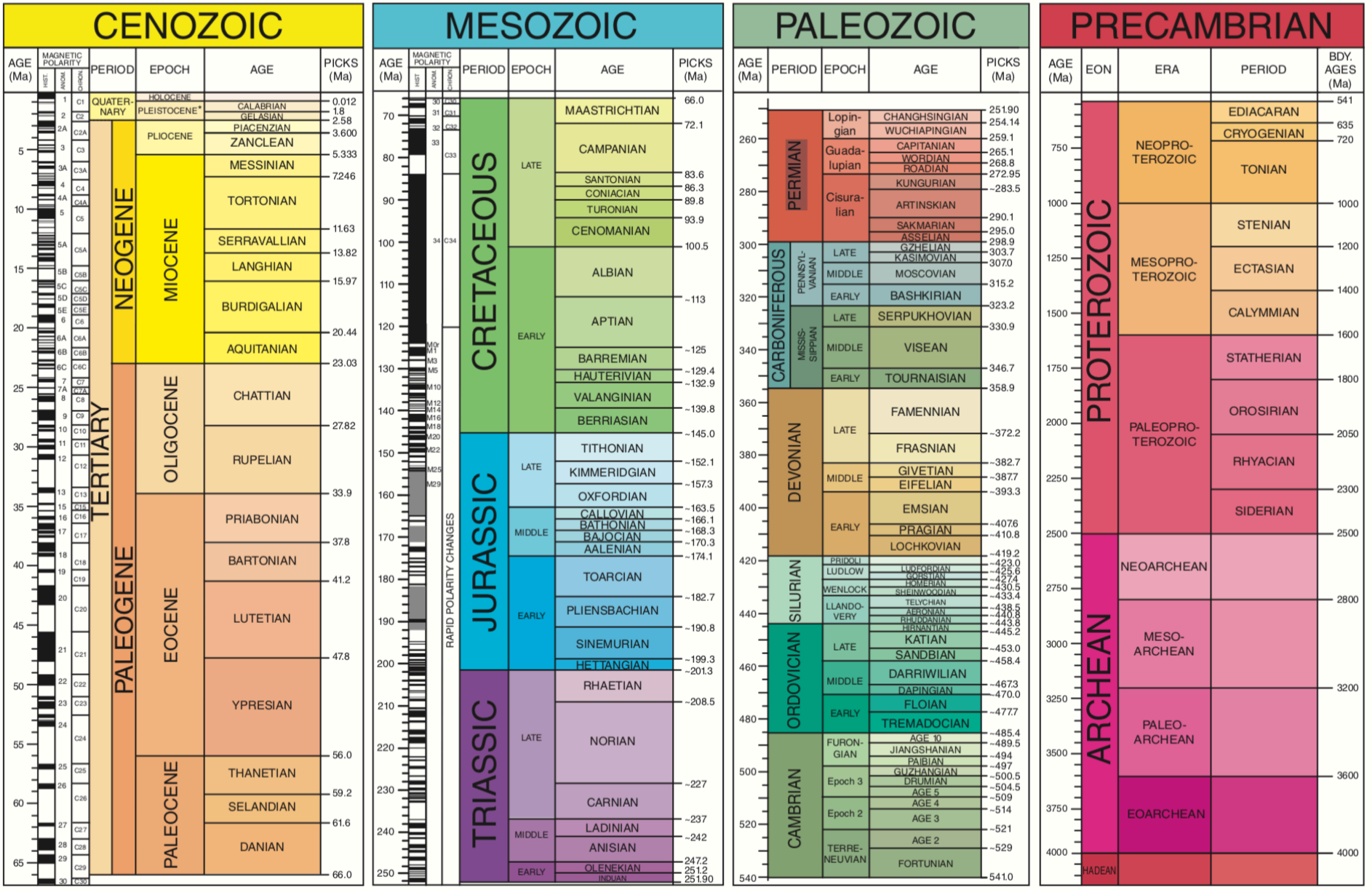
Using data and models to understand Earth's climate history

6.S898

Friday 9/27/19

David McGee, EAPS

GSA GEOLOGIC TIME SCALE v. 5.0



https://www.geosociety.org/documents/gsa/timescale/timescl.pdf

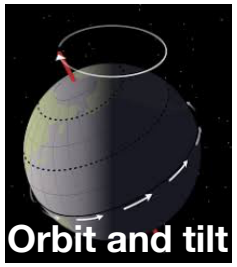
Today's goals

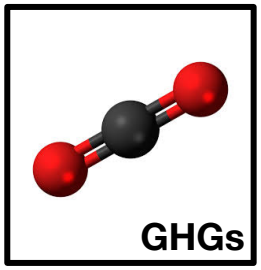
- Explain how measurements of geological archives can be used to make inferences about past climates
- Consider the implications of paleoclimate data for our understanding of the climate system
- Provide a few examples of the role of computation in paleoclimate research

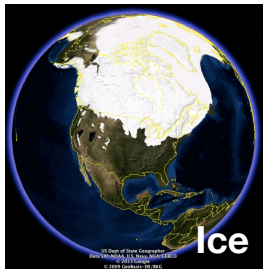
Outline

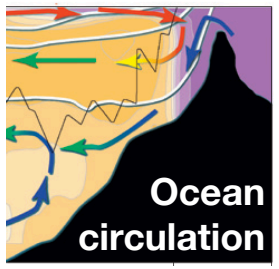
- Basics and challenges of making inferences proxy data
- Greenhouse climate in the Eocene
- Large-scale carbon release at the PETM
- Climates of the last 125,000 years
  - Ice sheets
  - Precipitation changes
- Next steps in paleoclimate model-data integration and comparison

Changes in Controls

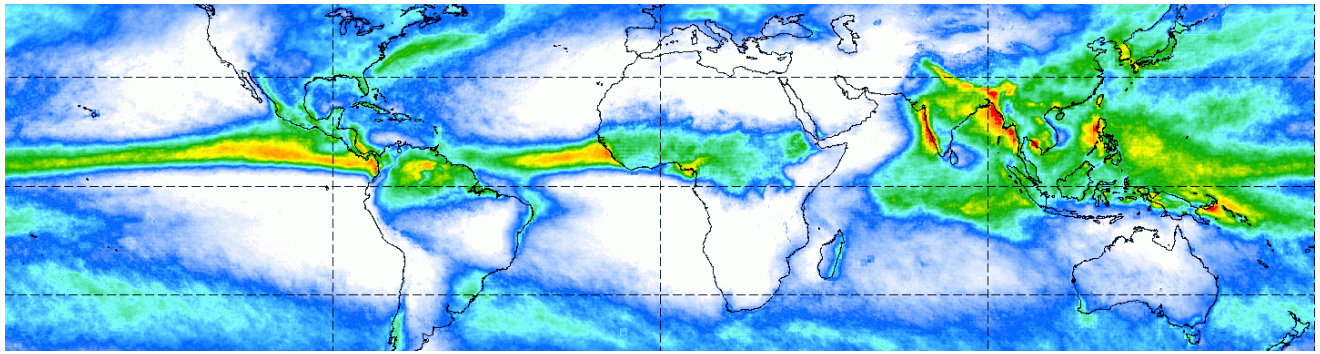




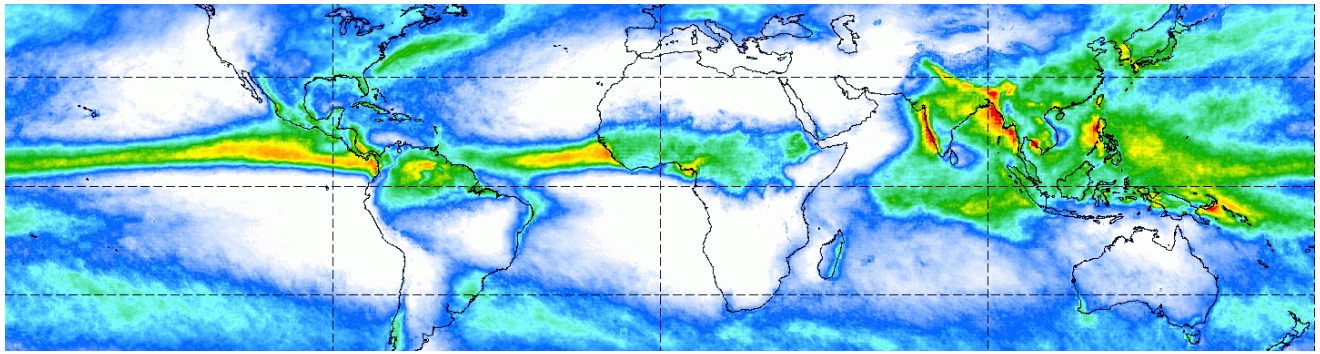




Climate response



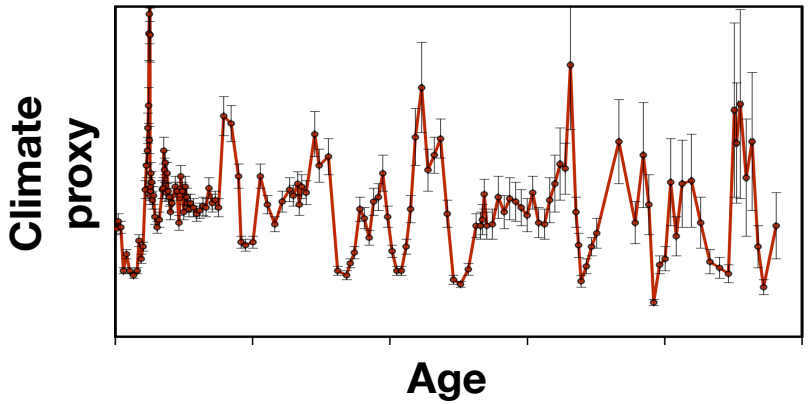
Climate response



Geological archives

Geological archives

Proxy records



Changes in Controls

Climate response

Geological archives

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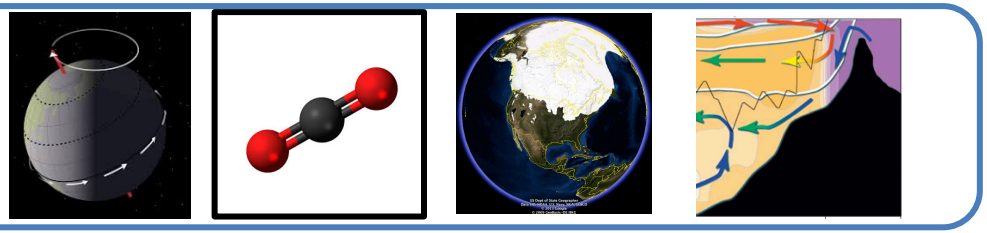
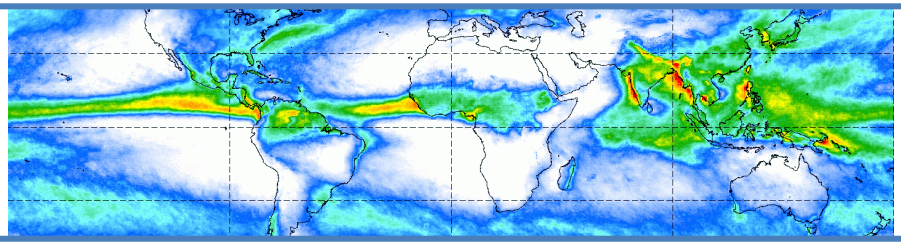
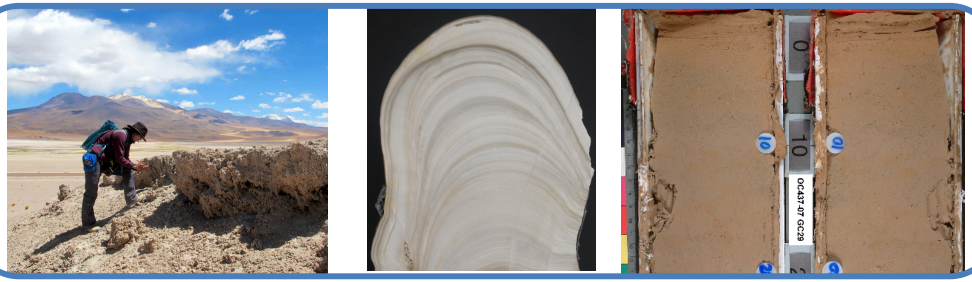
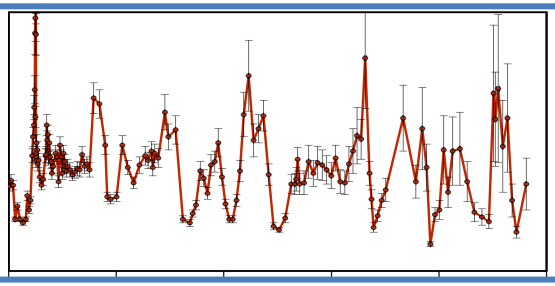
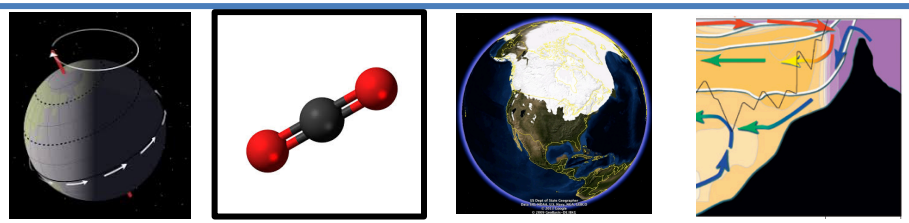




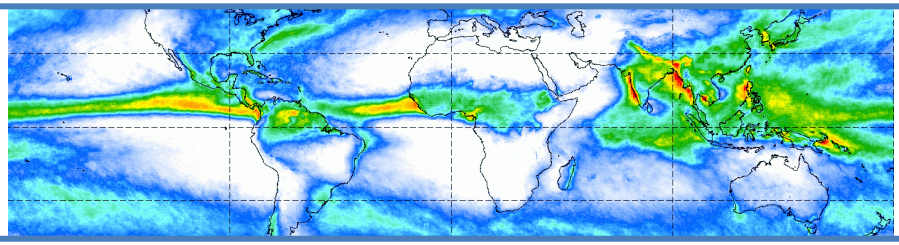




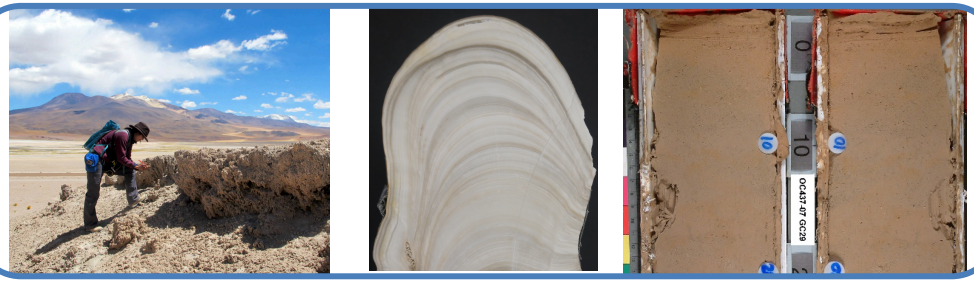
Changes in Controls



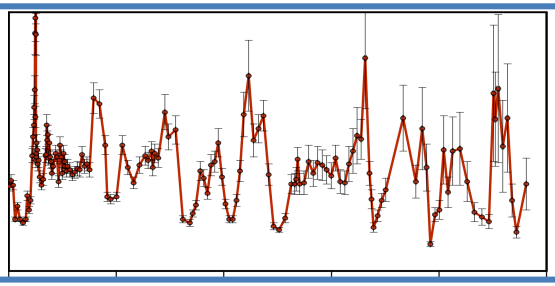
Climate response



Geological archives

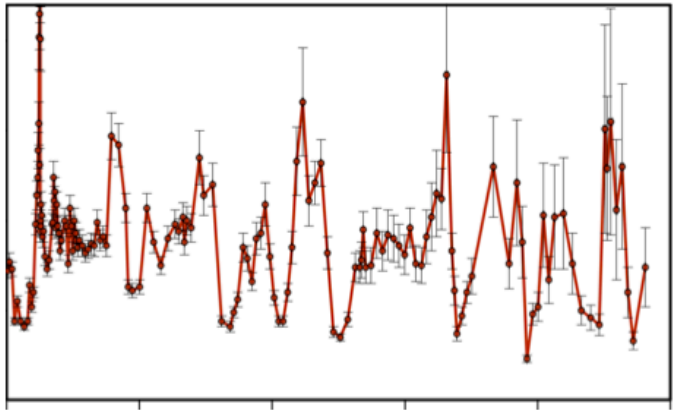


Proxy records

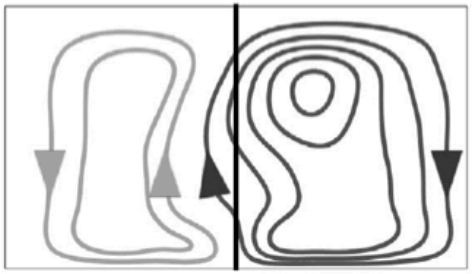


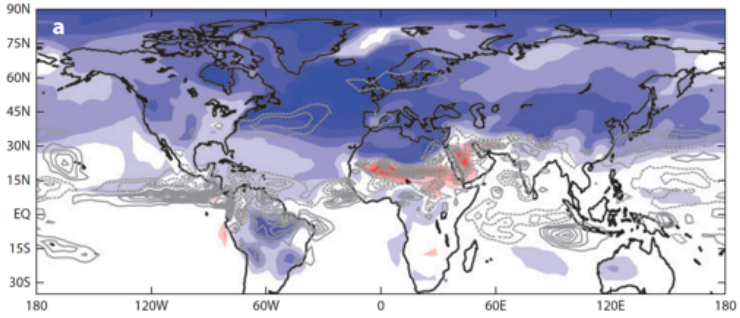
Data-based inferences

Data-based inferences

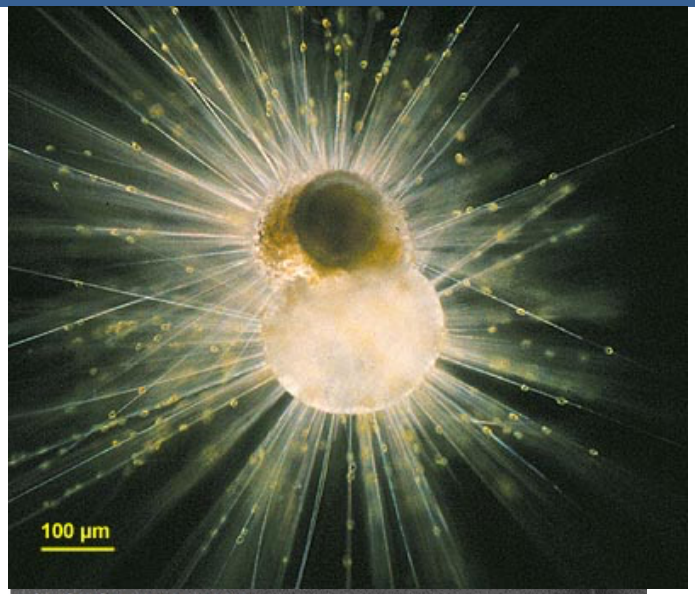


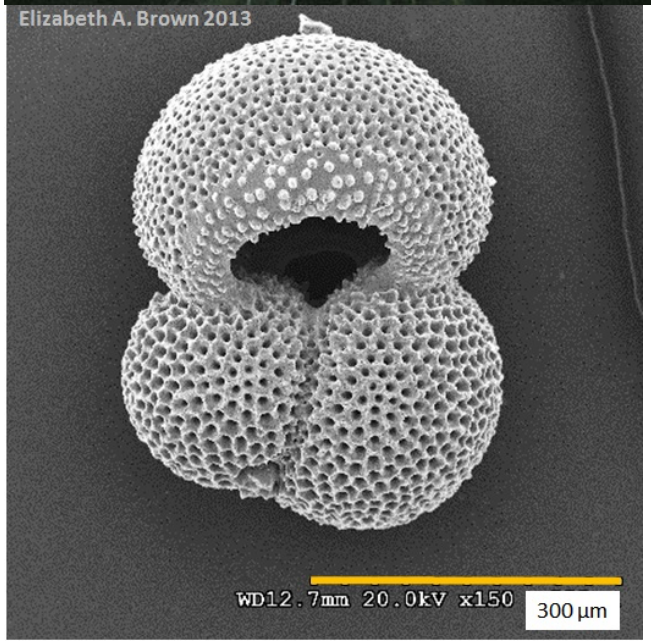
Expectations from theory and models

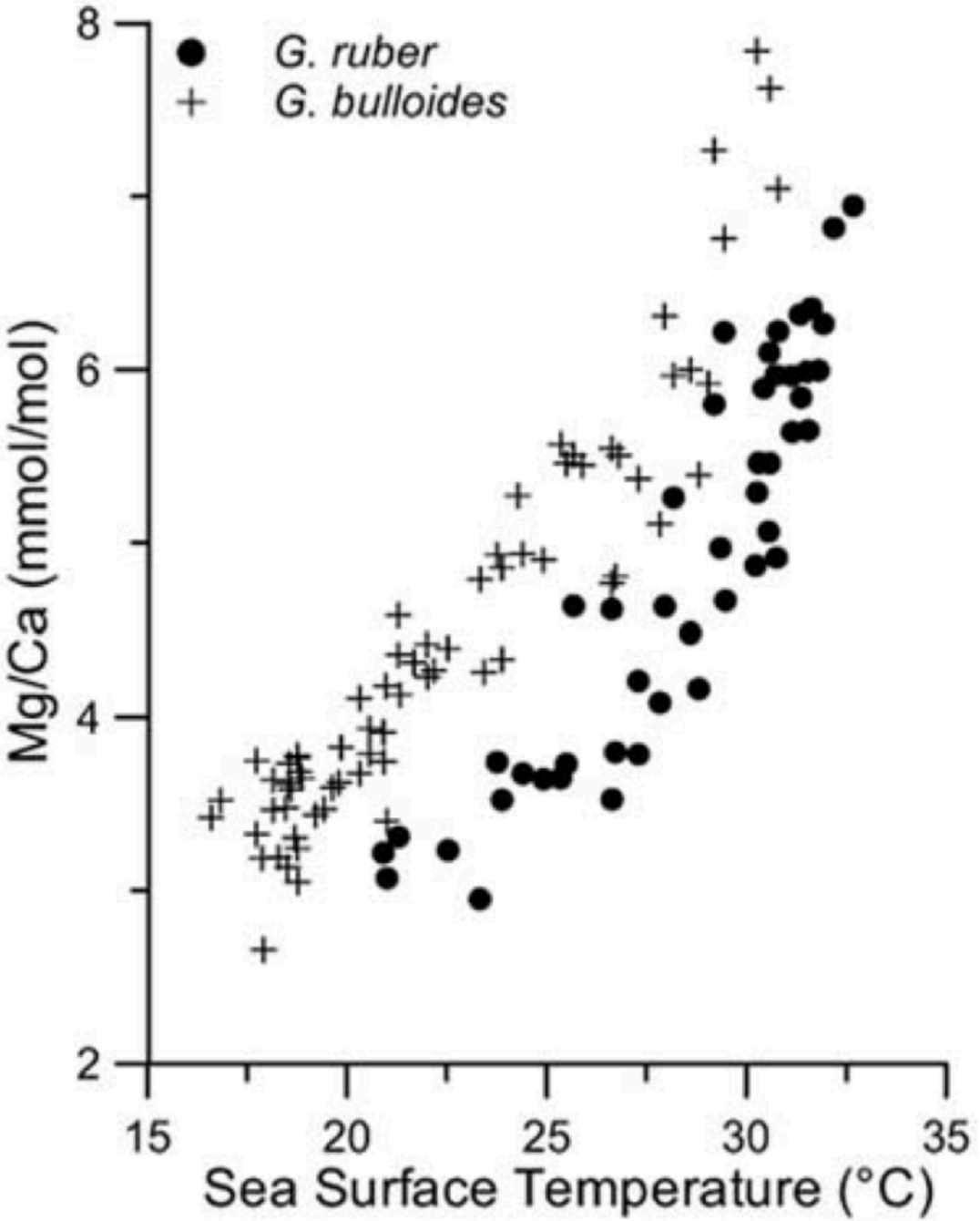




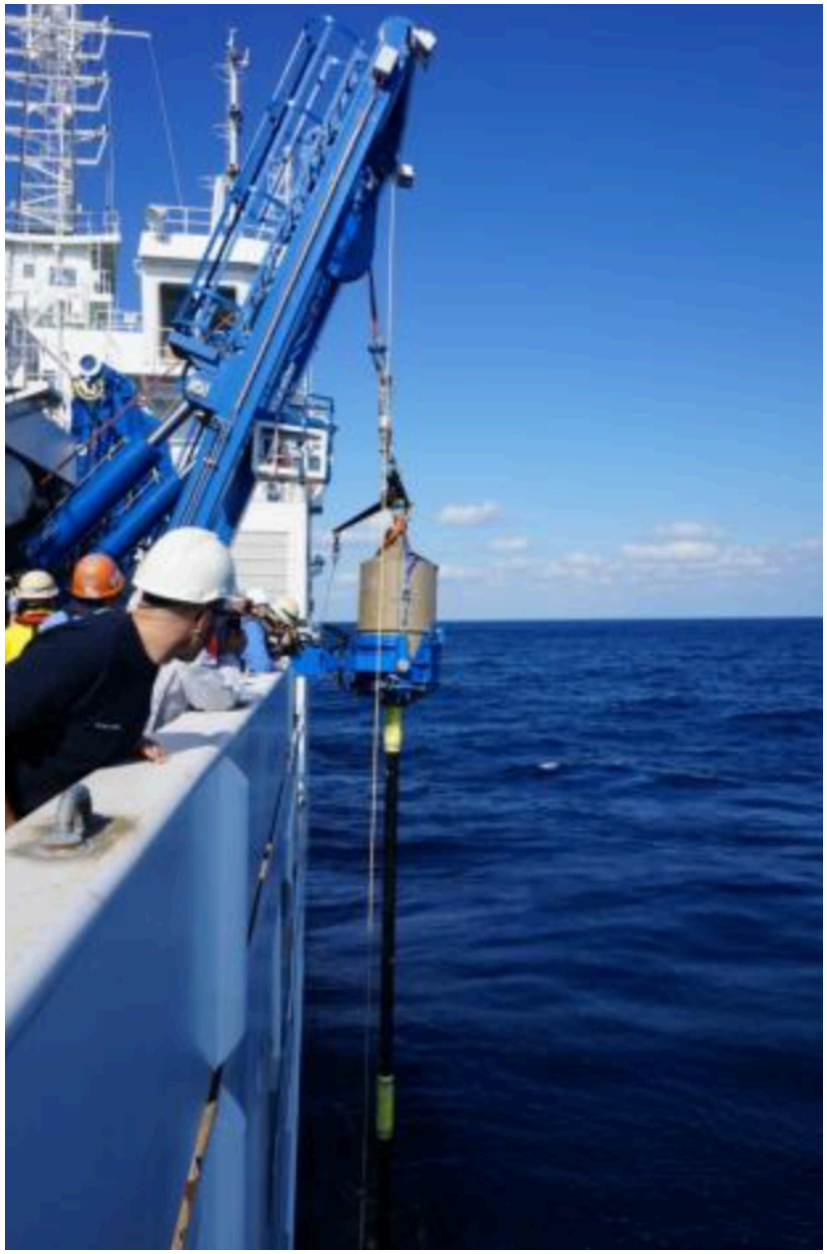
Example of paleoclimate reconstruction tools: Mg/Ca ratios in foraminifera

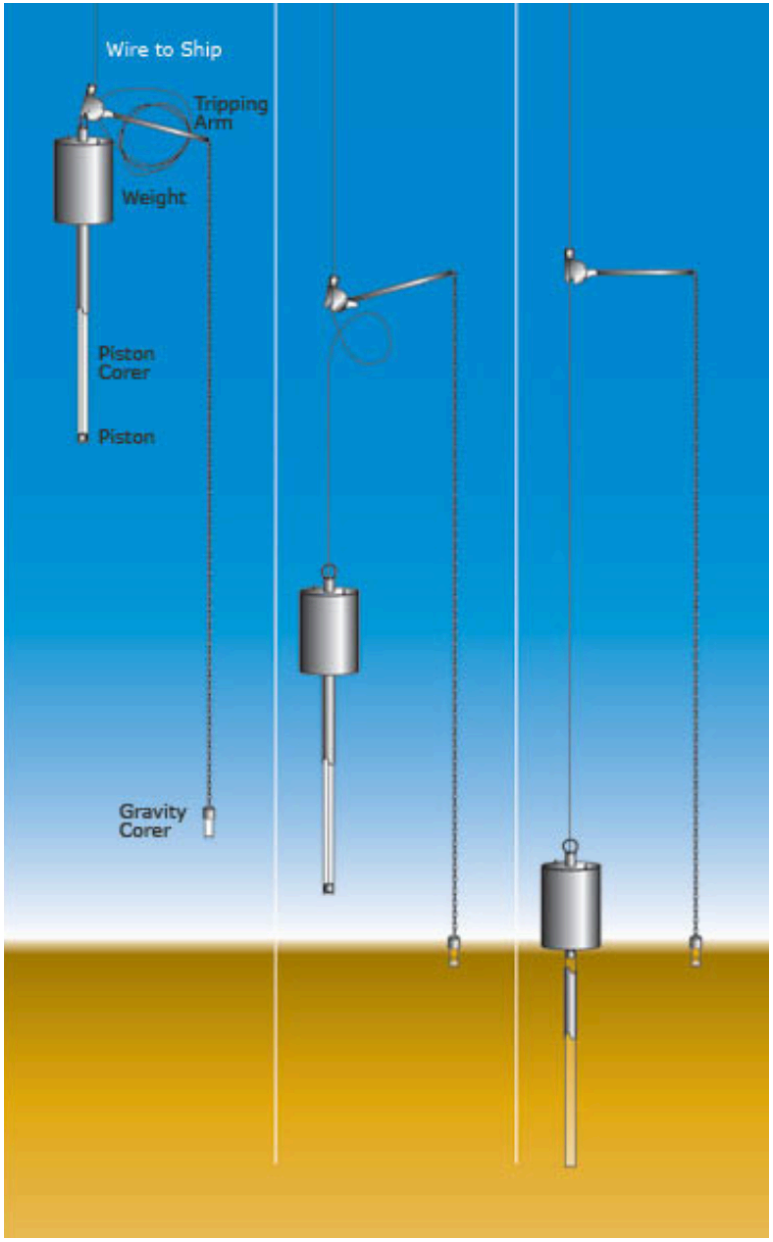






McConnell and Thunell
Paleoceanog. 2005




Wire to Ship
Tripping Arm
Weight
Piston Corer
Piston
Gravity Corer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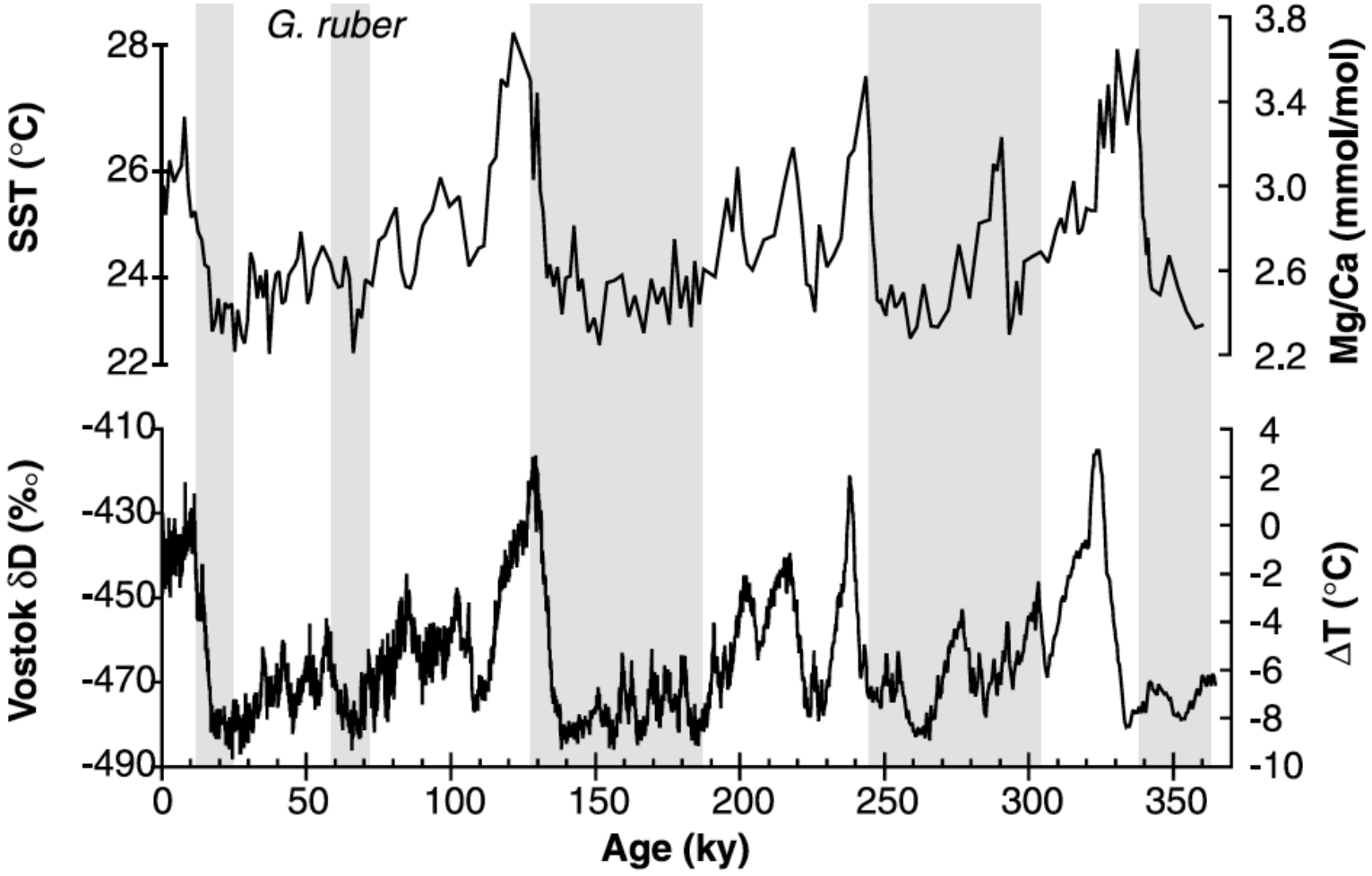


Lea et al., Science 2000

From deep-sea sediments to paleotemperature estimates:

What are assumptions or requirements involved in using Mg/Ca measurements of foraminifera in ancient sediments to reconstruct past temperatures and understand past climates?

Stepping back, what might be general requirements of paleoclimate archives and proxies?

A surface deposit preserved from alteration over long timescales

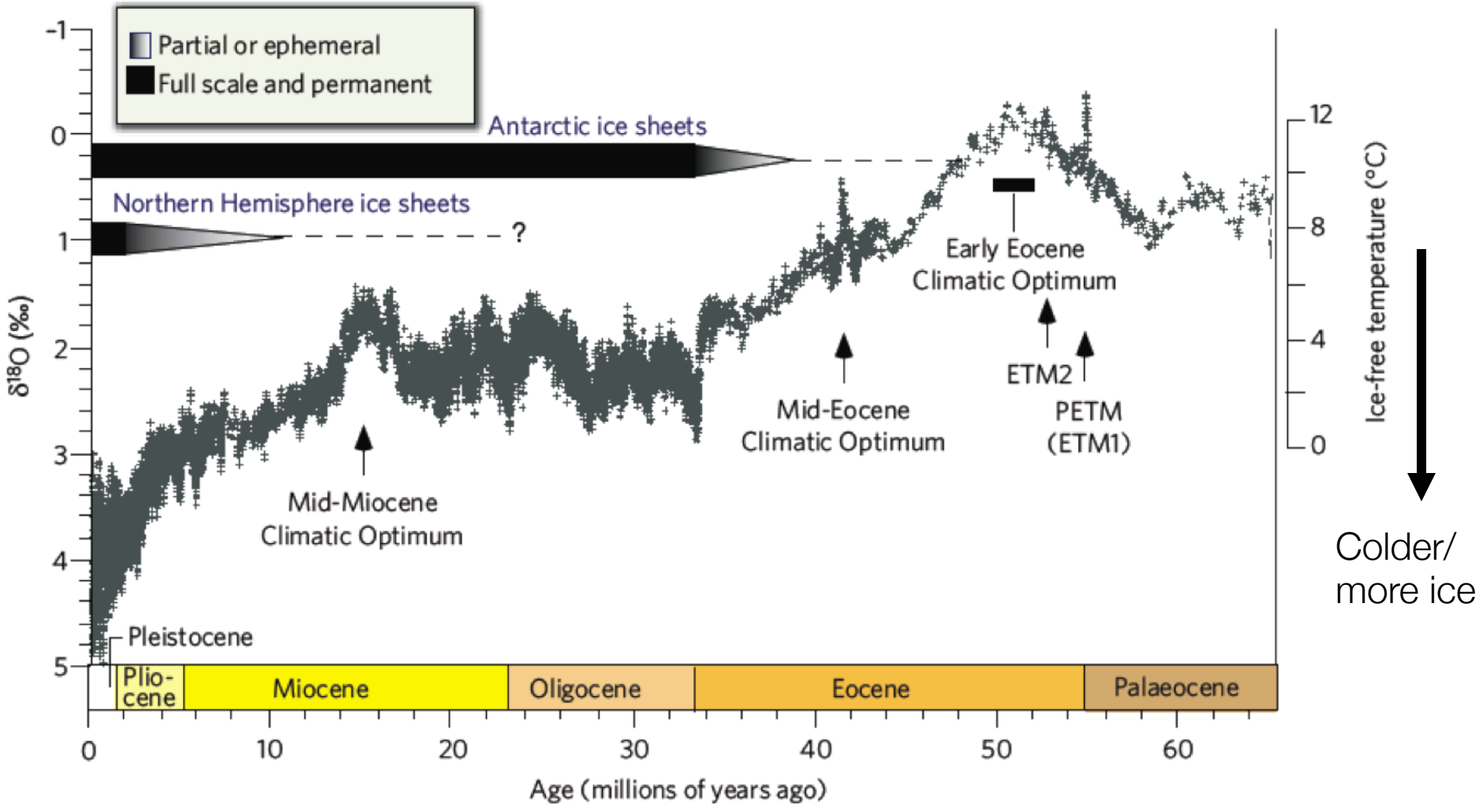
A method for telling time

A measurement that can be related to an environmental variable

What do we learn from paleoclimate proxies?

Climate over the last 65 Myr

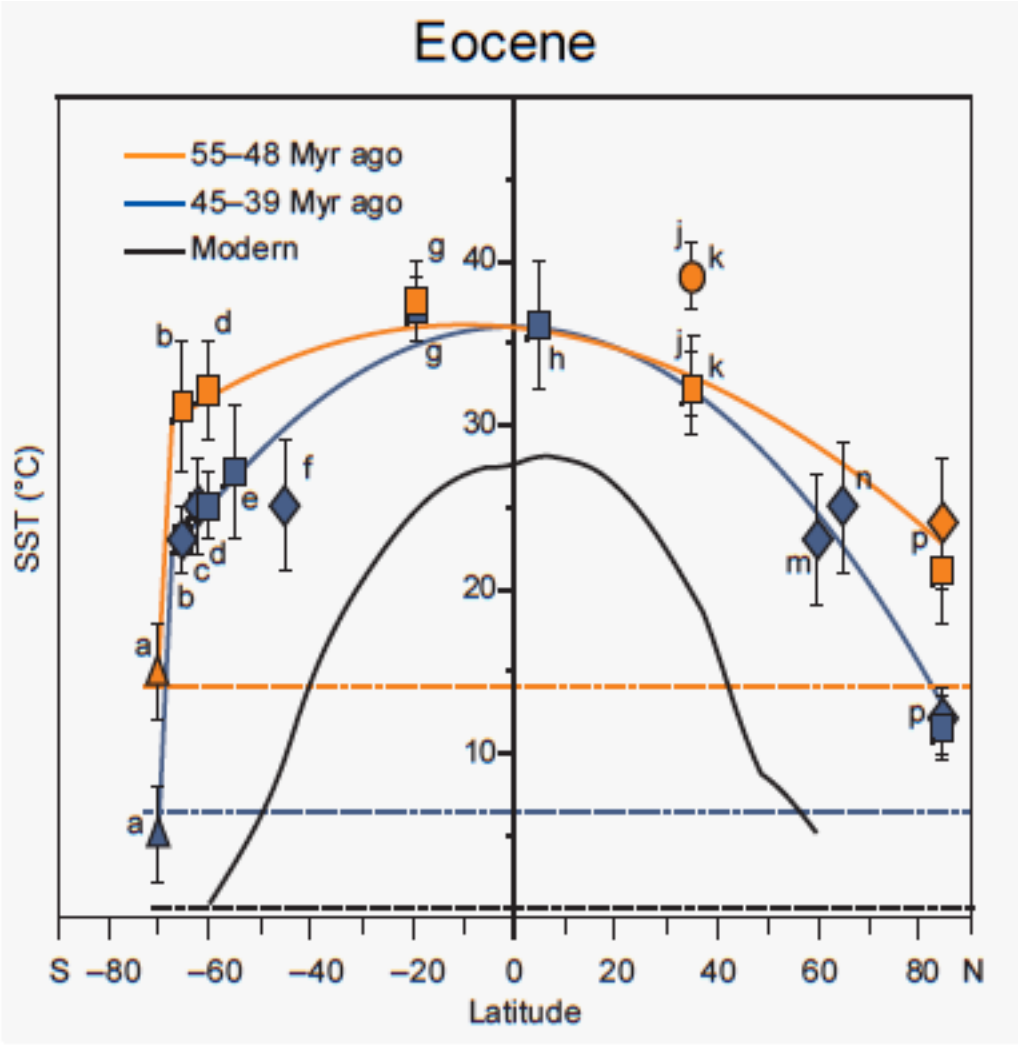
(beware the flipping x-axis…)



Zachos et al., Nature 2008

Greenhouse climates

Eocene (50 Myr ago) fossils from Wyoming, ~50°N paleolatitude

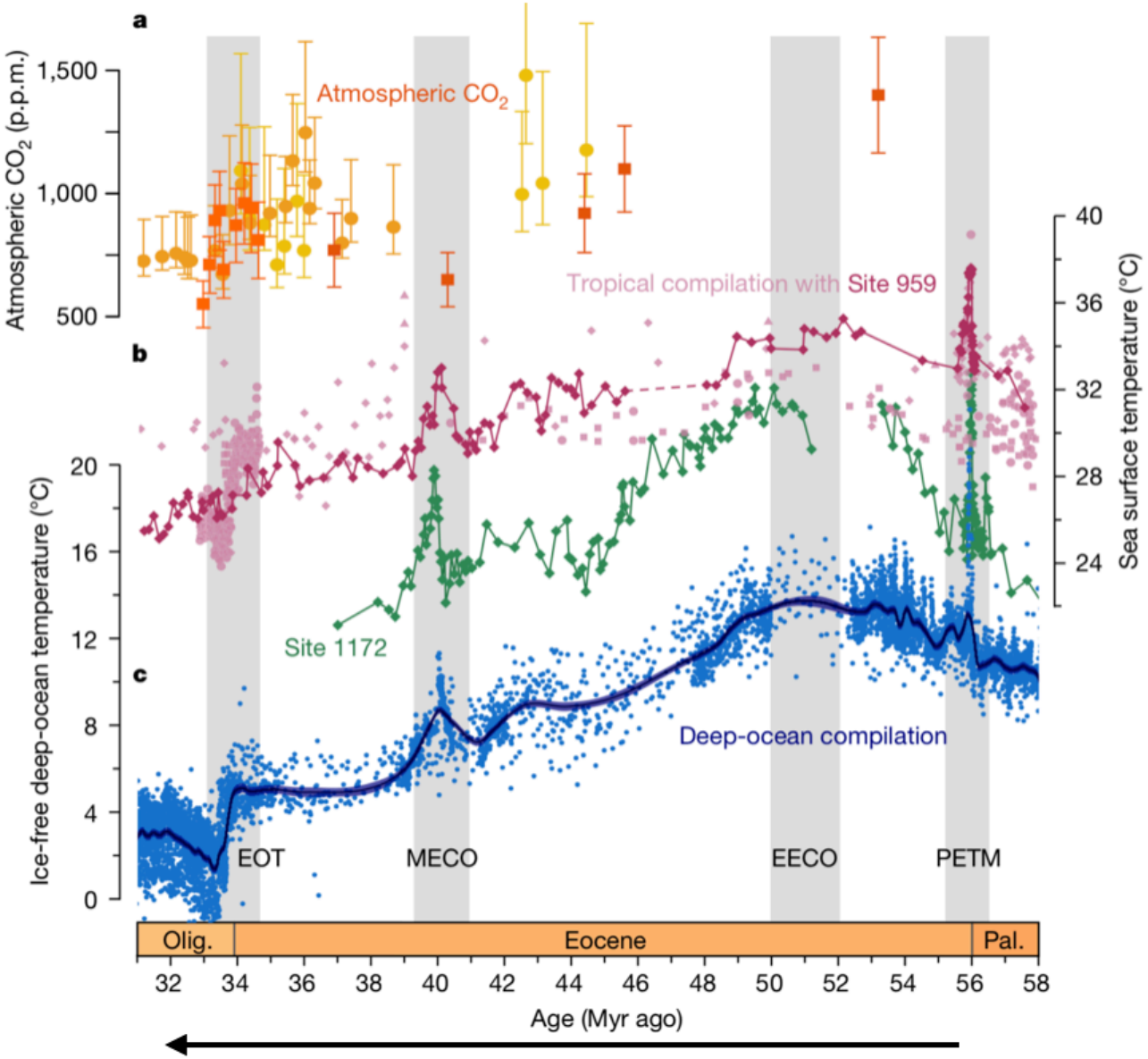


Latitudinal temperature profile in the Eocene

(SST: sea surface temperature)

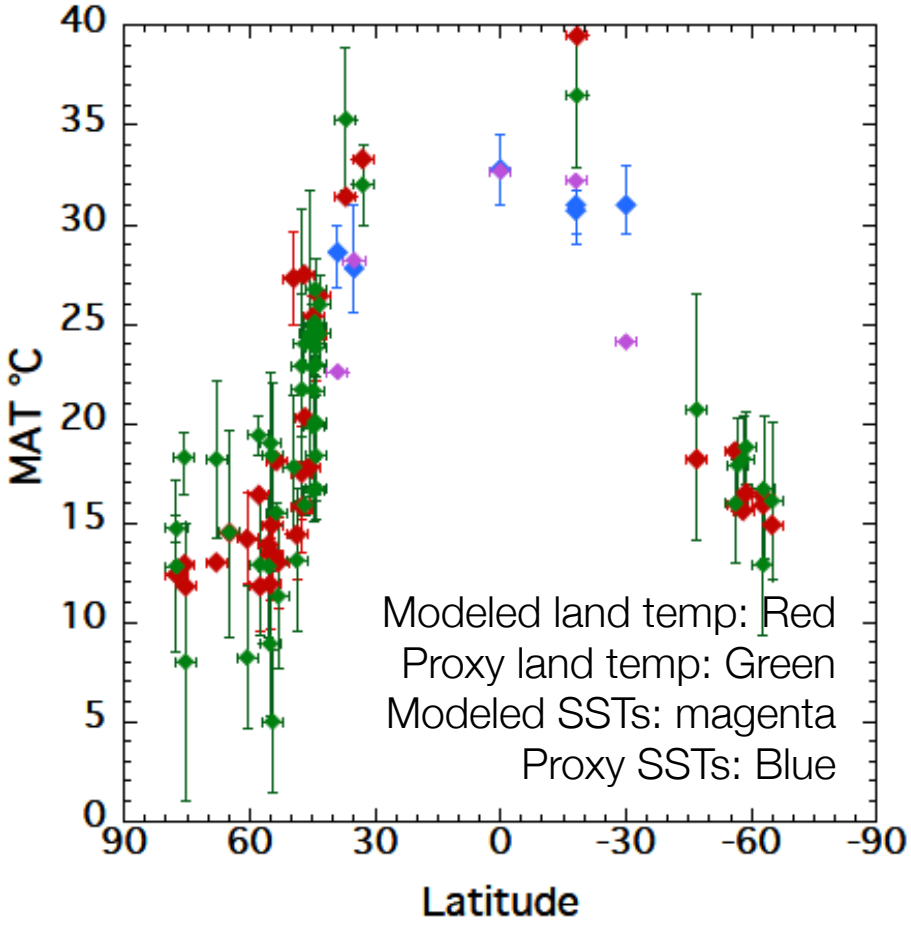
Montañez et al., Natl. Academy Press, 2011

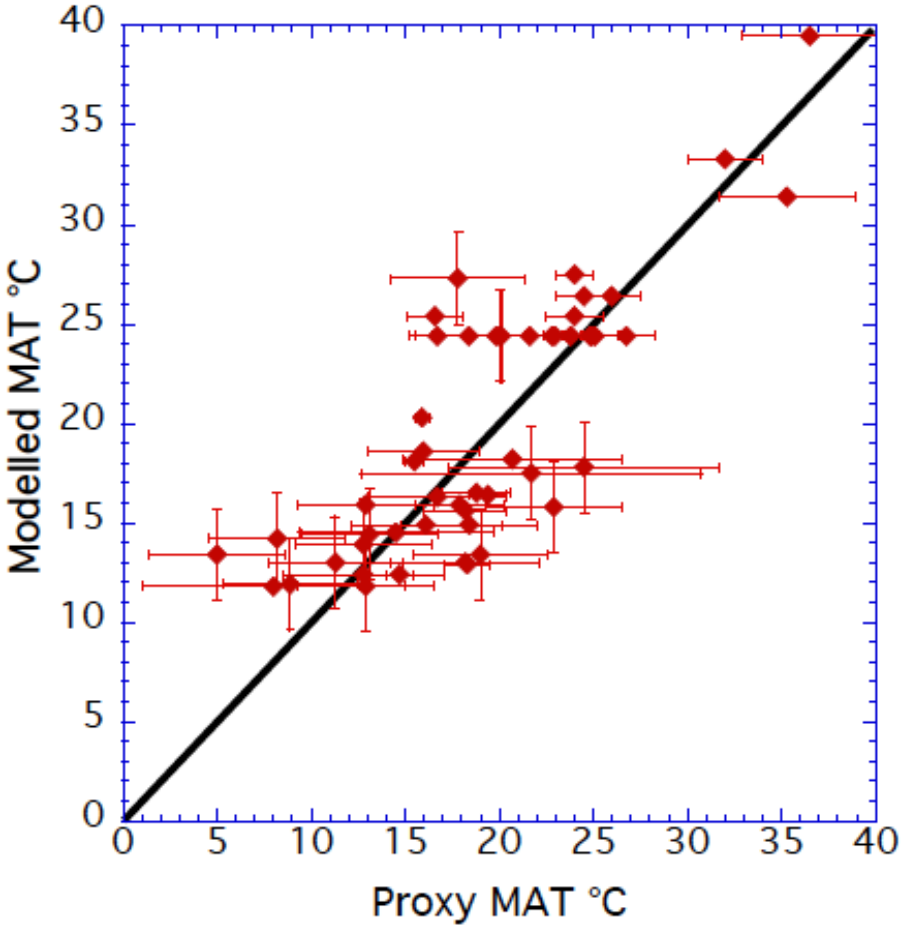
Greenhouse climates: Pronounced warming, esp. at high latitudes



Cramwinckel et al., Nature 2018

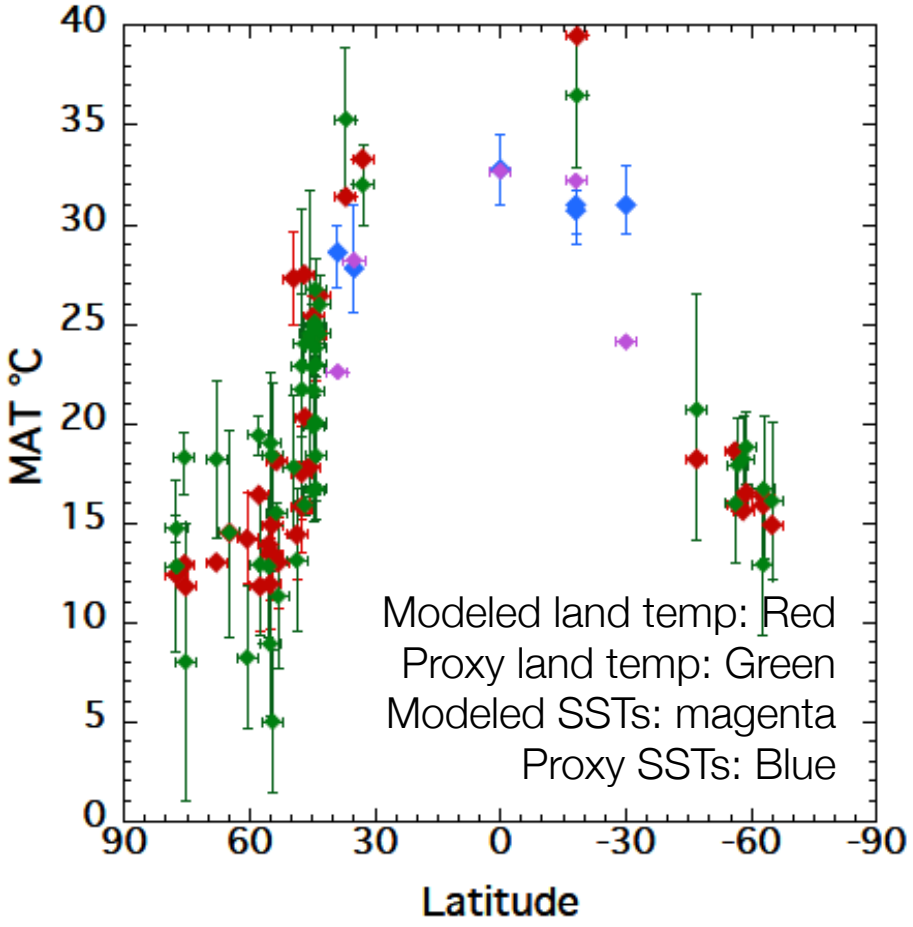
Model-data comparison, Eocene:

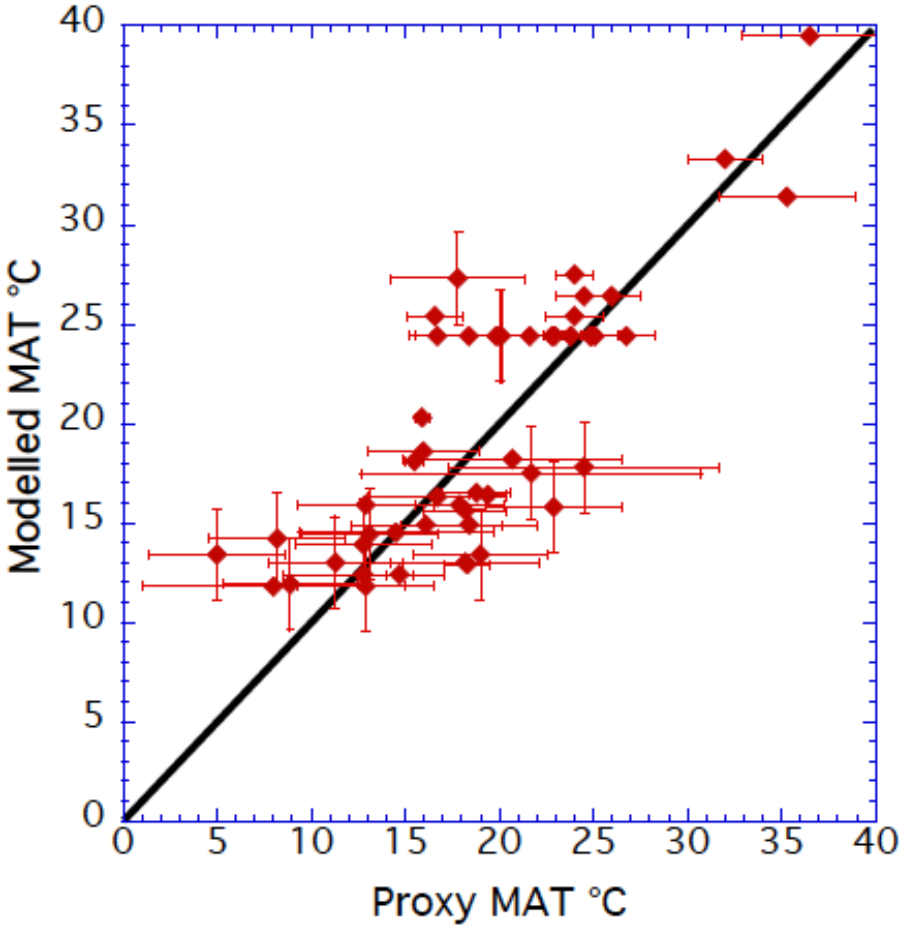




Huber and Caballero, Climate of the Past 2011

Model-data comparison, Eocene: Good match…when pCO_2 set to 4480 ppm





Huber and Caballero, Climate of the Past 2011

What’s missing?

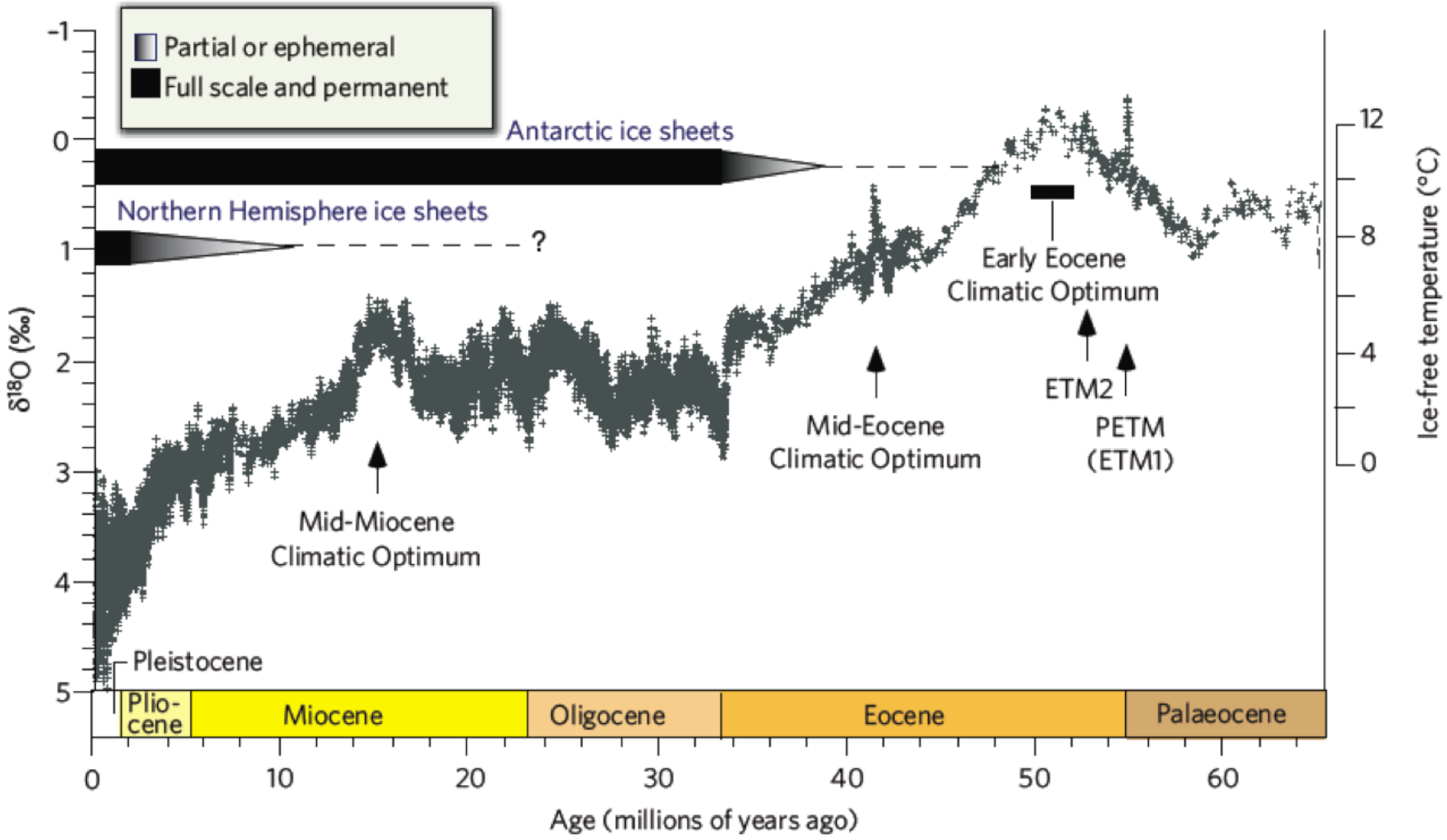
What's missing?

1. proxy data (for temps or CO_2) are wrong or misinterpreted

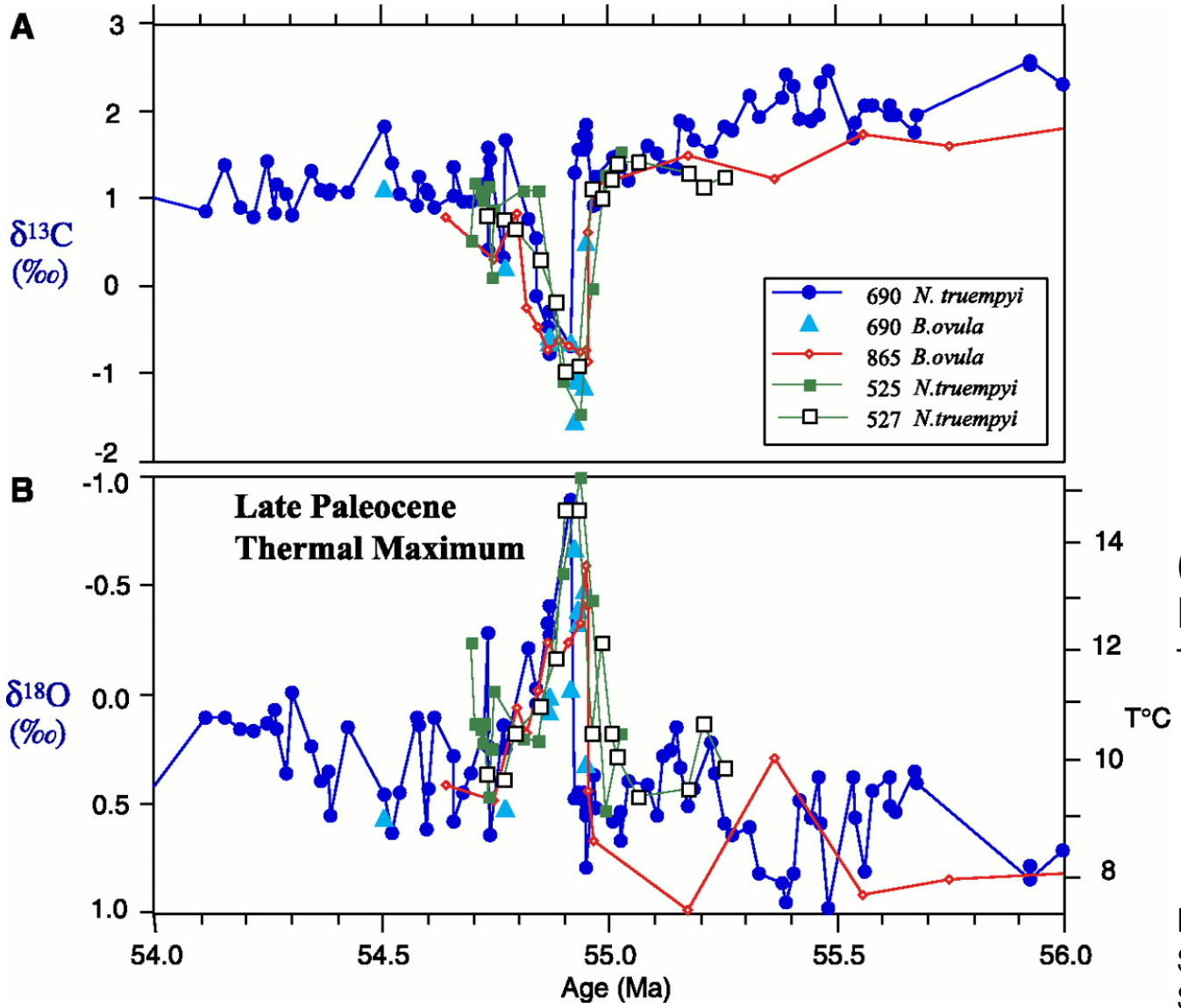
2. model boundary conditions are wrong

3. model physics are wrong
   -increased meridional heat transport not captured in models
   -reduced high-latitude cooling (due to increased high-latitude cloud cover) not captured in models
   -subtropical cloud cover decease in warm climates not captured in models

Another surprise from the Eocene: the PETM



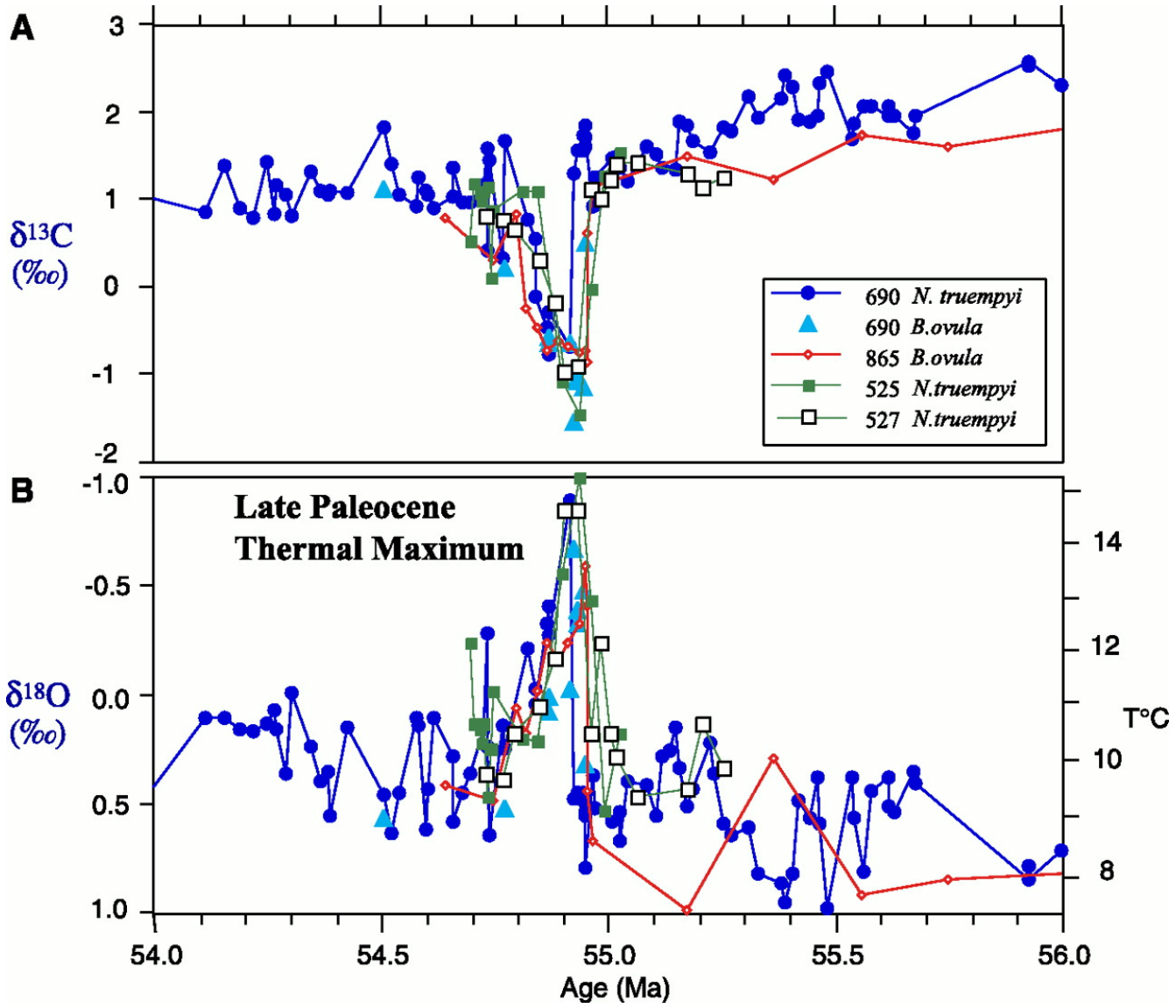
Benthic C and O isotope data



(now known as the Paleocene-Eocene Thermal Maximum)

Benthic forams
Sites 527 & 690 south Atlantic
Site 865 western Pacific
Zachos et al., Science 2001

Interpretation

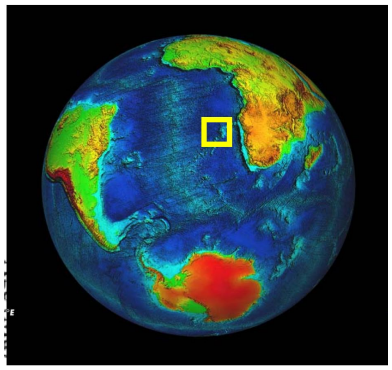


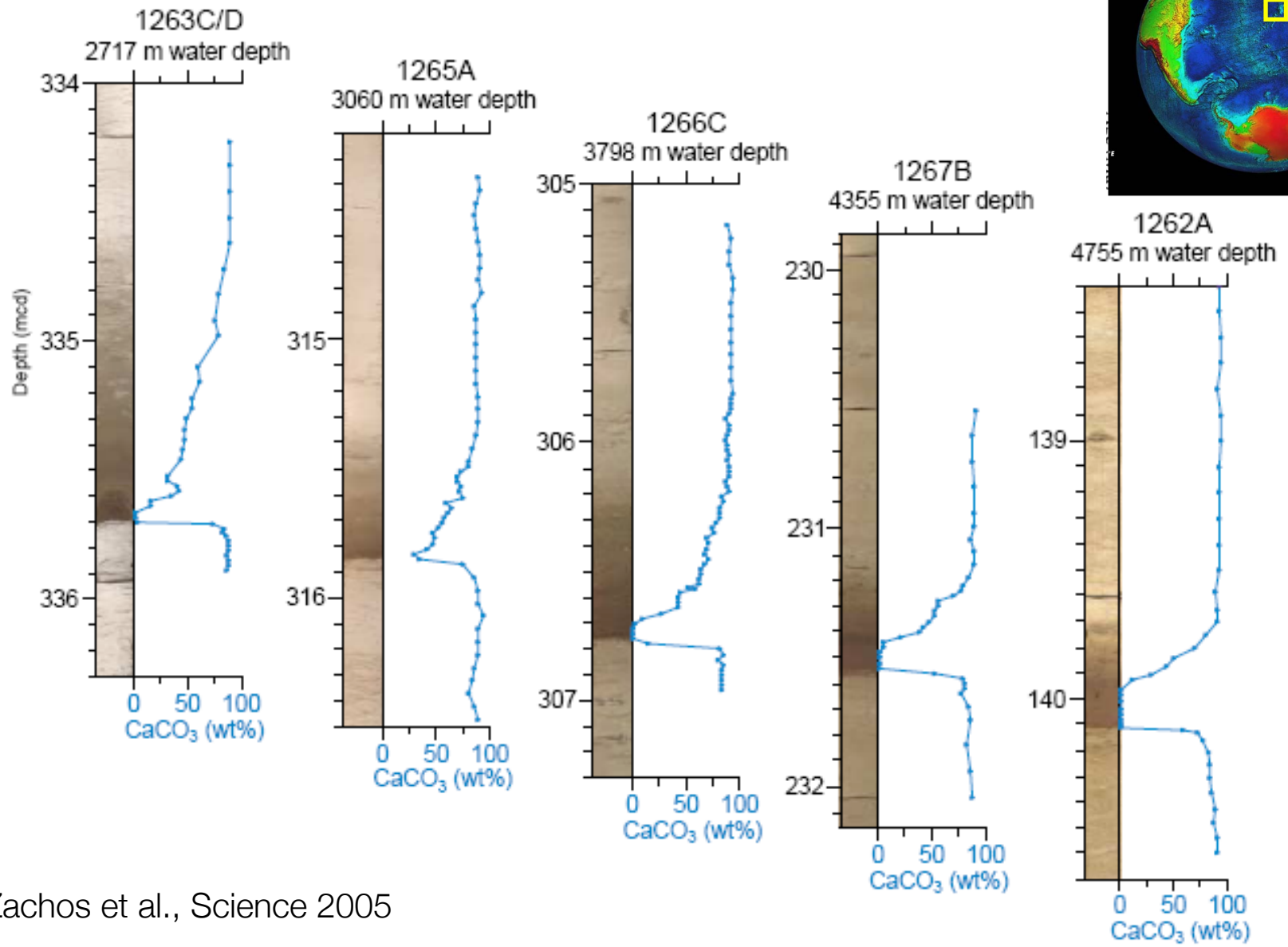
Rapid injection of C into ocean-atmosphere system

Rapid deep-sea (and therefore high-latitude surface) warming

Benthic forams
Sites 527 & 690 south Atlantic
Site 865 western Pacific
Zachos et al., Science 2001

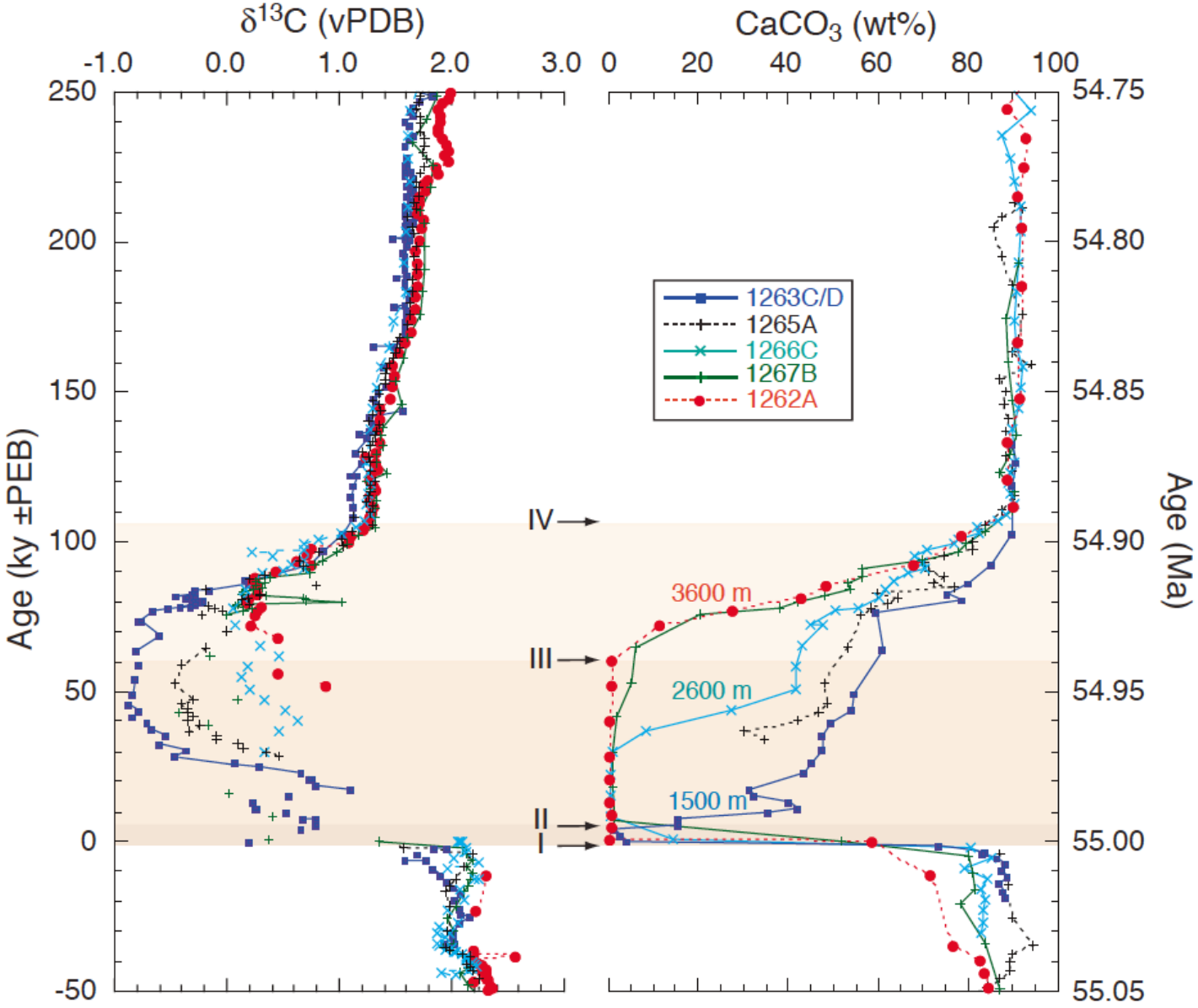
Carbonate dissolution during the PETM





Zachos et al., Science 2005

Carbonate dissolution during the PETM



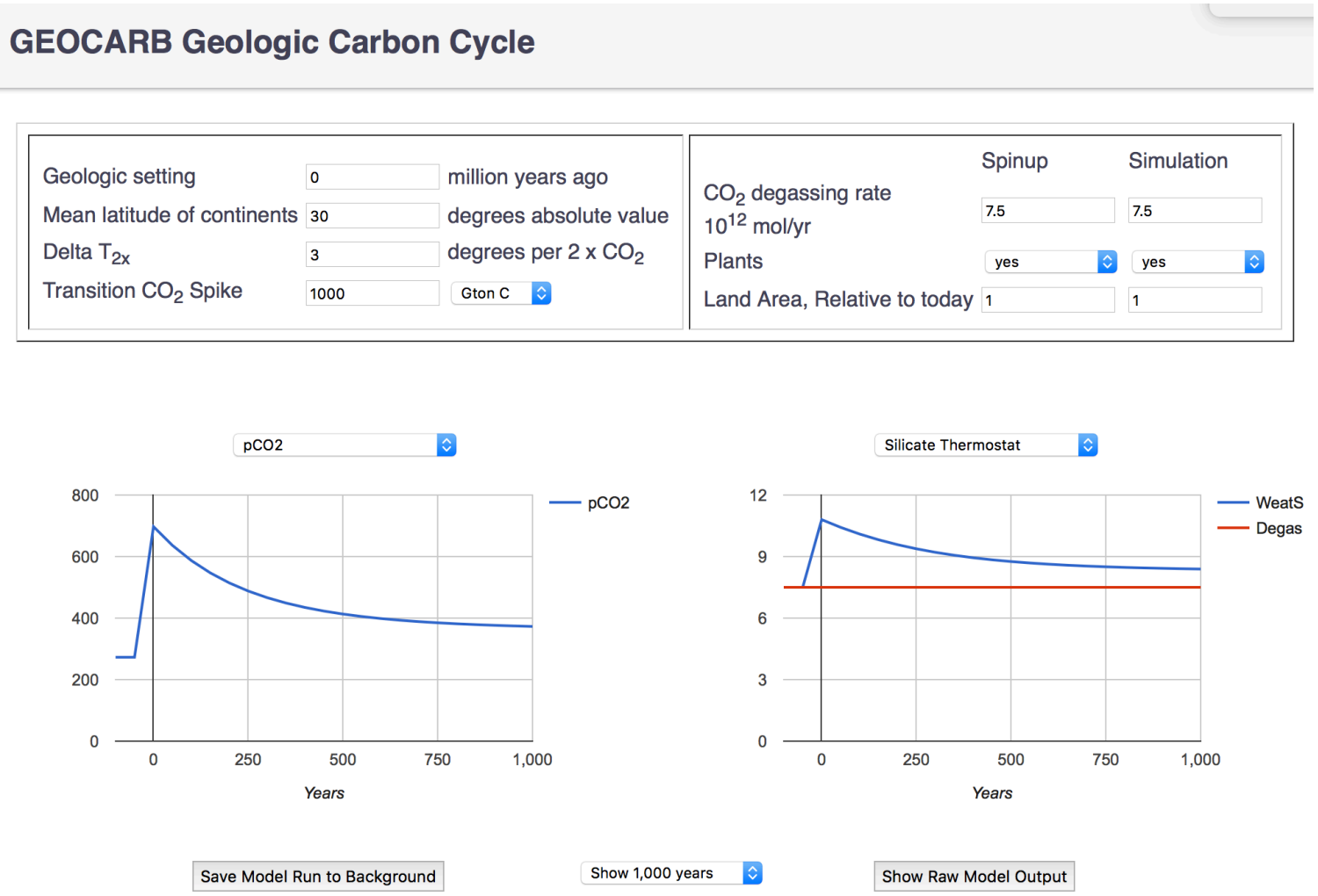
Rapid (<10 ky) shoaling of the calcite compensation depth (CCD) by more than 2 km in the South Atlantic

Gradual recovery (>100 ky)

Zachos et al., Science 2005

The fate of a carbon pulse

http://climatemodels.uchicago.edu/geocarb/



For a more detailed look at the carbon cycle…

cGENIE model:

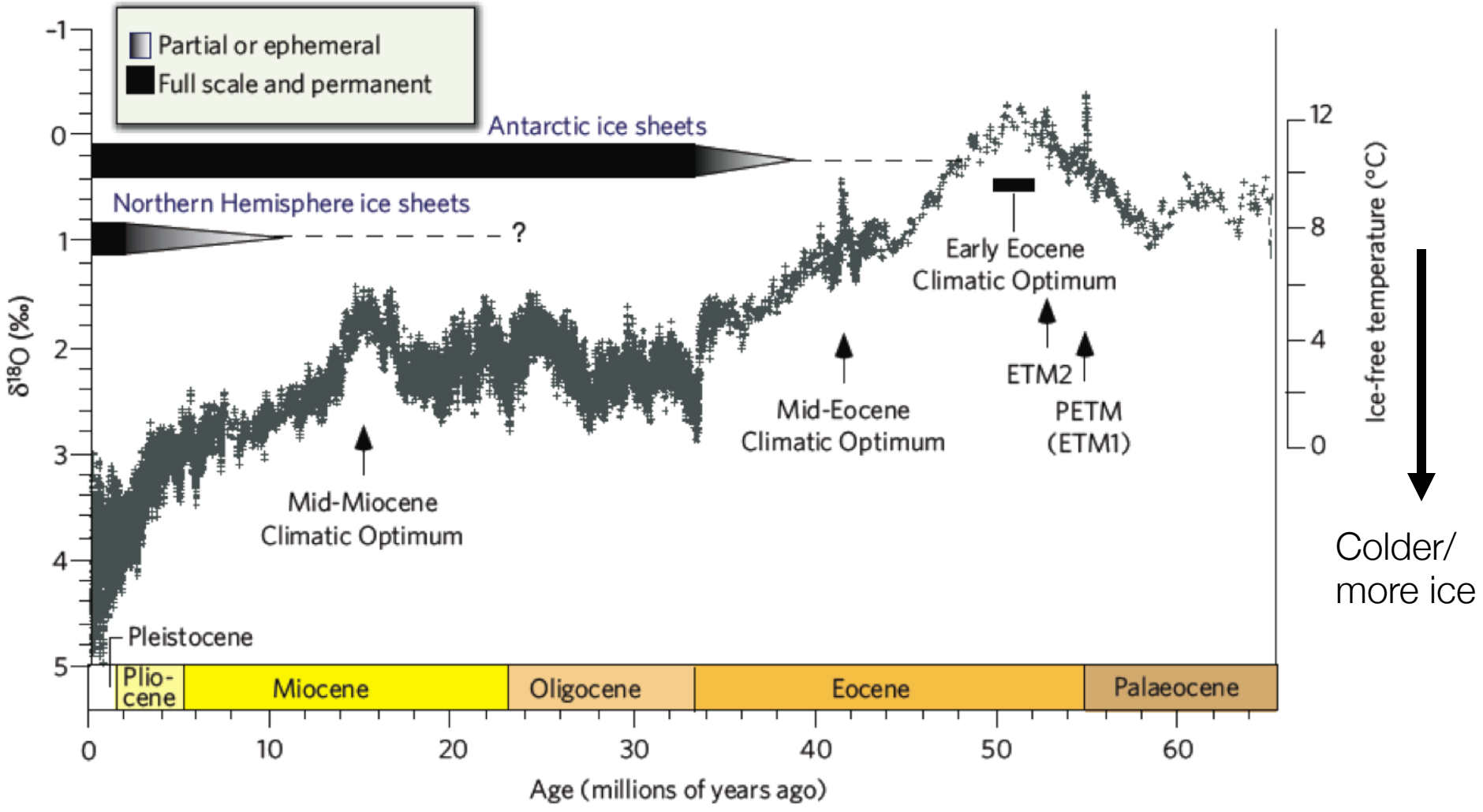
http://www.seao2.info/mycgenie.html

Potential causes of carbon release at the PETM

Proposed sources:

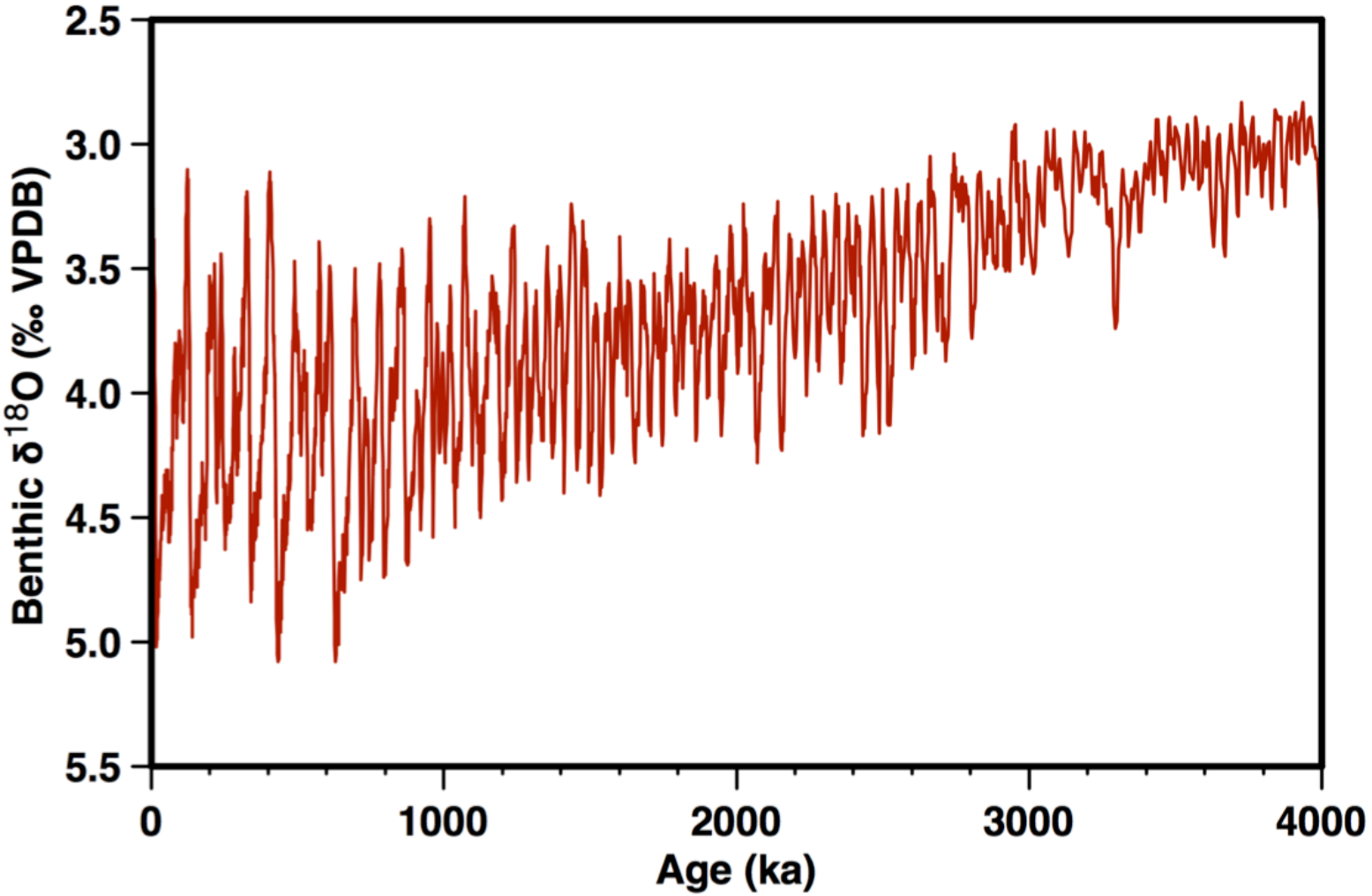
- Methane hydrates
- Drying of epicontinental (i.e. shallow) seas
- Comet impact
- Permafrost melting
- Dissolved organic carbon oxidation
- Wildfires
- Methane release from magmatic intrusion into organic-rich sediments

Climate over the last 65 Myr



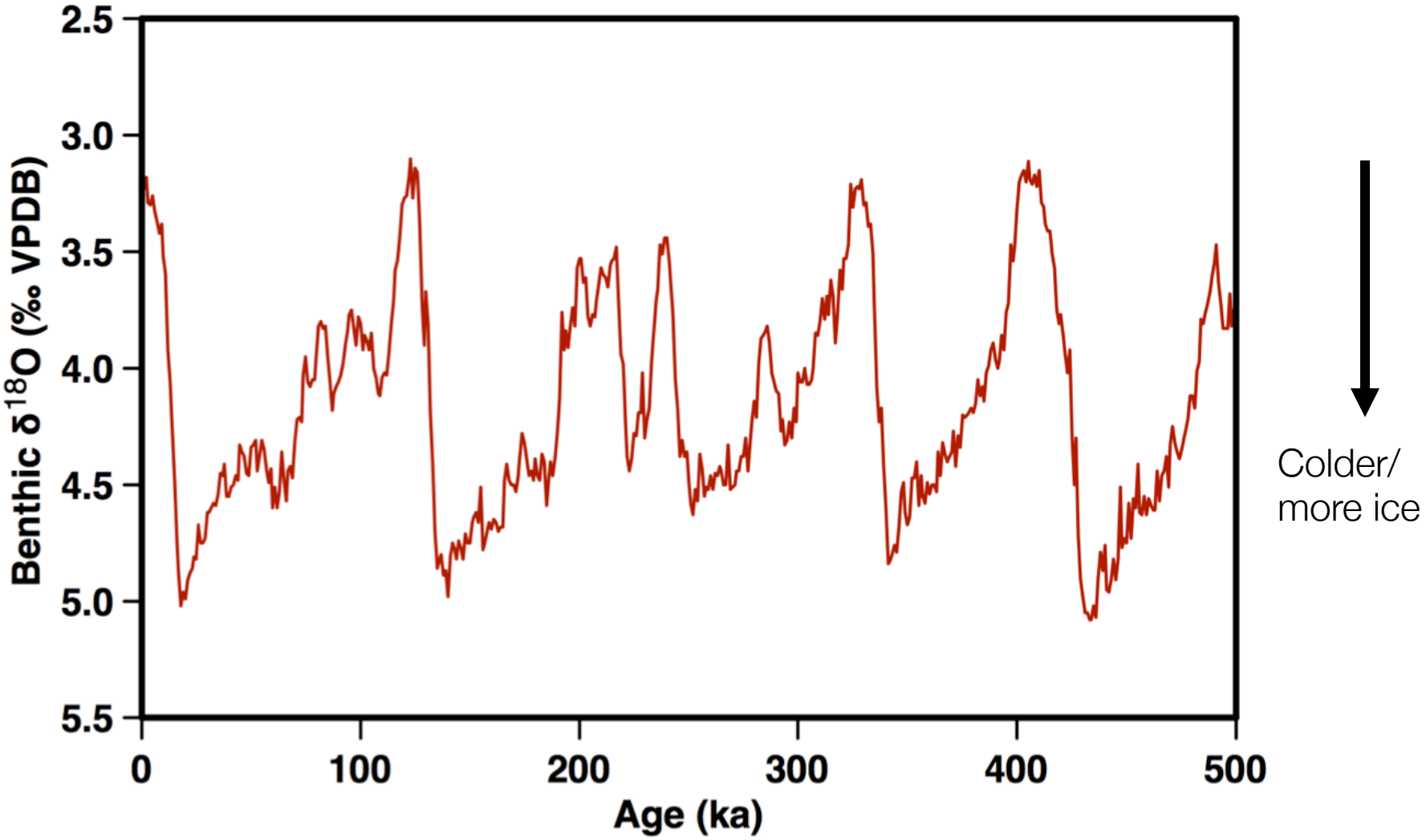
Zachos et al., Nature 2008

Glacial-interglacial cycles of the last 4 million years



Lisiecki and Raymo, Paleoceanography 2005

Glacial-interglacial cycles of the last 500,000 years

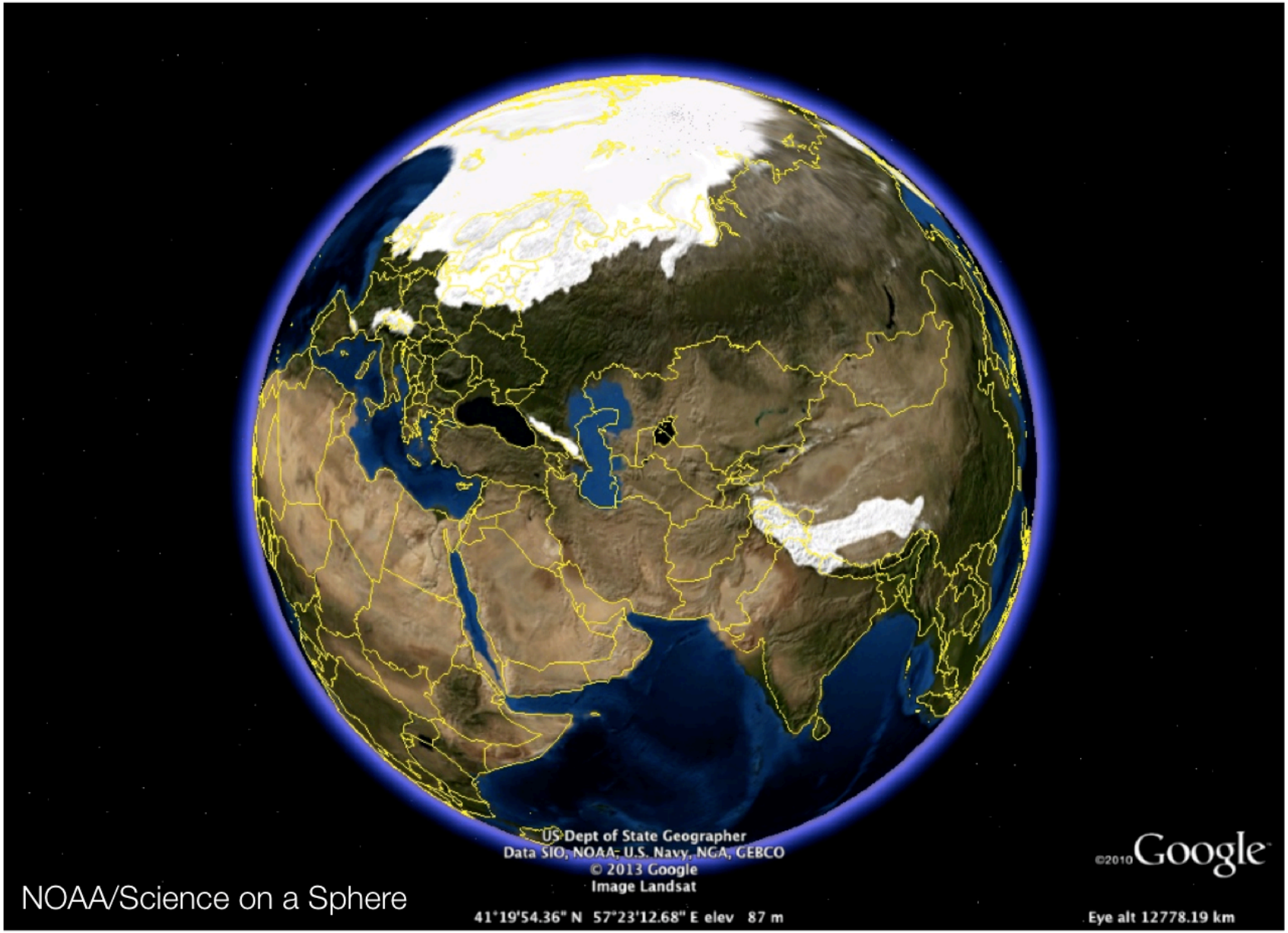


Lisiecki and Raymo, Paleoceanography 2005

Ice extent at the Last Glacial Maximum ~20 kyr ago

NOAA/Science on a Sphere

Ice extent at the Last Glacial Maximum ~20 kyr ago



NOAA/Science on a Sphere

Reconstructing sea level

Acropora palmata coral
Grows within 5 m of sea surface

Sea level ~125 m lower during the Last Glacial Maximum

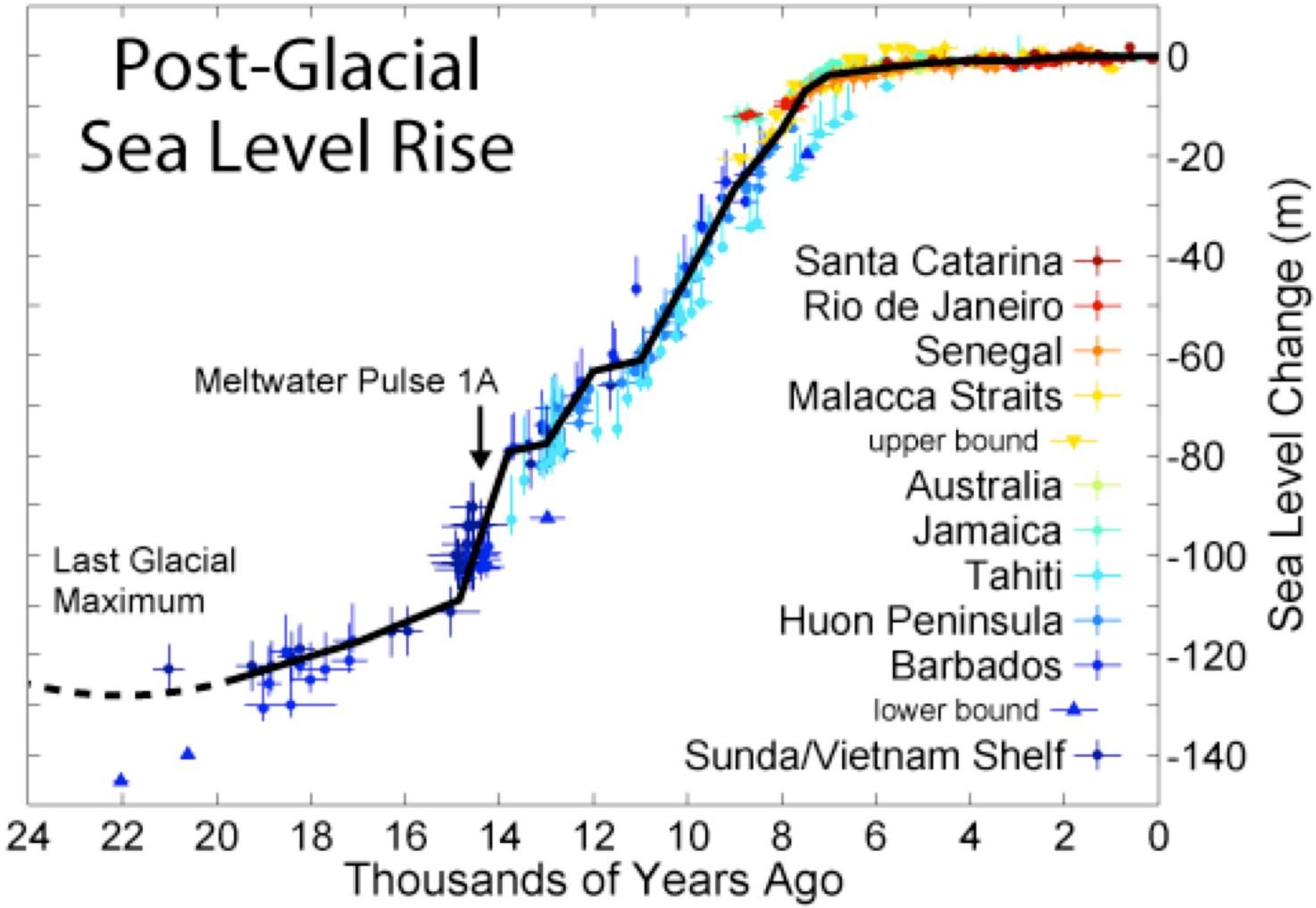
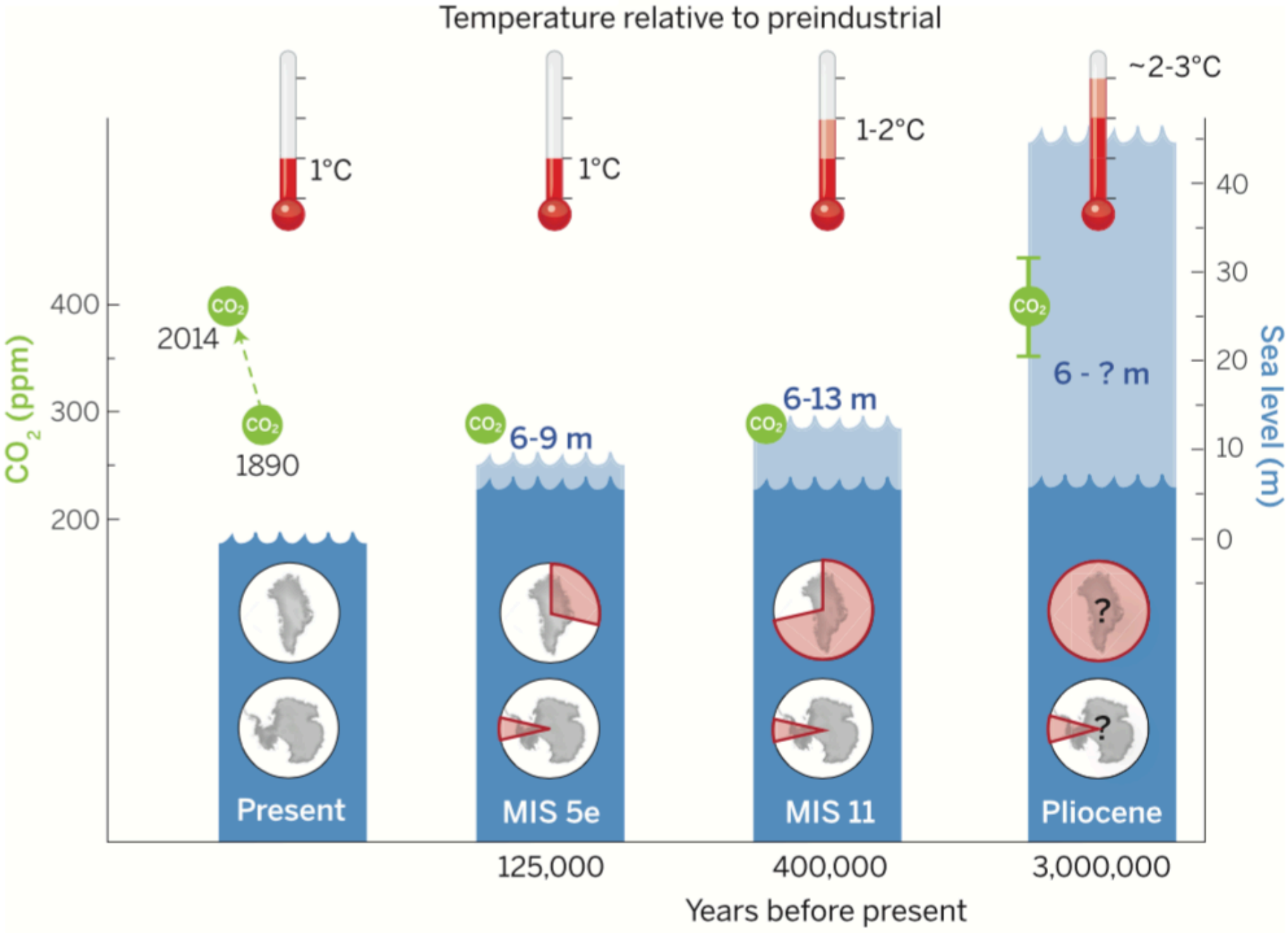
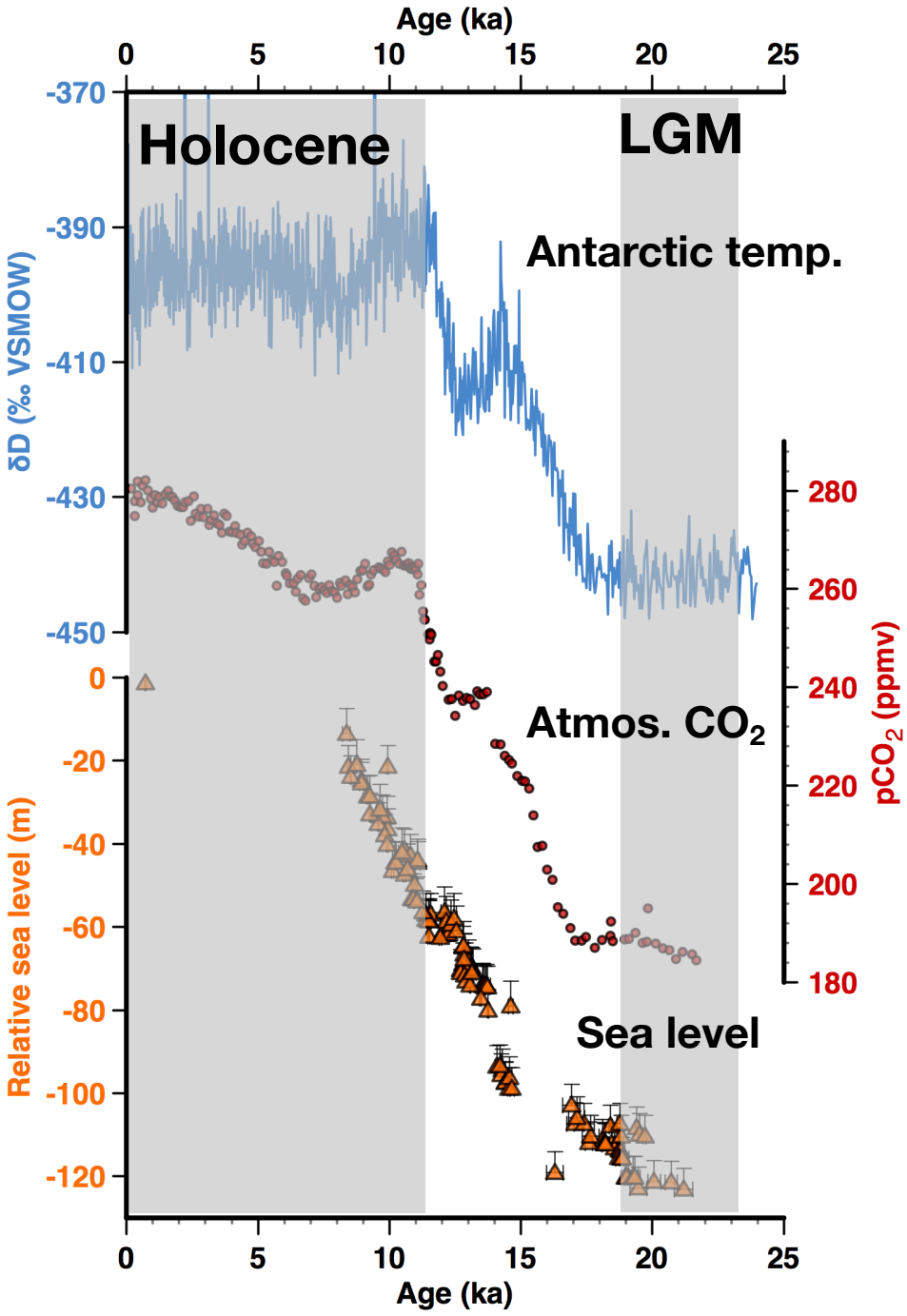


Image created by Robert A. Rohde/Global Warming Art



Dutton et al., Science 2015

Climate change over the last 25 ka

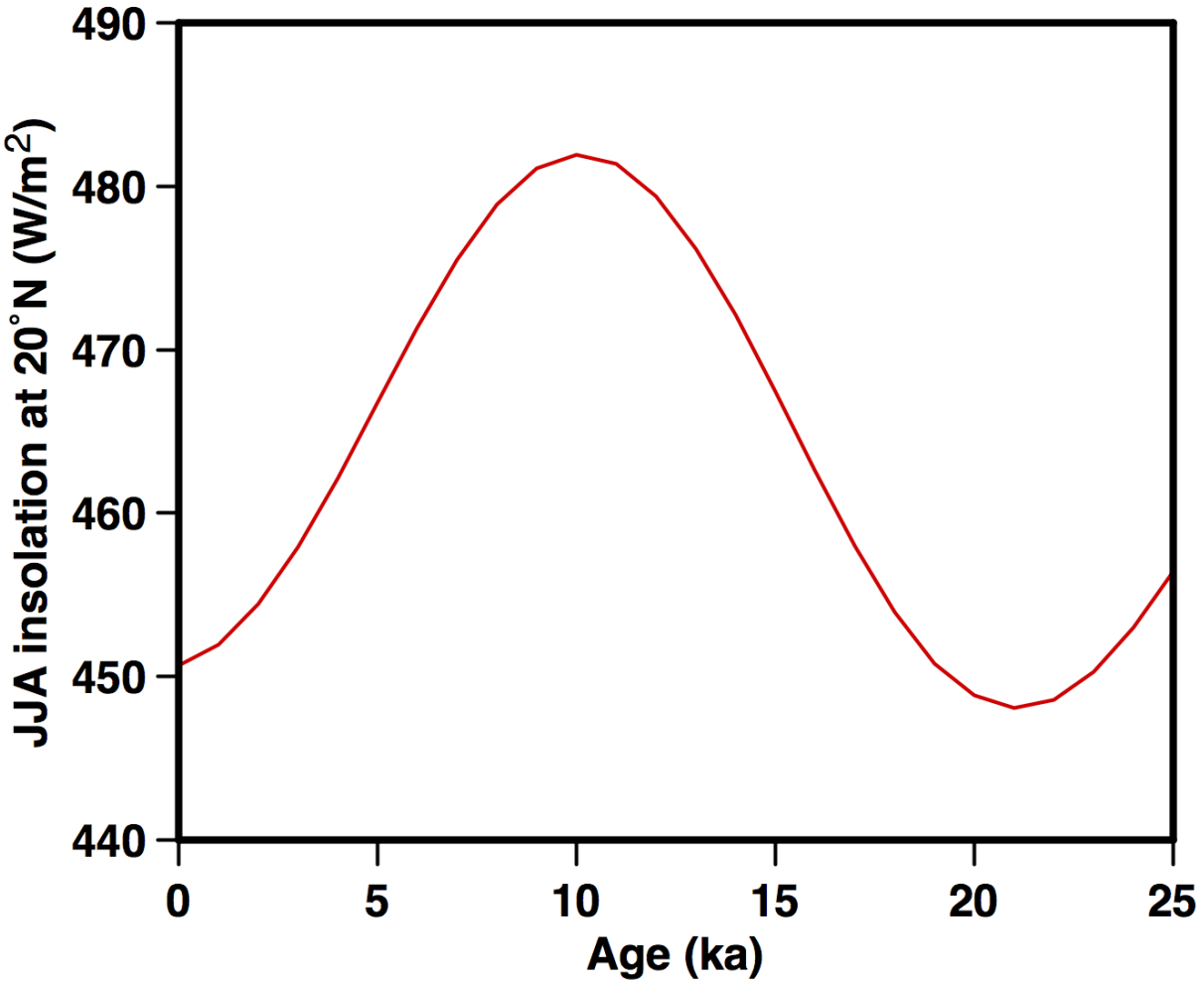


Glacial-interglacial transition

Jouzel et al., Science 2007
Monnin et al., Science 2001
Peltier and Fairbanks, QSR 2006

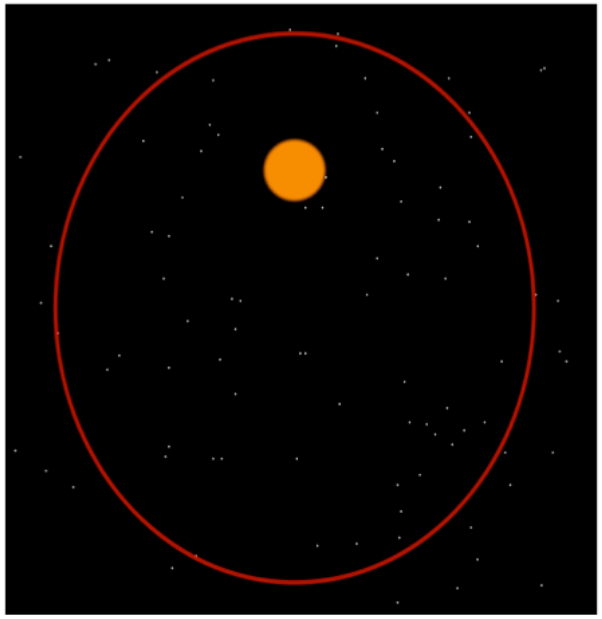
Climate change over the last 25 ka

Orbital changes

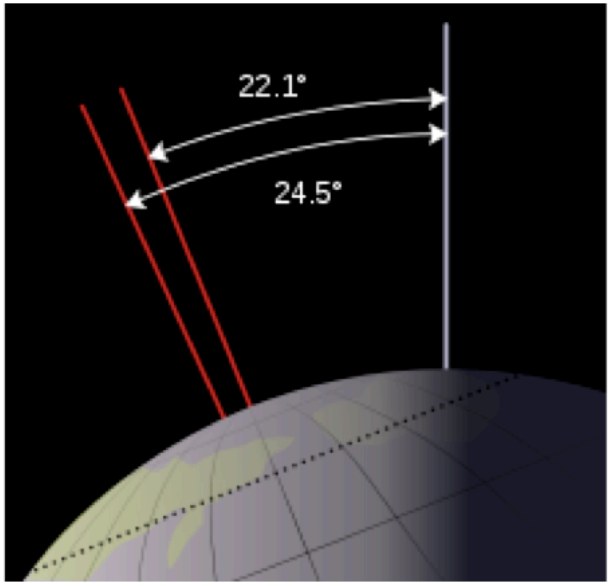


Laskar et al., Astron. & Astrophys. 2004

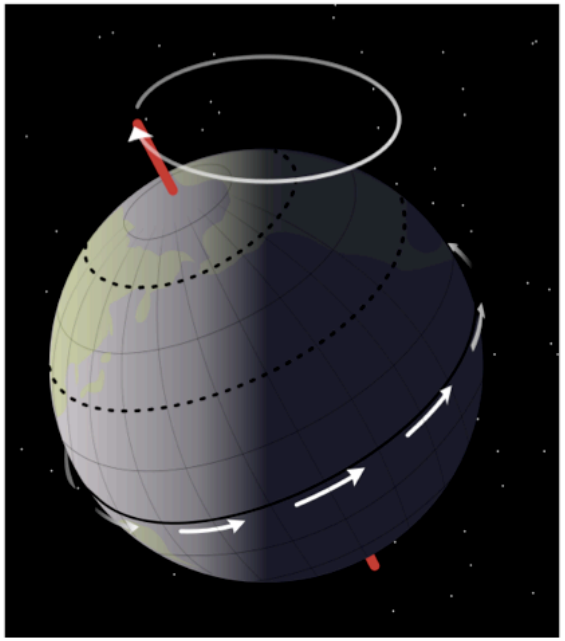
Orbital changes thought to pace climate change on timescales of 10s of thousands of years



Eccentricity
~100 kyr

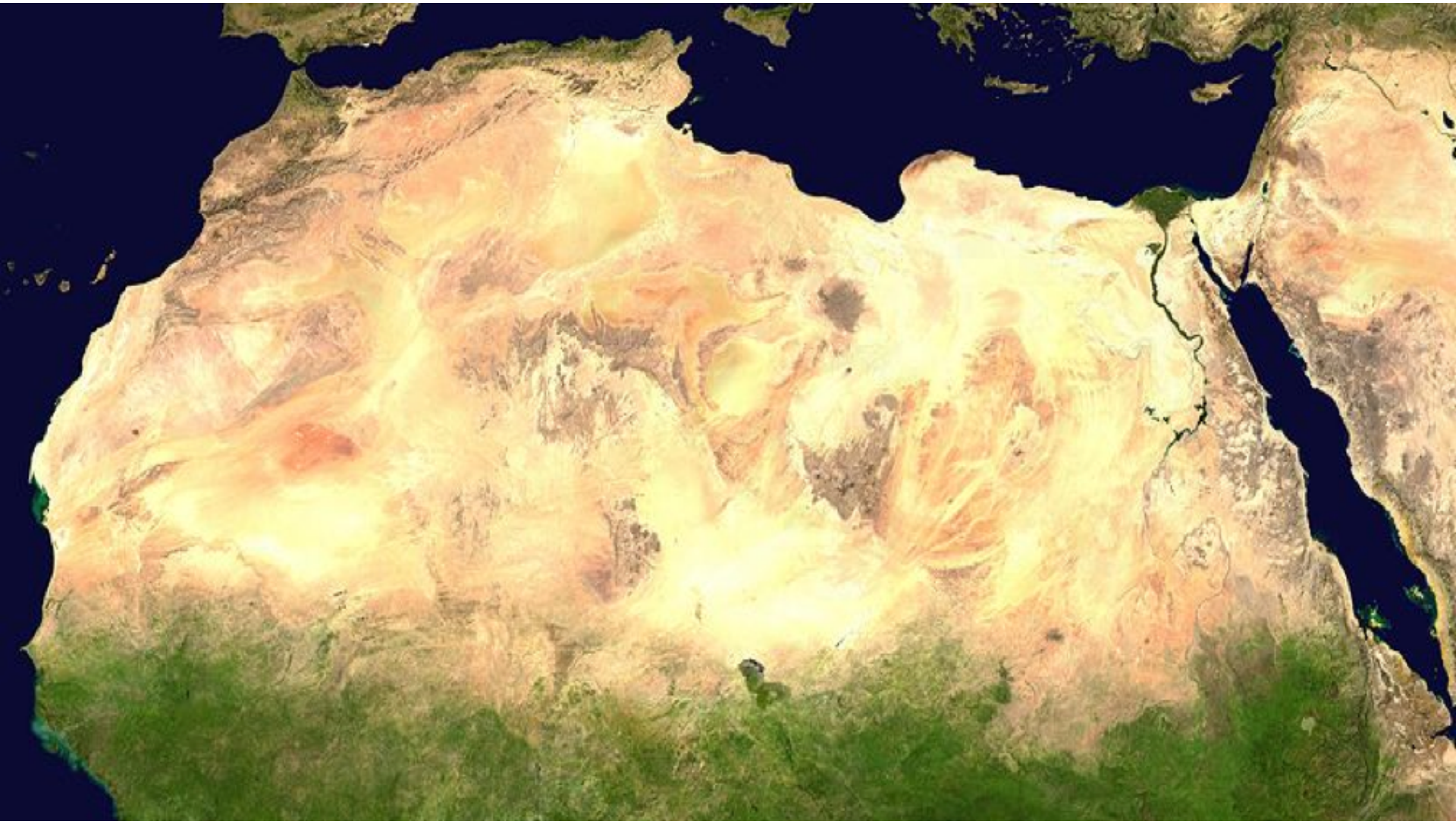


Obliquity (tilt)
~41 kyr

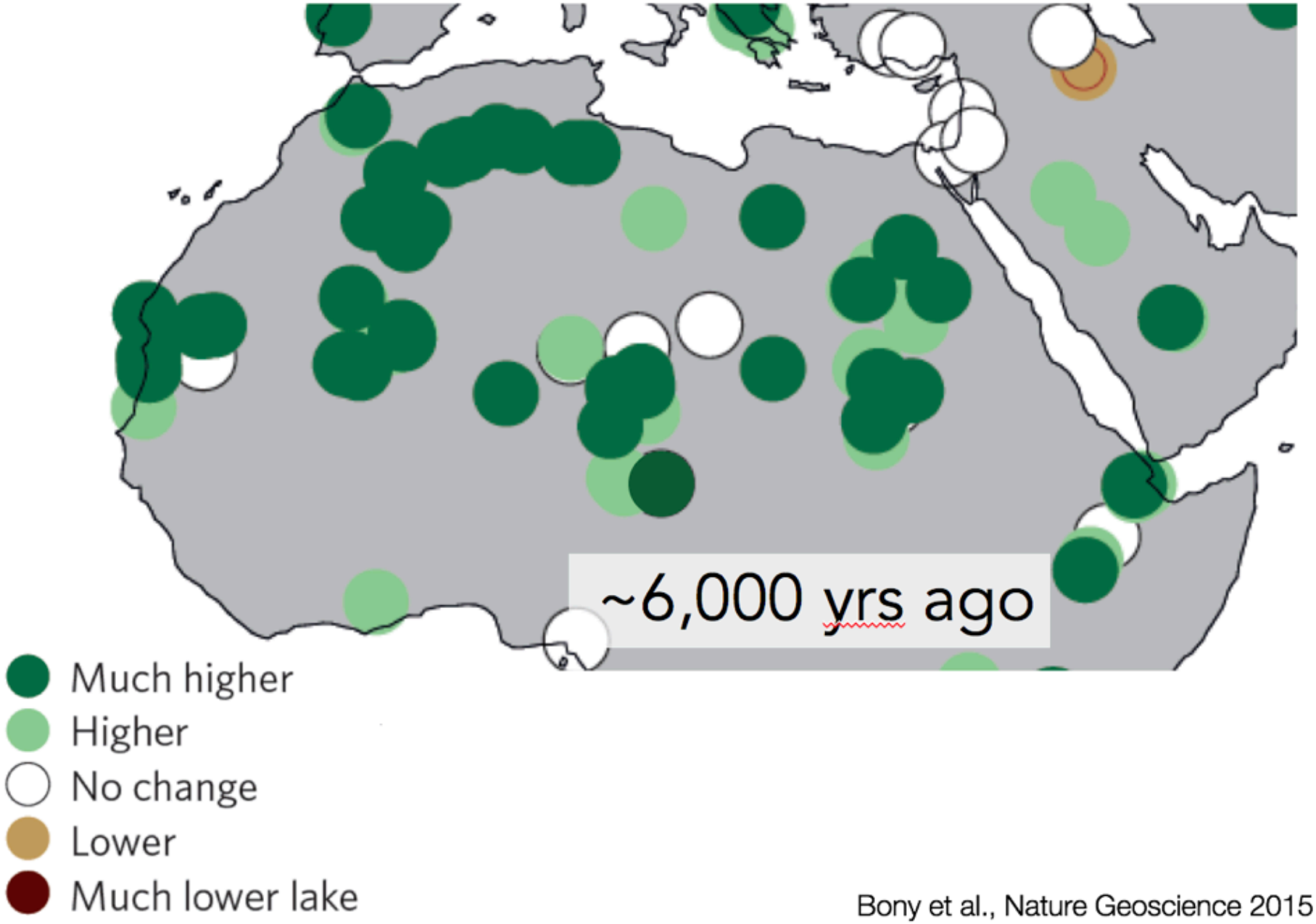


Precession
~22 kyr

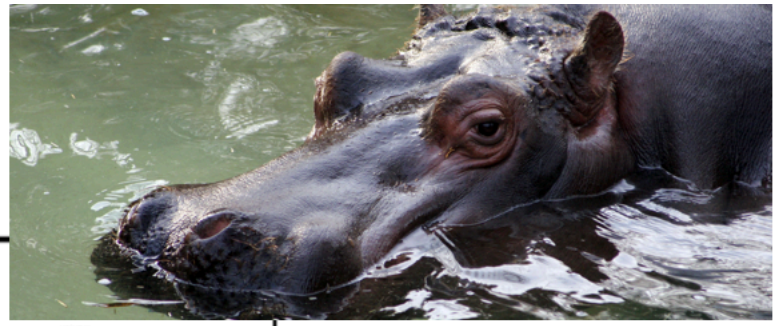
earthobservatory.nasa.gov

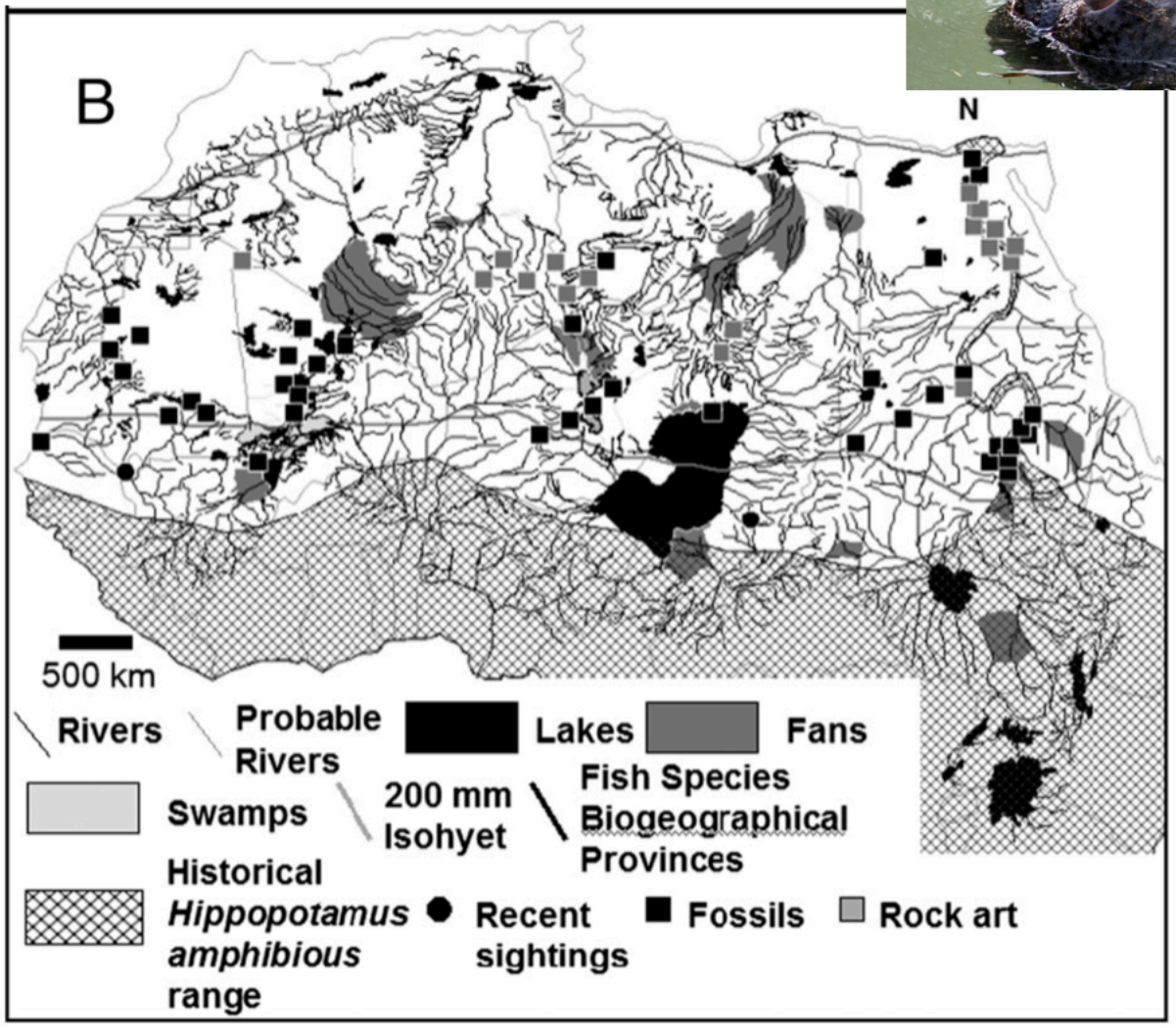


North African lake levels

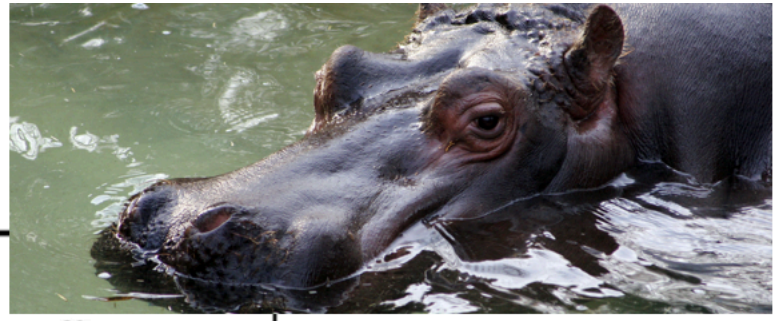


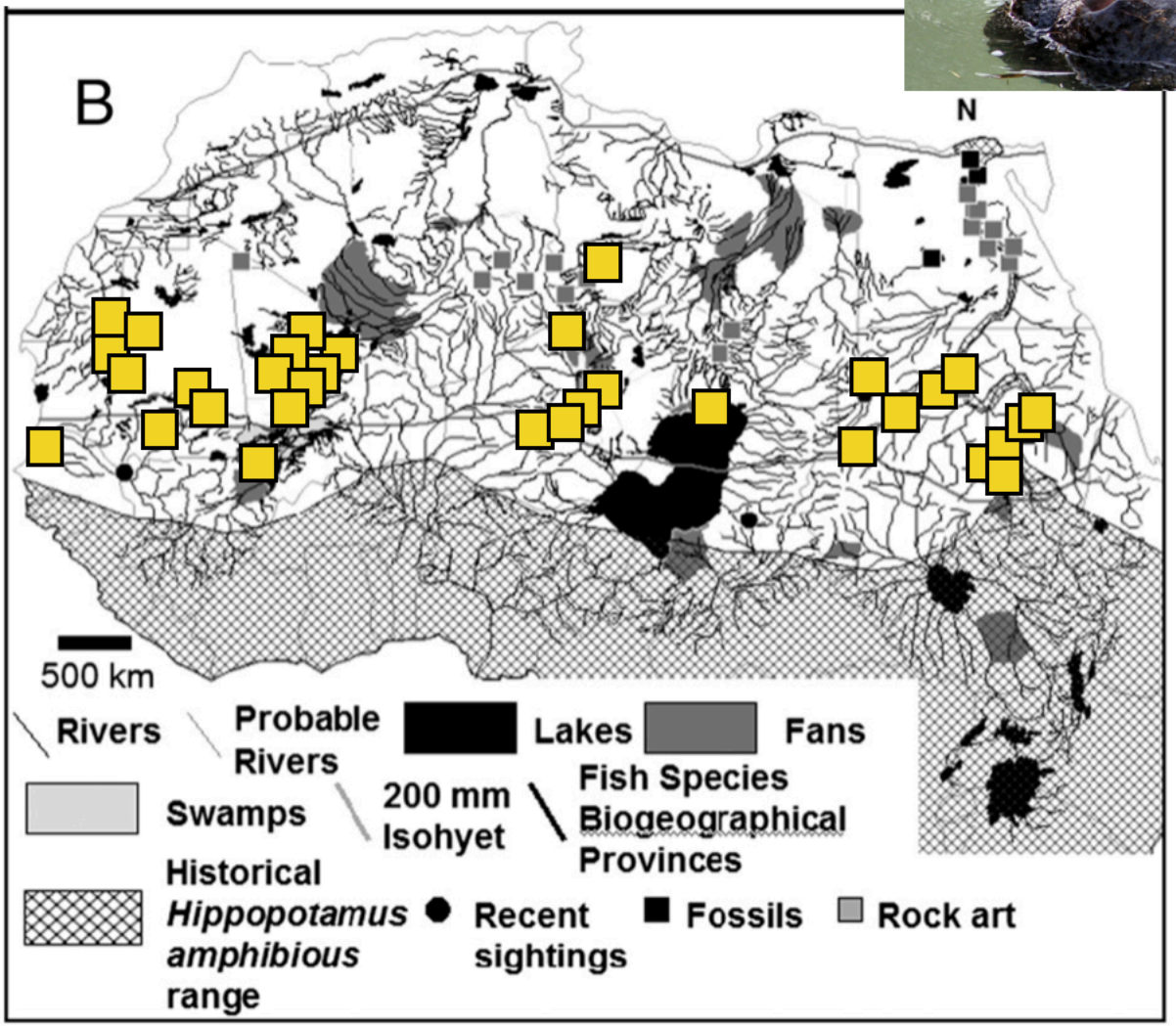
Bony et al., Nature Geoscience 2015





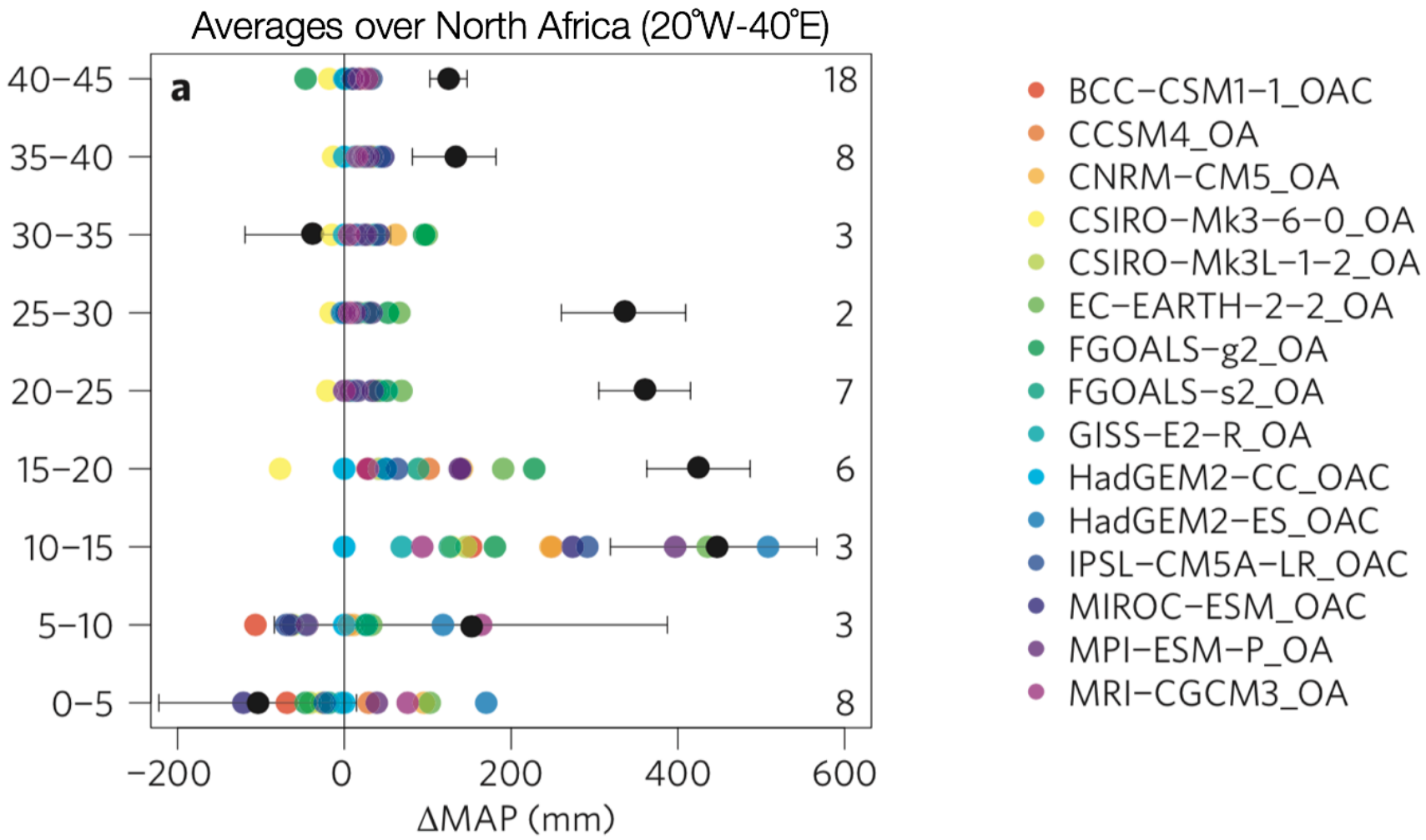
Drake et al., PNAS 2011





Drake et al., PNAS 2011

Testing the models used to project future changes using paleoclimate data



Black dots=6 ka mean annual precip (MAP) changes estimated from pollen
Numbers on right: number of sites contributing to each latitude band
Harrison et al., Nature Climate Change 2015

New directions at the intersection of computation and paleoclimate

- Transient paleoclimate simulations (TraCE-21ka)
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…but there is also still much to be done with theory and idealized models.