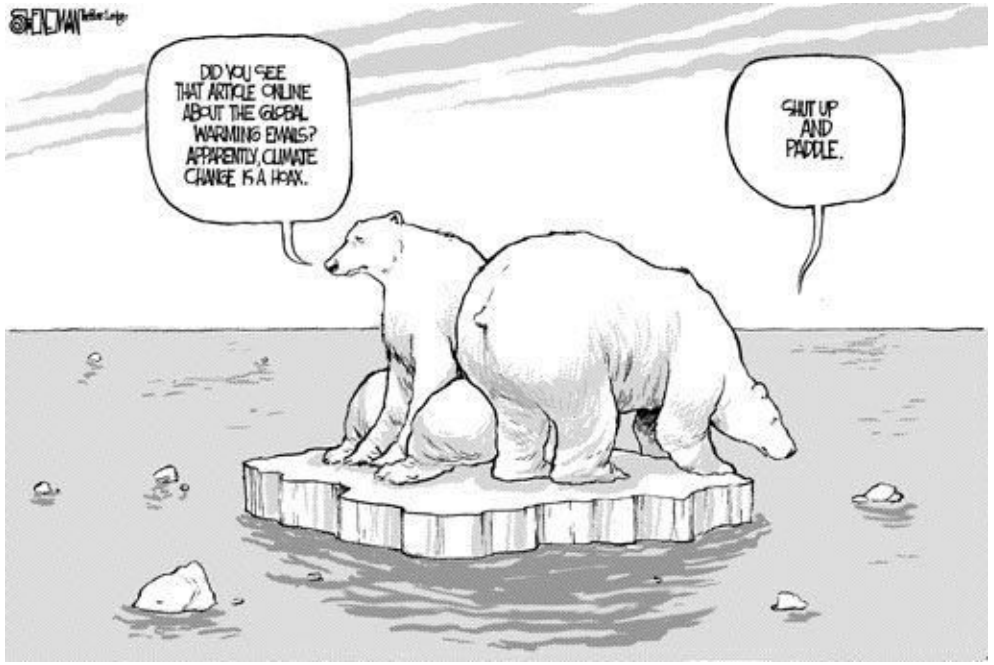

Class 12: Greenhouse to Icehouse, the last 50 million years

- What has climate done over the past 50 million years?
- What mechanisms explain the observed climate change?

Learning Objectives

1. Be able to describe the global temperature trend over the last ~50 million years
2. Describe the tools used to reconstruct this record and how each works
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Climate in the News

REUTERS

Scientists endorse mass civil disobedience to force climate action

Climate in the News

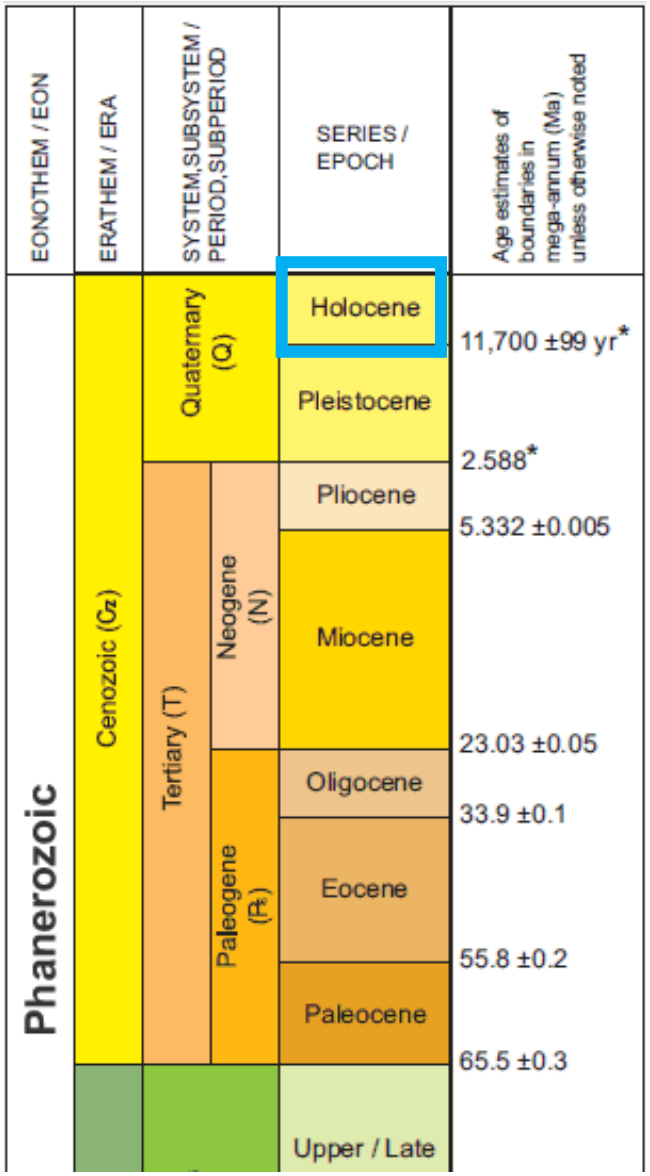
COMMENTARY

Stephen Leslie: A farmer on the frontline of climate action

By **Commentary**

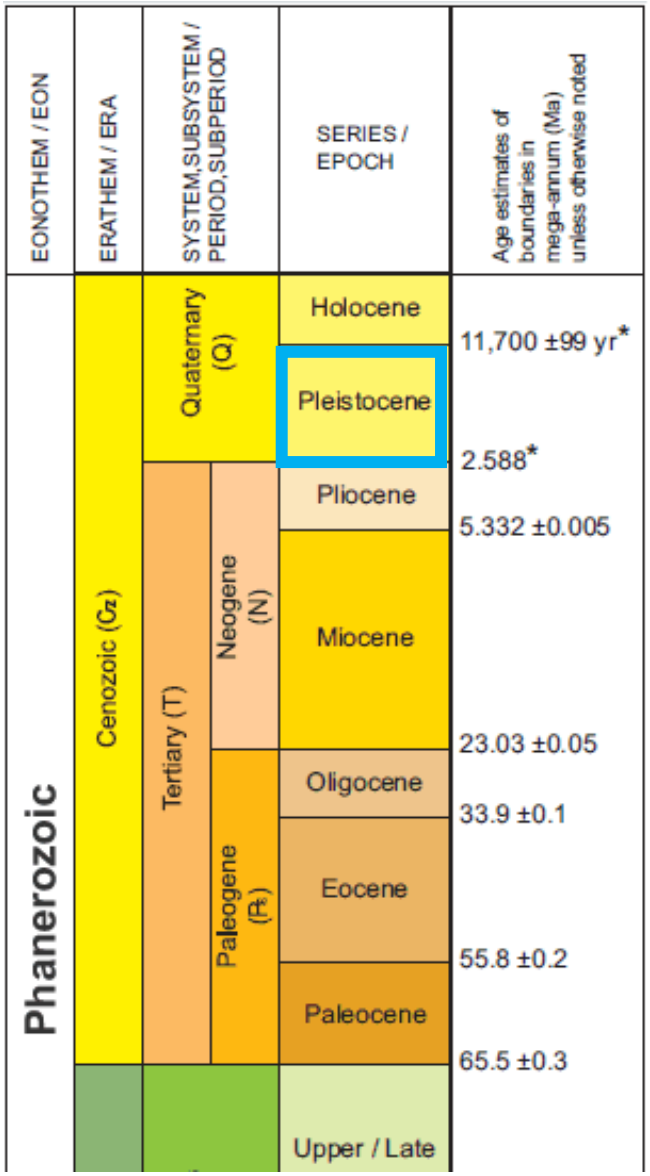
Oct 15 2019 | 7 reader footnotes

Review: Paleoclimate – Pleistocene



Holocene = 11,700 years ago to present

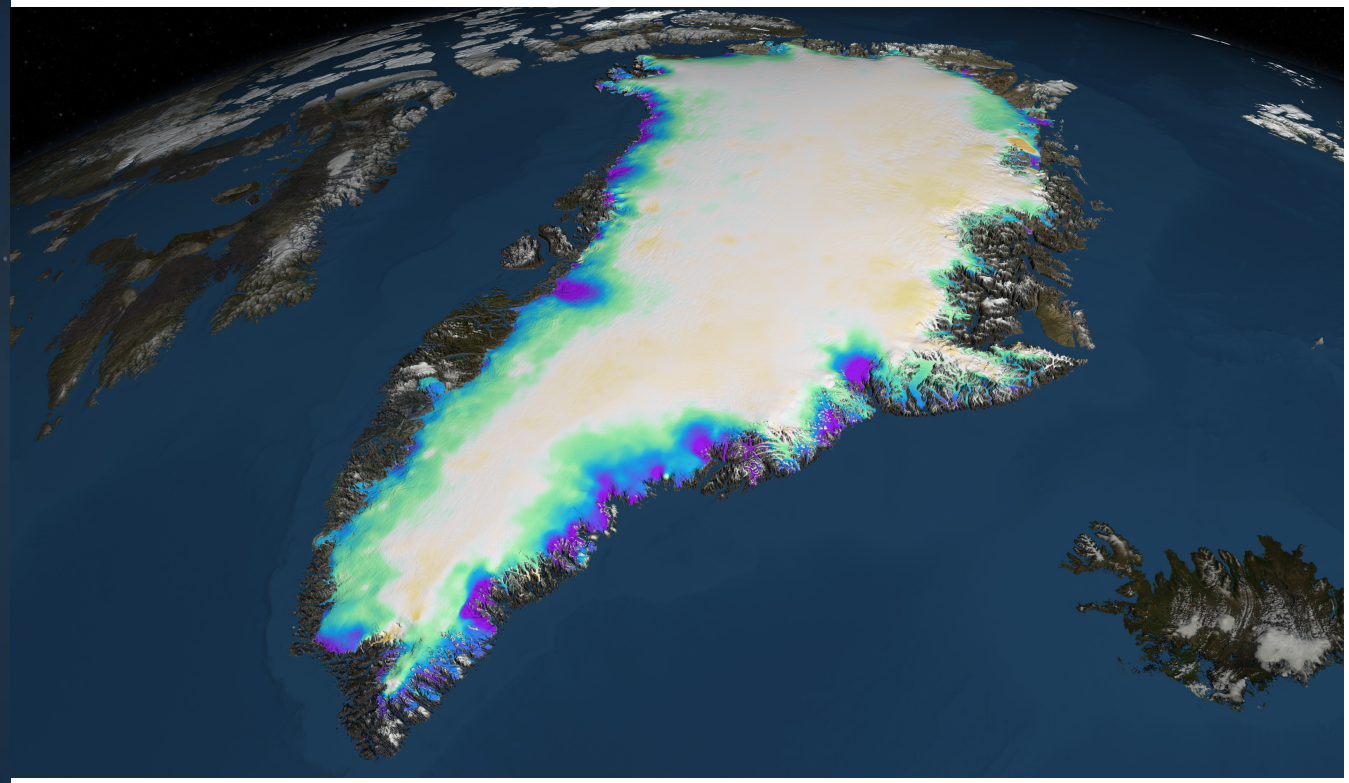
Review: Paleoclimate – Pleistocene



Holocene = 11,700 years ago to present

Pleistocene = ~2.6 million to 11,700 years ago

Review: Paleoclimate – Pleistocene



Review: Paleoclimate – Pleistocene

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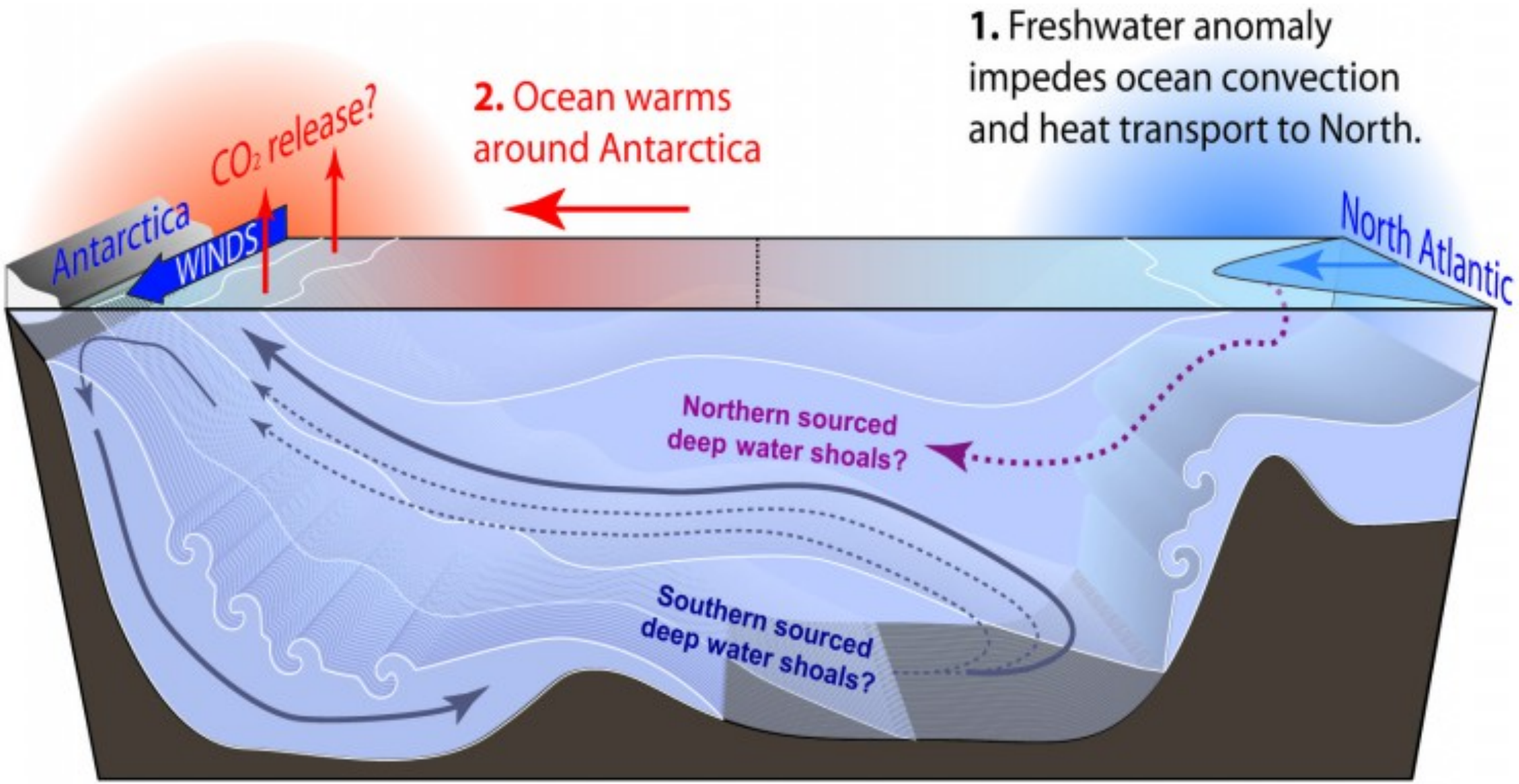
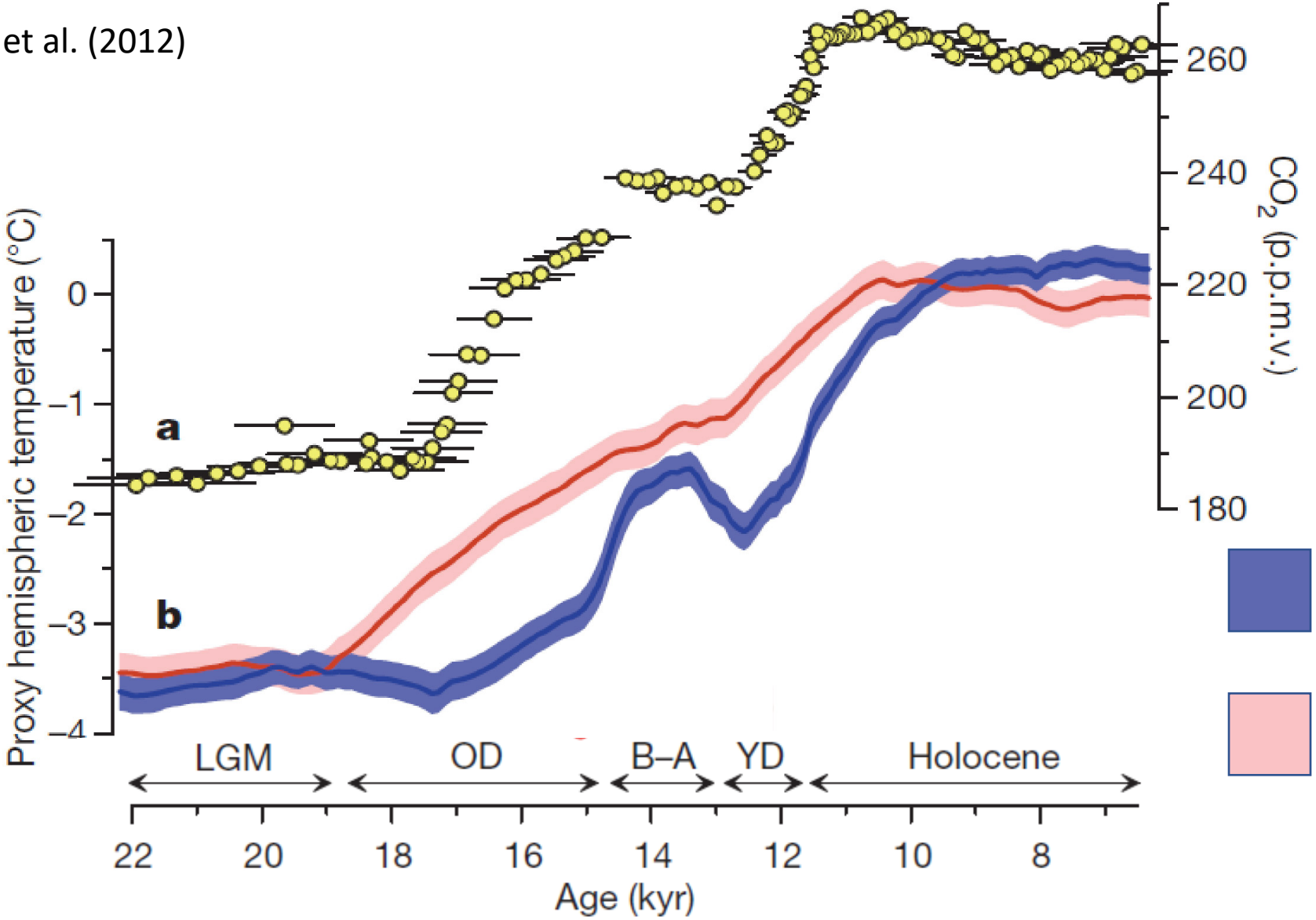


Review: Paleoclimate – Pleistocene

Figure from Shakun et al. (2012)



= Northern Hemisphere

= Southern Hemisphere

Last Glacial Maximum (~29-20 kyr)

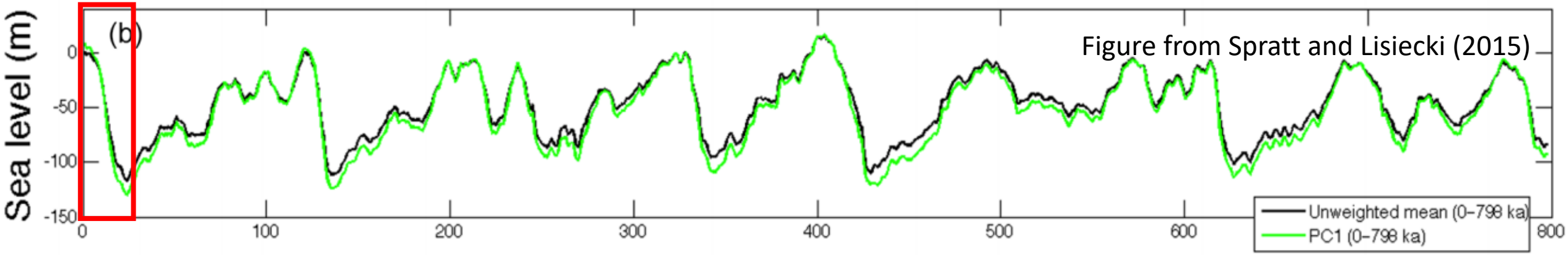


Figure from Spratt and Lisiecki (2015)

- Big ice sheets
- Sea level ~130 m lower than today
- Global temp ~3.5°C lower than today

Last Glacial Maximum (~29-20 kyr)

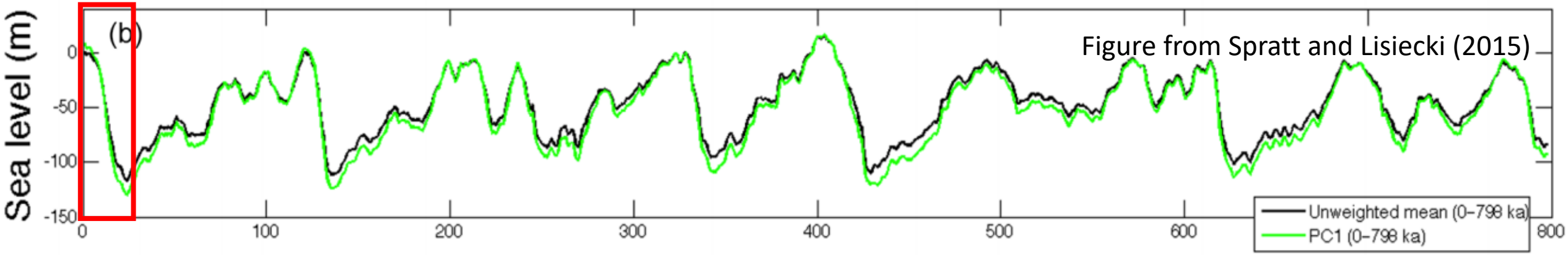


Figure from Spratt and Lisiecki (2015)

- Melting Northern Hemisphere ice sheets suppress AMOC
- Less downwelling and CO_2 sequestration in ocean
- Warms southern hemisphere, causing more CO_2 release

The Last Interglacial (~125 kyr)

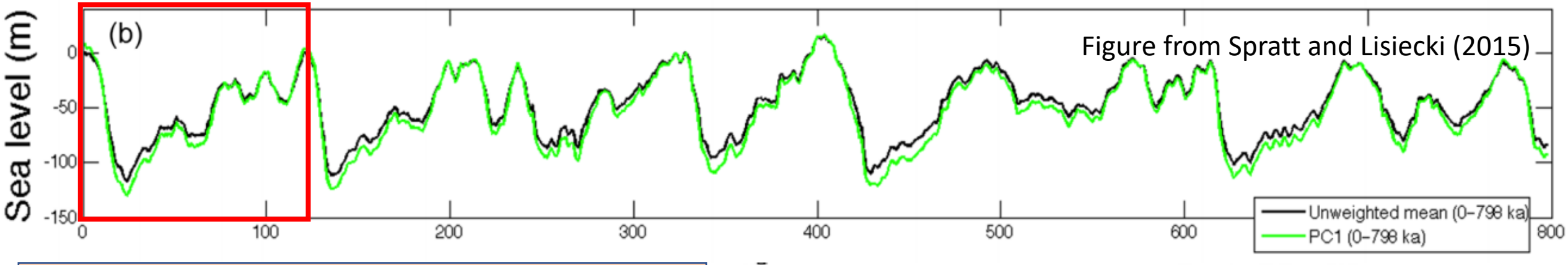
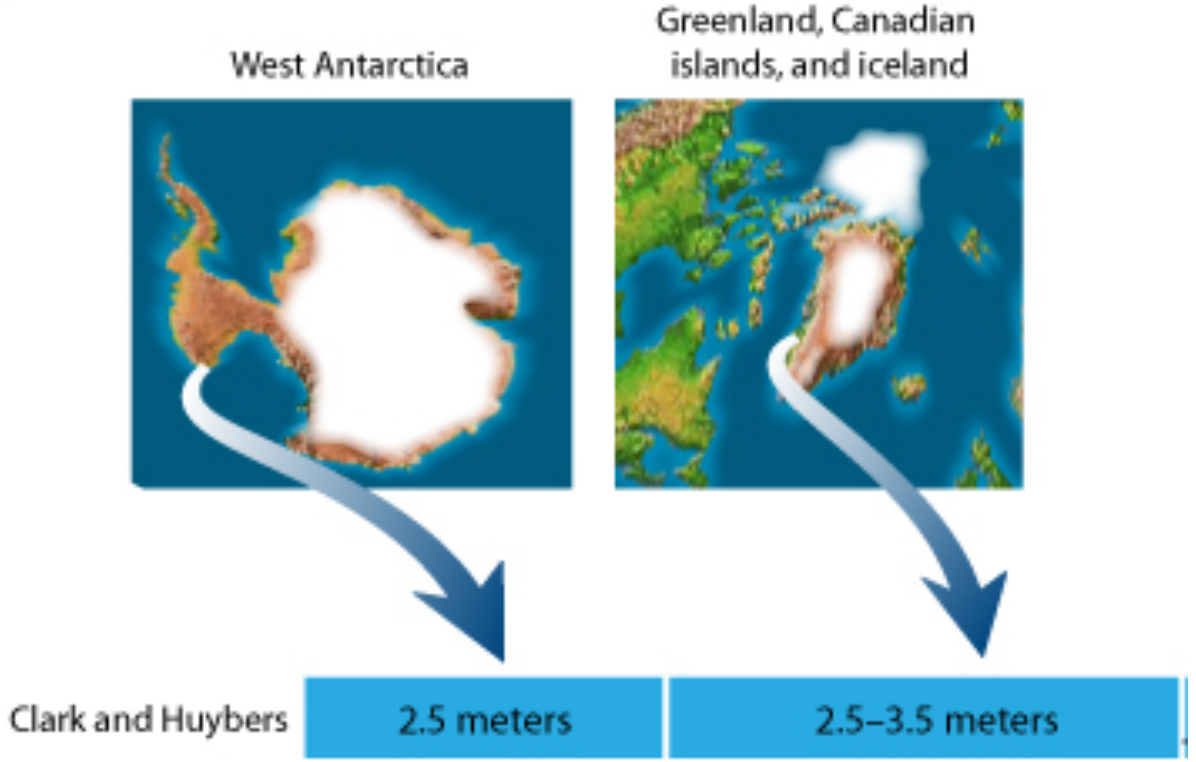
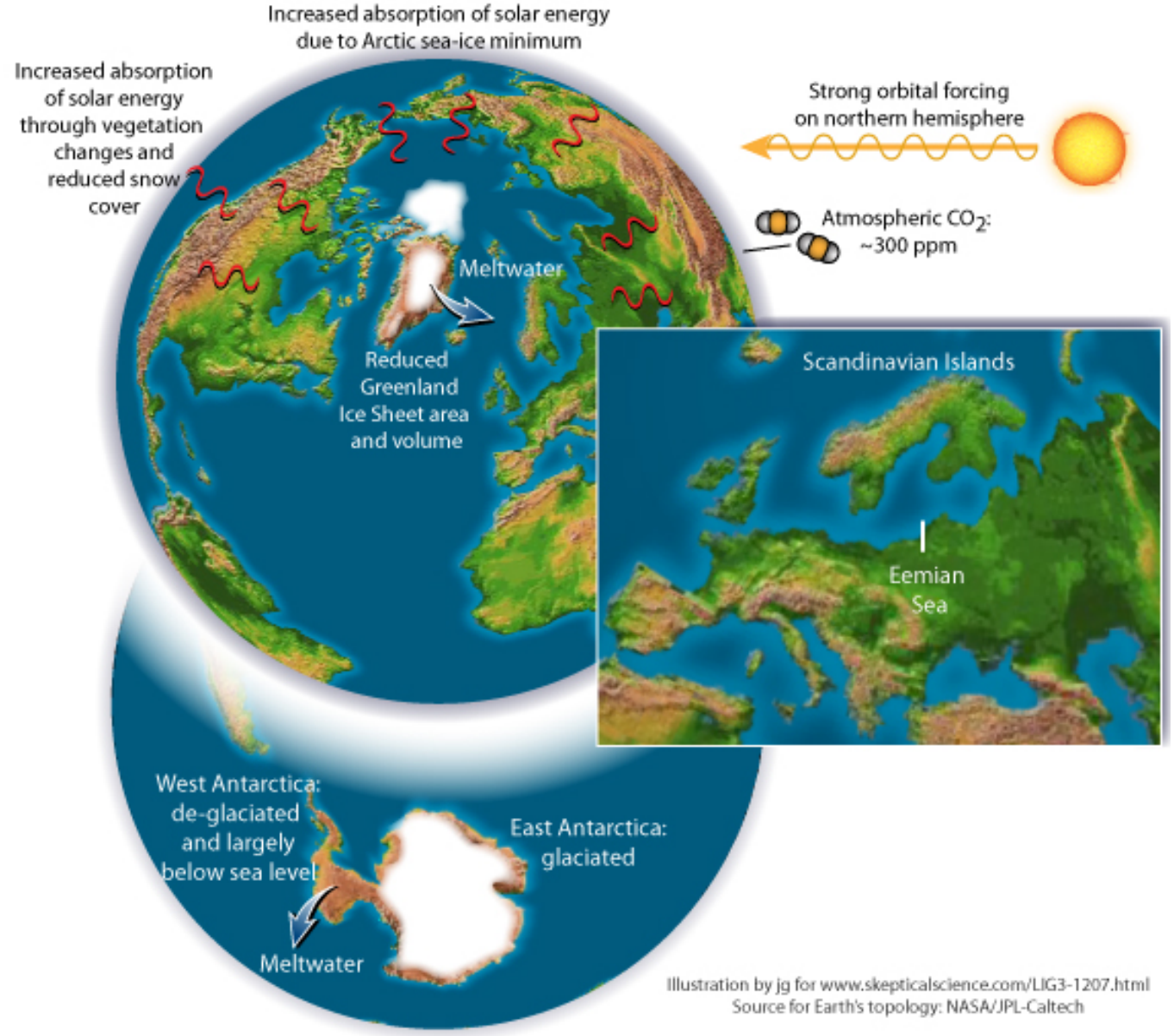


Figure from Spratt and Lisiecki (2015)

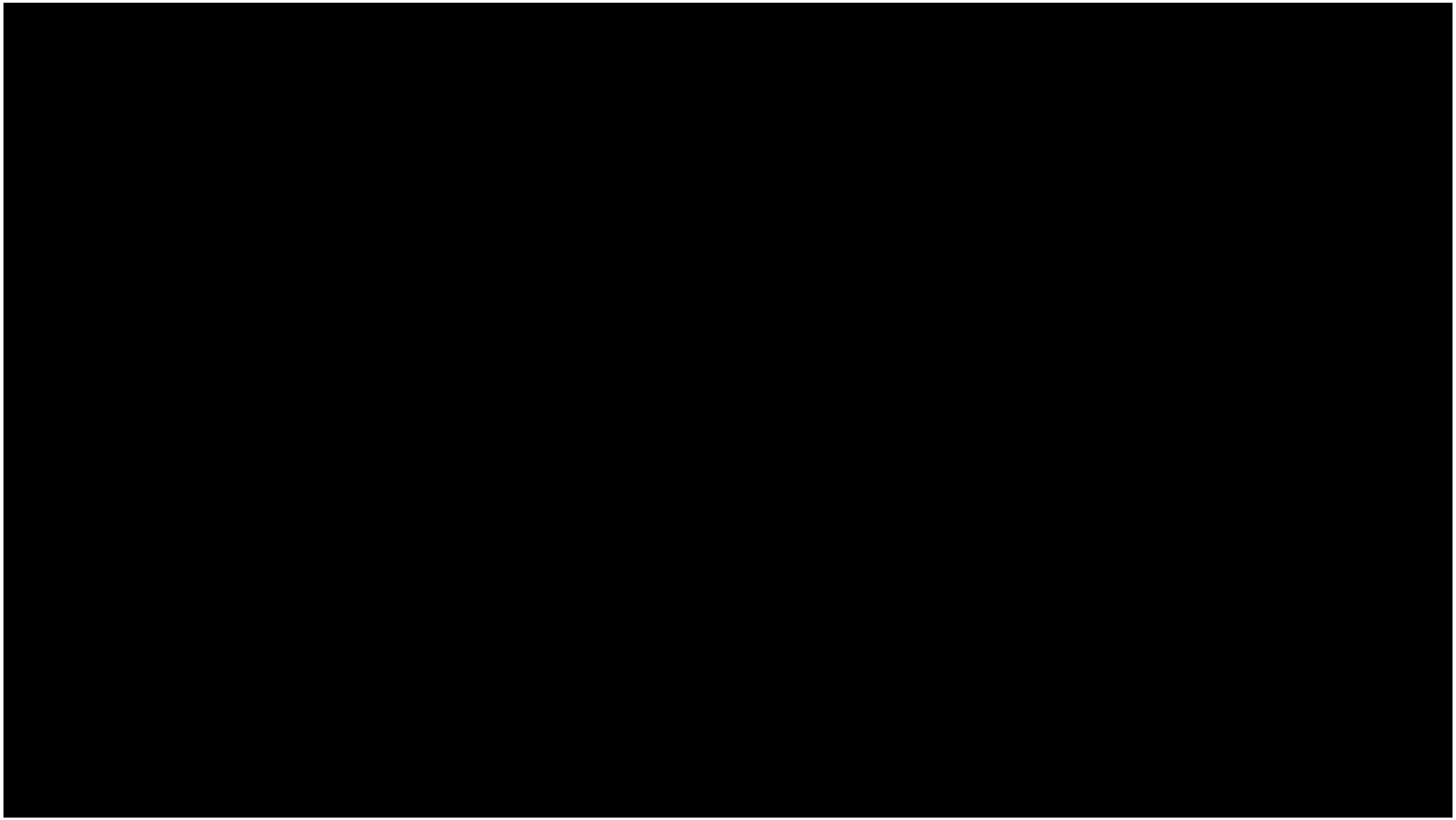
- Slightly warmer than today
- Sea level ~5 m higher than today
- Atmospheric CO_2 around 300 ppm



The Last Interglacial (~125 kyr)



Last Interglacial (~125 kyr) – Present



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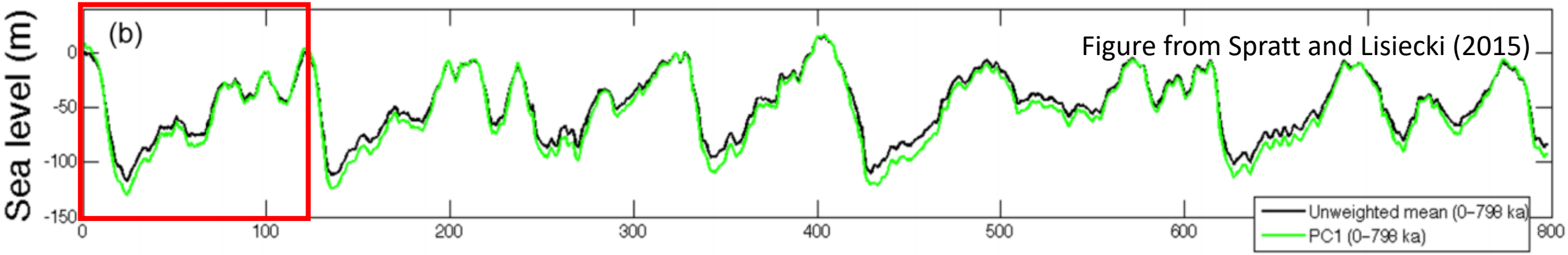


Figure from Spratt and Lisiecki (2015)

- Slow, bumpy build-up of glaciers and ice sheets (~100 thousand years)
- **Fast** melting (~15 thousand years for biggest ice sheets)

Last Interglacial (~125 kyr) – Present

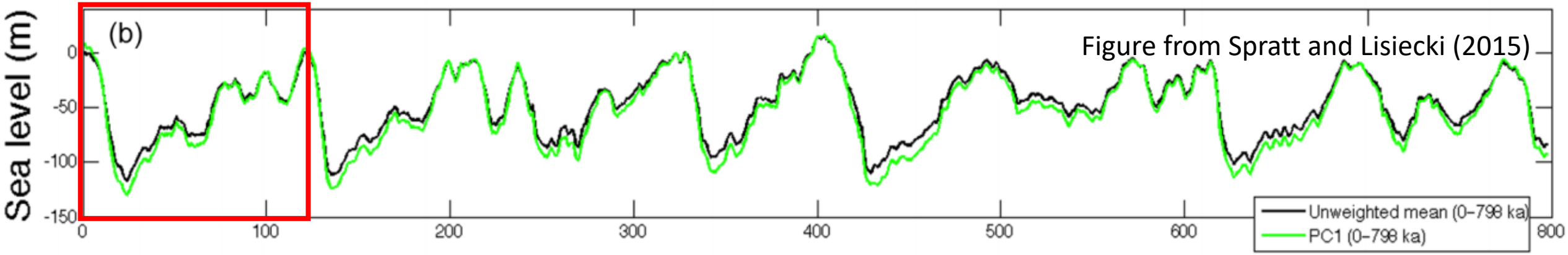
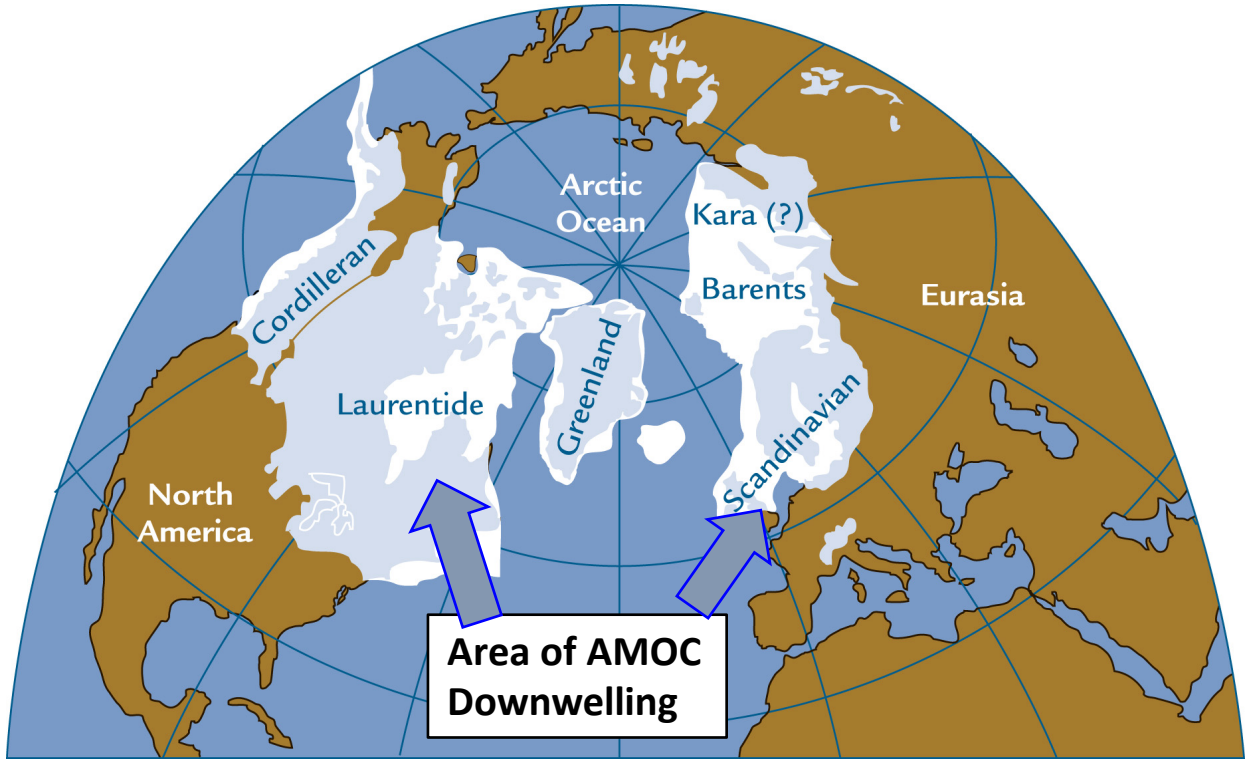
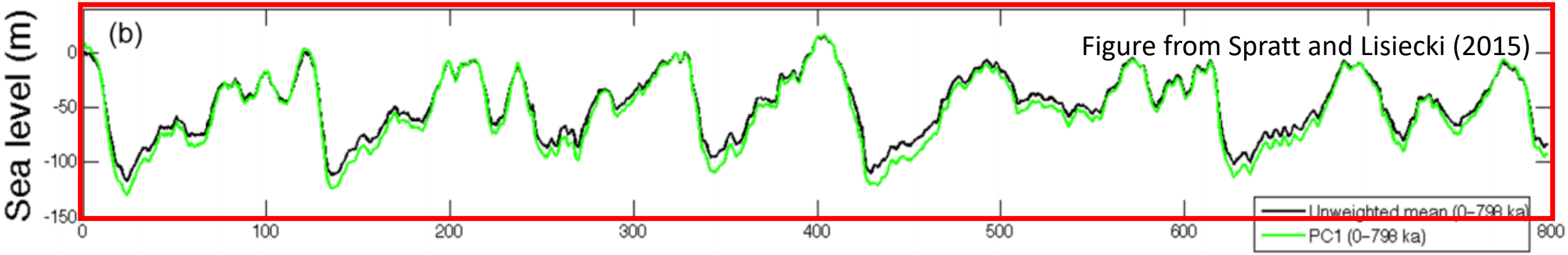


Figure from Spratt and Lisiecki (2015)

- As ice sheets build up around North Atlantic, water becomes saltier
- Downwelling and CO_2 sequestration **increase**



Sawtooth Pattern



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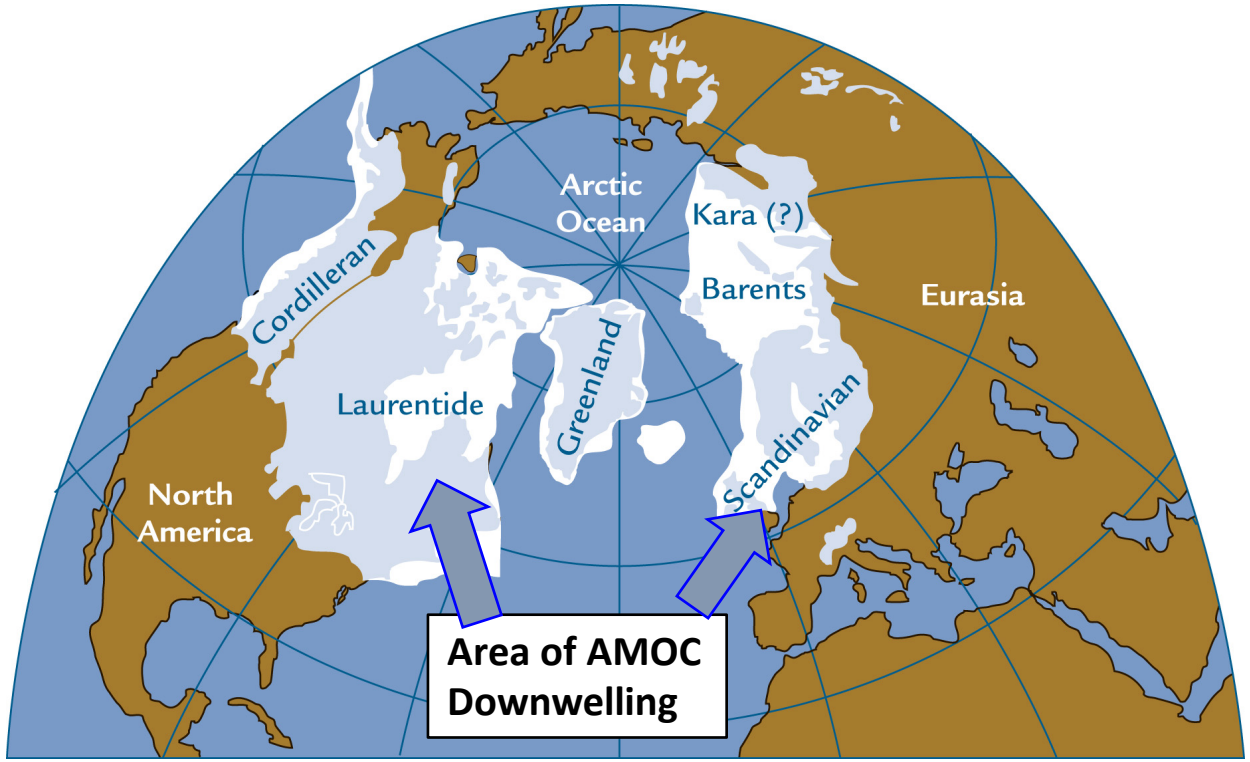
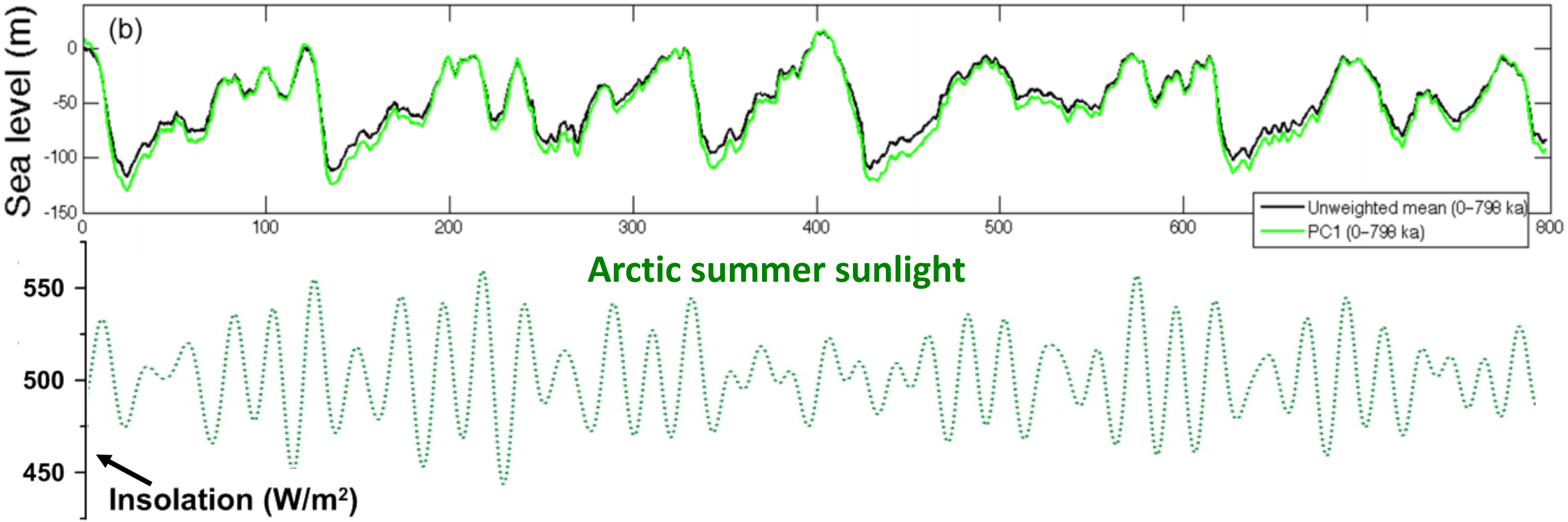
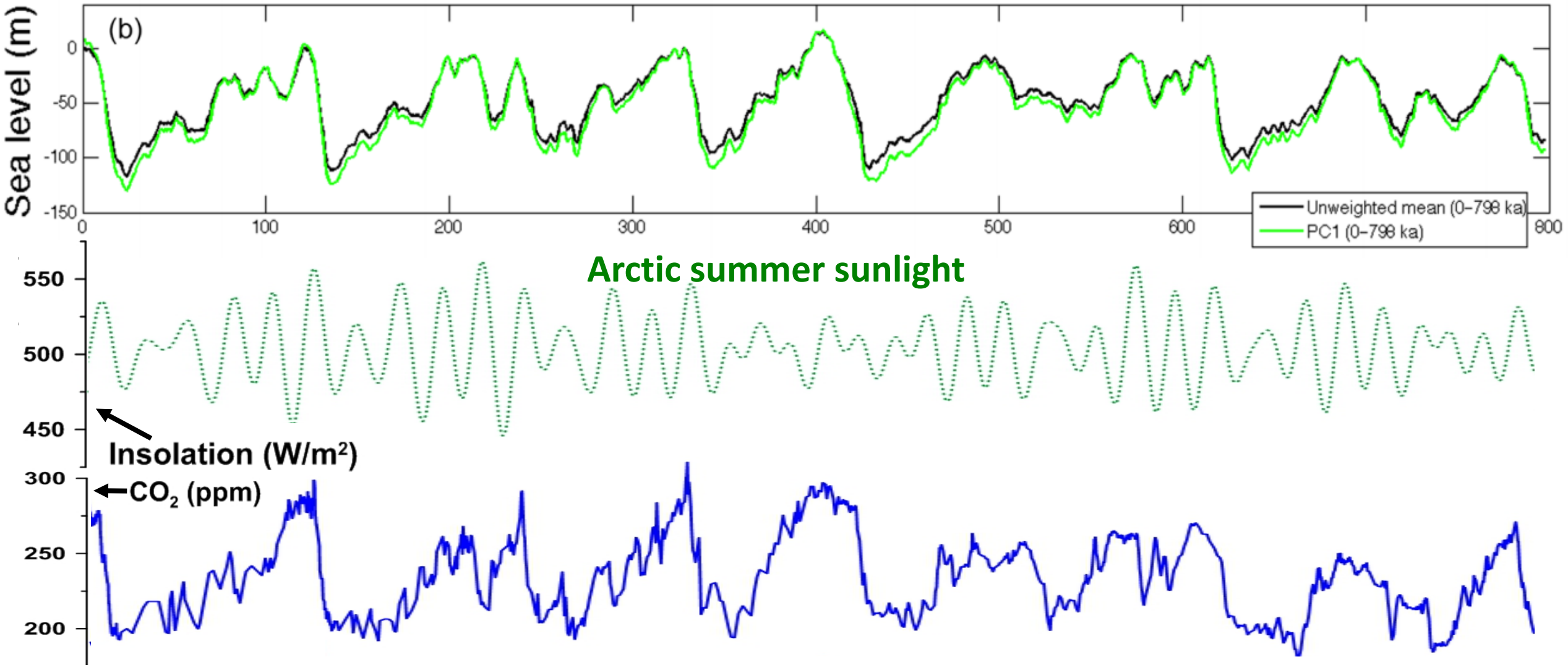


What causes the sawtooth pattern?



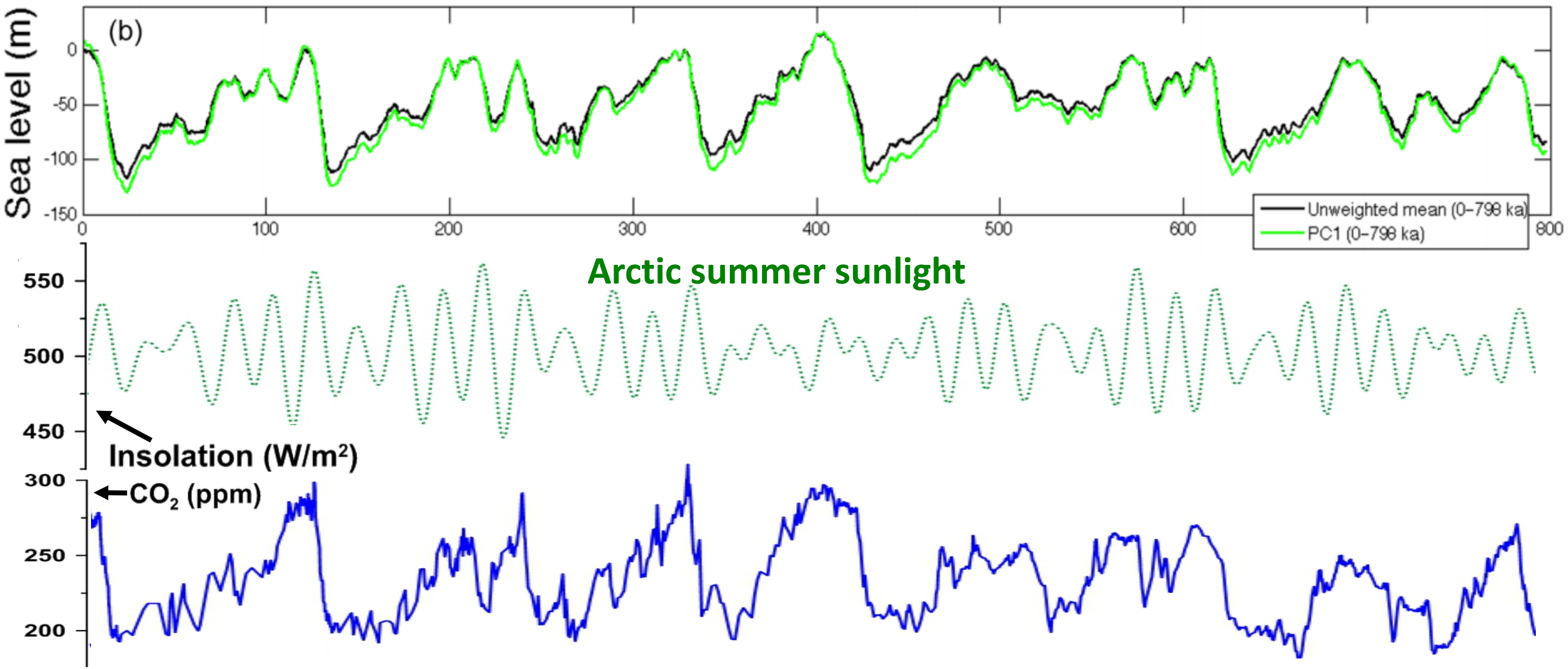
Partly due to orbital cycles

What causes the sawtooth pattern?



Partly due to feedbacks that change the carbon cycle

What causes the sawtooth pattern?

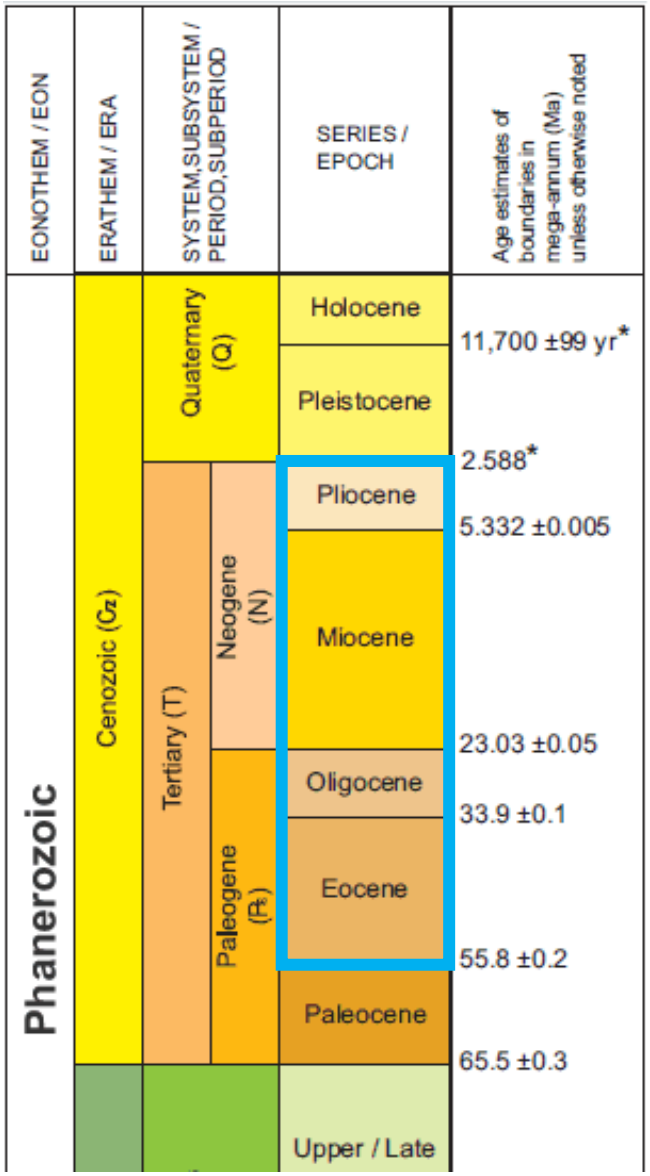


Partly due to ice sheets having a LOT of internal positive feedback loops!

Review: Paleoclimate – Pleistocene

Partly due to ice sheets having a LOT of internal positive feedback loops!

Today's Class: Paleoclimate – The Last 50 Million Years



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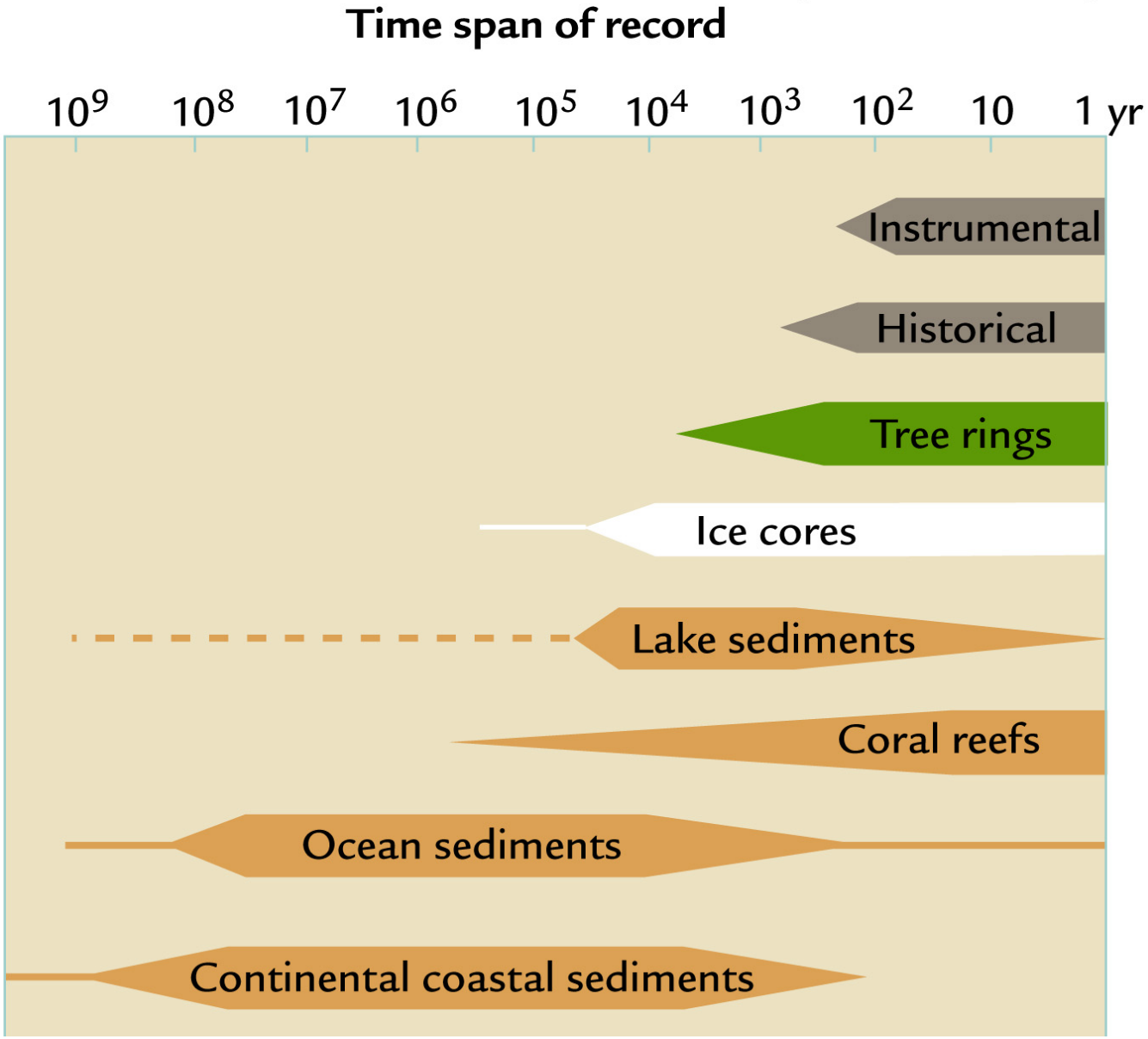
How we know what we know



How we know what we know

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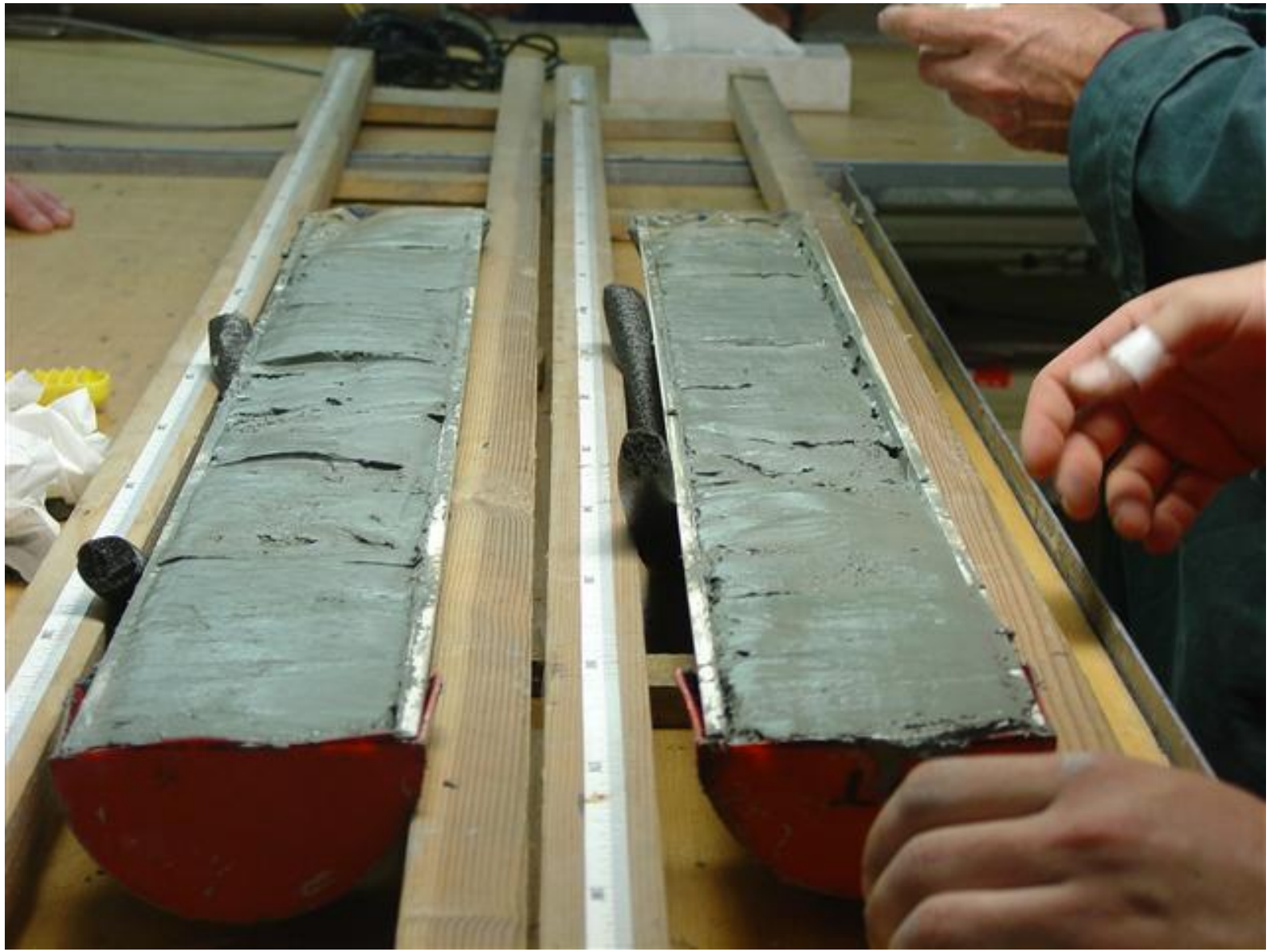
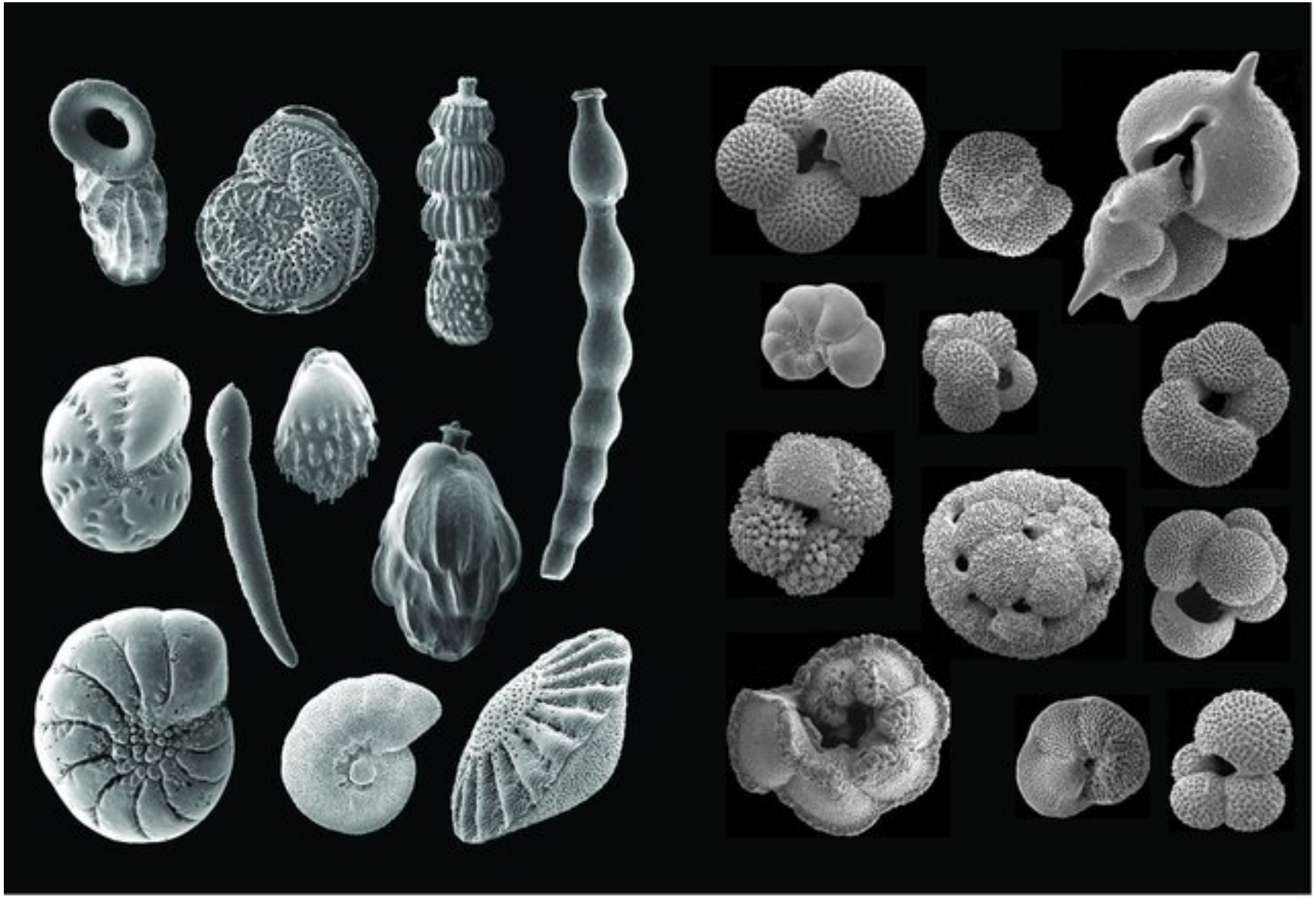


How we know what we know

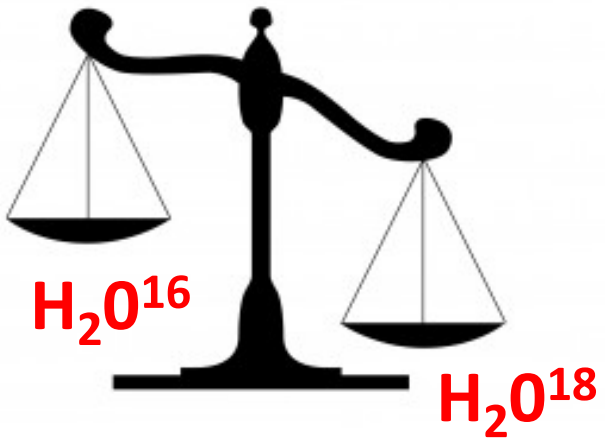
Tiny creatures build their skeletons using oxygen from ocean water

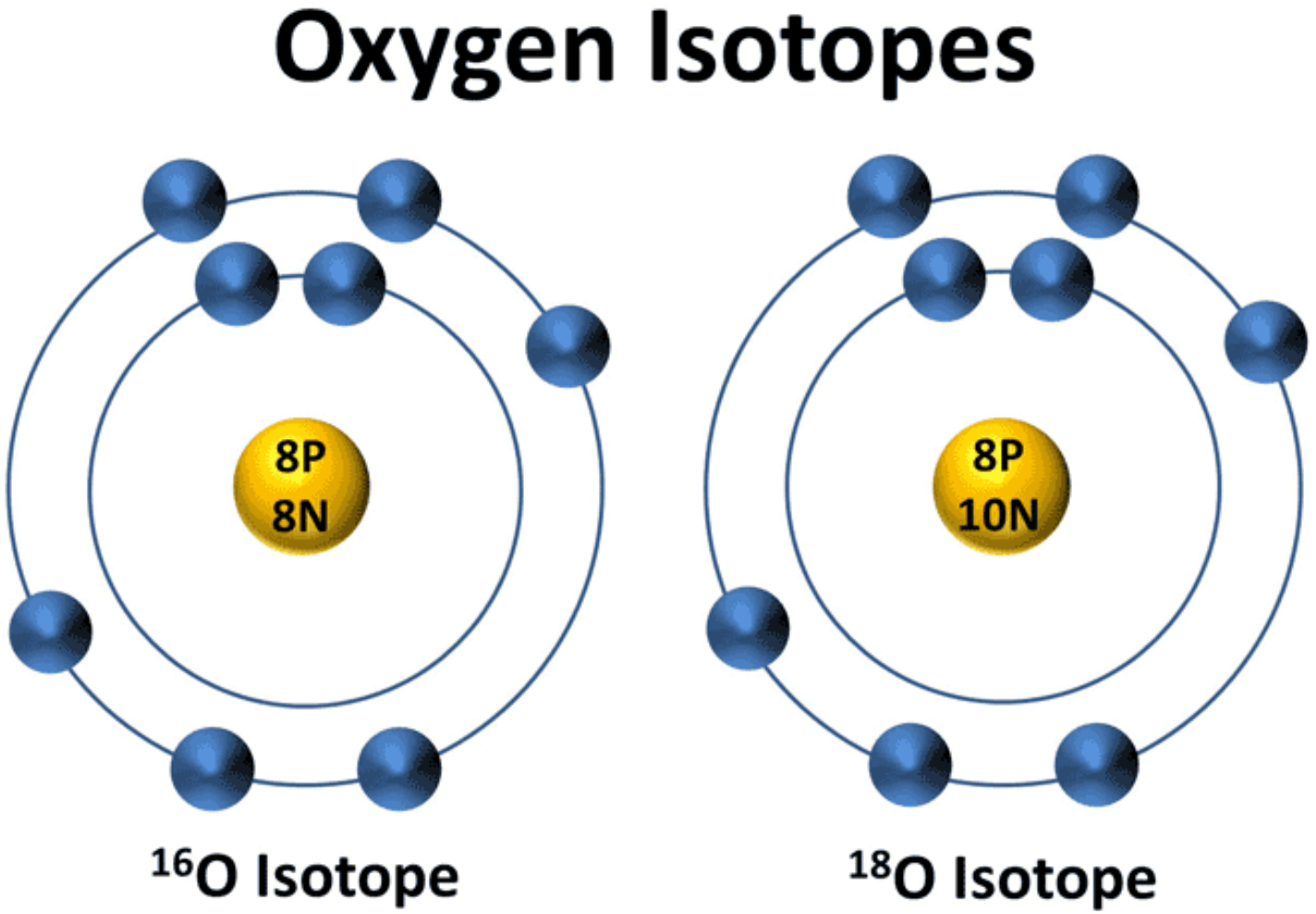
They inherit the oxygen isotope signature of the water



How we know what we know

^{16}O	^{17}O	^{18}O
15.9949	16.9991	17.9991
99.76%	0.04%	0.20%
Stable	Stable	Stable





How we know what we know

I know… oxygen isotopes are confusing. Here's what you need to know:

- Larger $\delta^{18}O$ = Colder water *and* more ice volume
- Smaller $\delta^{18}O$ = Warmer water *and* less ice volume
- Note: $\delta^{18}O$ is usually plotted upside down (the numbers increase as you go down) so that **up means warm**

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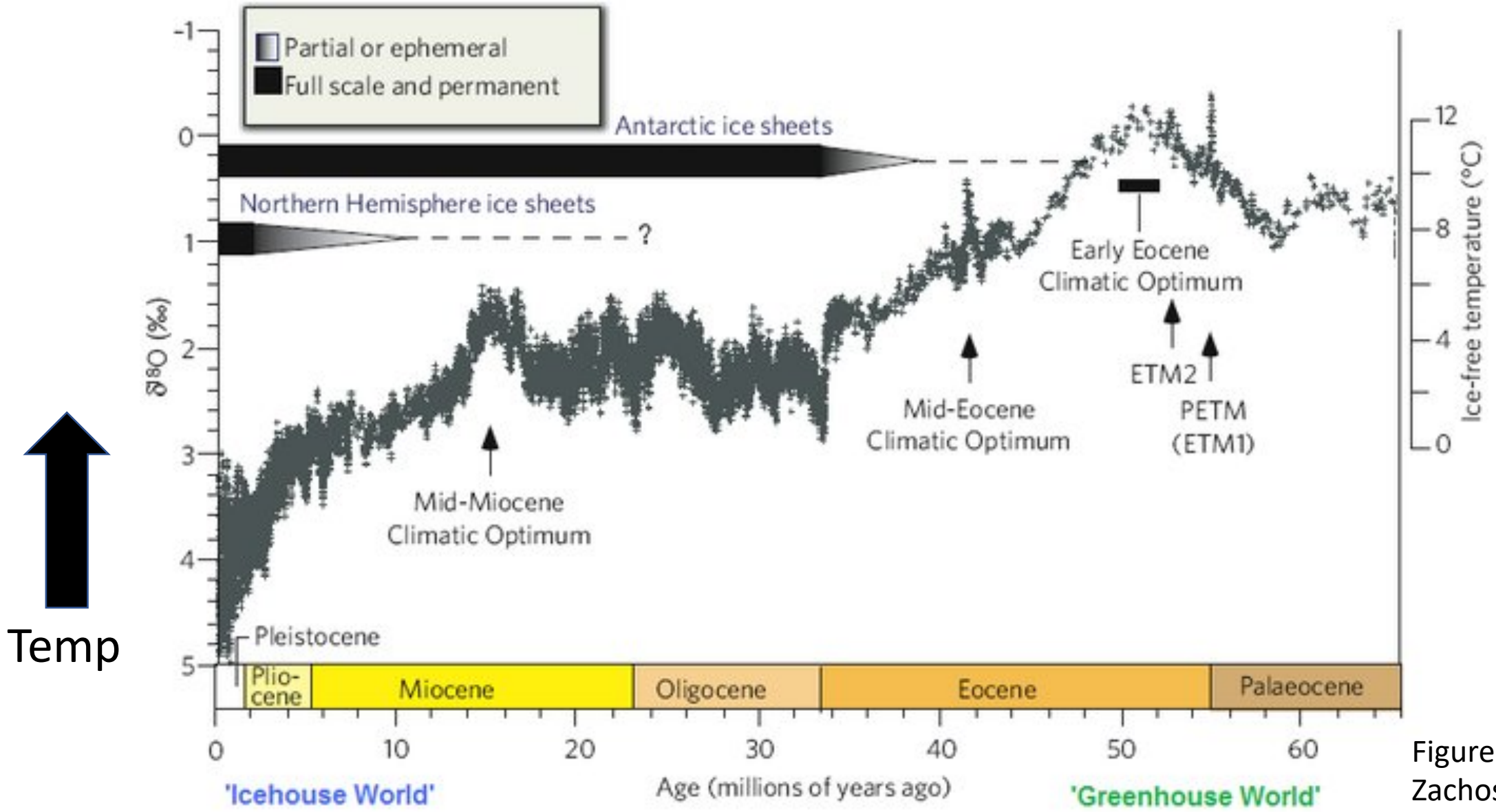
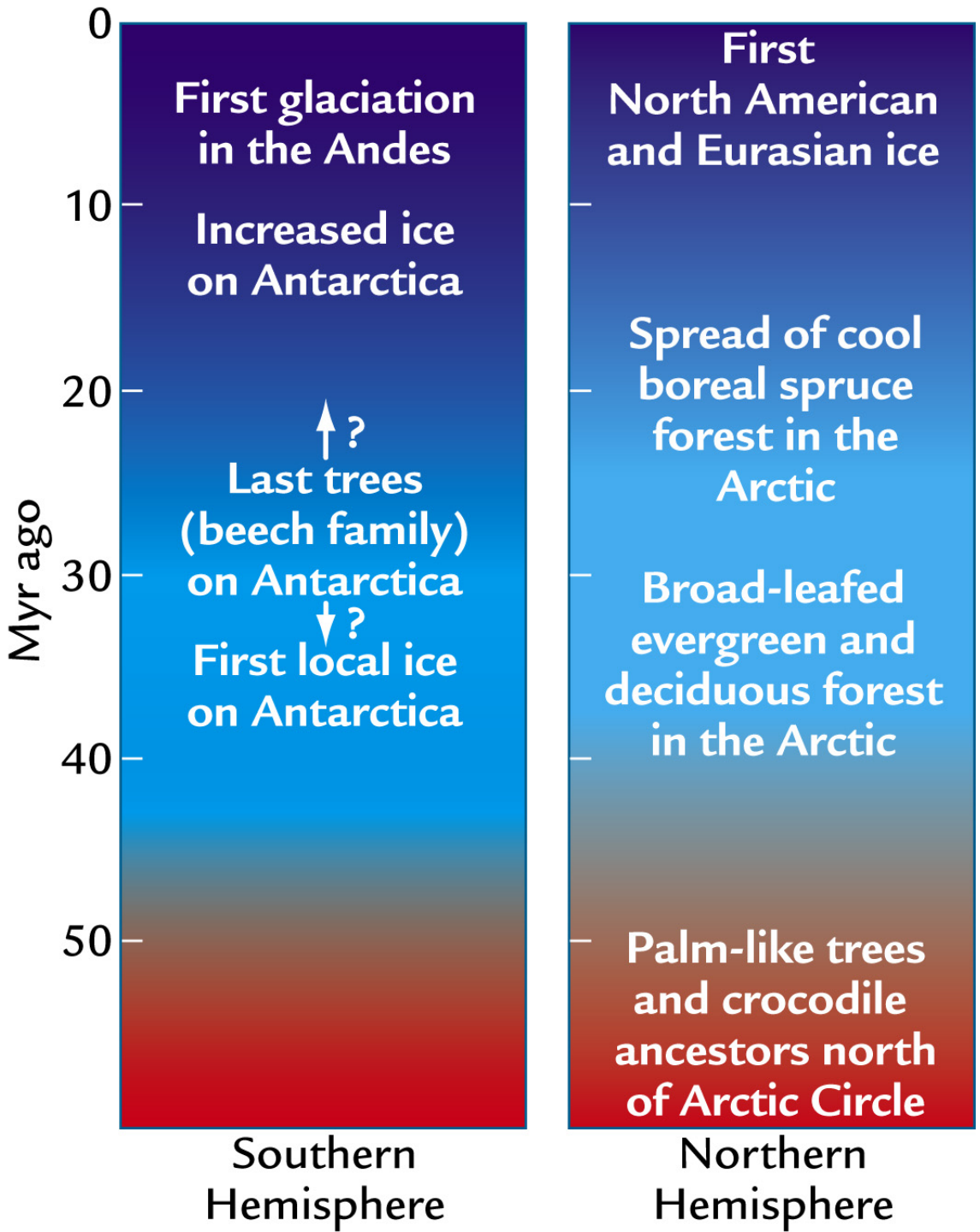
Big Picture Observations: The last 50 million years

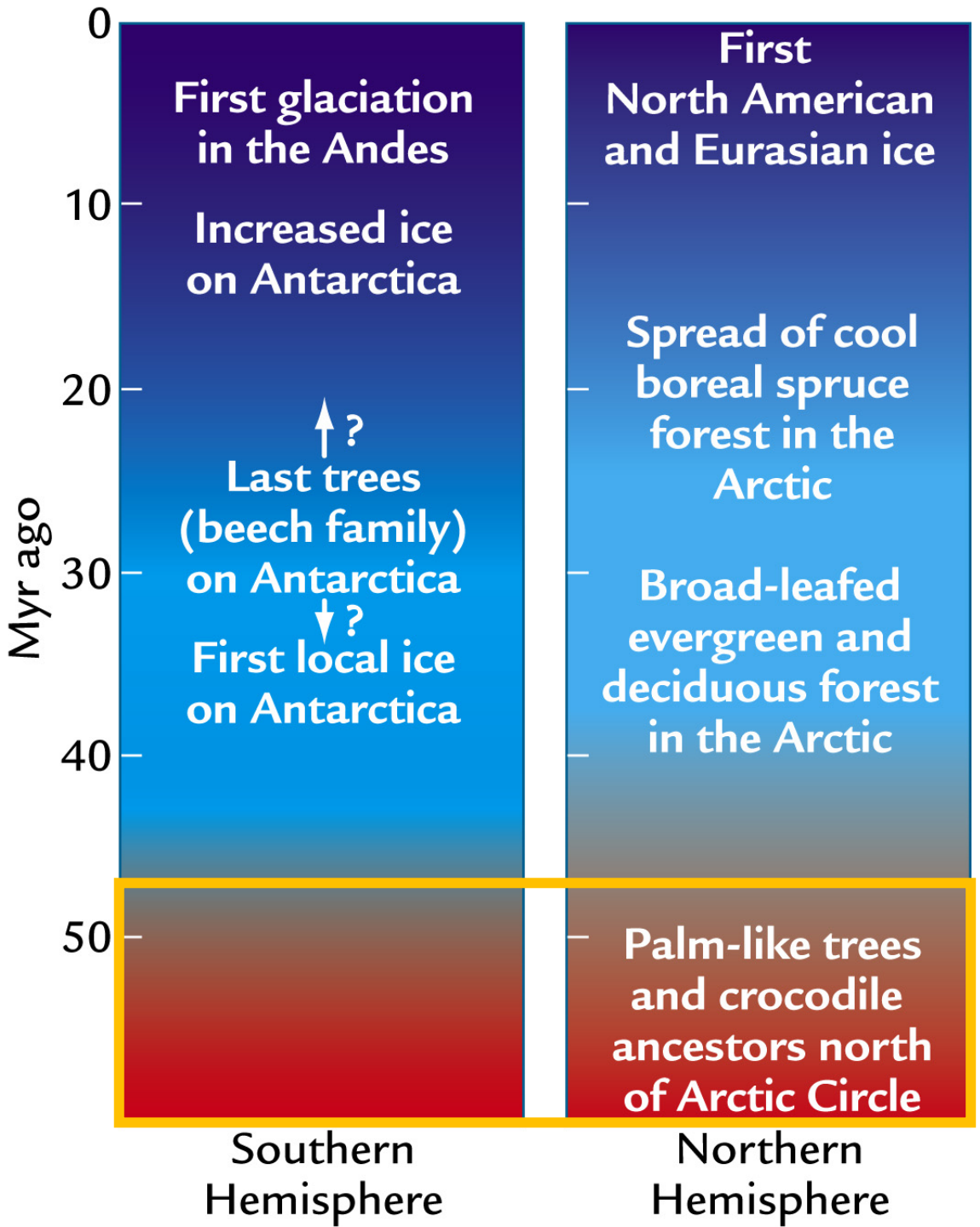


Temp

Figure from Zachos et al. (2008)

Big Picture Observations: The last 50 million years

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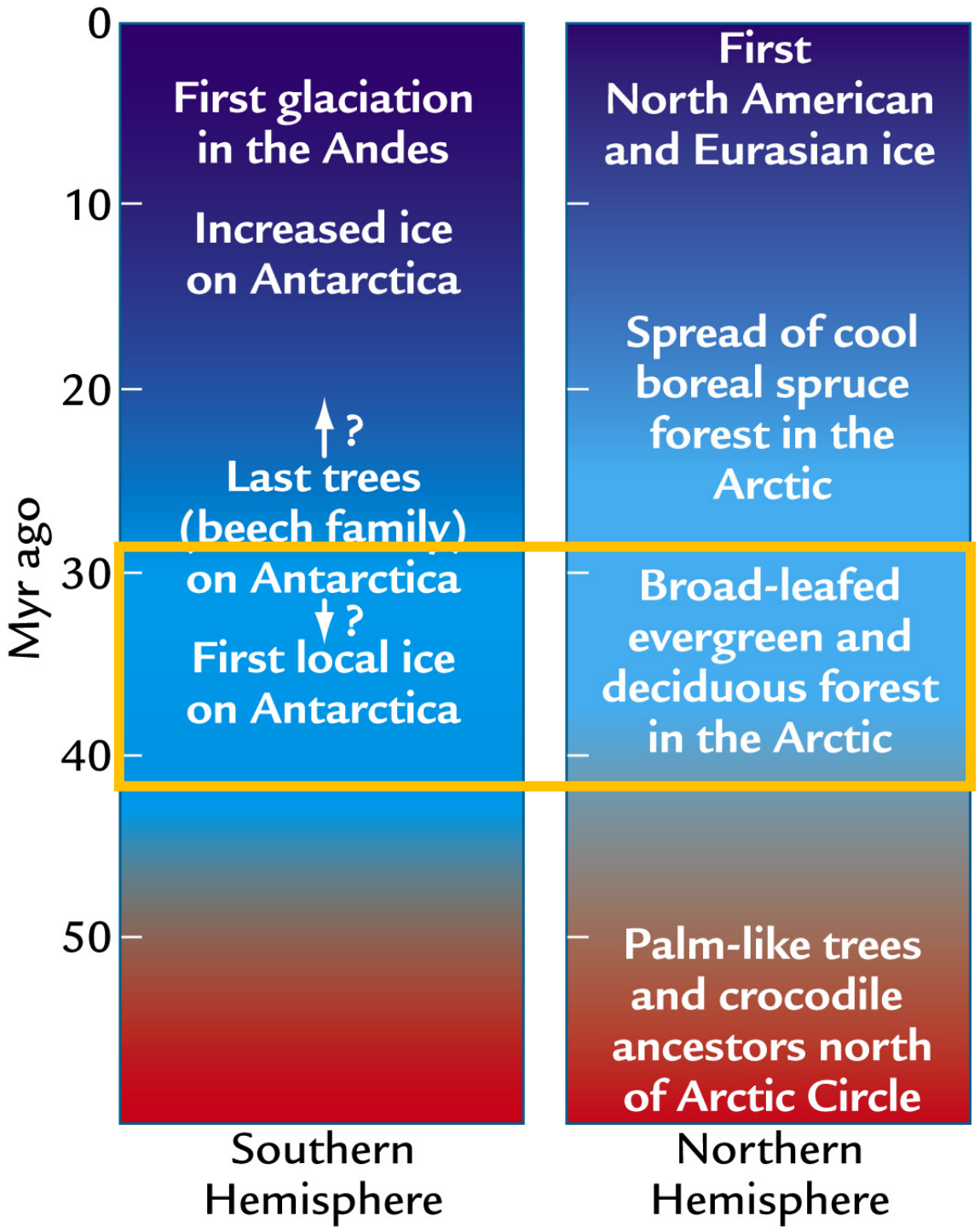
Myr ago
First glaciation in the Andes
Increased ice on Antarctica
?
Last trees (beech family) on Antarctica
?
First local ice on Antarctica
First North American and Eurasian ice
Spread of cool boreal spruce forest in the Arctic
Broad-leafed evergreen and deciduous forest in the Arctic
Palm-like trees and crocodile ancestors north of Arctic Circle
Southern Hemisphere
Northern Hemisphere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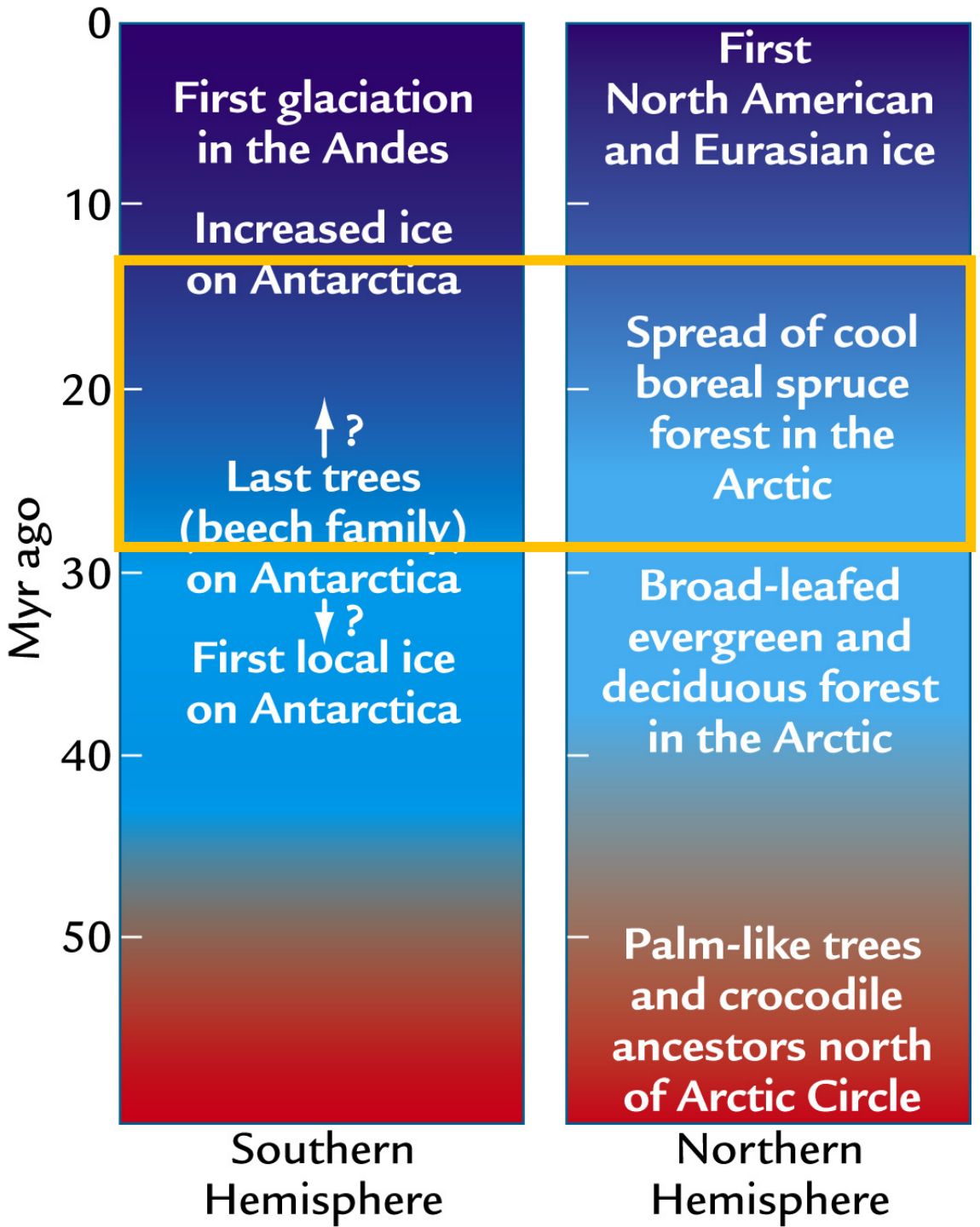
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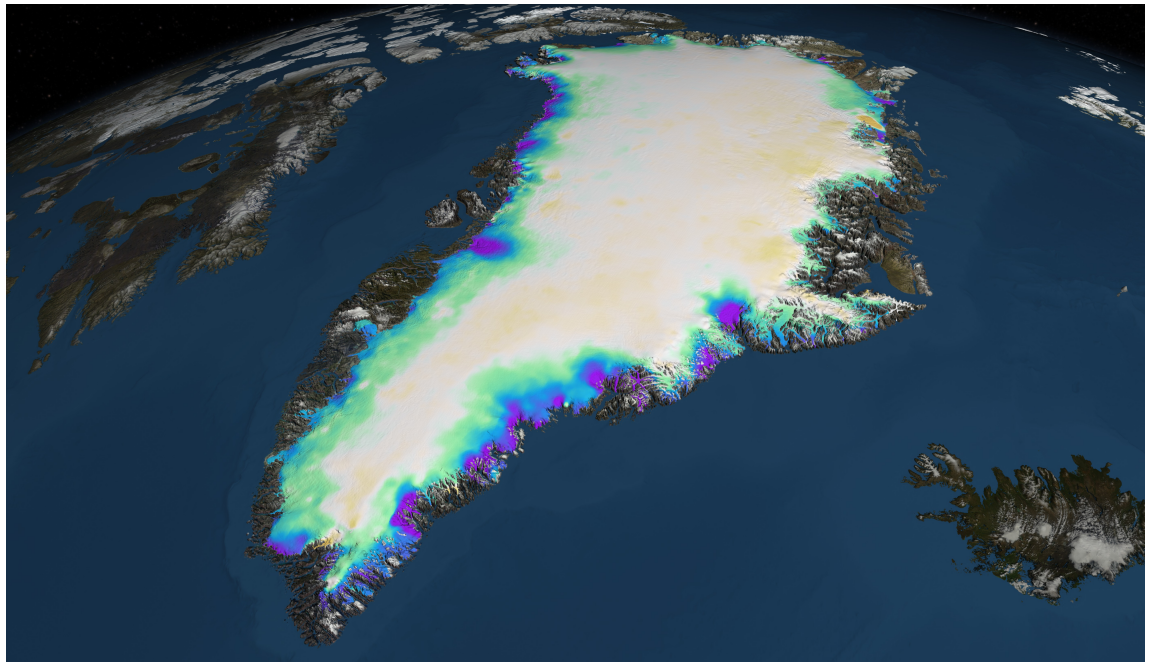

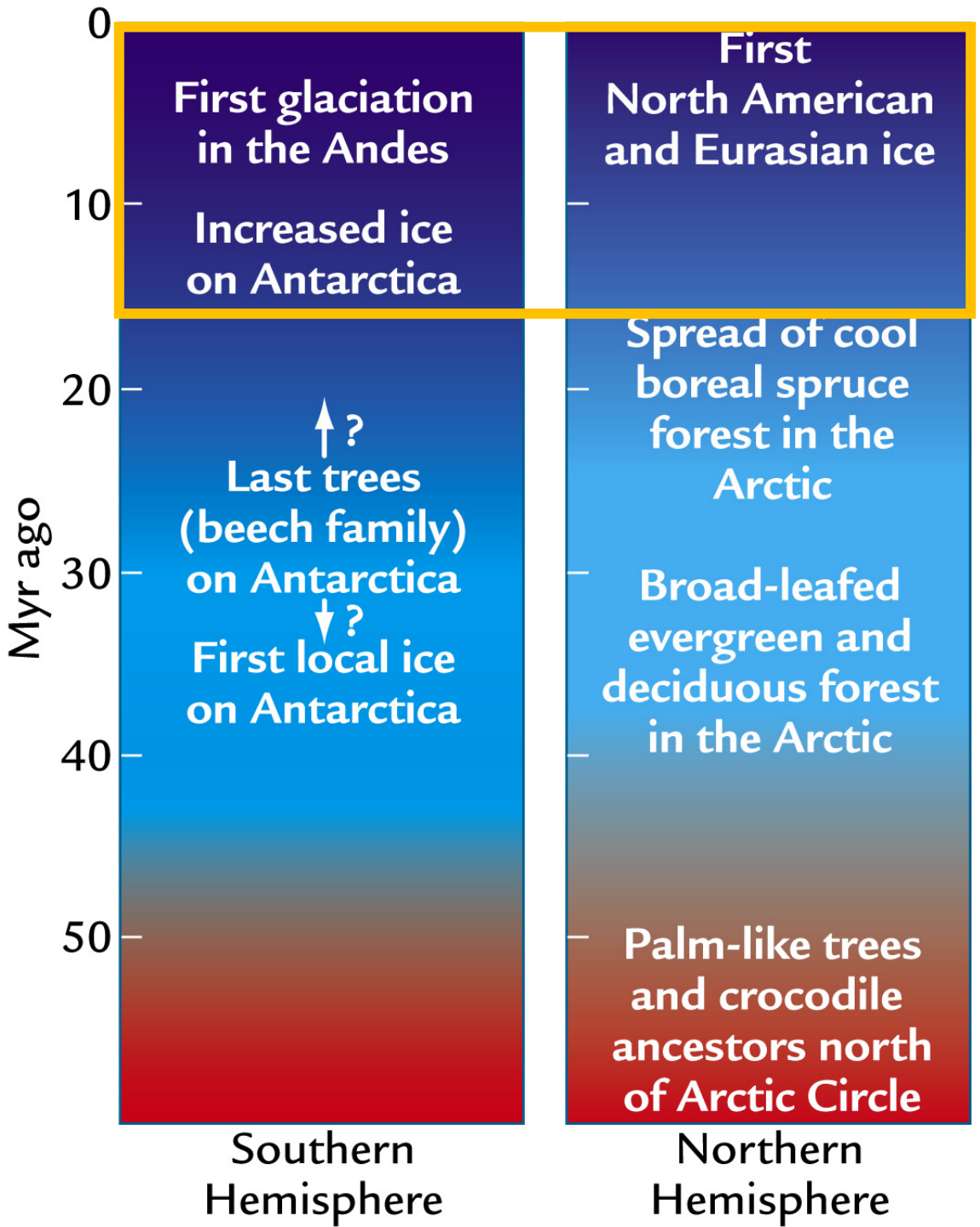
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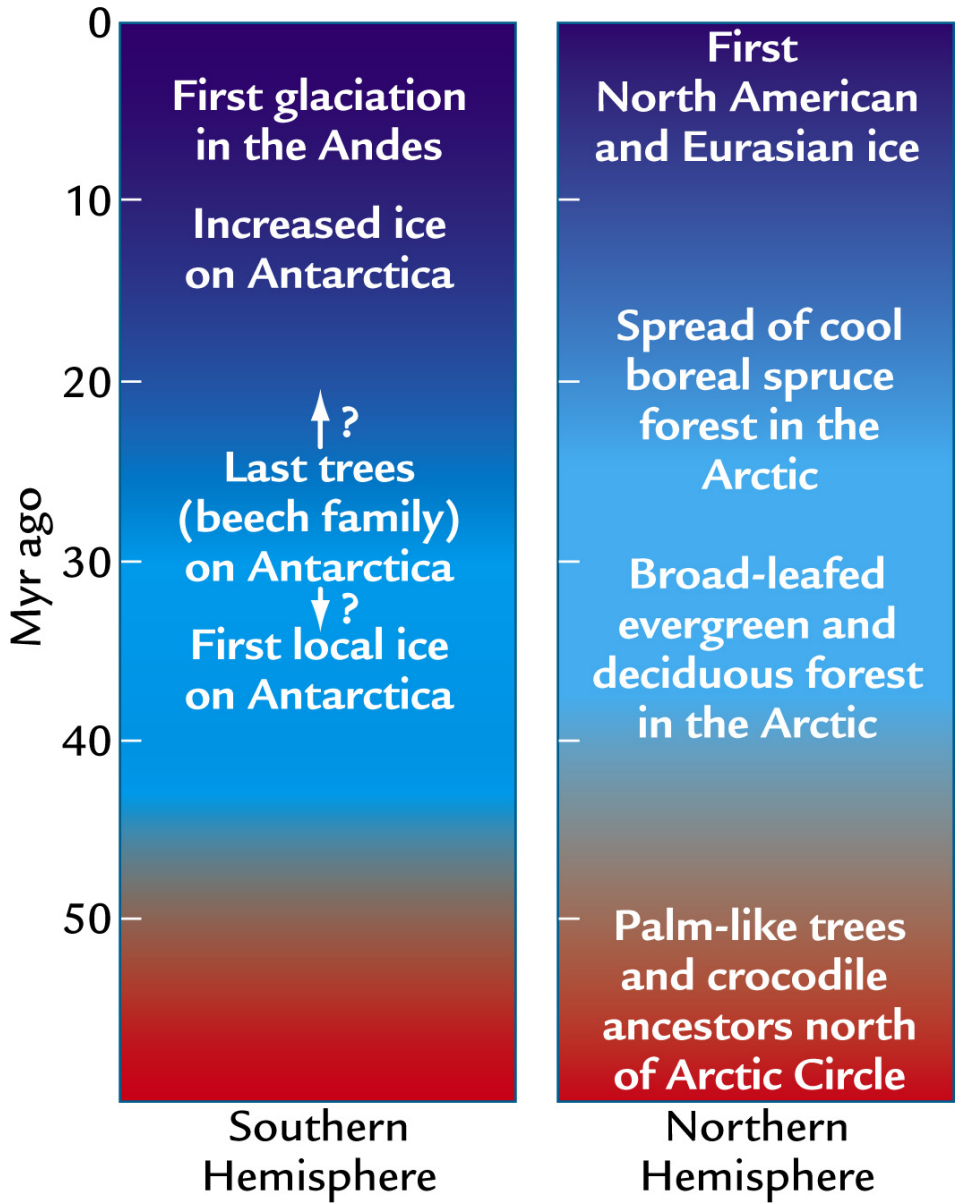
What explains the cooling?

Multiple Hypotheses:

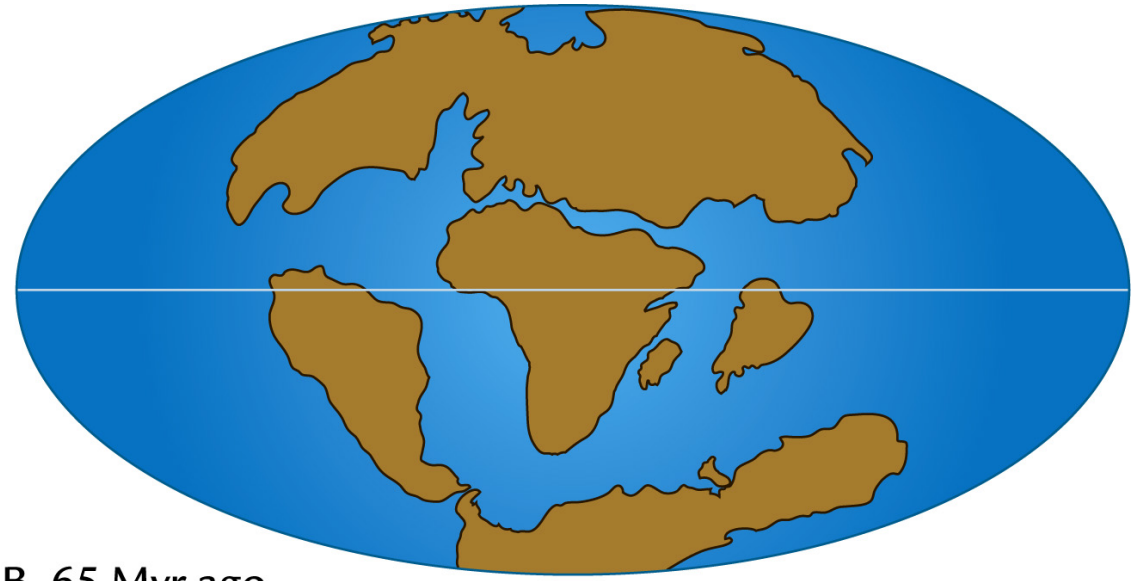
- Gateway Hypothesis
- Changes in CO_2
- Increased Volcanism
- Uplift Weathering Hypothesis



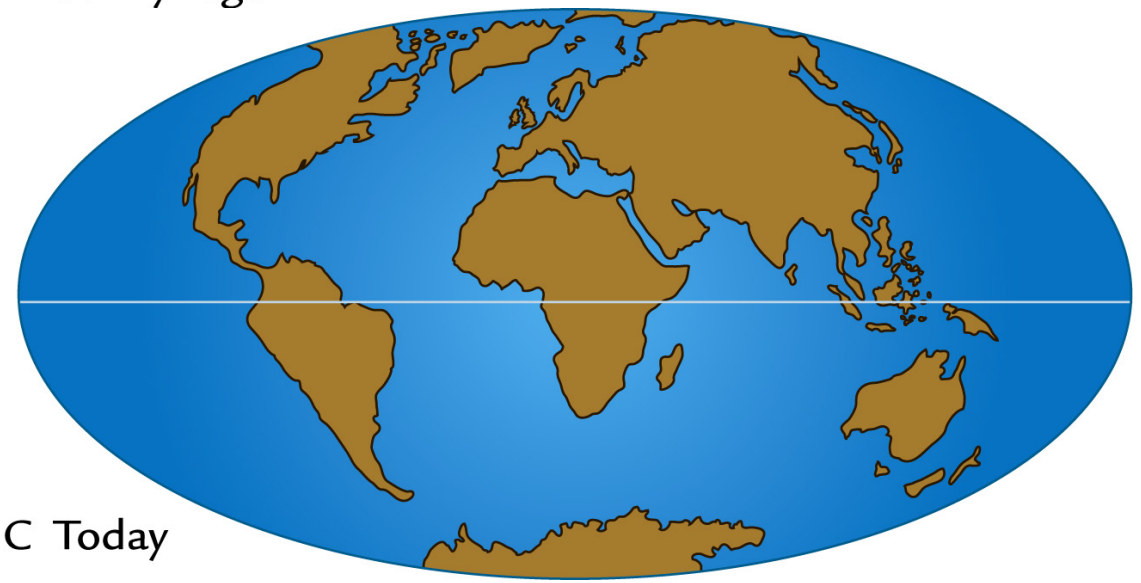
What explains the cooling?

Gateway Hypothesis:

- Continents moved in last 50 million years



B 65 Myr ago

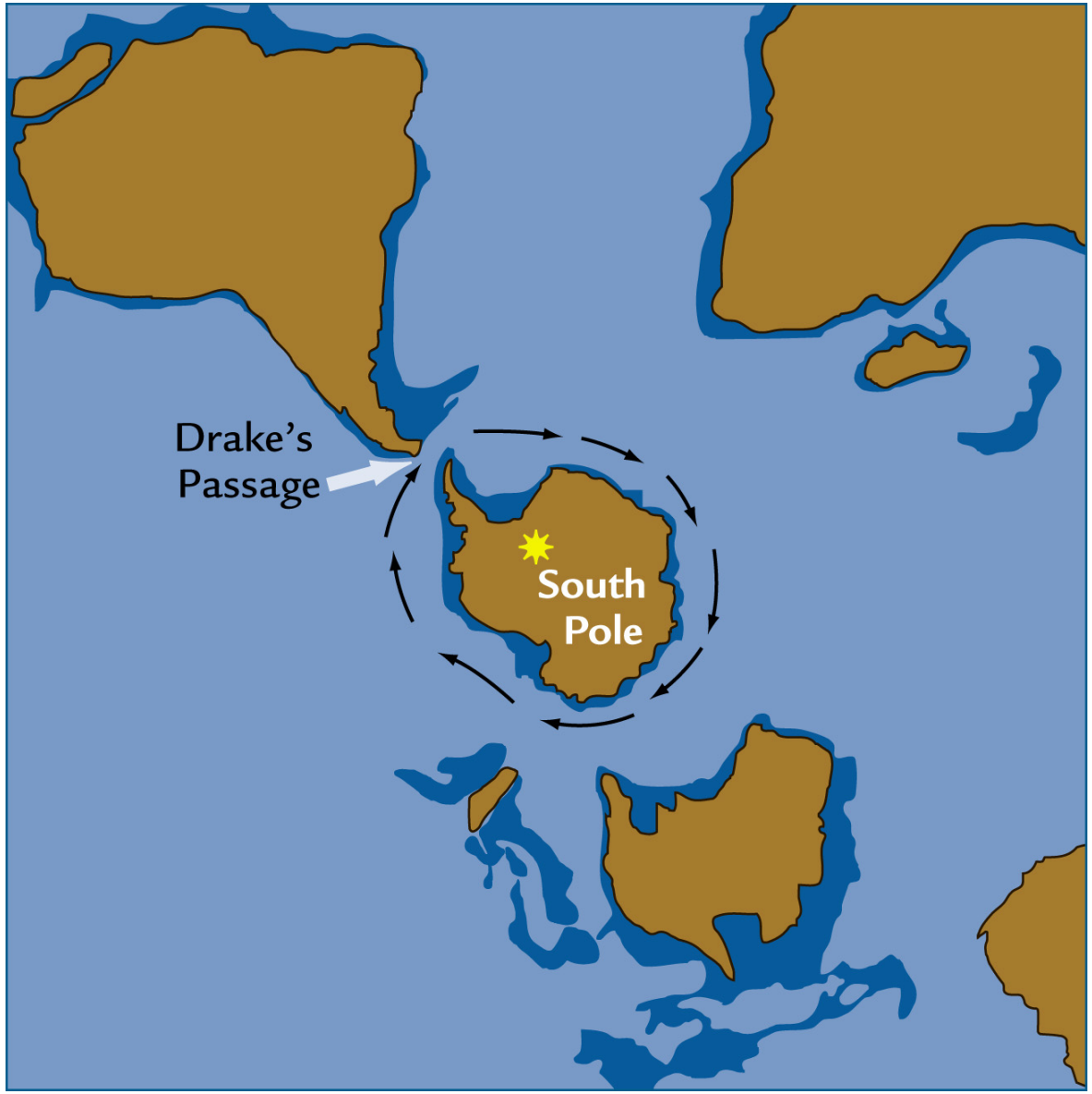


C Today

What explains the cooling?

Gateway Hypothesis:

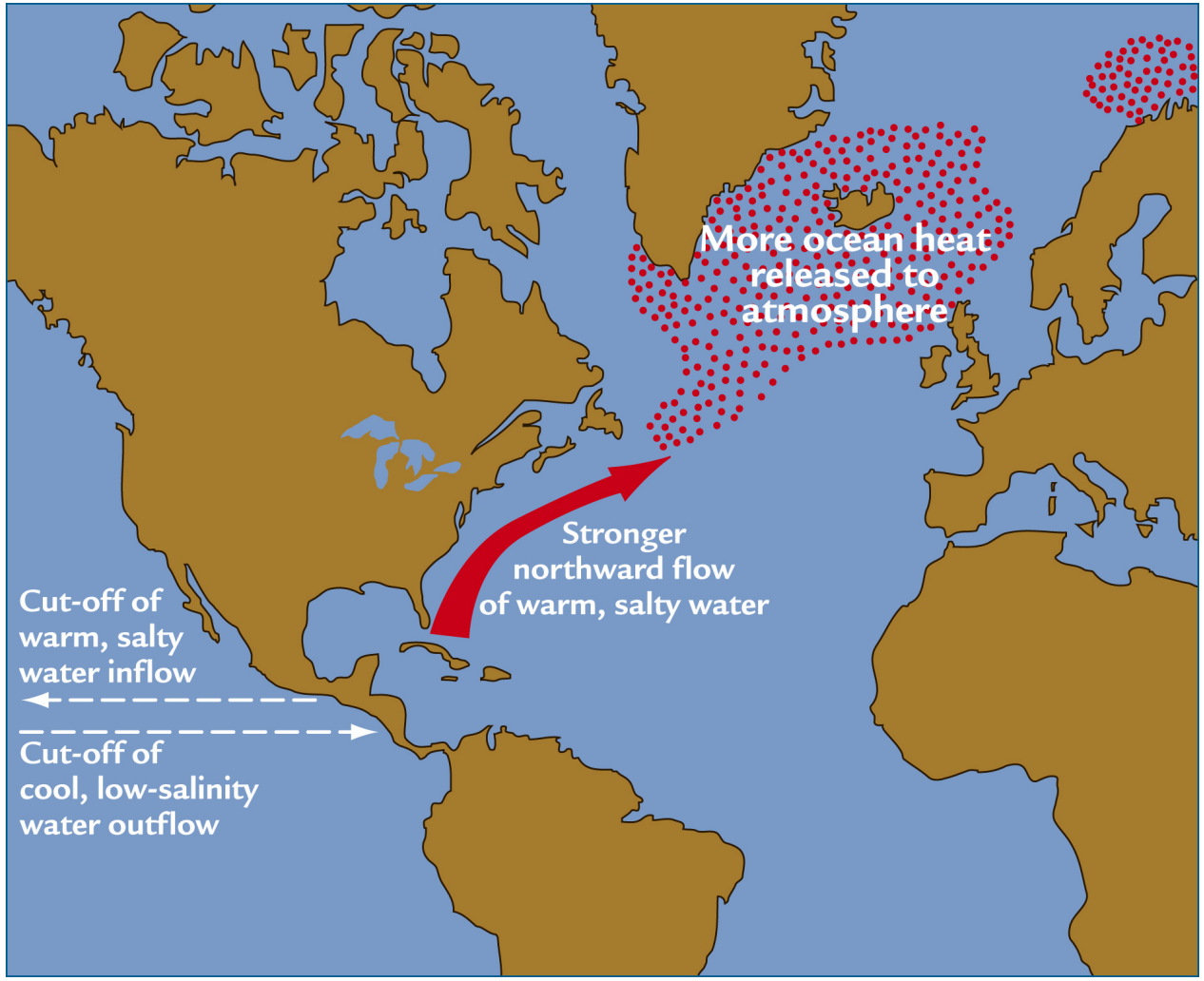
- Continents moved in last 50 million years
- This changed ocean currents!



What explains the cooling?

Gateway Hypothesis:

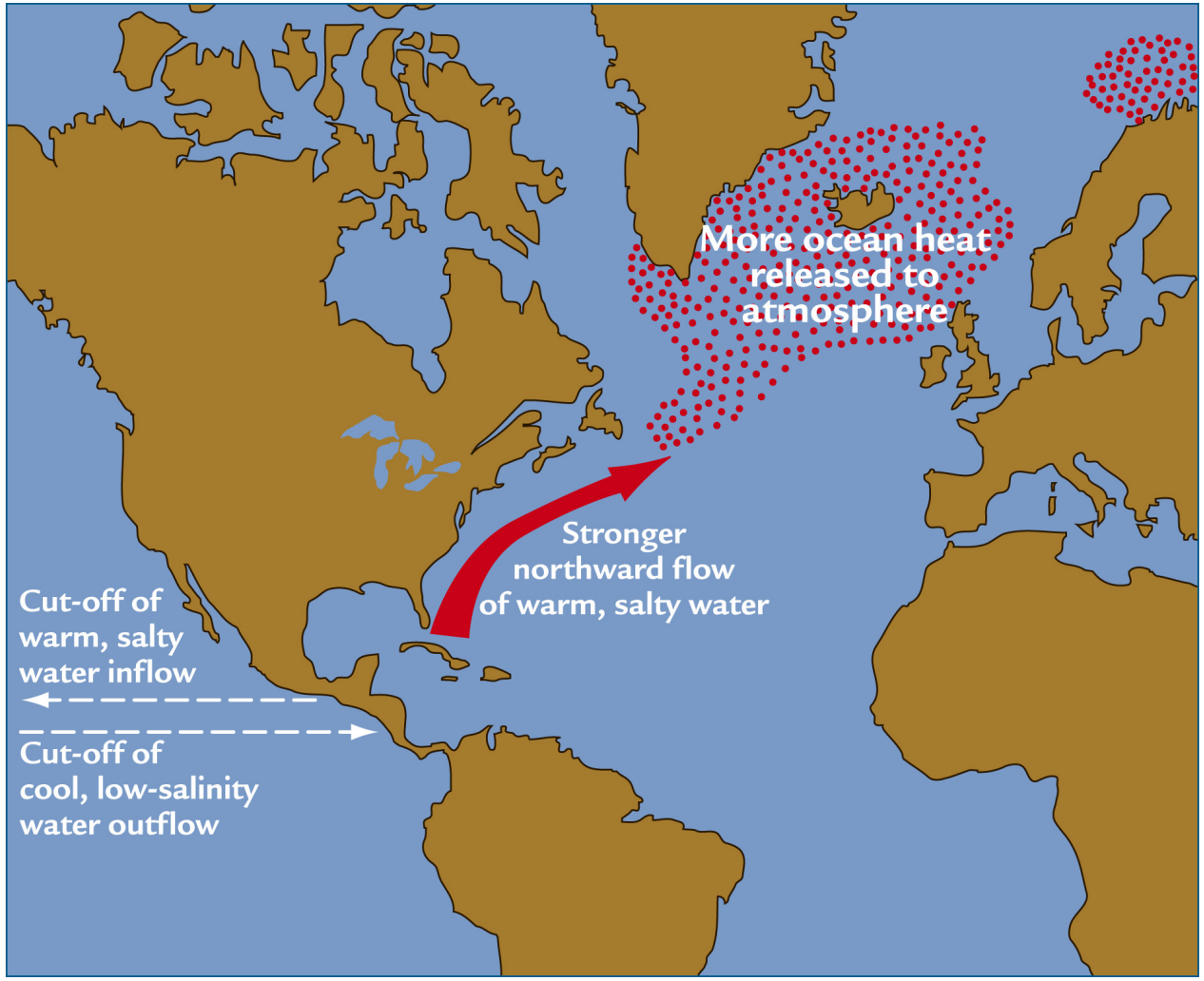
- Continents moved in last 50 million years
- This changed ocean currents!
- Hypothesis states that these changes (1) isolated and cooled Antarctica, and (2) started the AMOC



What explains the cooling?

Gateway Hypothesis:

However, data and models don't support these changes alone causing the cooling



What explains the cooling?

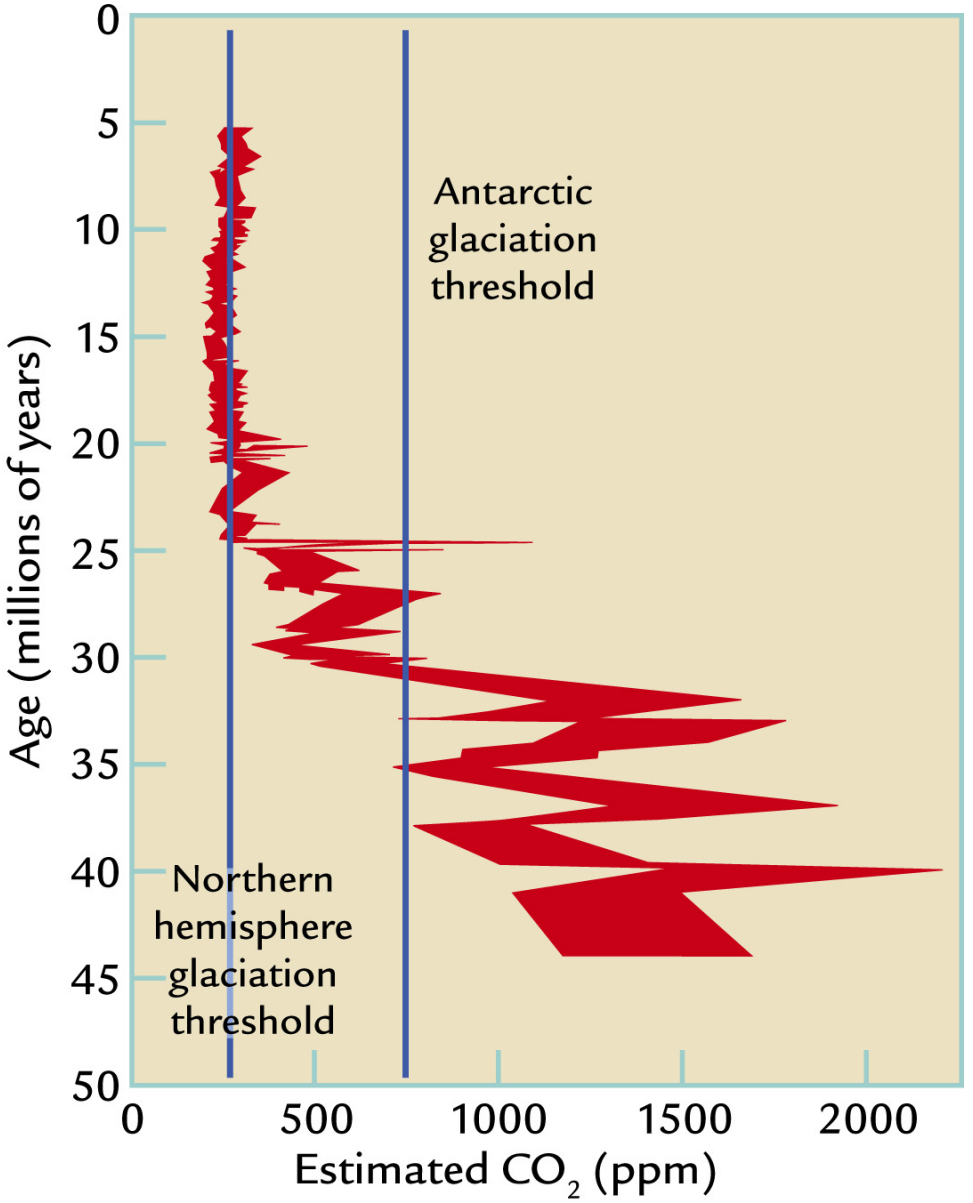
Changes in CO_2:

- Did CO_2 lower?
- Harder to test!
- Ice cores only go back 800,000 years
- No direct measurements of CO_2 concentrations past that

What explains the cooling?

Changes in CO_2:

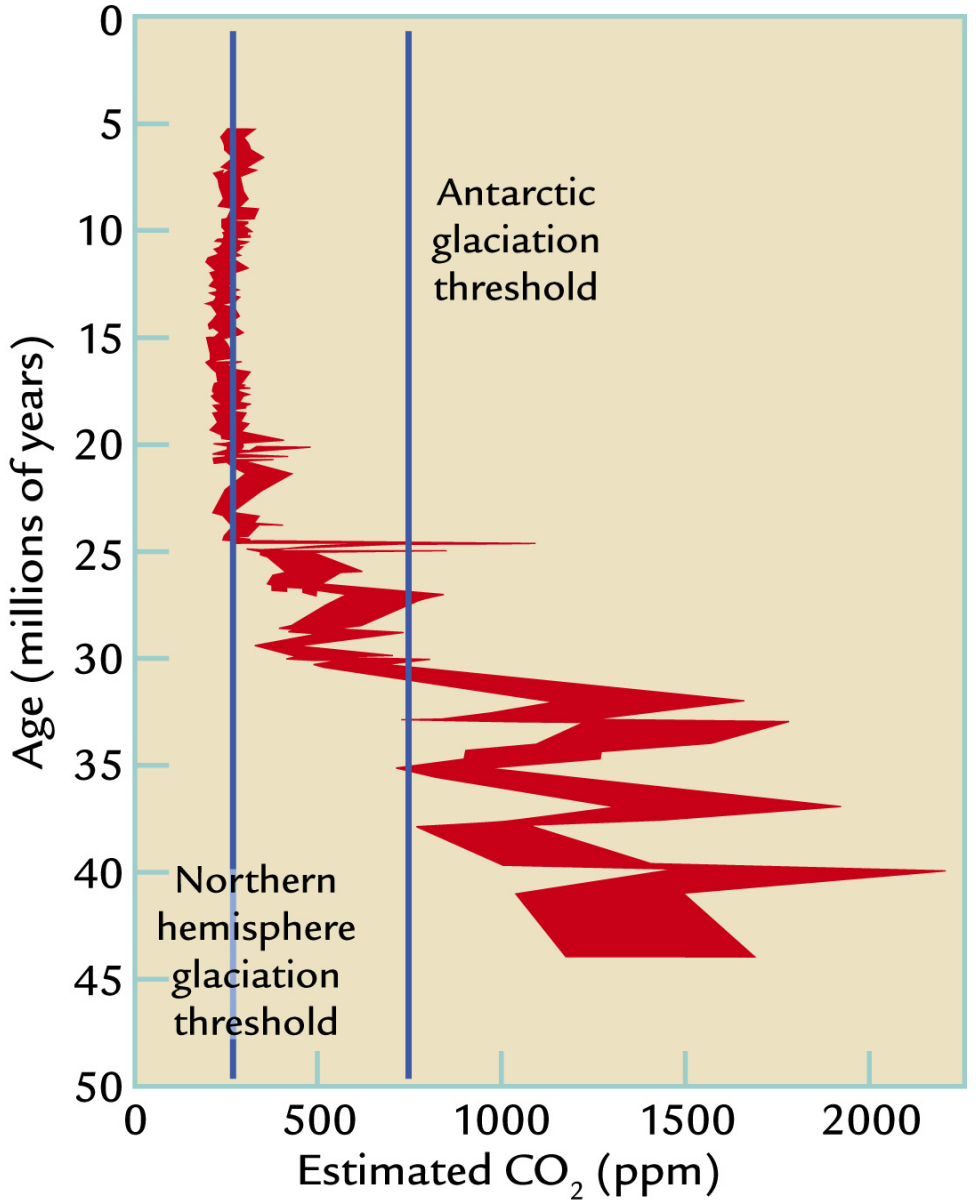
- Some proxies exist to *estimate* CO_2 concentrations from ocean sediment cores
- Larger uncertainty in estimations the further back you go
- Overall, though, looks valid!



What explains the cooling?

Spreading Rate Hypothesis:

- Ok, so why did CO_2 levels drop?

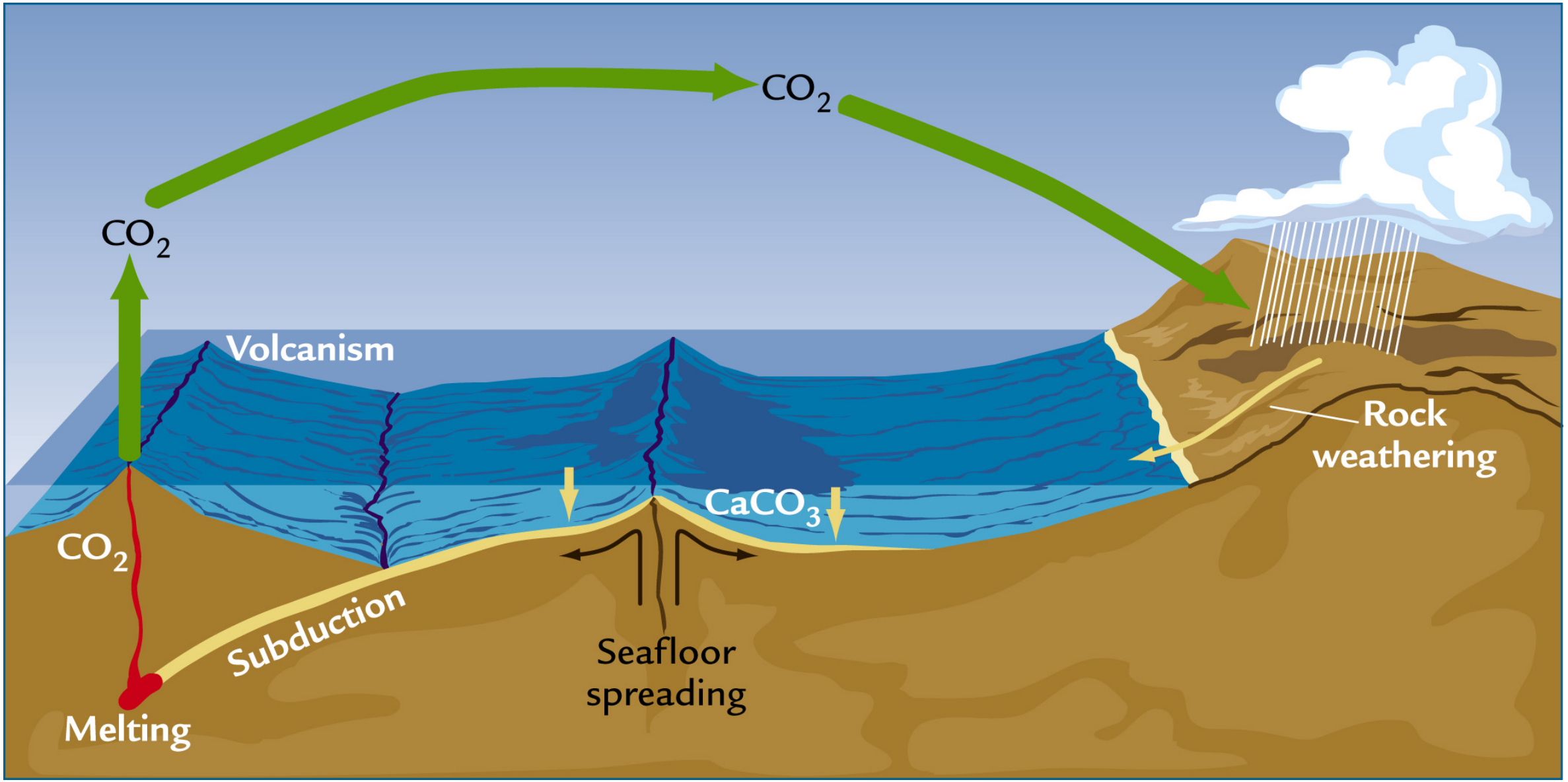


What explains the cooling?

Spreading Rate Hypothesis:

- Ok, so why did CO_2 levels drop?
- Increased volcanism?

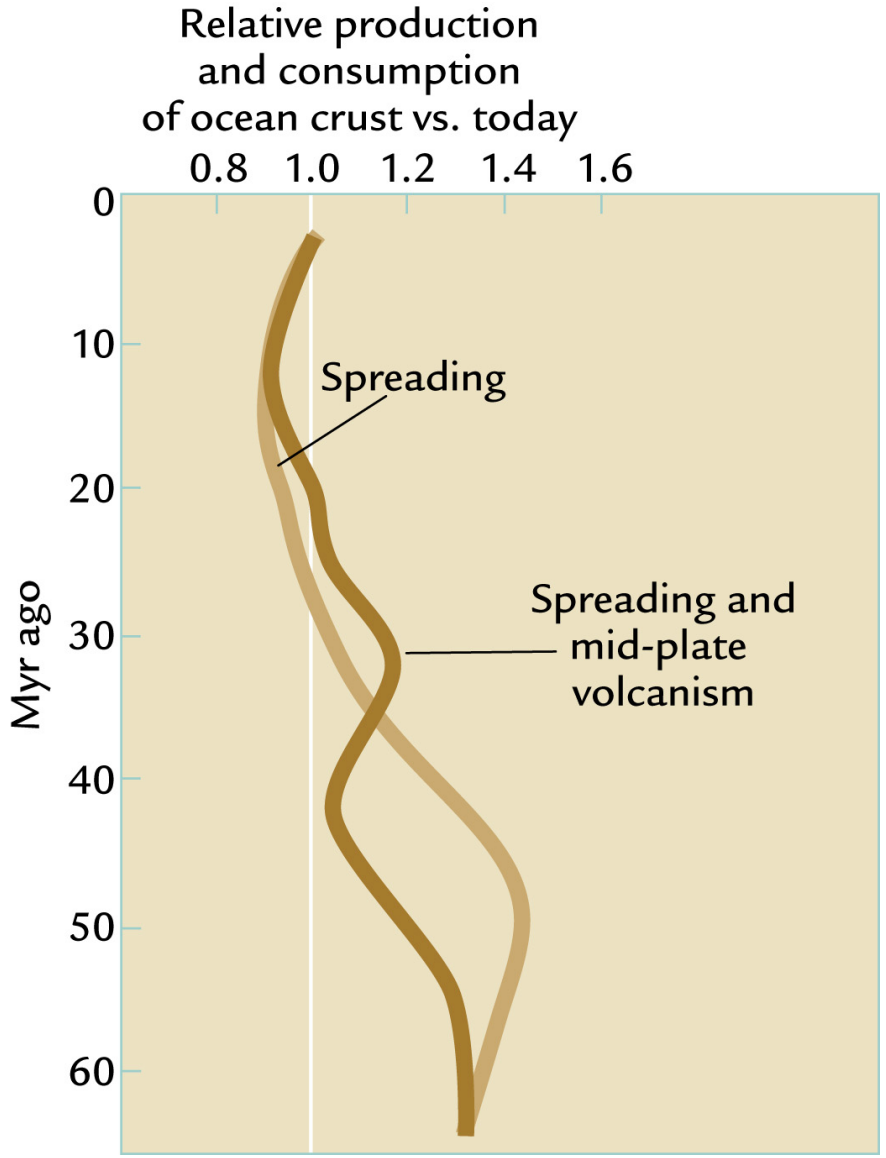
What explains the cooling?



What explains the cooling?

Spreading Rate Hypothesis:

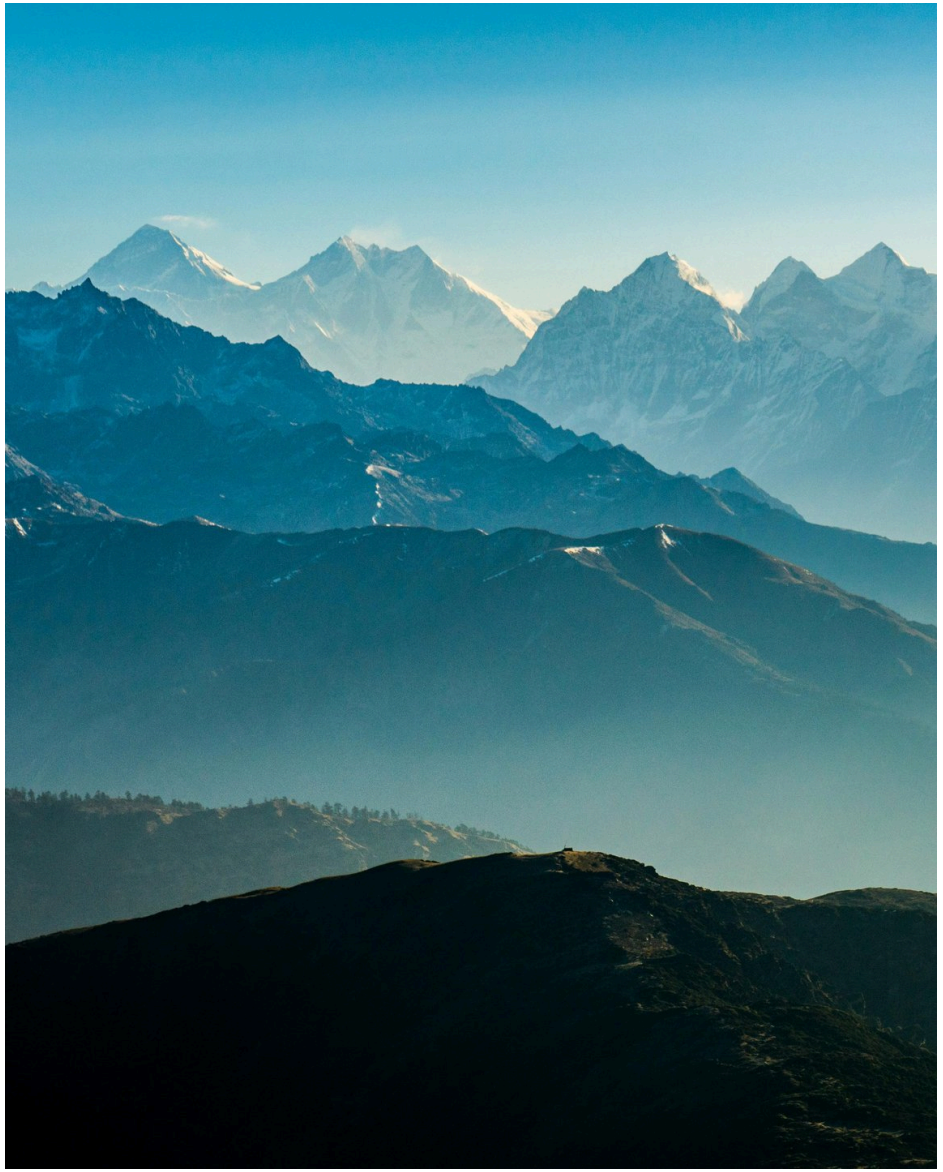
- Ok, so why did CO_2 levels drop?
- Increased volcanism?
- Can explain some of the reduction, but not after ~15 million years ago



What explains the cooling?

Uplift Weathering Hypothesis:

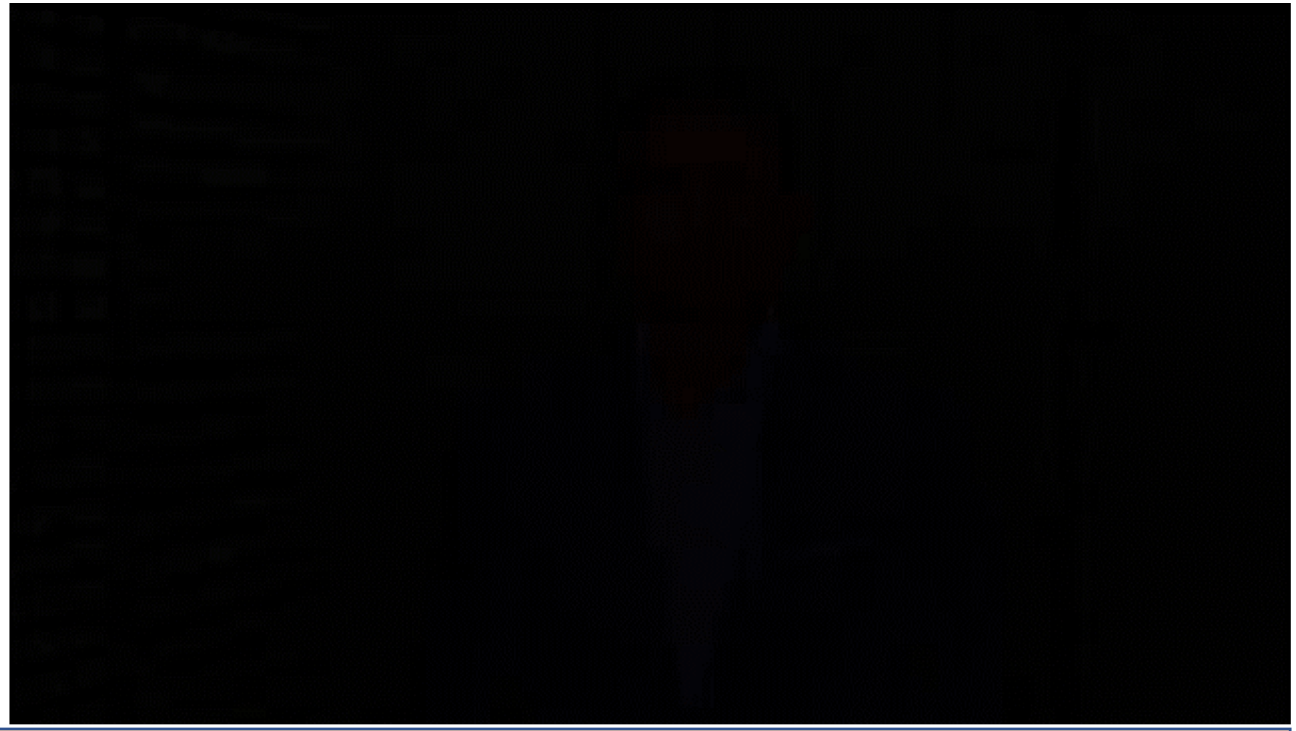
- Ok, so why did CO_2 levels drop until the Pleistocene?
- Building the Himalayan Mountain, caused a global increase in chemical weathering
- Started around 55 million years ago



What explains the cooling?

It was most likely due to a combination of **reduced volcanism** and **increased weathering** that led to a **reduction in atmospheric CO_2**

Scientist Profile: Dr. Maureen Raymo



Dr. Maureen Raymo is the Director of the Lamont-Doherty Core Repository at Columbia University. The work she has done over her career has vastly improved our understanding of ice ages, rapid climate change, the uplift-weathering hypothesis, and the long-term oxygen-isotope record. In 2014, she became the first woman to win the Wollaston Medal for geology in its 183-year history

Today's Class: Paleoclimate – The Last 50 Million Years

Learning Objectives

1. Be able to describe the global temperature trend over the last ~50 million years
2. Describe the tools used to reconstruct this record and how each works
3. Identify and explain one hypothesis about the causes of global temperature change over the last 50 million years
4. Explain why information about climate over the last 50 million years is relevant to climate change today

How we know what we know → Big Picture: The last 50 million years → Causes of climate change in last 50 million years → Relevance to present climate change

Why is this relevant?

1. Gives us time periods to observe with higher CO_2 levels

2. Gives us a better understanding of how CO_2 and temperature are linked

3. Shows us how the climate system is different in a warmer world