Class 11: Pleistocene (11.7 ka – 2.5 Ma) Climate Change

- What has climate done over the past ~2.5 million years?
- What mechanisms explain the observed climate change?

Learning Objectives

1. Describe Earth's orbital cycles and be able to explain how they influence climate over geologic time scales of thousands to hundreds of thousands of years
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3. Explain the 'sawtooth' climate pattern that dominated the Pleistocene, the last 2.7 My
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Climate in the News

The Washington Post
Democracy Dies in Darkness

Climate and Environment

The world needs a massive carbon tax in just 10 years to limit climate change, IMF says

The international organization suggests a cost of $75 per ton by 2030.

The group found that a global tax of $75 per ton by the year 2030 could limit the planet's warming to 2 degrees Celsius (3.6 degrees Fahrenheit), or roughly double what it is now. That would greatly increase the price of fossil-fuel-based

Climate in the News

Mother Jones

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ENVIRONMENT OCTOBER 10, 2019

If Power Shutoffs Are the New Normal in California, PG&E Needs to Do More than Provide Charging Stations

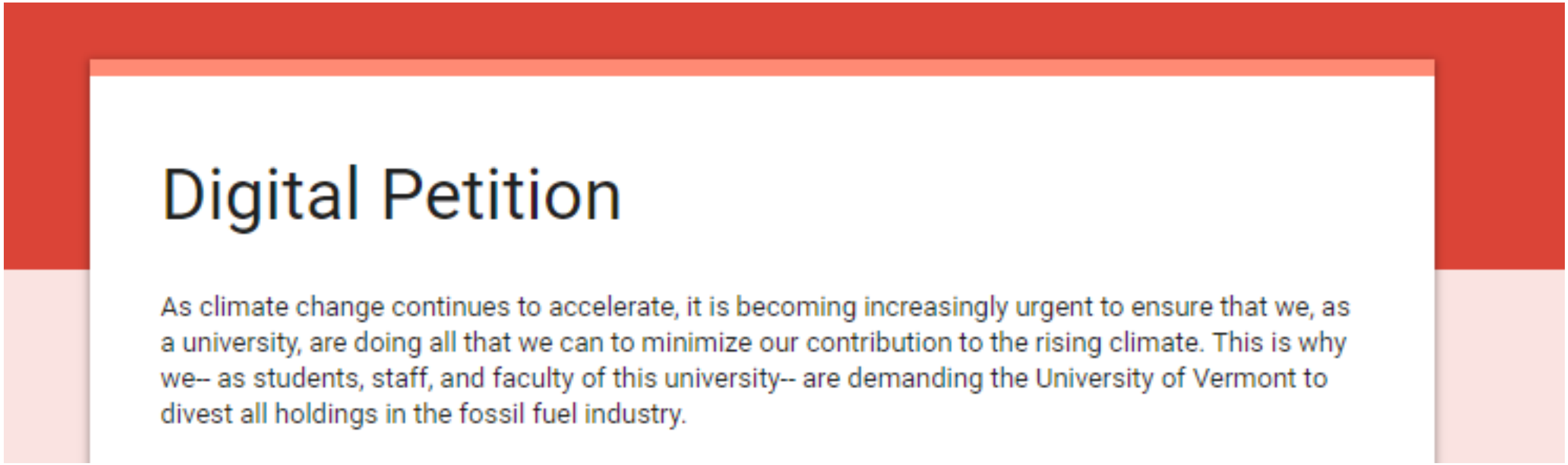
"What are we learning from this? Because this is crazy."

MARISA ENDICOTT
Fellow
Bio

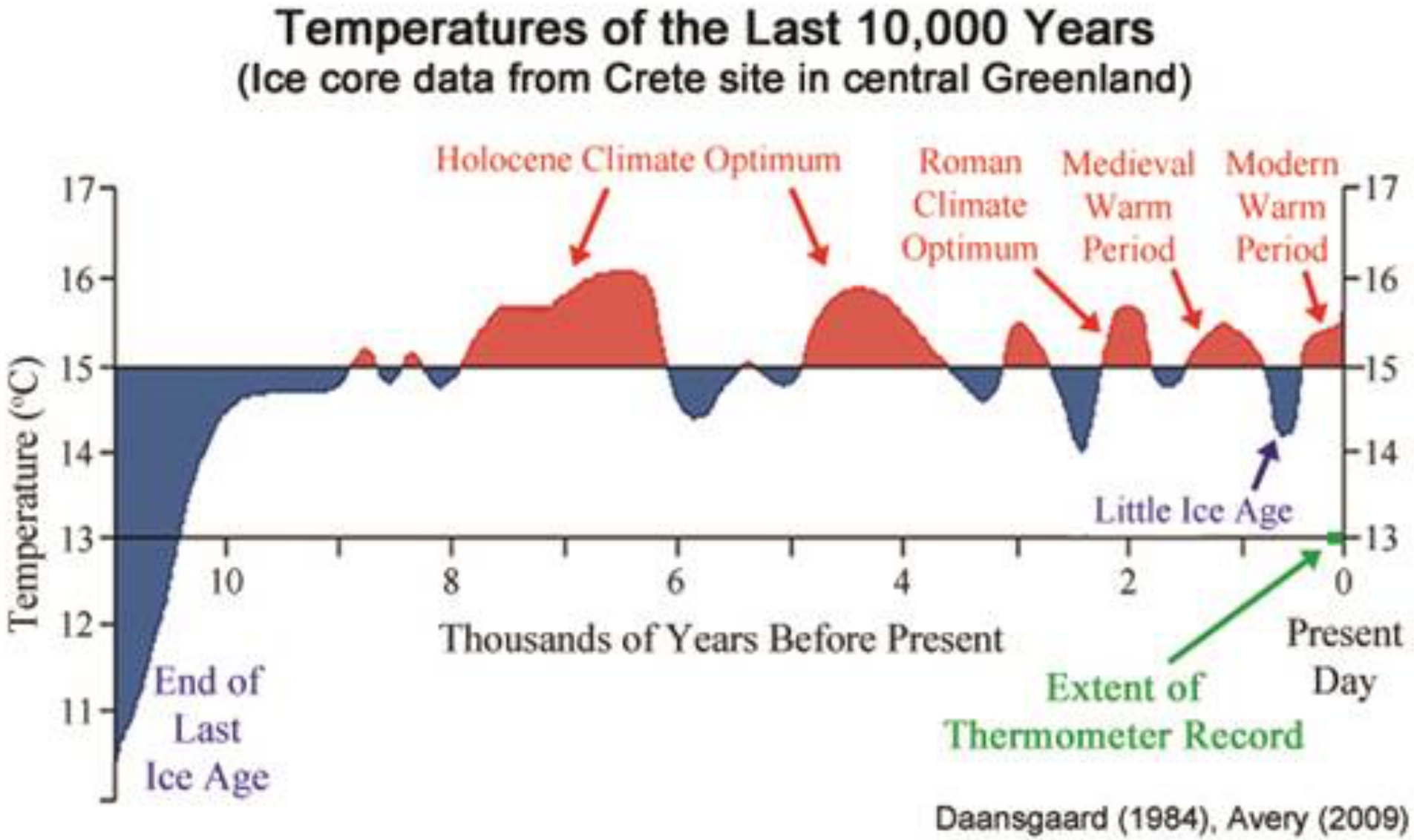
"I'm frustrated. I'm angry," Joanie, who lives in the Oakland hills, tells me in the parking lot. "What are we learning from this? Because this is crazy." She doesn't completely trust PG&E's stated reasons for shutting off the electricity, hinting it might have something to due with the financial losses it's incurred due to fires and litigation. The company declared bankruptcy in January after its role in sparking recent wildfires led to lawsuits and major payouts.

Student Climate Action

go.uvm.edu/divest



Review: Paleoclimate – Industrial & Holocene



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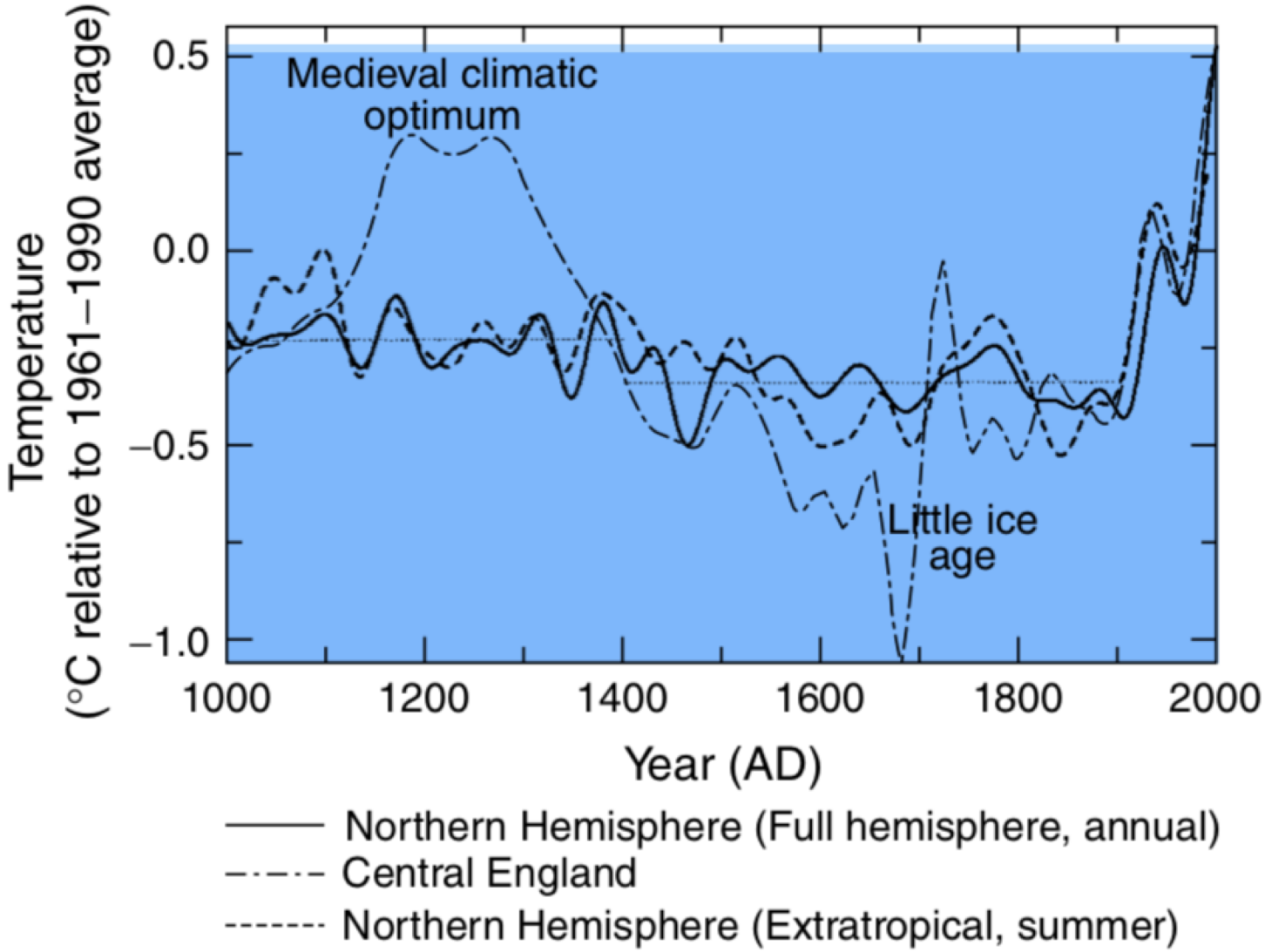

Review: Paleoclimate – Industrial & Holocene

ARCHAEOLOGY

A publication of the Archaeological Institute of America

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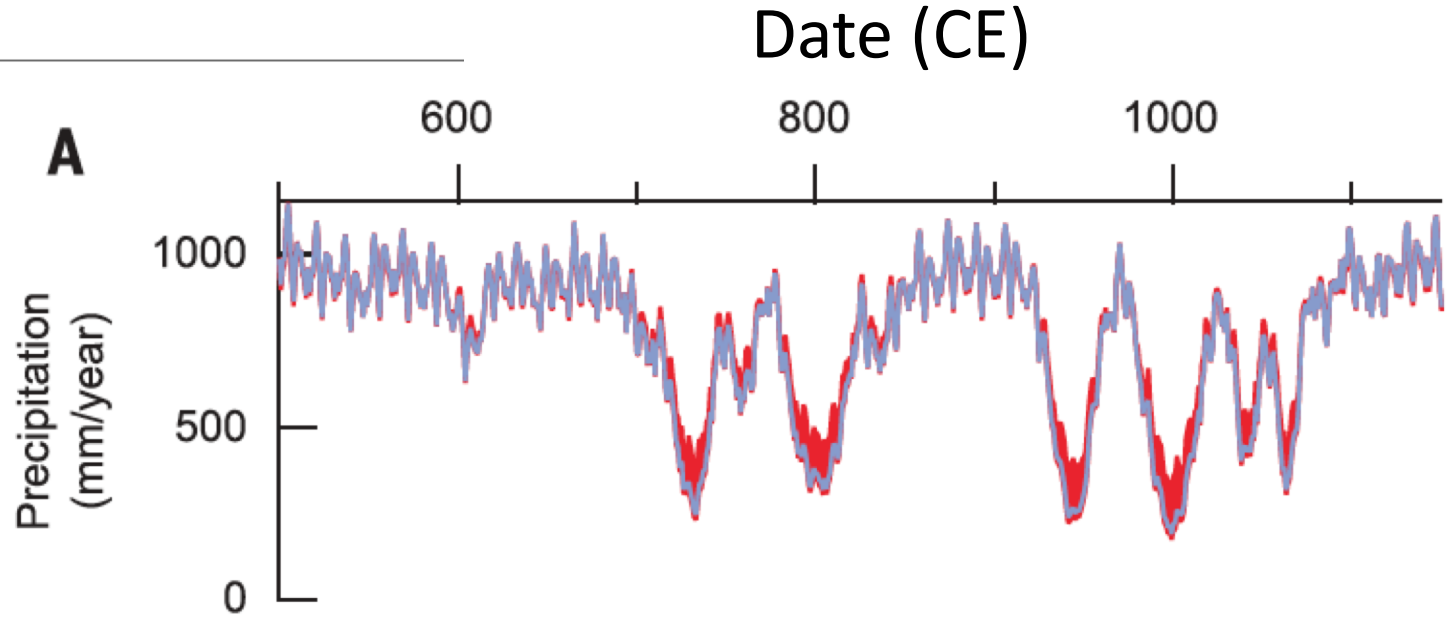
Scientists Measure Maya Drought With "Fossil Water"



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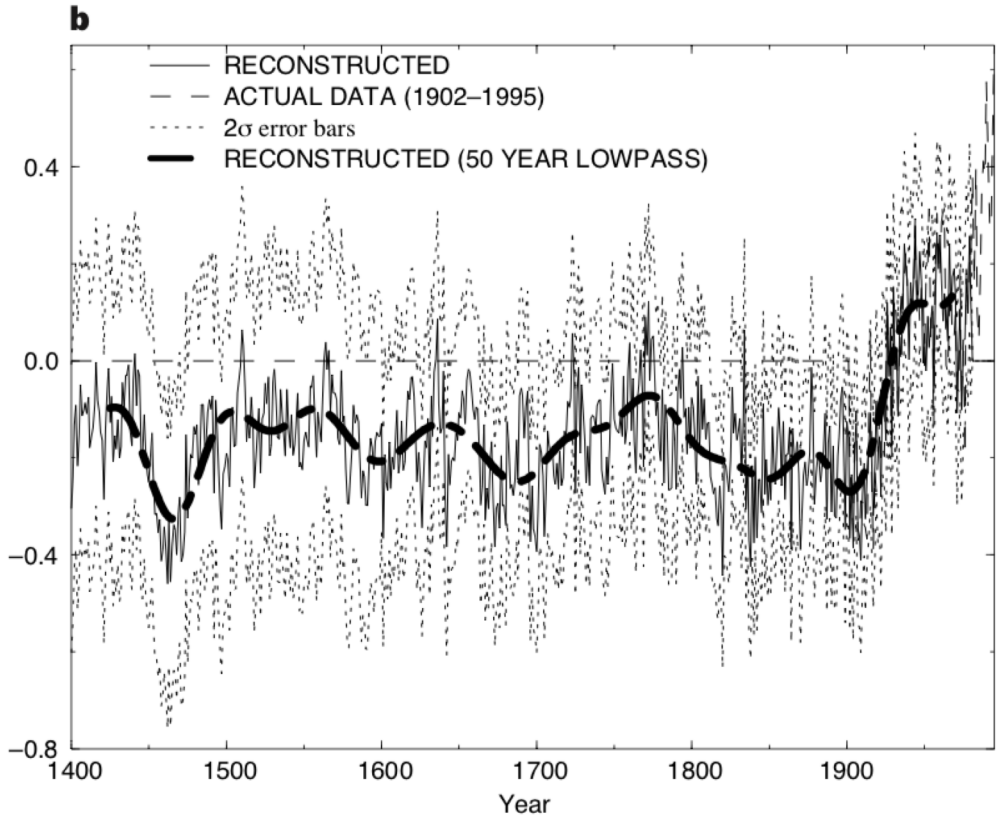

Global-scale temperature patterns and climate forcing over the past six centuries

Michael E. Mann*, Raymond S. Bradley* & Malcolm K. Hughes†

* *Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003-5820, USA*
† *Laboratory of Tree Ring Research, University of Arizona, Tucson, Arizona 85721, USA*

Spatially resolved global reconstructions of annual surface temperature patterns over the past six centuries are based on the multivariate calibration of widely distributed high-resolution proxy climate indicators. Time-dependent correlations of the reconstructions with time-series records representing changes in greenhouse-gas concentrations, solar irradiance, and volcanic aerosols suggest that each of these factors has contributed to the climate variability of the past 400 years, with greenhouse gases emerging as the dominant forcing during the twentieth century. Northern Hemisphere mean annual temperatures for three of the past eight years are warmer than any other year since (at least) AD 1400.

Today's Class: Paleoclimate – The Pleistocene

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Last Glacial Maximum to the Holocene → The Last 150,000 Years → The 'Sawtooth' Climate Pattern → Pleistocene Comparisons to Present Climate

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Last Glacial Maximum (~29-20 ka) to the Holocene

- BIG changes once we look past the Holocene
- Big ice sheets over North America, Scandinavia, Eurasia at Last Glacial Maximum
- Sea level ~130 m lower than today
- Global temp ~3.5°C lower than today

Figure from Stokes (2017)

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- Global rise in temperature and CO_2 from LGM to Holocene
- Rising incoming solar radiation in key areas can explain some of the warming
- What about the weird ups and downs?
- What explains CO_2 rise?

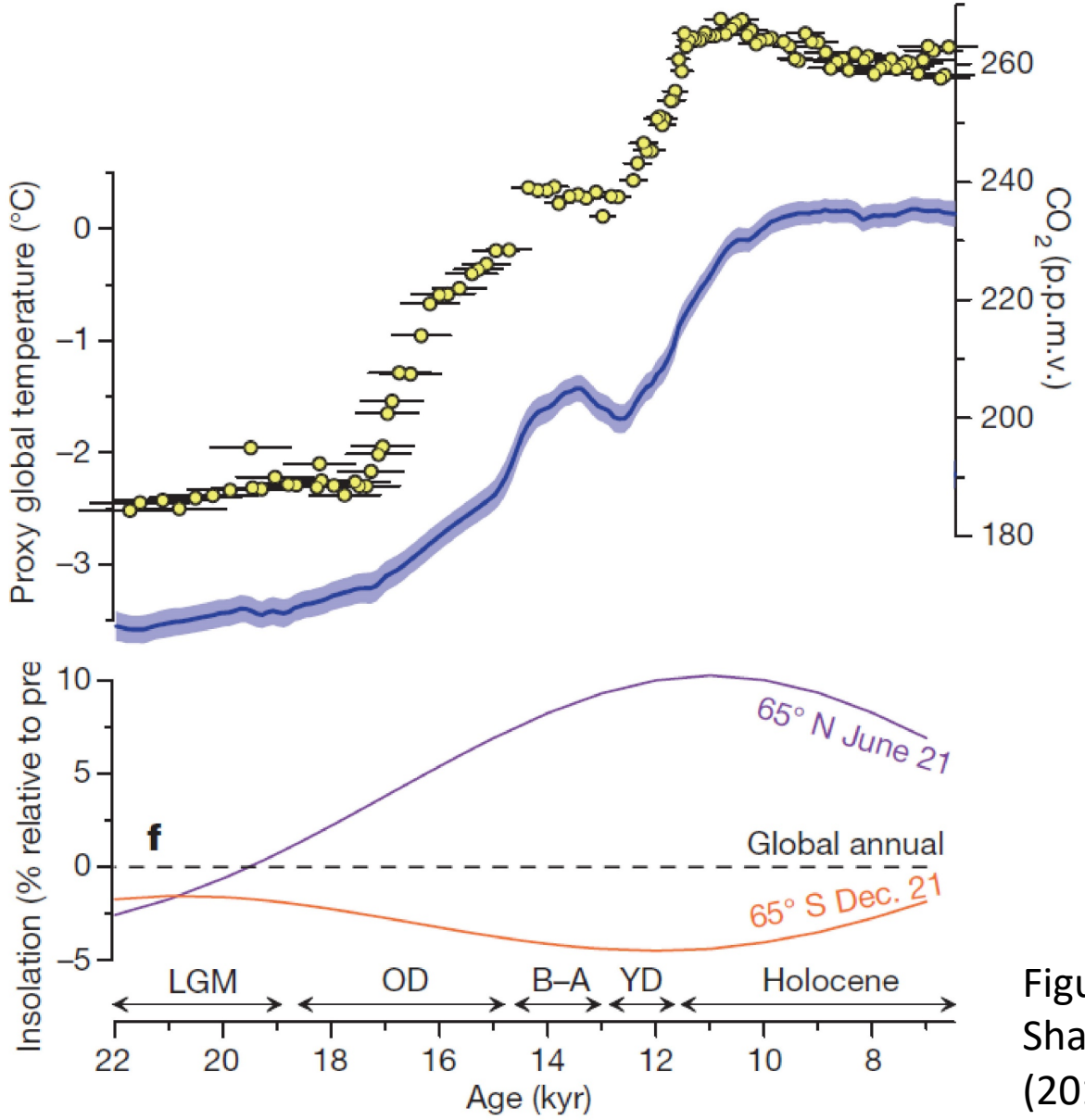
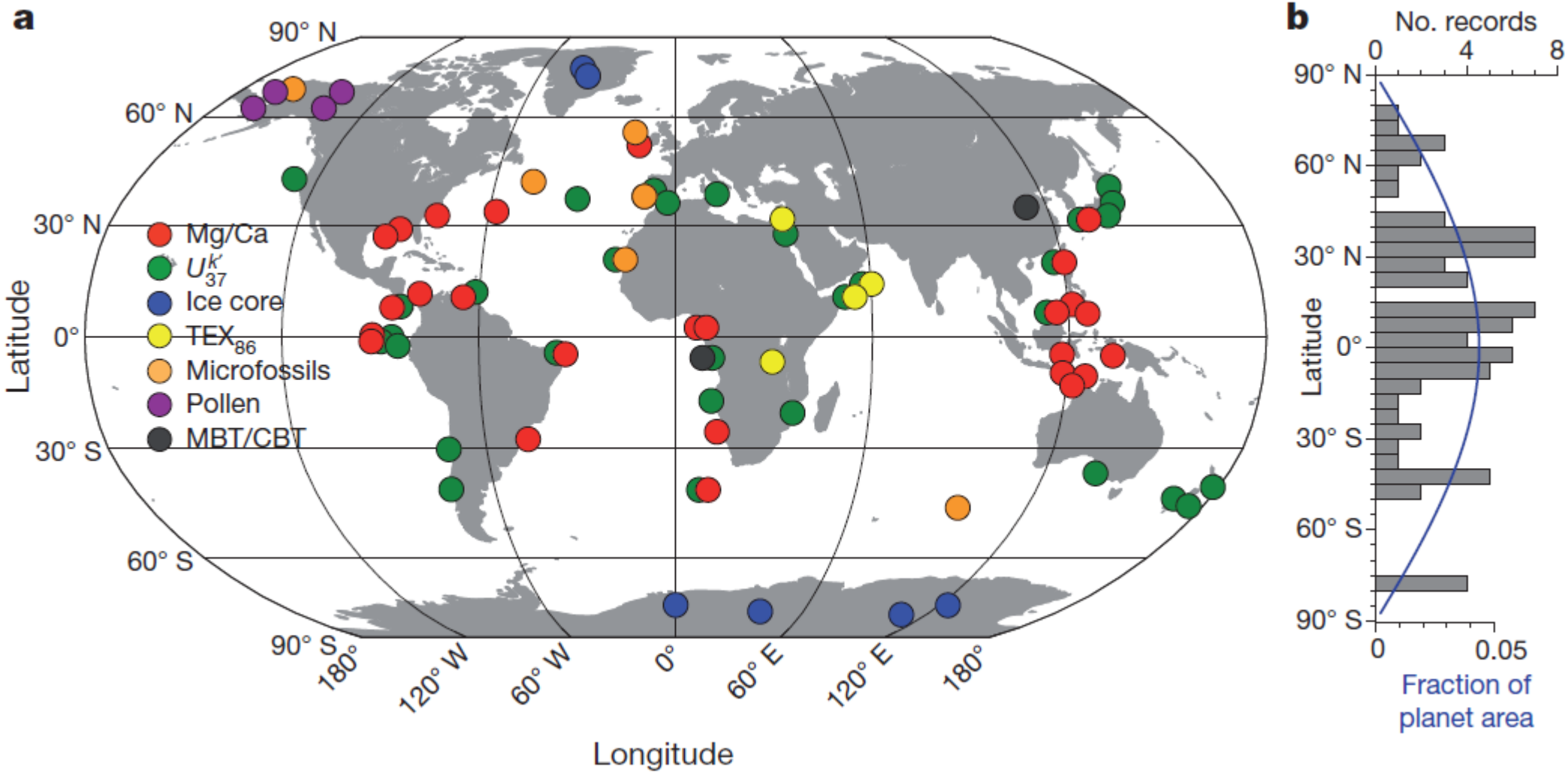


Figure from Shakun et al. (2012)

Last Glacial Maximum (~29-20 ka) to the Holocene



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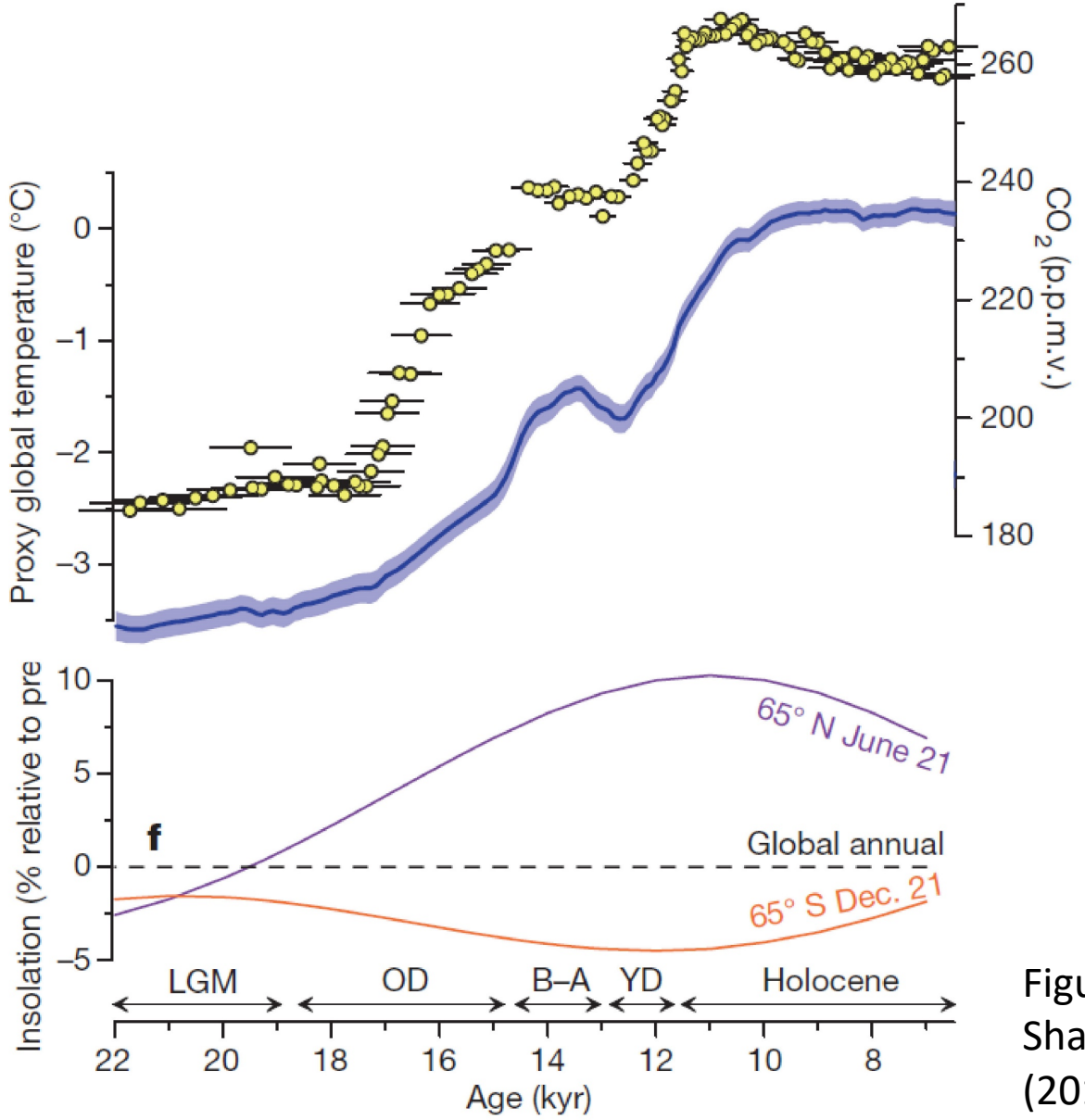

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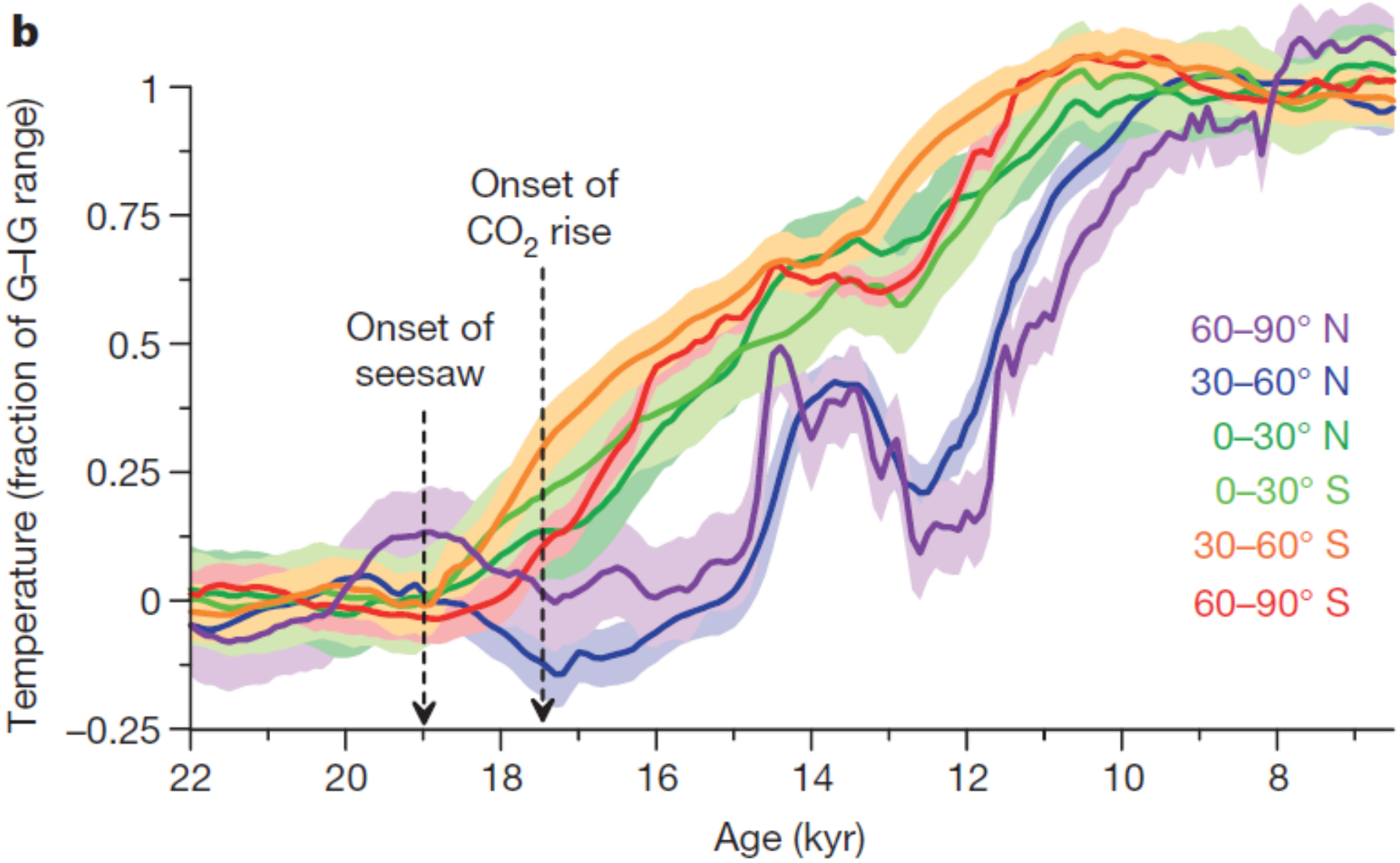


Figure from Shakun et al. (2012)

Last Glacial Maximum (~29-20 ka) to the Holocene

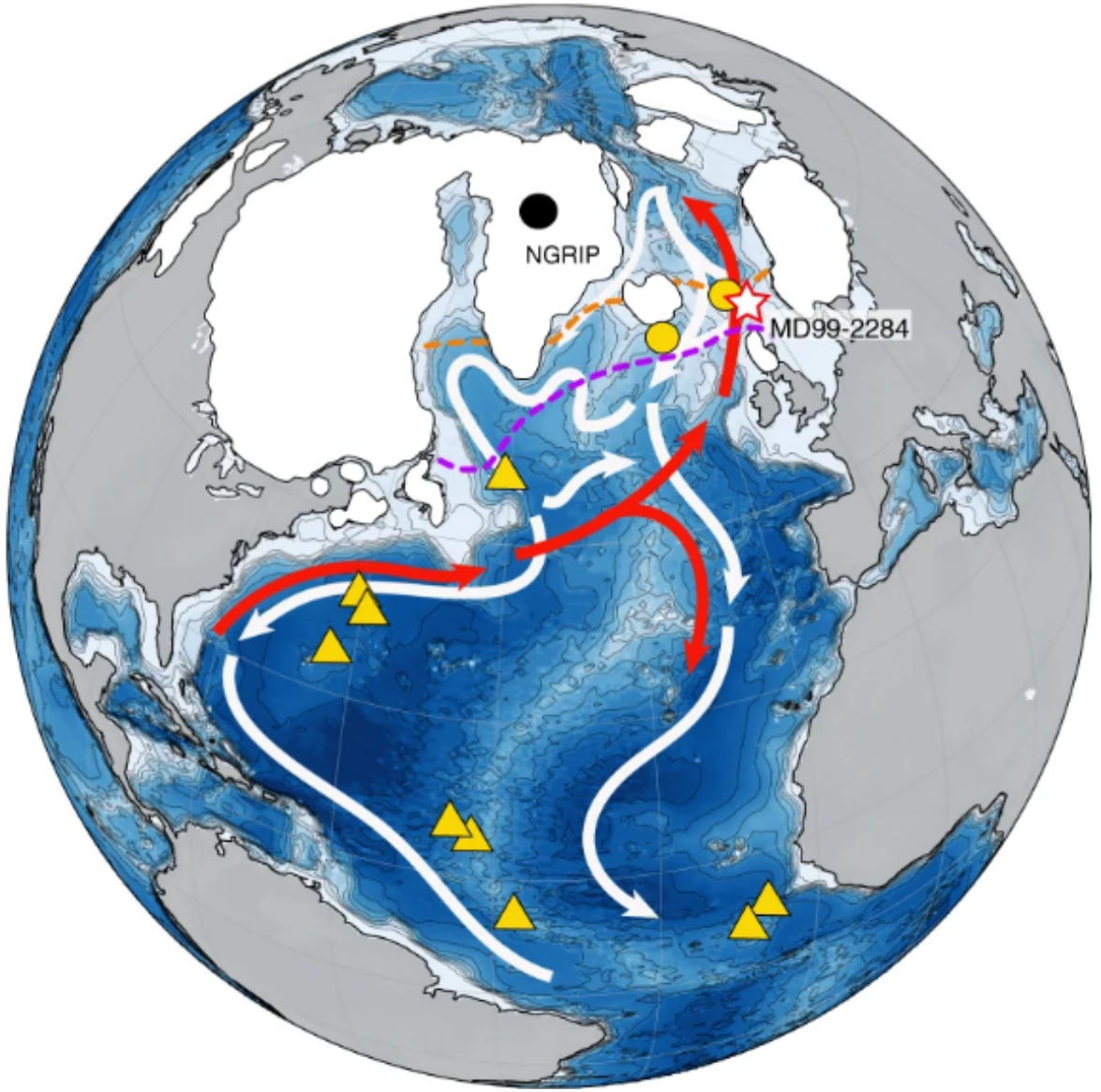


Figure from Muschitiello et al. (2019)

Last Glacial Maximum (~29-20 ka) to the Holocene

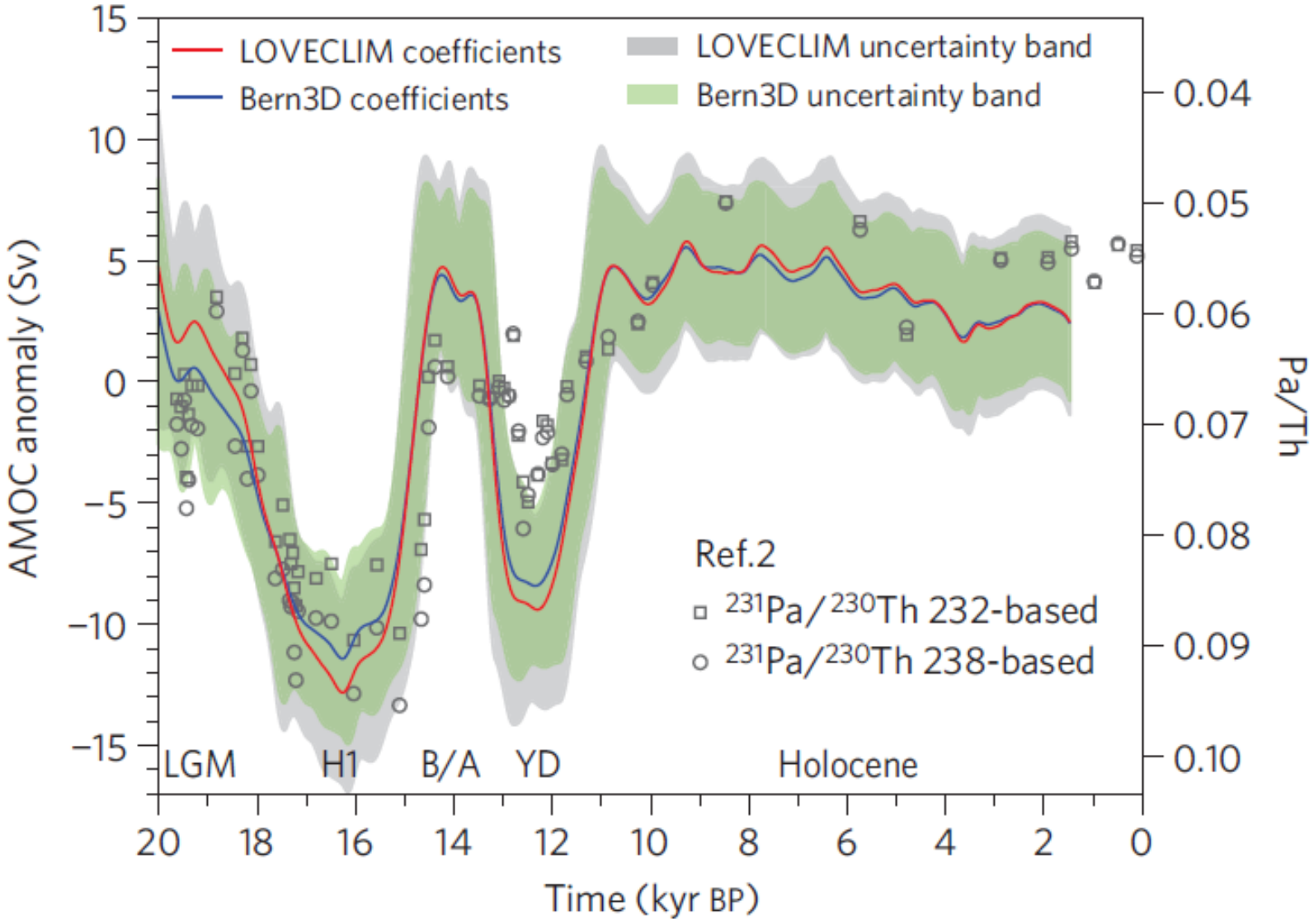
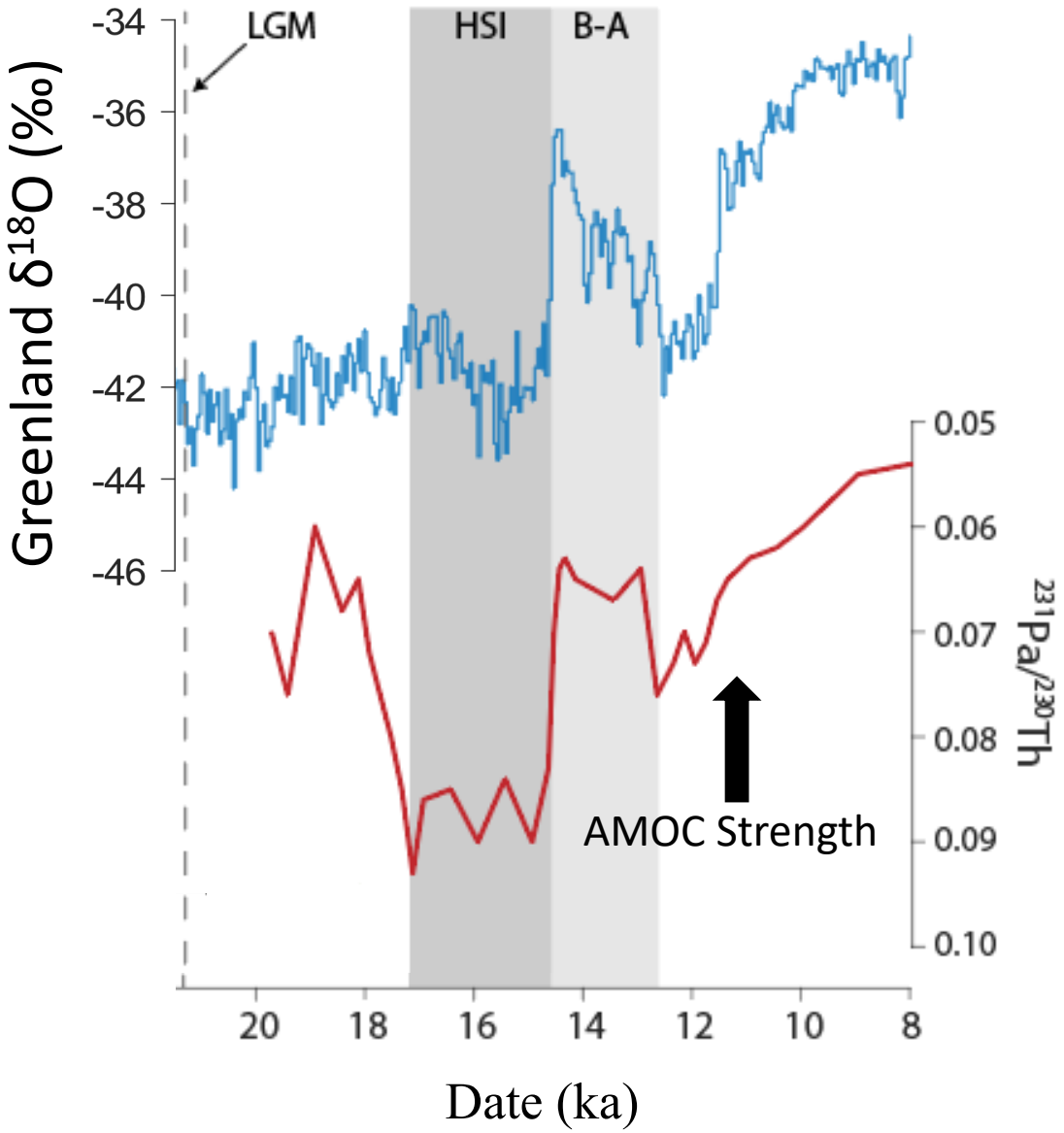


Figure from Ritz et al. (2013)

Last Glacial Maximum (~29-20 ka) to the Holocene

- Meltwater from melting ice sheets disrupted the AMOC
- Less heat transported into North Atlantic with weak AMOC
- Periods of abrupt cooling and warming in North Atlantic during deglaciation



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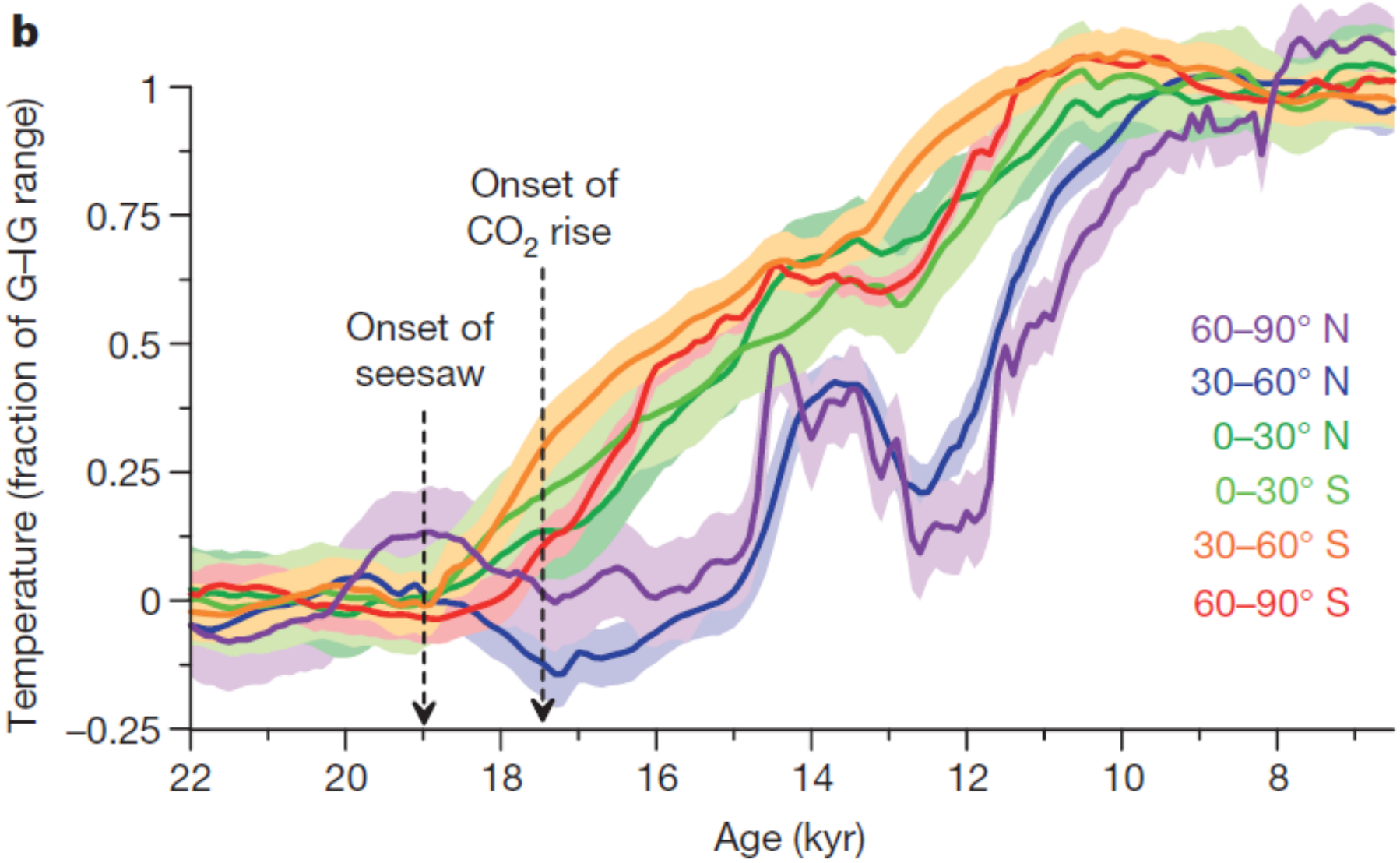

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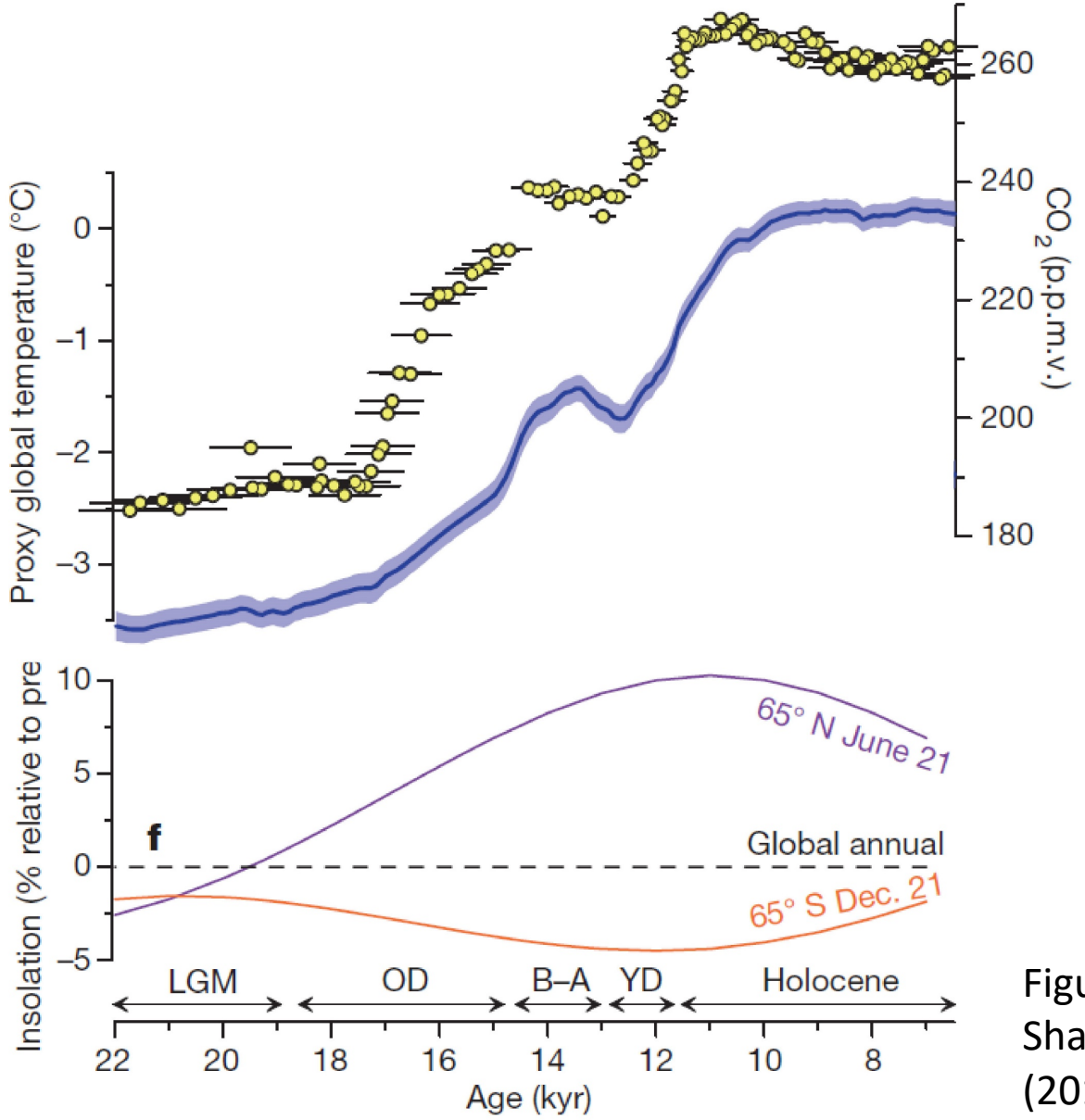


Figure from Shakun et al. (2012)

Last Glacial Maximum (~29-20 ka) to the Holocene

ARTICLE

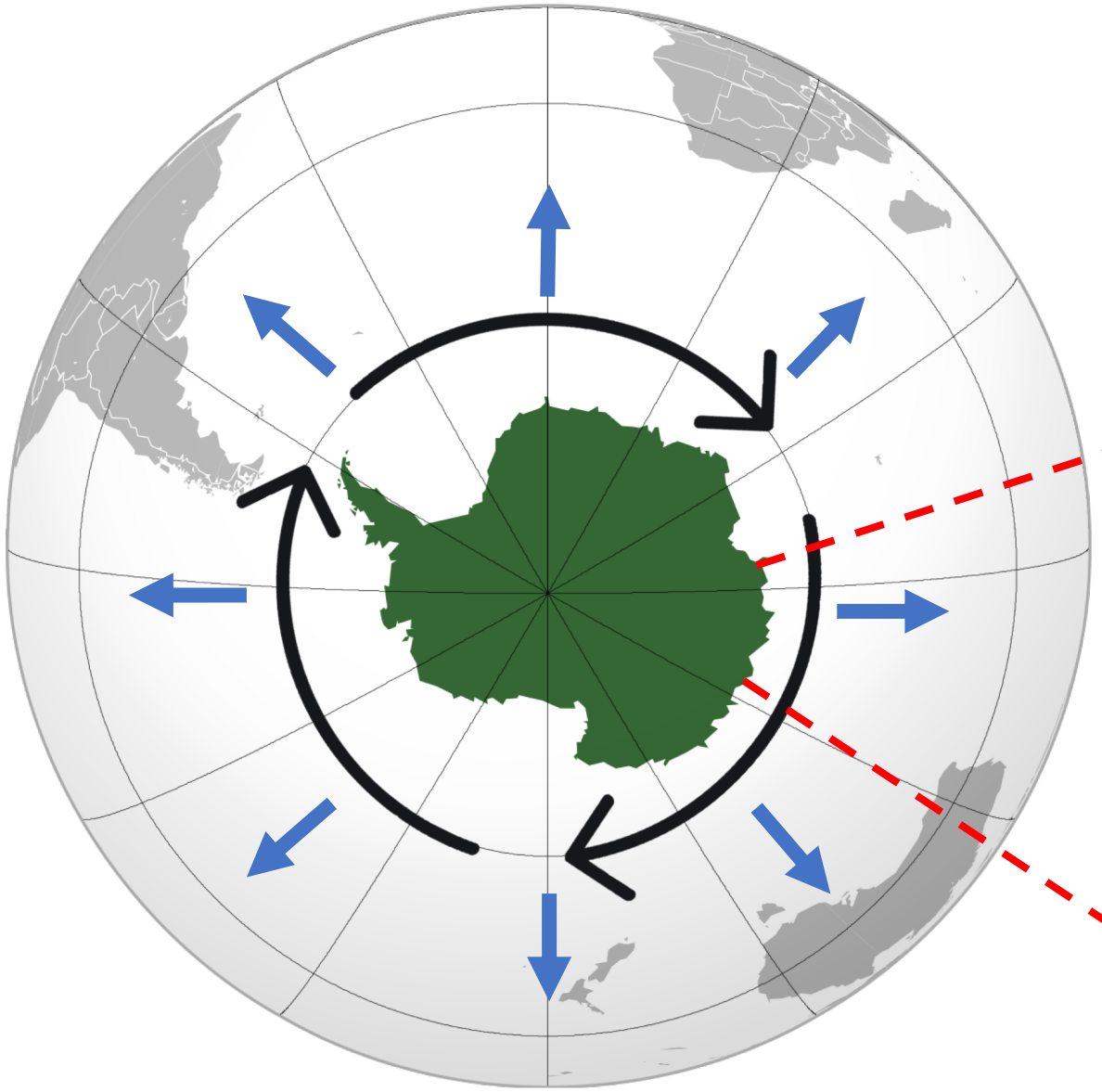
doi:10.1038/nature10915

Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation

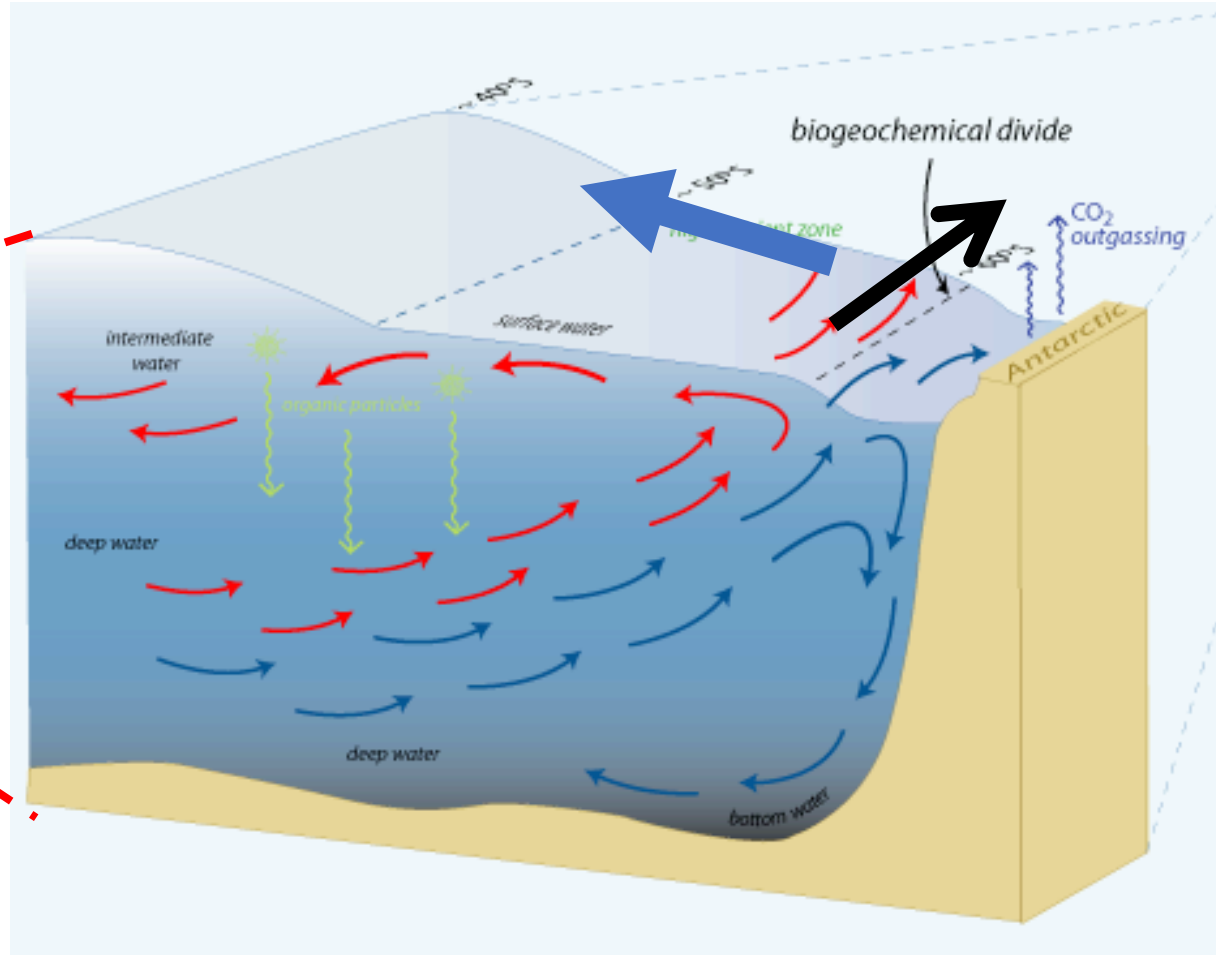
Jeremy D. Shakun[1,2], Peter U. Clark[3], Feng He[4], Shaun A. Marcott[3], Alan C. Mix[3], Zhengyu Liu[4,5,6], Bette Otto-Bliesner[7], Andreas Schmittner[3] & Edouard Bard[8]

(2012)

Reminder: Southern Ocean Upwelling



Wind-driven currents cause upwelling off the coast of Antarctica



Deglaciation Change in Upwelling

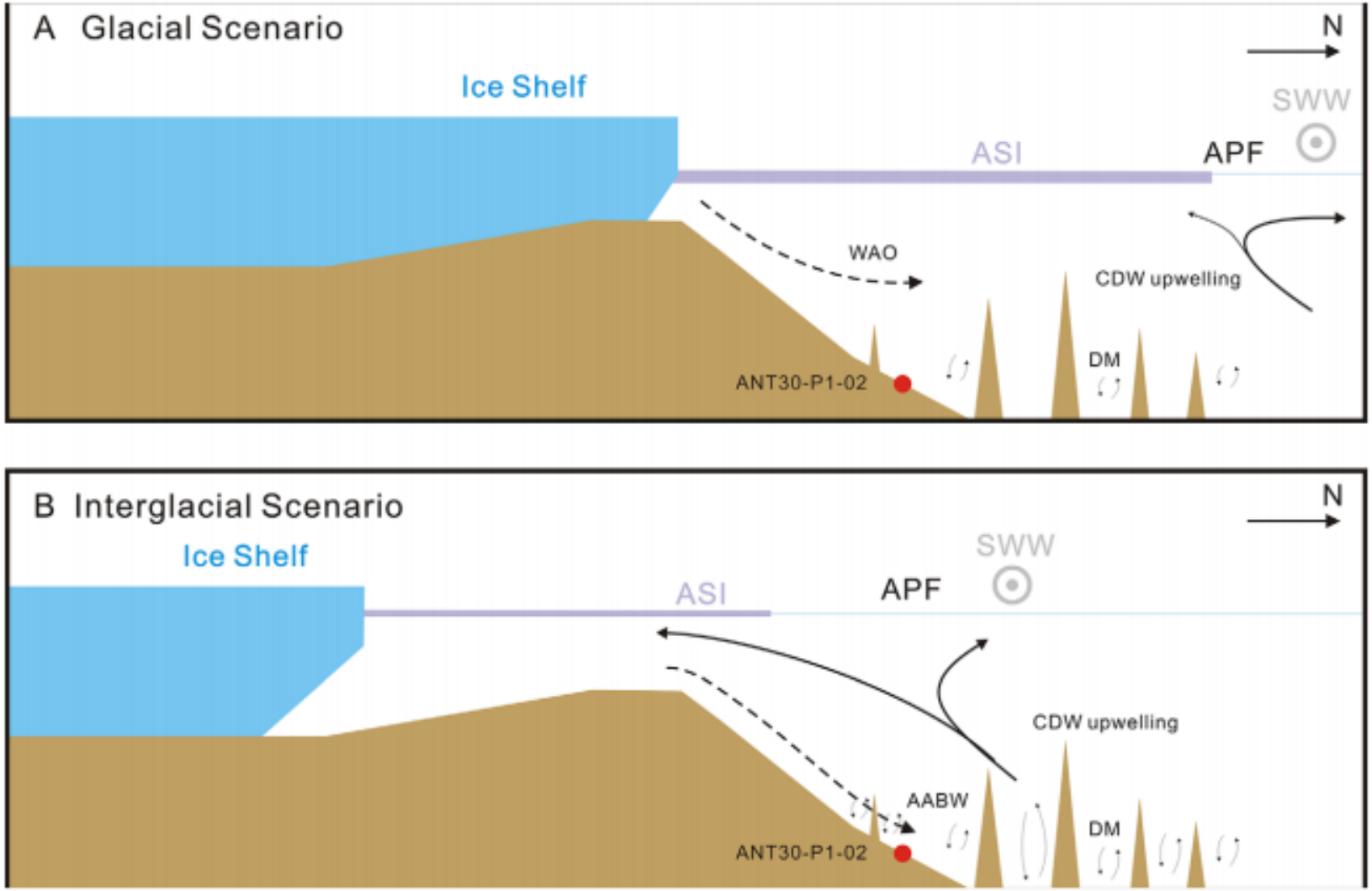
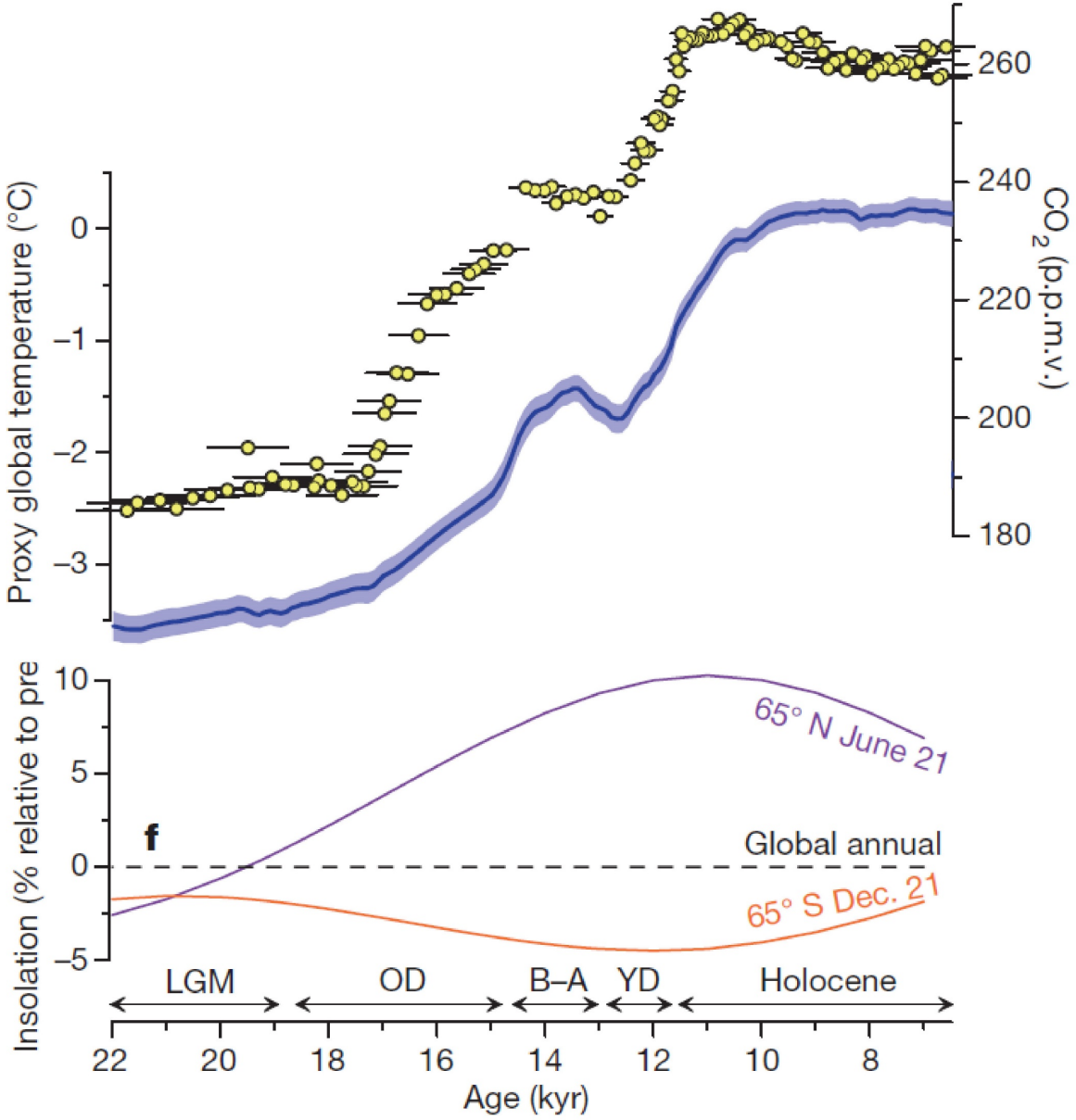


Figure from Wu et al. (2018)

Deglaciation ‘Story’

1. Increasing insolation causes Northern Hemisphere ice sheets to begin shrinking
2. Meltwater into North Atlantic slows AMOC
3. North Atlantic cools, South Atlantic warms
4. Reduced Antarctic sea ice leads to increased upwelling (increasing carbon flux to atmosphere)
5. AMOC eventually recovers, causing more ice sheet melt
6. Repeat…



Scientist Profile: Professor Jeremy Shakun

Jeremy Shakun is a paleoclimatologist based out of Boston College. His research focuses on how the cryosphere has influenced and responded to climate change in Earth's past. He has had several important publications including the Deglacial CO_2 – Temperature relationship and a recent paper on the long-term stability of the East Antarctic Ice Sheet.

Today's Class: Paleoclimate – The Pleistocene

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The Last 150,000 Years

- Build-up to maximum glacial conditions (LGM)
- Climate changes driven by orbital forcing *and* feedbacks within the global climate system
- Example: expanding Antarctic sea ice reducing ocean-atmosphere carbon exchange, leading to further cooling

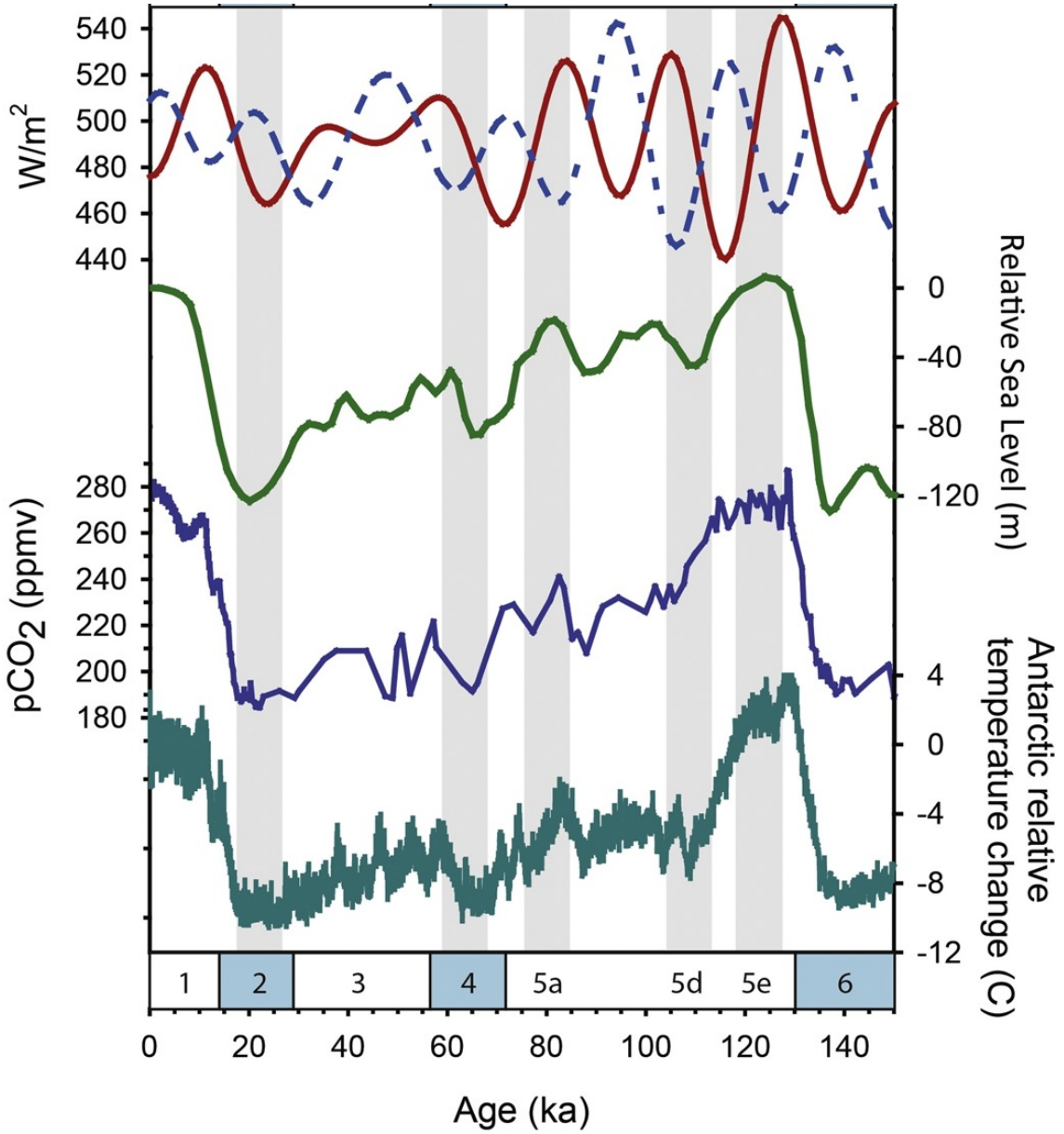
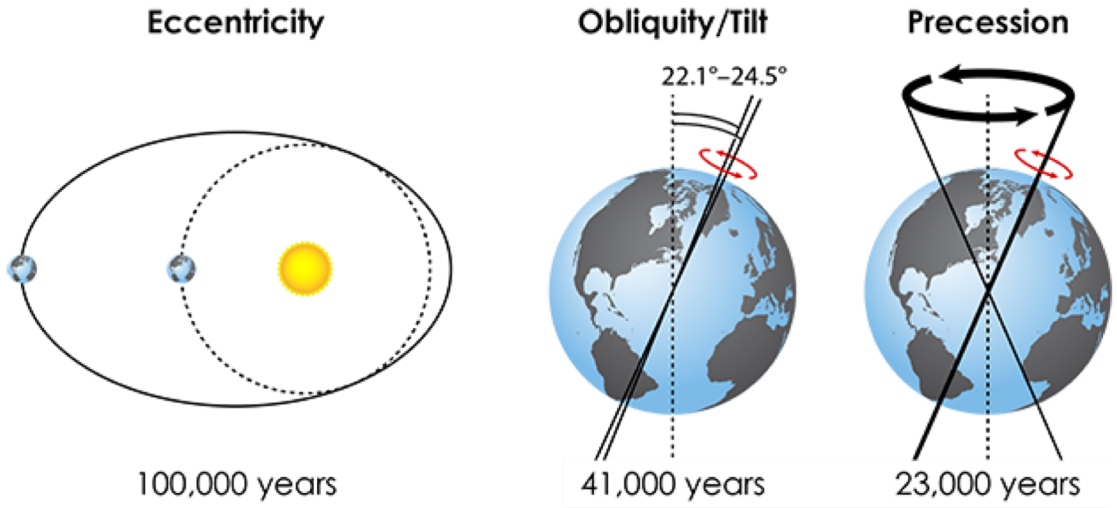
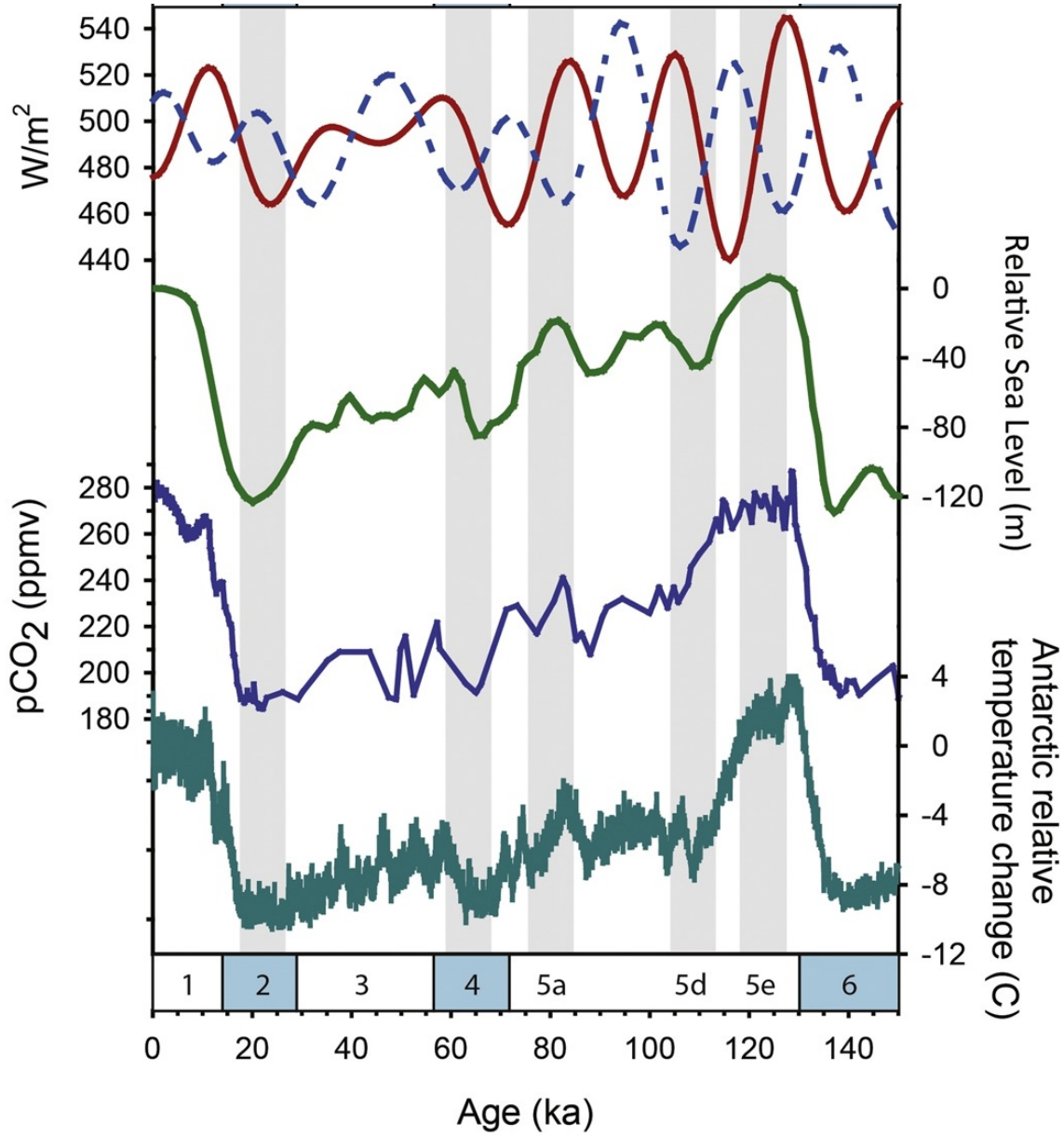


Figure from Kohfield and Chase (2017)

Revisiting Orbital Cycles





The Last 150,000 Years

Another feedback:

- Orbital-induced cooling causes ice to form around North Atlantic
- This means more water is being exported out of the Atlantic and staying on land
- This makes the North Atlantic saltier, enhancing downwelling
- This leads to more carbon being sequestered in the deep ocean, reducing atmospheric concentration
- Which leads to more cooling…

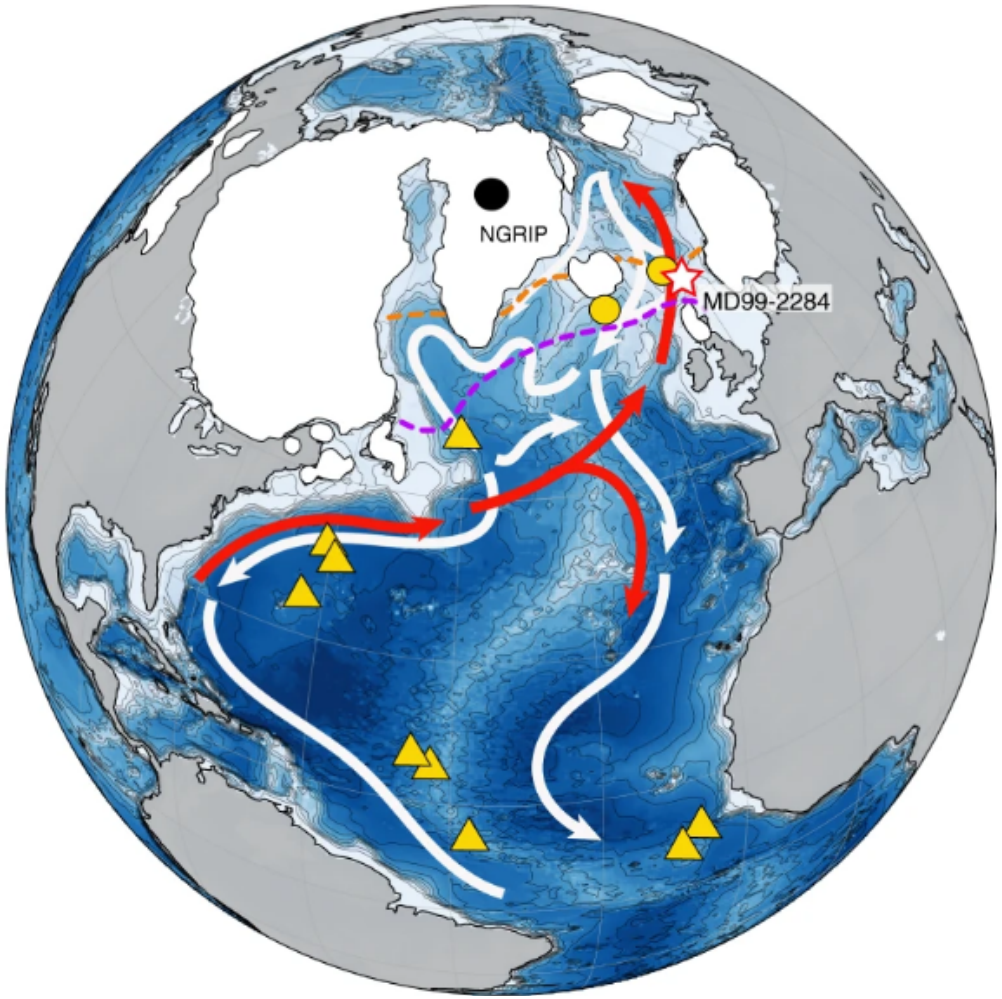
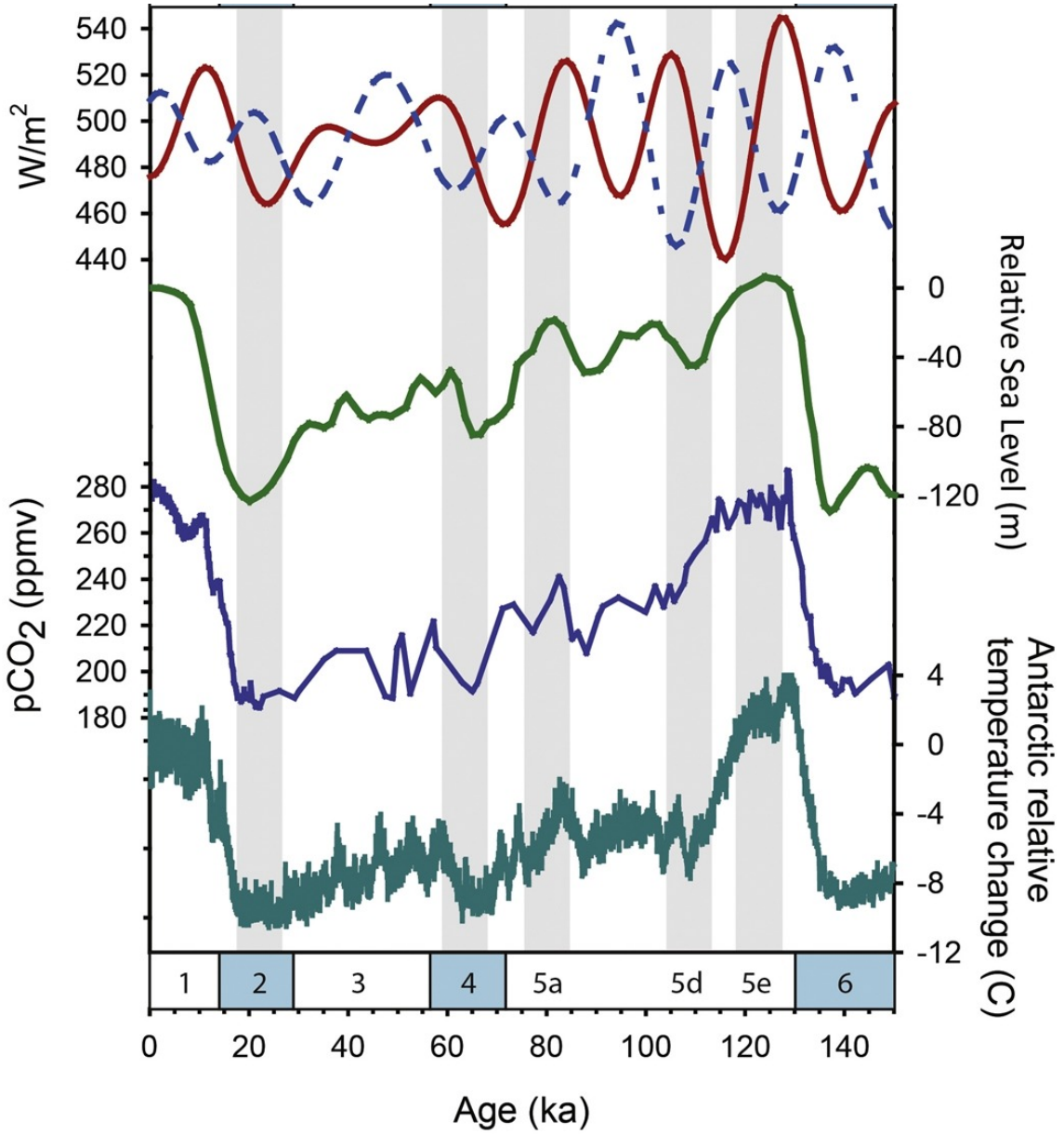


Figure from Kohfield and Chase (2017)

The Last 150,000 Years

- Ice sheets grow best when summer and winter are both mild
  - Less melting in summer, more precipitation in winter
- The last 150,000 years shows a full eccentricity cycle, with precessional swings getting milder and milder
- Periods of glacial buildup and retreat, but overall increase in glacial volume up to Last Glacial Maximum



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The ‘Sawtooth’ Climate Pattern

Long periods of glacial build-up (~80-100 kyr)

Rapid deglaciation (~10 kyr)

Product of *both* orbital forcing *and* internal climate feedbacks

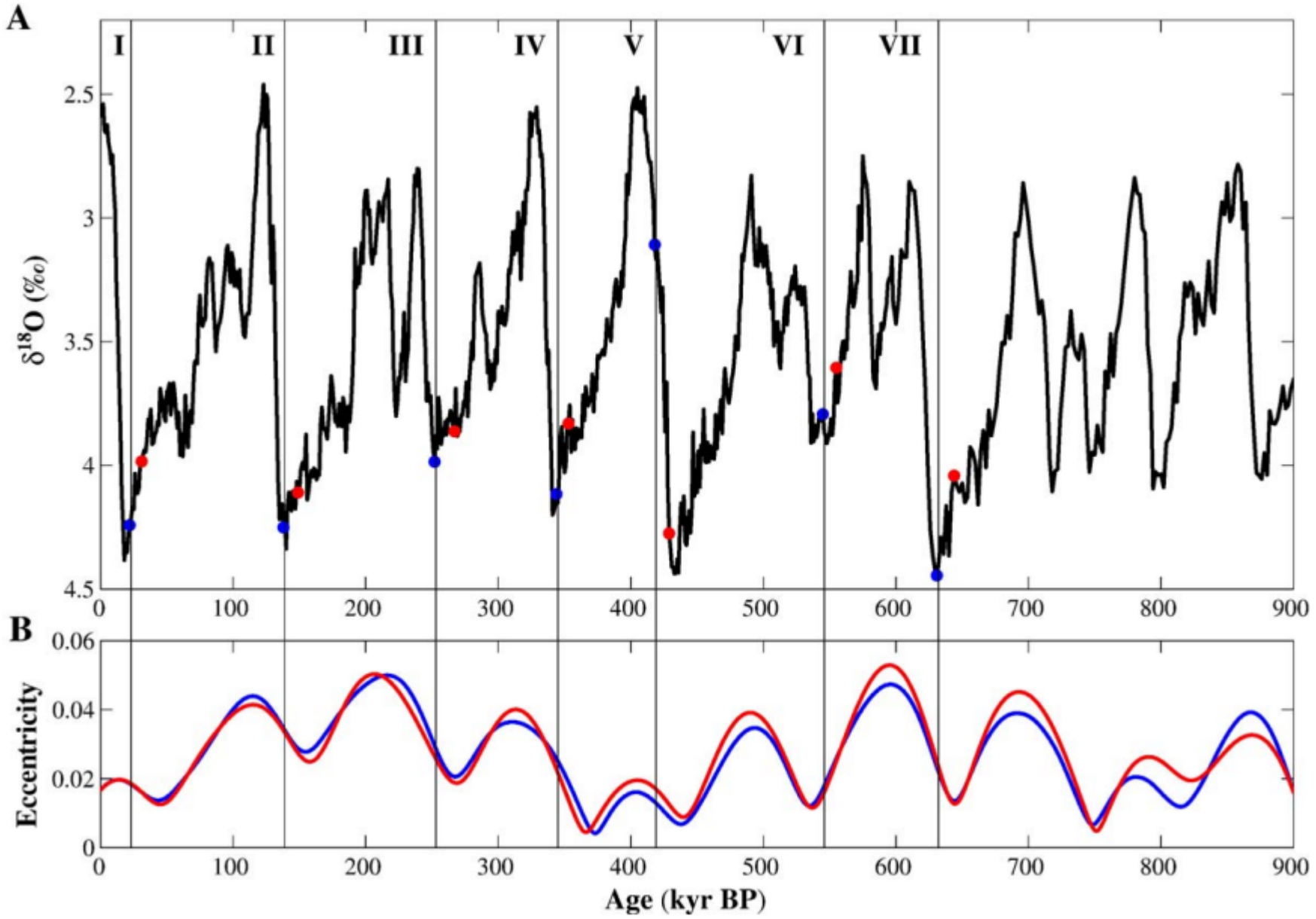
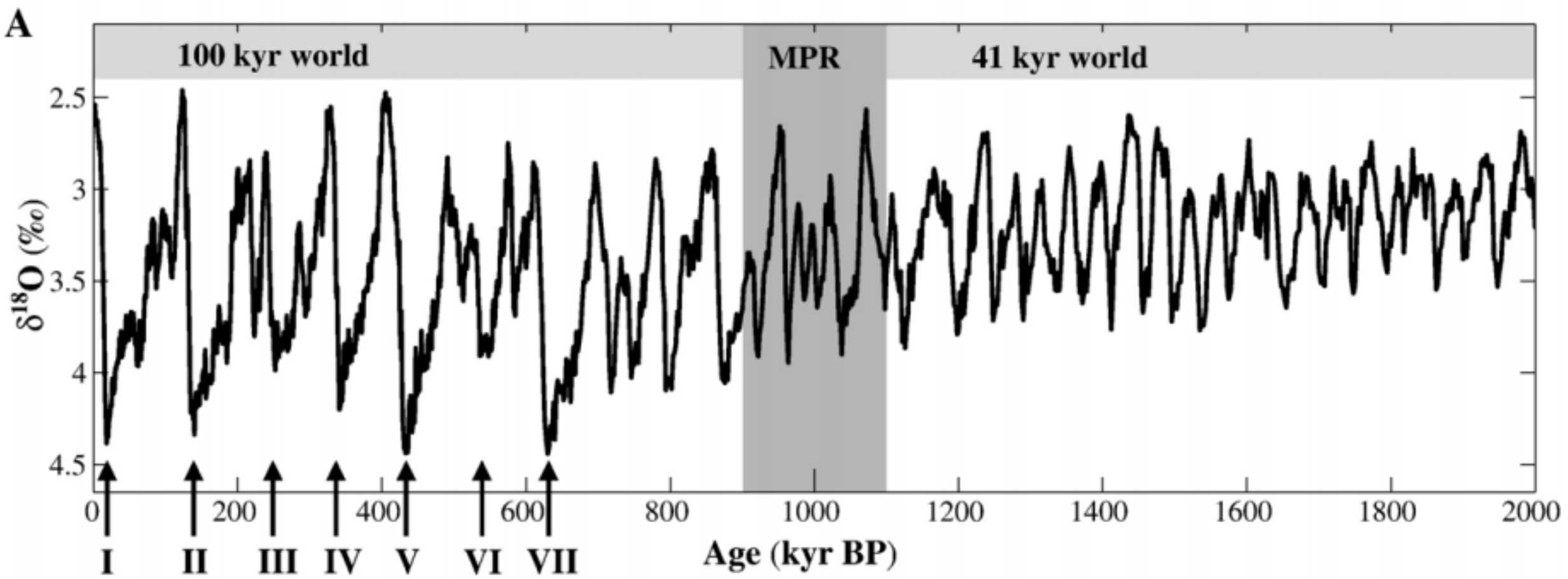


Figure from Shulz and Zeebe (2006)

Mystery: Mid-Pleistocene Transition



Sawtooth pattern was in ~41 kyr cycles until 1.1 – 0.9 million years ago, then it transitioned into ~100 kyr cycles

Mystery: Mid-Pleistocene Transition

Hypothesis:

- At beginning of Pleistocene, lots of soft sediment (regolith) overlying North America
- Ice sheets forming on soft sediment were thinner, more mobile
- Ice sheets at this time more susceptible to changes in obliquity, deglaciation every ~41 kyr

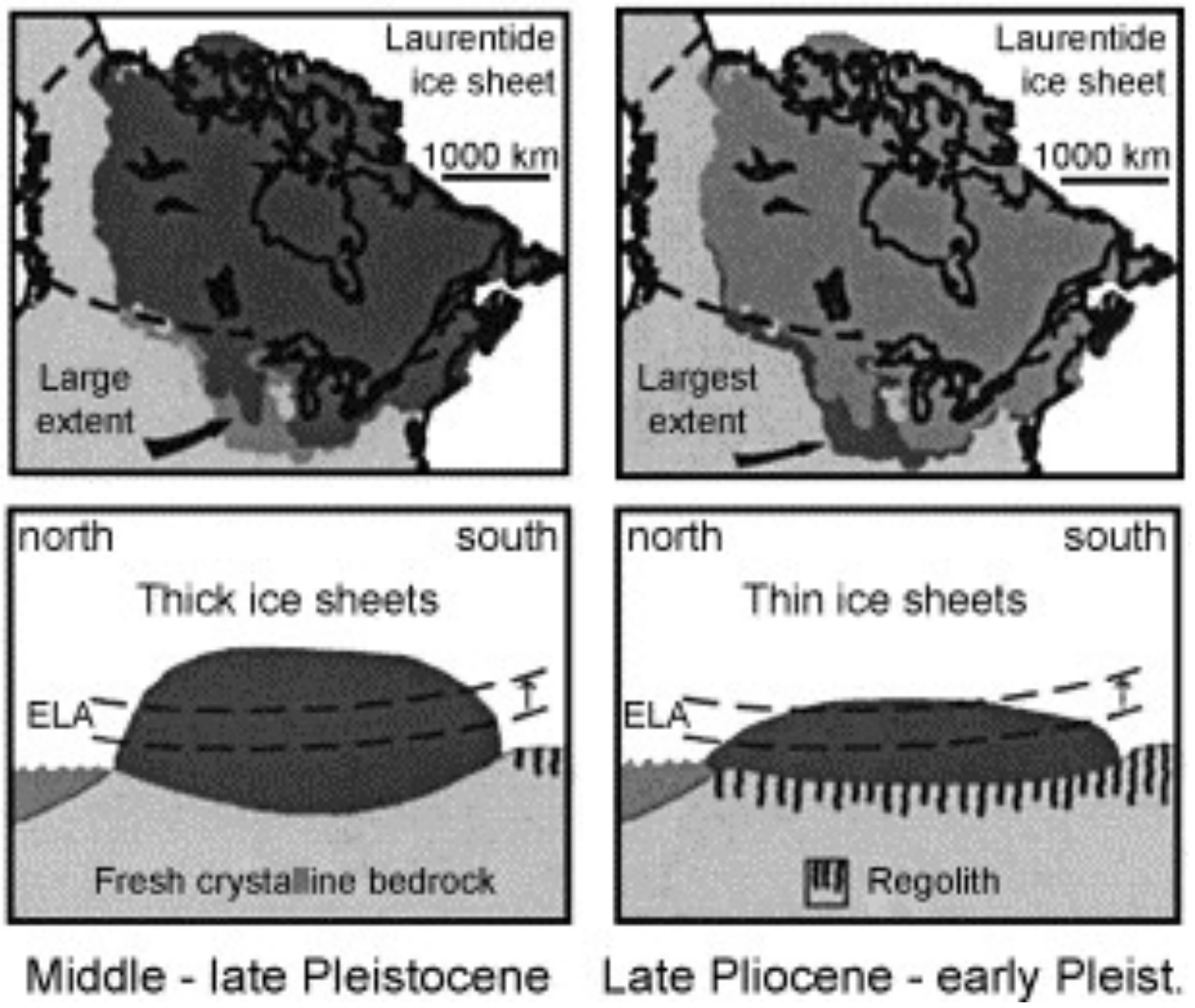
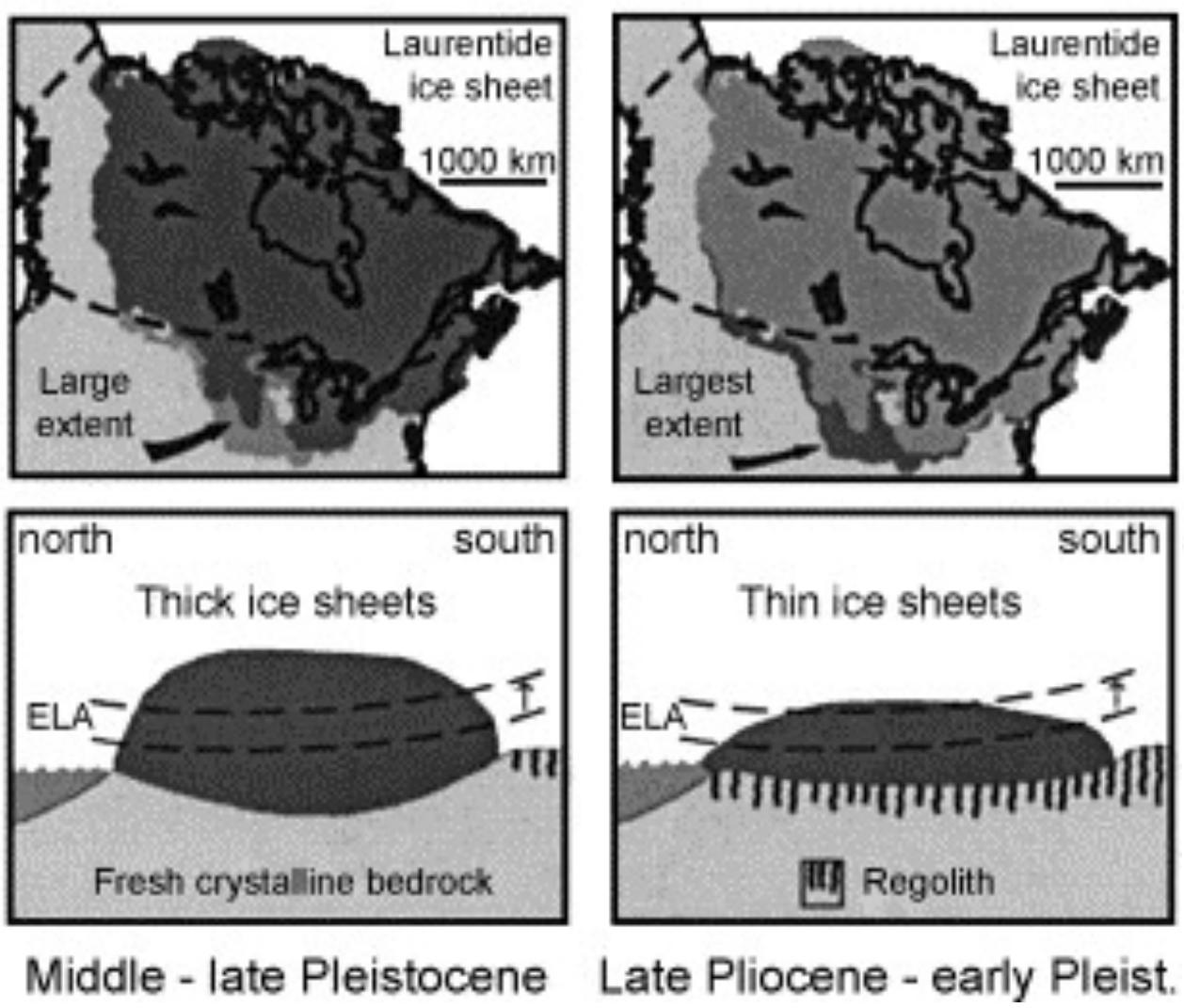


Figure from Roy et al. (2004)

Mystery: Mid-Pleistocene Transition

Hypothesis:

- After ~1 million years of repeated glaciations, soft sediment scraped off continents
- Ice sheets now forming on hard bedrock. Due to friction, ice sheets less mobile, grow thicker
- Ice sheets now could survive through obliquity changes, only deglaciate every ~100 kyr



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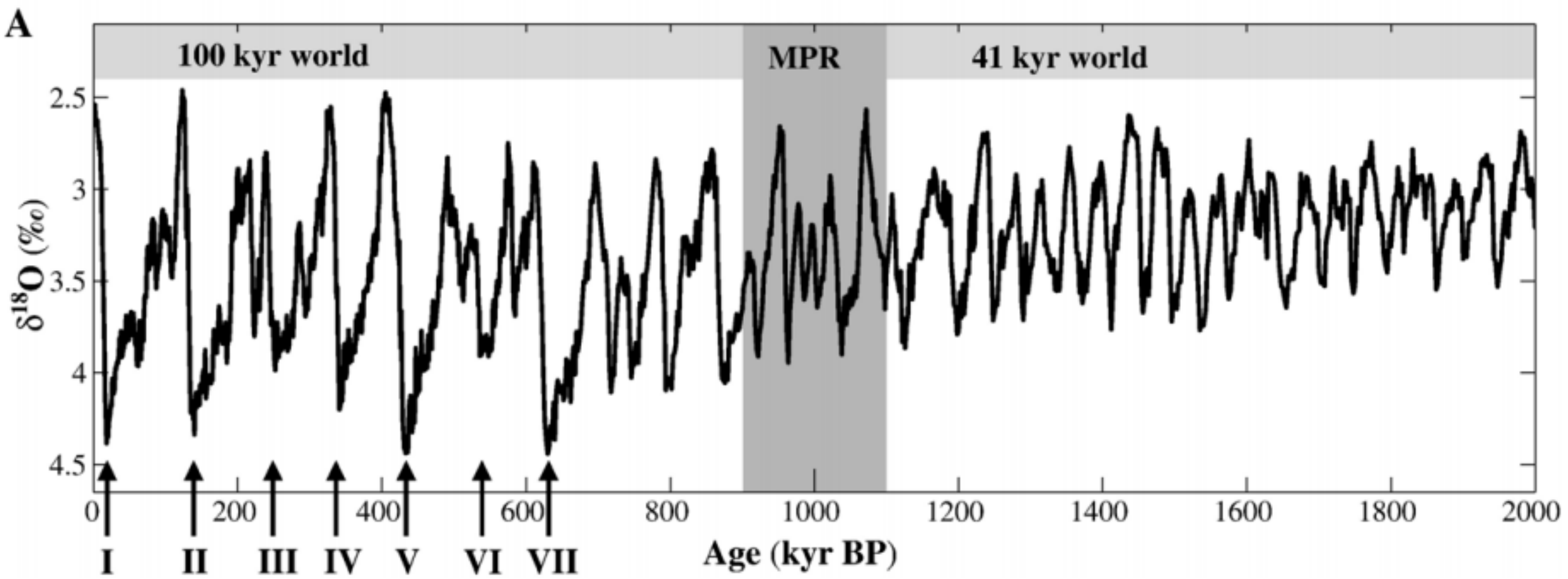

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Pleistocene Compared to Present

Question:

- Is the present global warming due to orbital cycles and/or natural climate system feedbacks?
- Peak insolation for 65°N summer was around 10,000 years ago
- According to our understand of the Pleistocene, we should be entering into a glacial build-up period
- Our carbon emissions are pushing us in the *other* direction

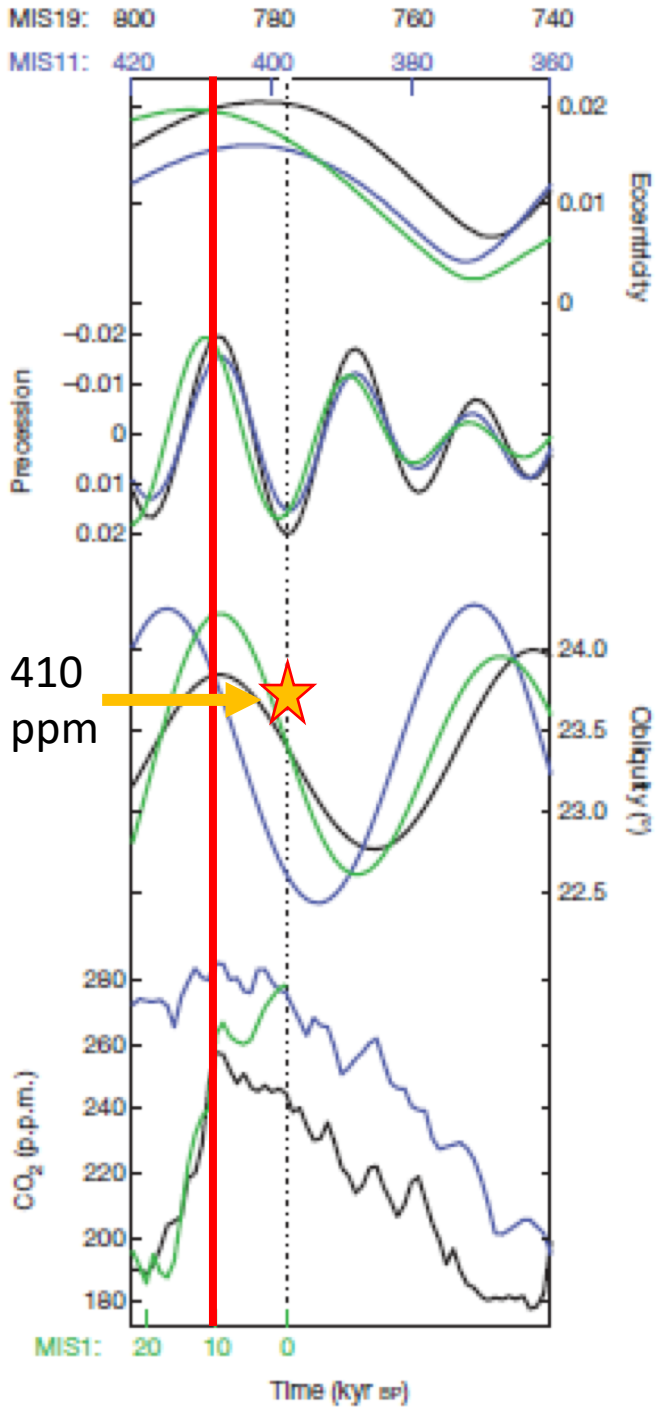

Figure from Ganopolski et al. (2016)

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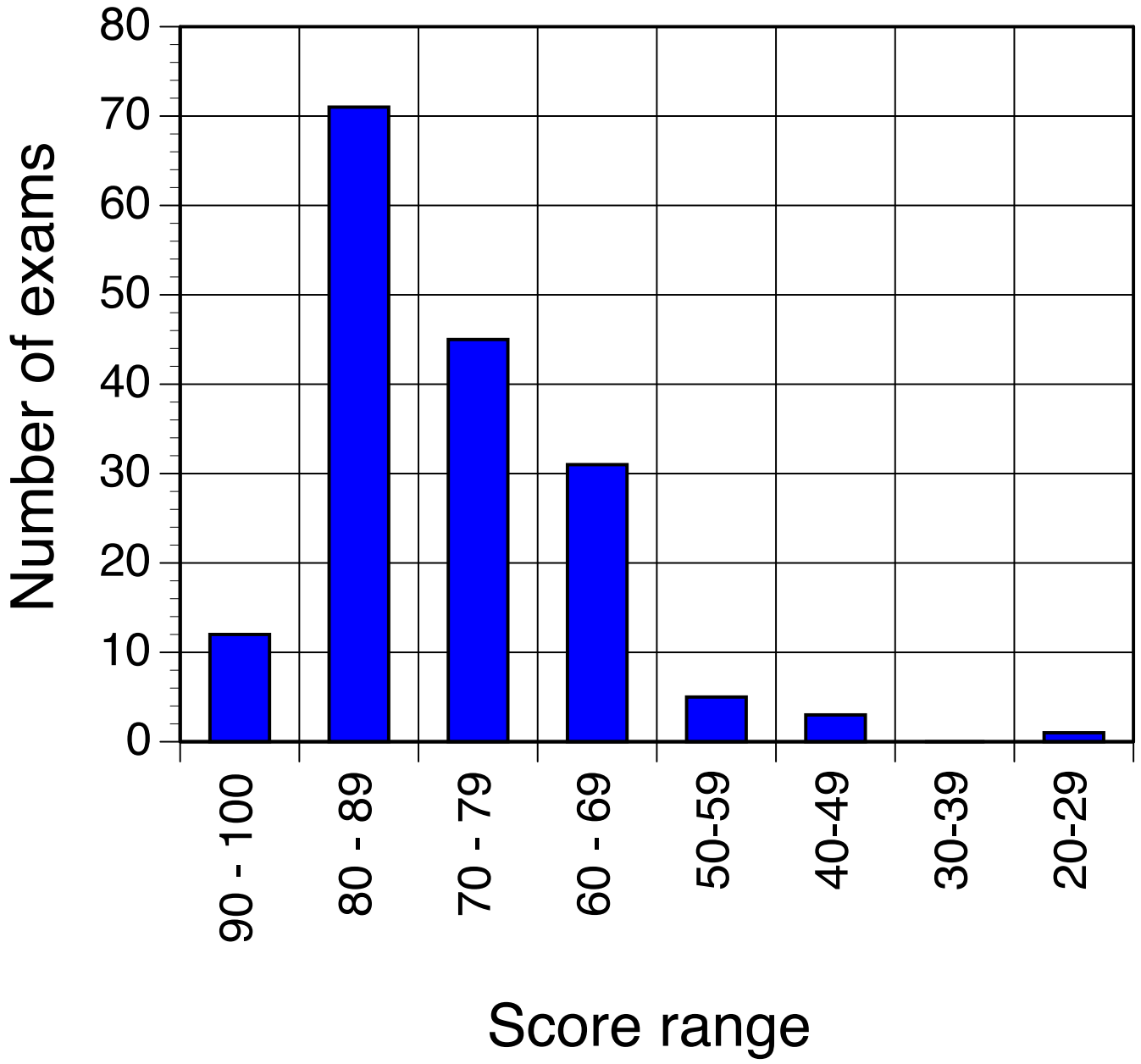
Today's Class: Paleoclimate – The Pleistocene

The Pleistocene..

- is characterized by glacial/interglacial cycles,
- that follow a regular pattern (the 'sawtooth'),
- that are caused by both orbital forcing changes and natural feedbacks,
- which provide critical information about how Earth's climate system work,
- and that confirm that natural forcings do not explain current warming.

Exam 1

- All three of us graded a series of 5 exams to calibrate and develop a key
- Chris and Mae Kate graded most exams
- We created rubric with points for partial credit
- Most people answered all questions
- Essays were strong



Median = 80%, a bit low (I aim for 83-84)

163/172 passed (>60%)

Most in B range

Our bad, The exam was 1 question too long

Strategies for next exam

- Even though open book/open note, you need to study for several hours – not enough time to look things up in exam (by design)
- Make note sheets as you study and have them at exam
- Don’t lift sentences/phrases from web sites and the book; this is plagiarism. “Use quotation marks and a citation” (Halsted, 2019).
- Read all questions before answering; answer the ones you know well first and quickly; return later to those you know less well
- Put some answer down for every question.
- Follow length suggestions

If you would like to improve your score….

- You may **rewrite one of the short answer questions**
- You must submit your rewrite on blackboard **by Friday October 18 at midnight** – no extensions
- We will regrade whatever question you submit and **add it to your exam grade**
- **You are on your honor,** this must be your own work

If you don’t agree with how your exam was graded…

- **Submit a written statement to Paul by email by Friday October 18, Midnight**. Late statements not accepted.
- Comments must be stated **by question number**.
- In your statement for each question, explain **exactly** what it was that you don’t think was properly graded. **If you have issues for more than one question, write a statement for each question.**
- I will review your explanation(s) and then regrade each question you called out. **Your grade may go up or it may go down on each question and on the exam.**

Please come see us and others if you need help with study hints, accommodation, more time on tests

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