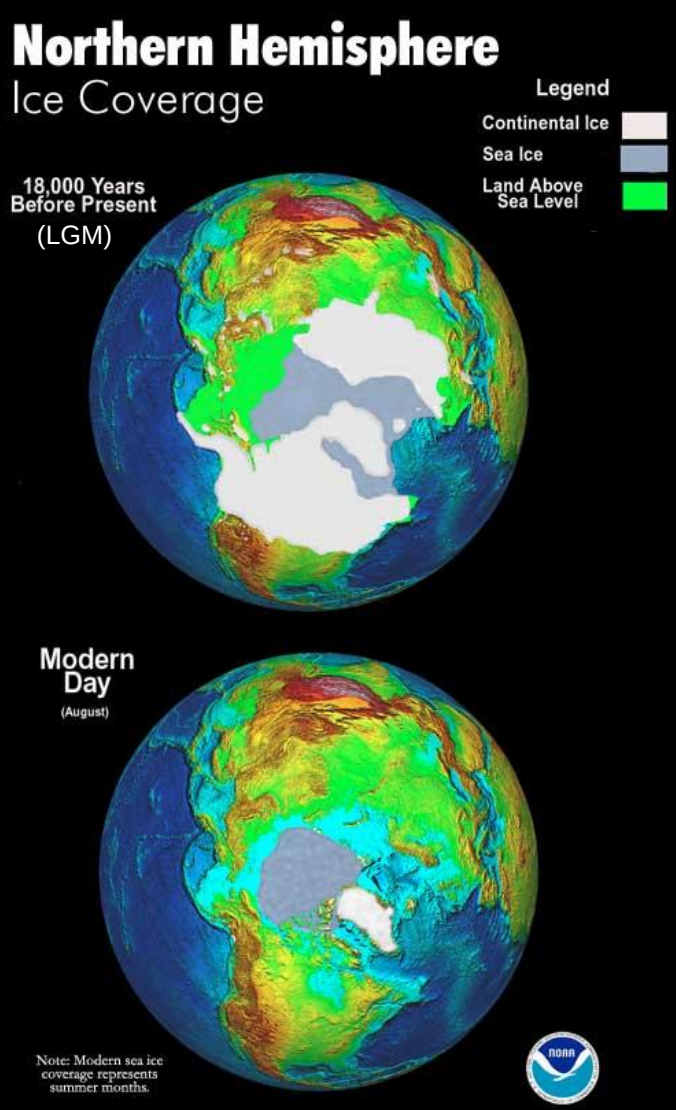
Sea Level Rise



Eustatic sea level change = globally averaged signal

Global sea level rise is NOT uniform



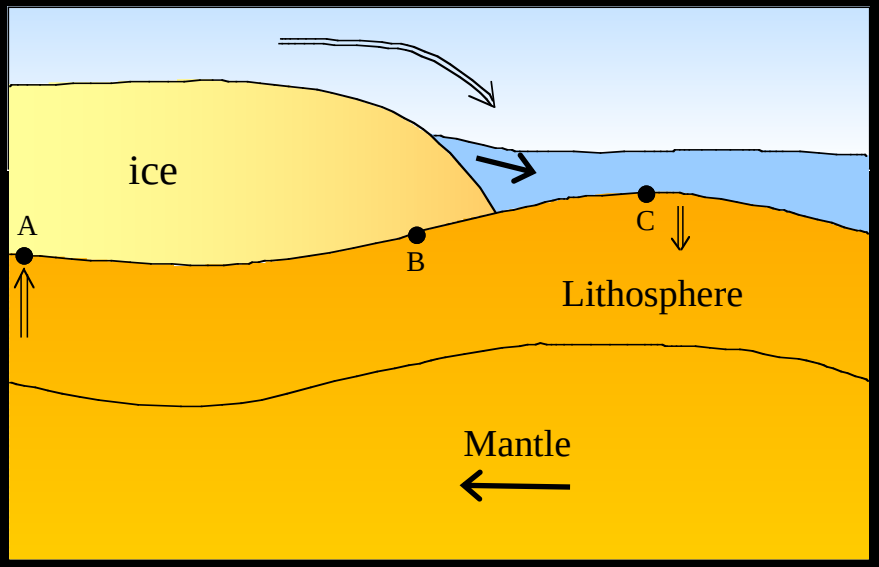
Processes that dominate the sea level signal during the Quaternary

(1) The "eustatic" sea level 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 -- sometimes called glacial isostatic adjustment (GIA), the non-eustatic component, or the isostatic component

What are isostatic effects?

Perturbations to the Earth's gravity field and solid surface associated with glacial isostatic adjustment (GIA) cause the total (observable) sea-level change to depart from the eustatic curve

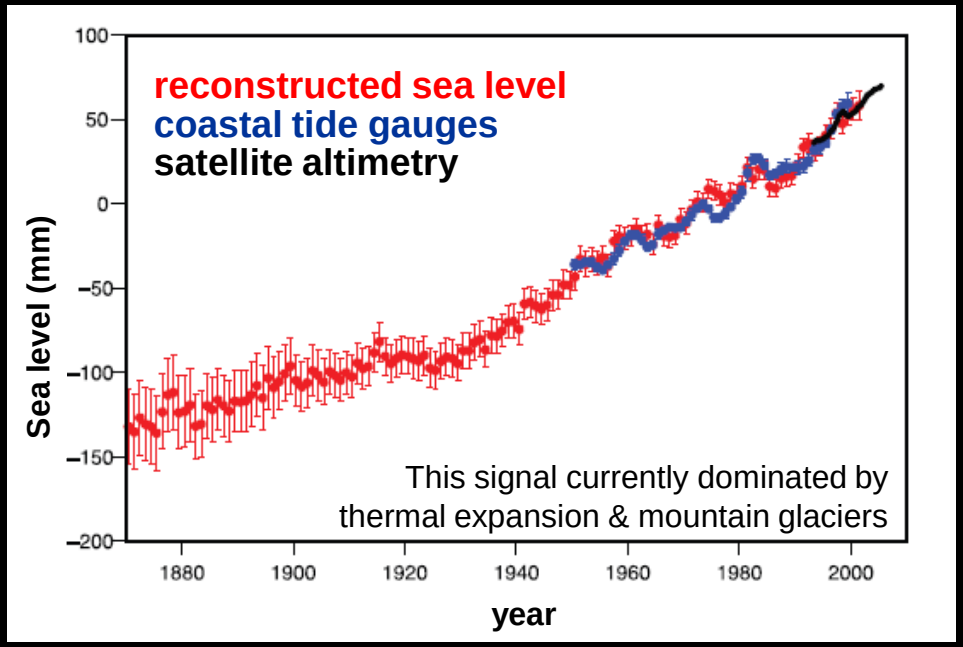


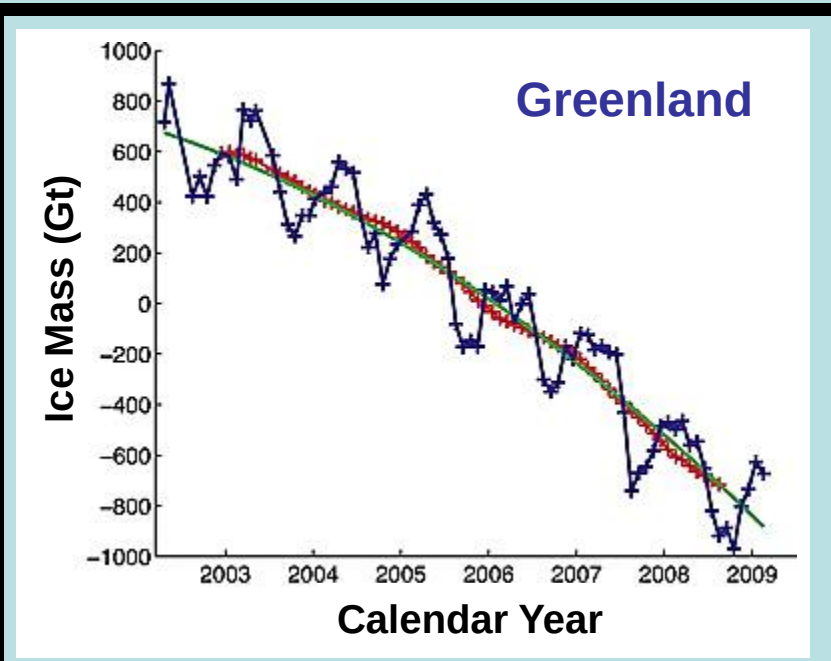
- Solid Earth deformation
- Hydro-isostatic component
- Gravitational component
- Rotational component

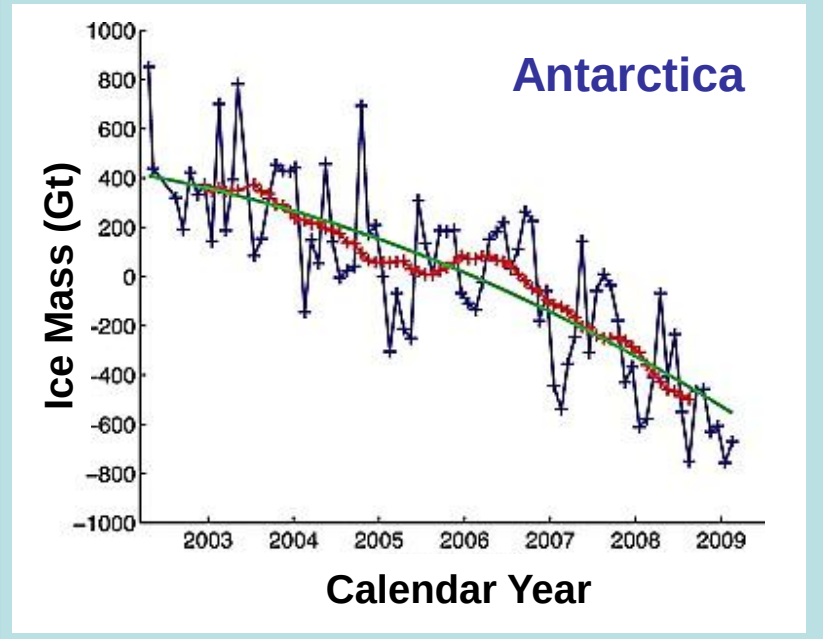
Eustatic sea level is not a directly measurable quantity and so must be estimated by subtracting a model-derived estimate of non-eustatic contributions from observations.

…refer to Milne & Mitrovica (2008) QSR

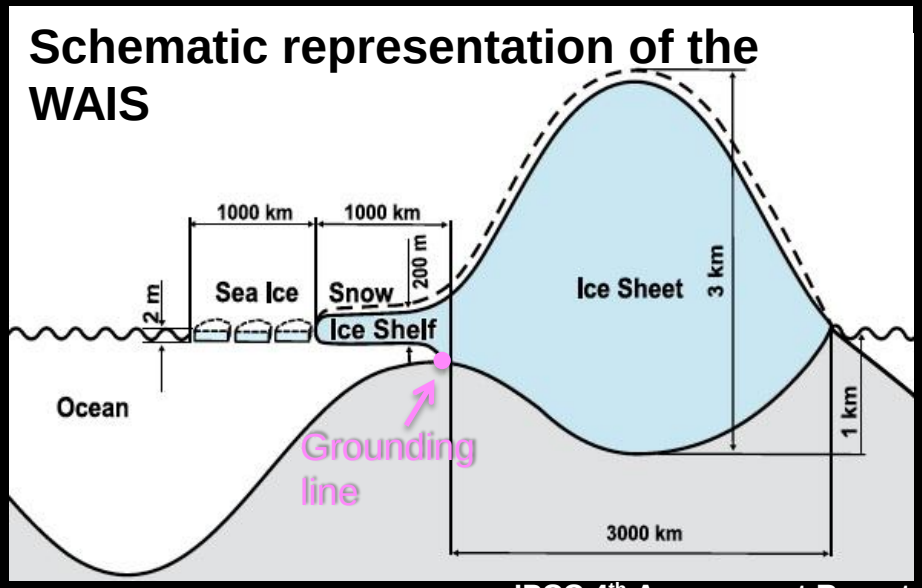
Sea Level Rise & the Role of Large Ice Sheets







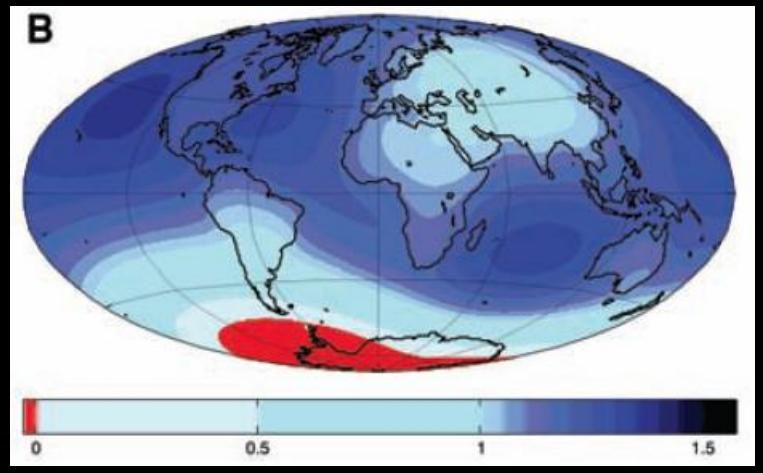
Instability of the Western Antarctic Ice Sheet



IPCC 4th Assessment Report

Marine-based sectors of the WAIS are susceptible to rapid dynamical retreat of the grounding line associated with warmer surface waters in the region…it could float if thinned sufficiently.

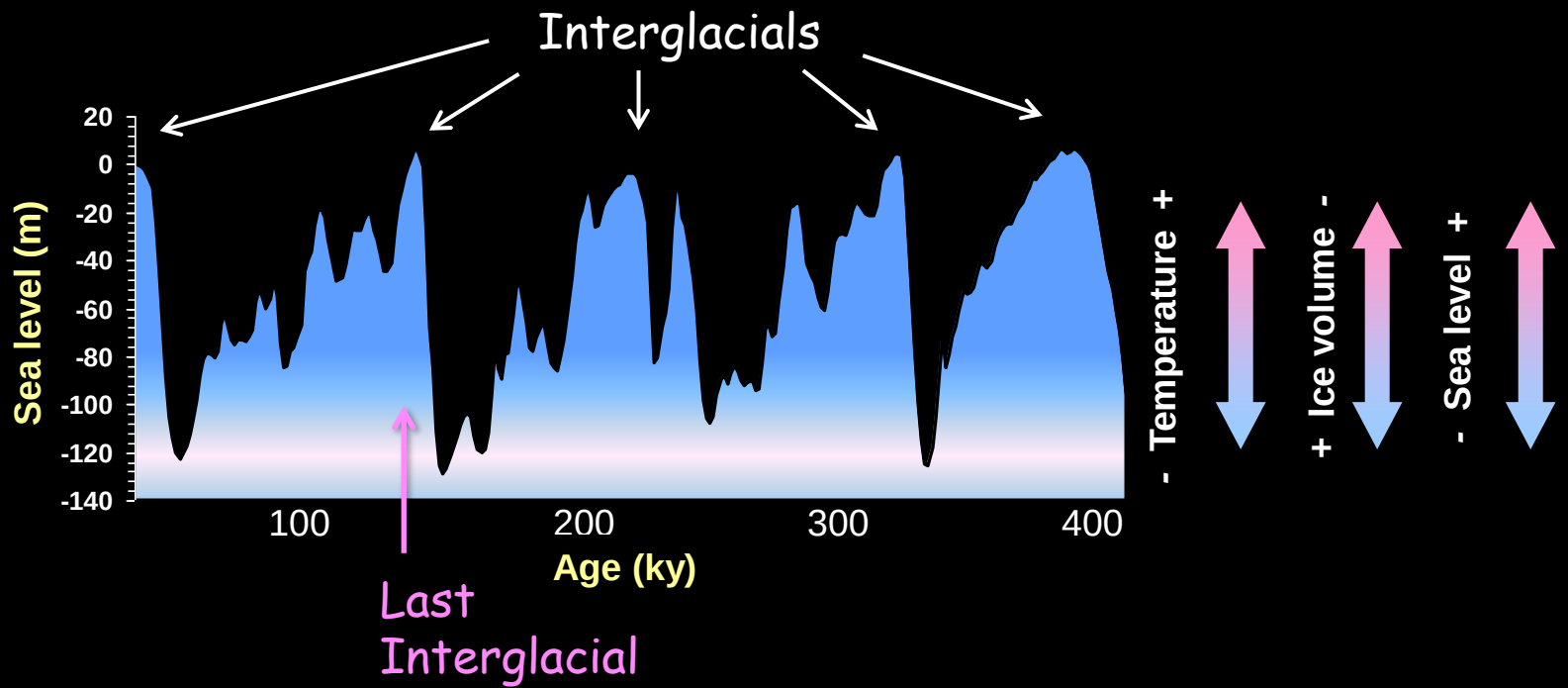
How would sea level respond to WAIS collapse?



Mitrovica et al. (2009) *Science*

IPCC AR4: Dynamic Ice Sheets…what is the upper bound?

"Further accelerations in ice flow of the kind recently observed in some Greenland outlet glaciers and West Antarctic ice streams could increase the ice sheet contributions substantially, but quantitative projections cannot be made with confidence … The state of understanding prevents a best estimate from being made."



What can we learn from studying past climate & sea level?

Maximum eustatic (global) sea level attained

– sensitivity of sea level to changes in temperature

Stability of sea level

– are warm periods characterized by rapid oscillations in sea level that reflect rapid changes in large ice sheets…Did the WAIS collapse?

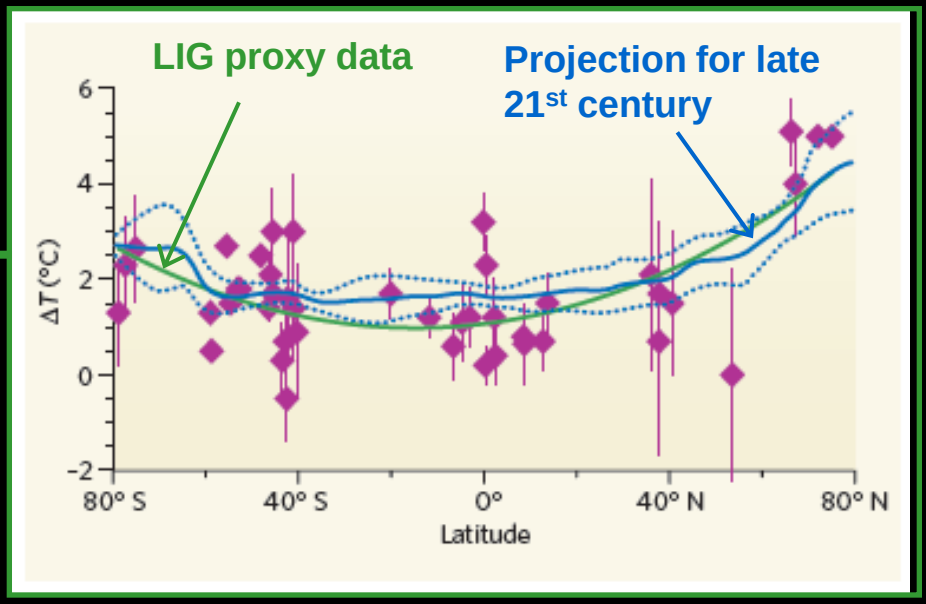
Timing and Duration of sea level highstands

– response of sea level to external triggers such as changes in solar insolation, temperature, precipitation, etc.

Why are we interested in Last Interglacial (LIG) sea levels?

~125 thousand years ago (ka)

- The LIG was globally warmer than today—and reached similar temperatures to those projected for the late 21st century

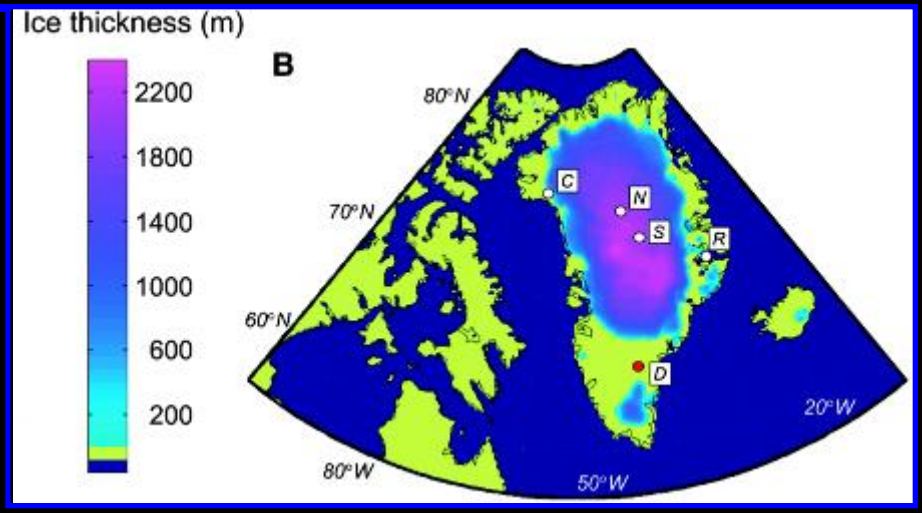


Clark & Huybers (2009) *Nature*

- Globally, LIG paleoshorelines appear to be higher than present sea level by at least several meters.

- Several publications suggest that the LIG was punctuated by multiple, rapid sea level oscillations (~ 1 to 5 meters in magnitude)

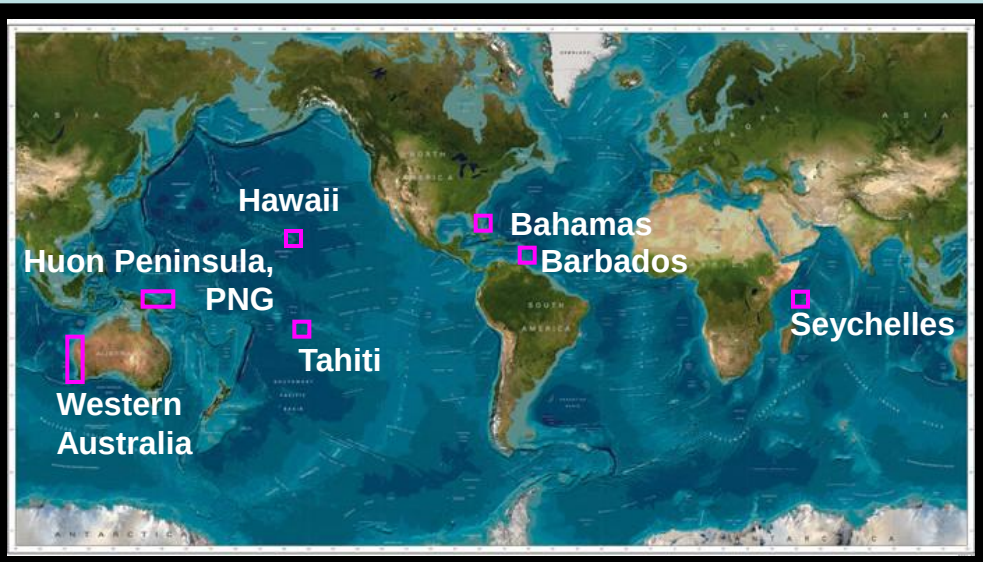
Western Antarctic Ice Sheet (WAIS) instability?



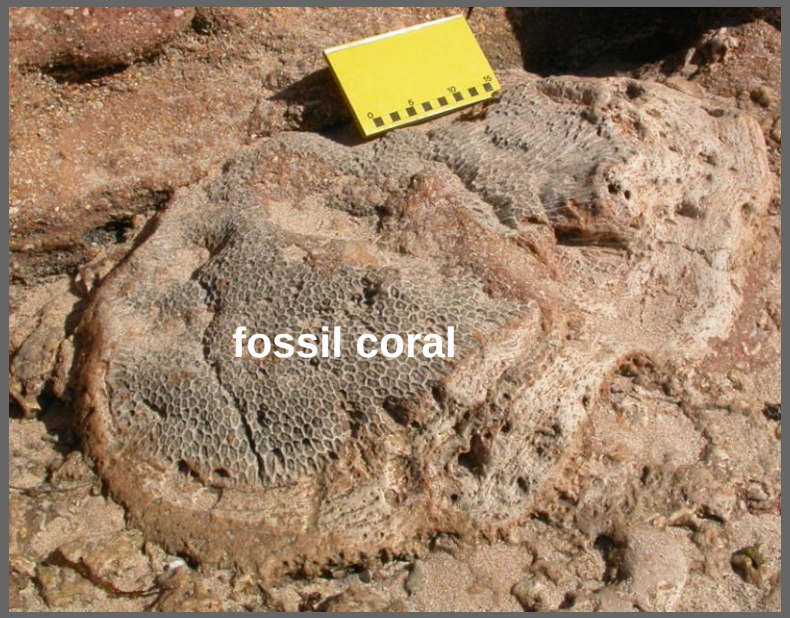
Otto-Bliesner et al. (2006) *Science*

Fossil Corals Record Past Position of Sea Level

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



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



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

Sea Level Reconstruction over the last glacial cycle

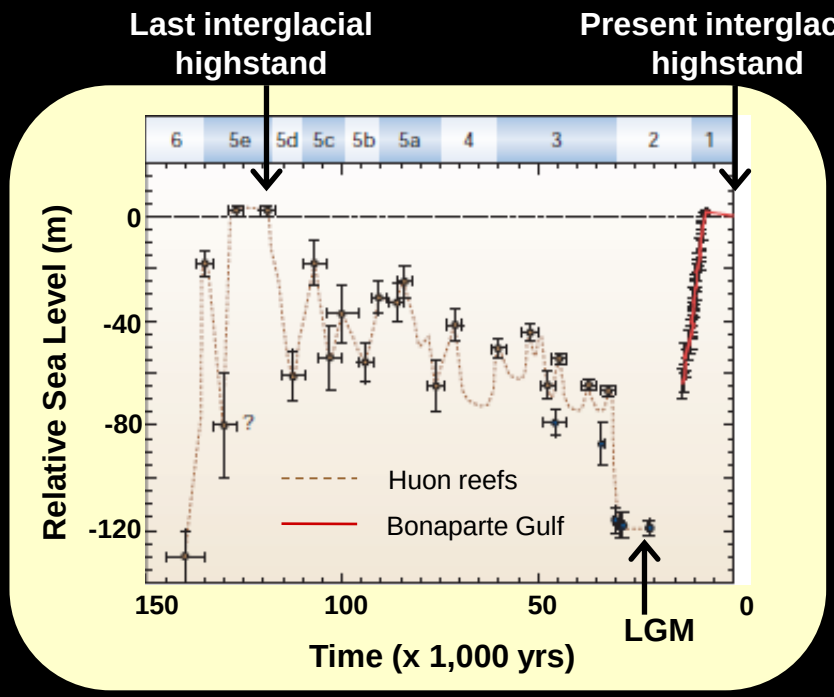


Figure modified from Lambeck et al. (2002) *Nature*

Reconstructing LIG Sea Level

My approach to understand and reconstruct LIG sea level change is 3-fold:

Fieldwork & Geochemistry (U-Th dating) ⟷ **Data Compilation** ⟷ **Isostatic Modeling (Geophysics)**

Western Australia

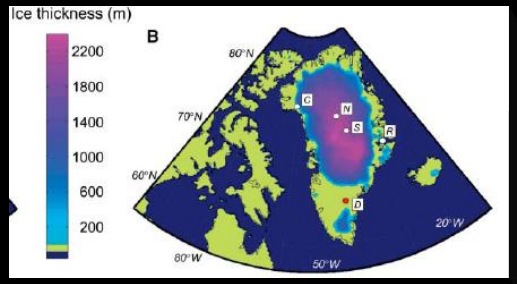
Cape Range Region

Fieldwork component:

Increase resolution of data in the far-field

Seychelles

Implications for Ice Volume During the LIG



The Greenland ice sheet (GIS) melted extensively during the last interglacial period

Koerner (1989) *Science*; Koerner & Fisher (2002) *Ann. Glac.*

Evidence from the base of ice cores

Sea-level contribution of 4 to 5.5m from the GIS is likely

Cuffey & Marshall (2000) *Nature*

GIS & other circum-Arctic ice fields likely contributed 2.2 to 3.4 m of sea-level rise within the first 3000 years of the last interglacial

Otto-Bliesner et al. (2006) *Science*

Models

Our maximum eustatic sea level estimates from these far-field sites:

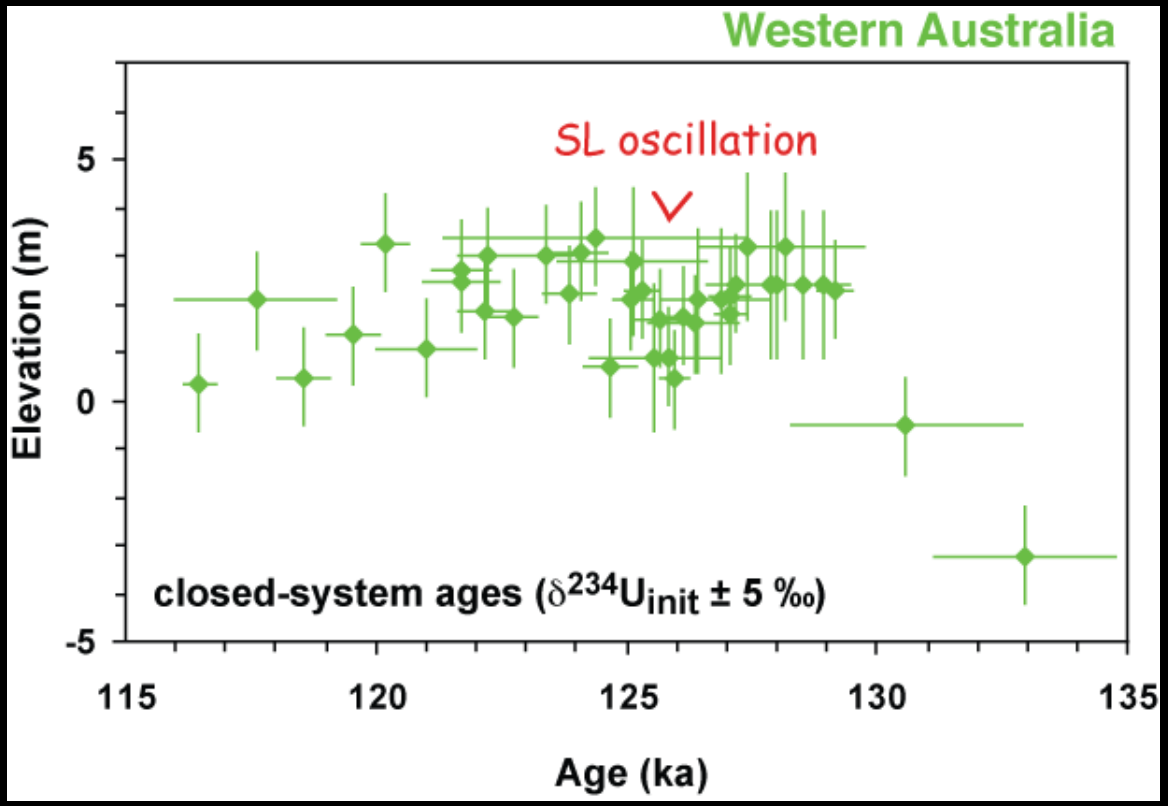
Seychelles: **+ 8 m** RSL → **~ +10 m** ESL

WA: **+ 3.5 m** RSL → **~ +6 m** ESL

** **If LIG seas were more than +4 meters above present mean sea level, then this requires a significant contribution from Antarctica.**

What about oscillations in sea level?

YES: at least one if not more sea level oscillations occurred during the LIG



Rates of sea level change are ~1 – 2 m/1000 yrs
(10 cm/100 yrs)

Summary of Conclusions from Compiled LIG Coral U-Th age – elevation data paired with Isostatic Modeling

(Dutton & Lambeck, *in review, Science*)

(1) Maximum Elevation:

+6 m above present mean sea level, or if the granitic Seychelles are indeed tectonically stable, then up to +10 m

(2) Duration of SL Highstand:

Eustatic SL exceeds that of present by ~129-130 ka and drops below this level at 116 ka

(3) Number of sea level oscillations:

Widespread evidence for one SL drop by 1 (or maybe up to 2) meter(s) followed by a recovery to similar, if not slightly higher position. Event occurs within the timespan of 2 kyr.

Implications for Future Sea Level Change

Strong Sensitivity of Sea Level to Warming Temperatures

(1) Maximum Elevation:
+6 m above present mean sea level, or if the granitic Seychelles are indeed tectonically stable, then up to +10 m

Sea Level Highstand is Initiated Prior to Peak NH summer insolation

(2) Duration of SL Highstand:
Eustatic SL exceeds that of present by ~129-130 ka and drops below this level at 116 ka

Reasonable to expect some rapid changes in large ice sheets

(3) Number of sea level oscillations:
Widespread evidence for one SL drop by 1 (or maybe up to 2) meter(s) followed by a recovery to similar, if not slightly higher position. Event occurs within the timespan of 2 kyr.

…although mechanisms driving these changes not yet clear & ice sheets involved have yet to be identified