

Earth's Climate: Past, Present and Future; Concerns and Solutions

Week 2: Thursday April 6, 2017

Paul Belanger

Earth's past climate history and what caused those changes

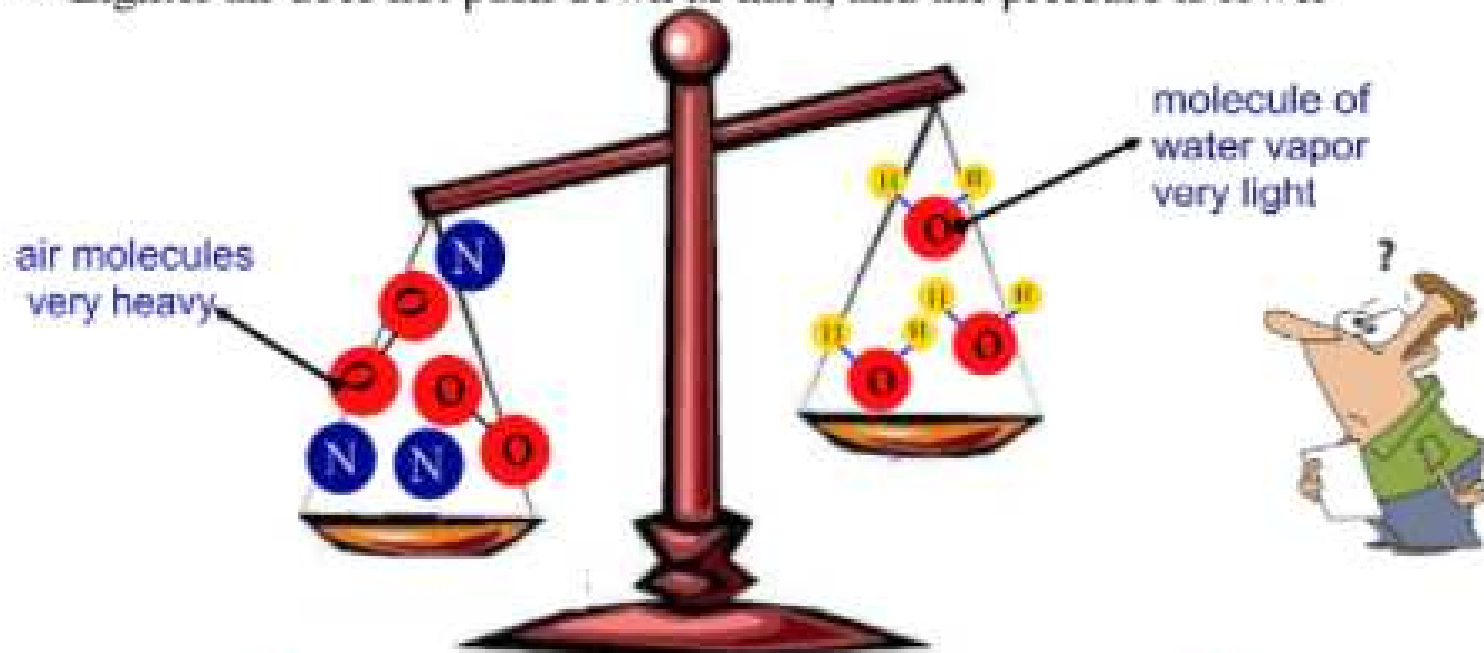
- 1. Earth's deep past before the Cambrian (600 MaBP): hot and cold**
- 2. Earth's past: Cambrian onward: mostly hot-house Earth; 100s parts per million (ppm)**
- 3. Climate trend in the Cenozoic – the last 65 million years; proxy data from 3600ppm to <200 ppm.**
- 4. More recent past: 180-280 part per million; how do we know – empirical data. Preview of next week's field trip**
- 5. Today: 400 ppm and growing 2-3ppm/year**

But first

- Finishing slides from last week

Air Pressure - Water Vapor (Humidity)

- Water vapor is lighter than the oxygen, nitrogen, and hydrogen molecules that make up our air.
- So as you add water vapor to the air, the air becomes lighter
- Lighter air does not push down as hard, and the pressure is lower




- as water vapor increases, air pressure decreases

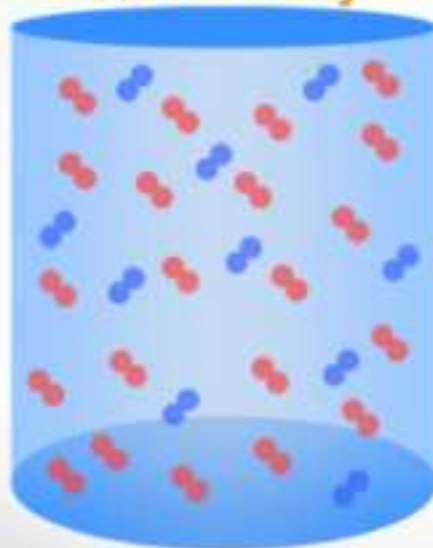
Humidity

 = Nitrogen (N_2)

 = Oxygen (O_2)

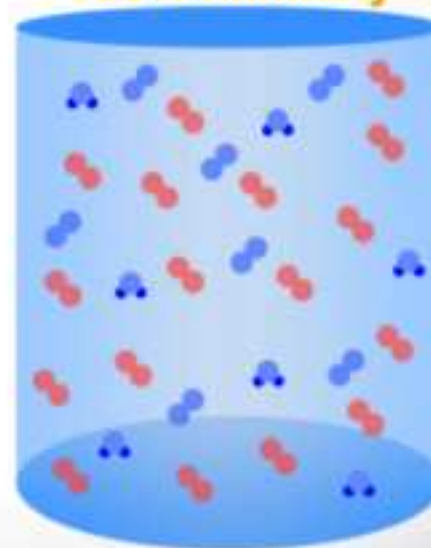
 = Water Vapor (H_2O)

0% Humidity



Mass = 440

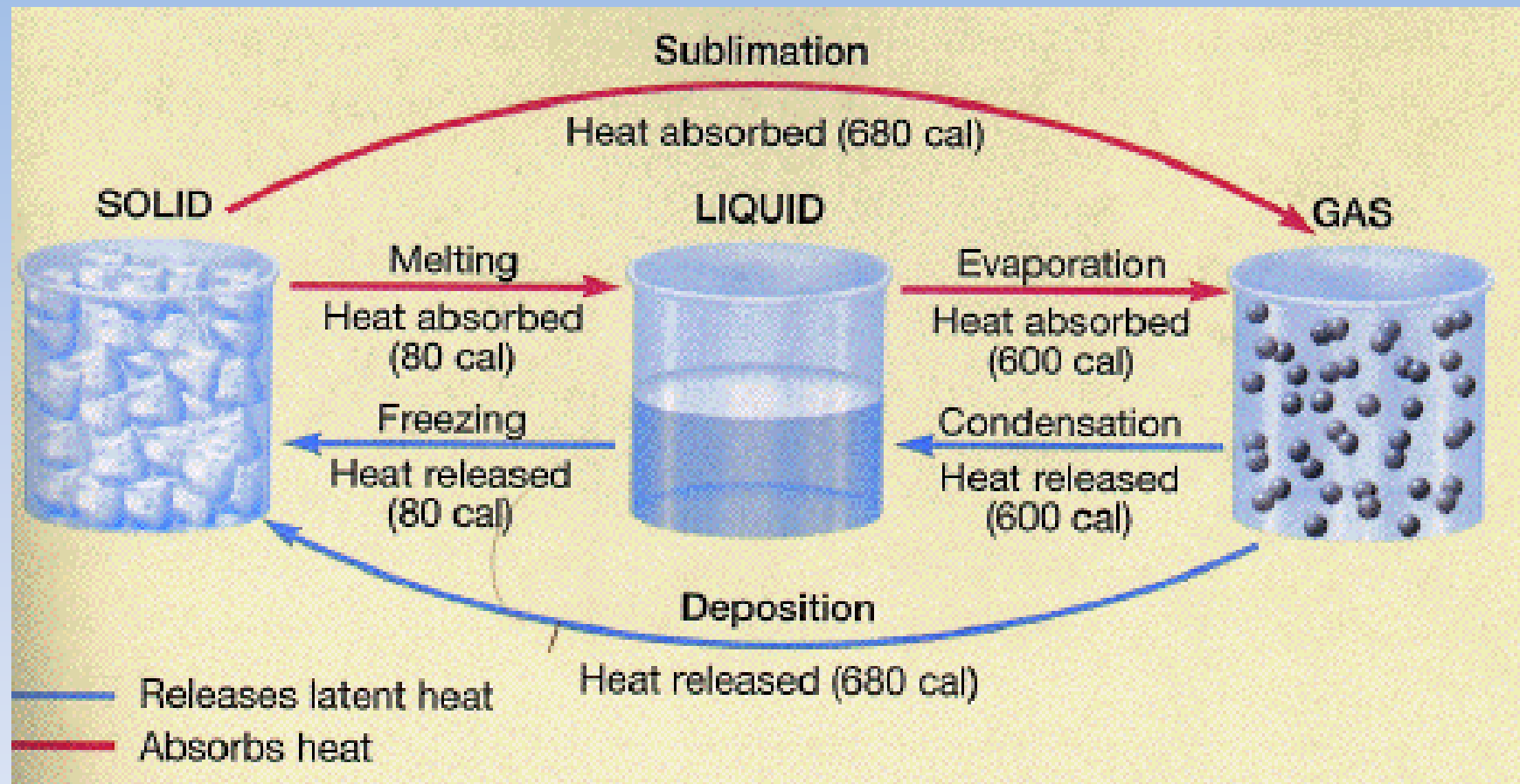
100% Humidity



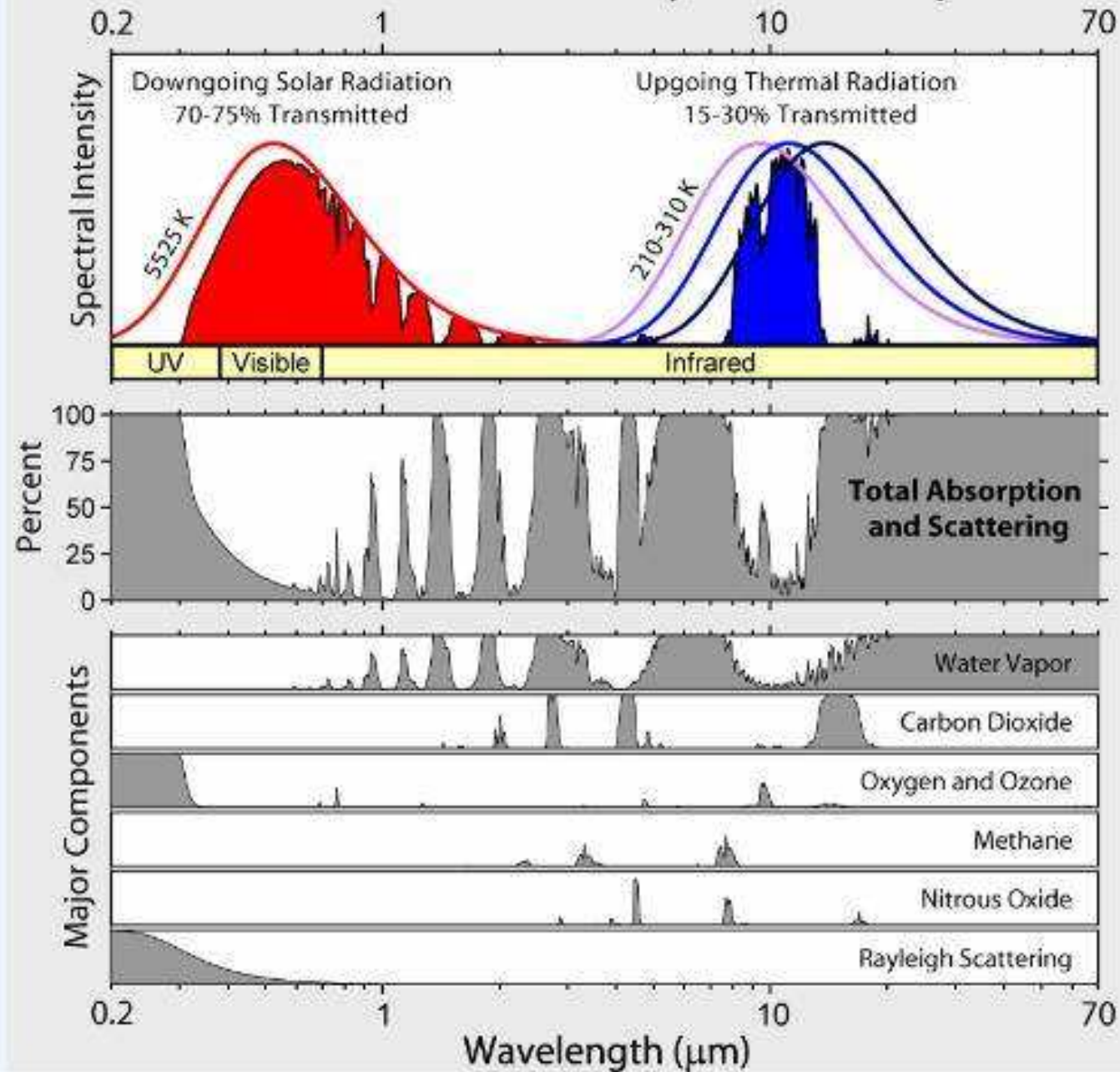
Mass = 420

[boldmethod](#)

The Energy in phase changes



Radiation Transmitted by the Atmosphere



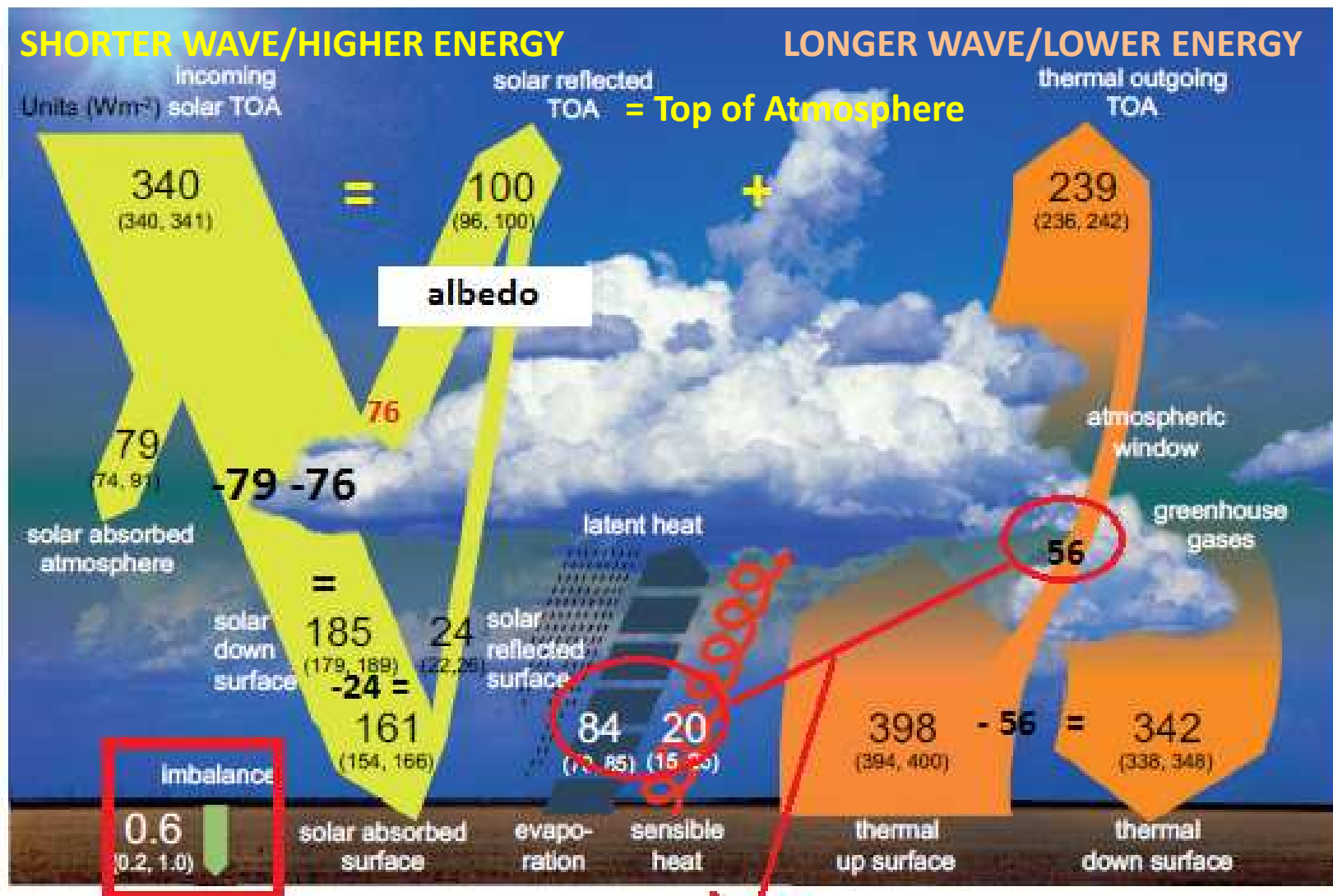


Figure 2.11: | Global mean energy budget under present-day climate conditions. Numbers show magnitudes of the individual energy fluxes in W m^{-2} , adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)

161 + 342 = 503 - 2 outside
vs. 84 + 20 + 398 = 502 - 3 inside
arrows

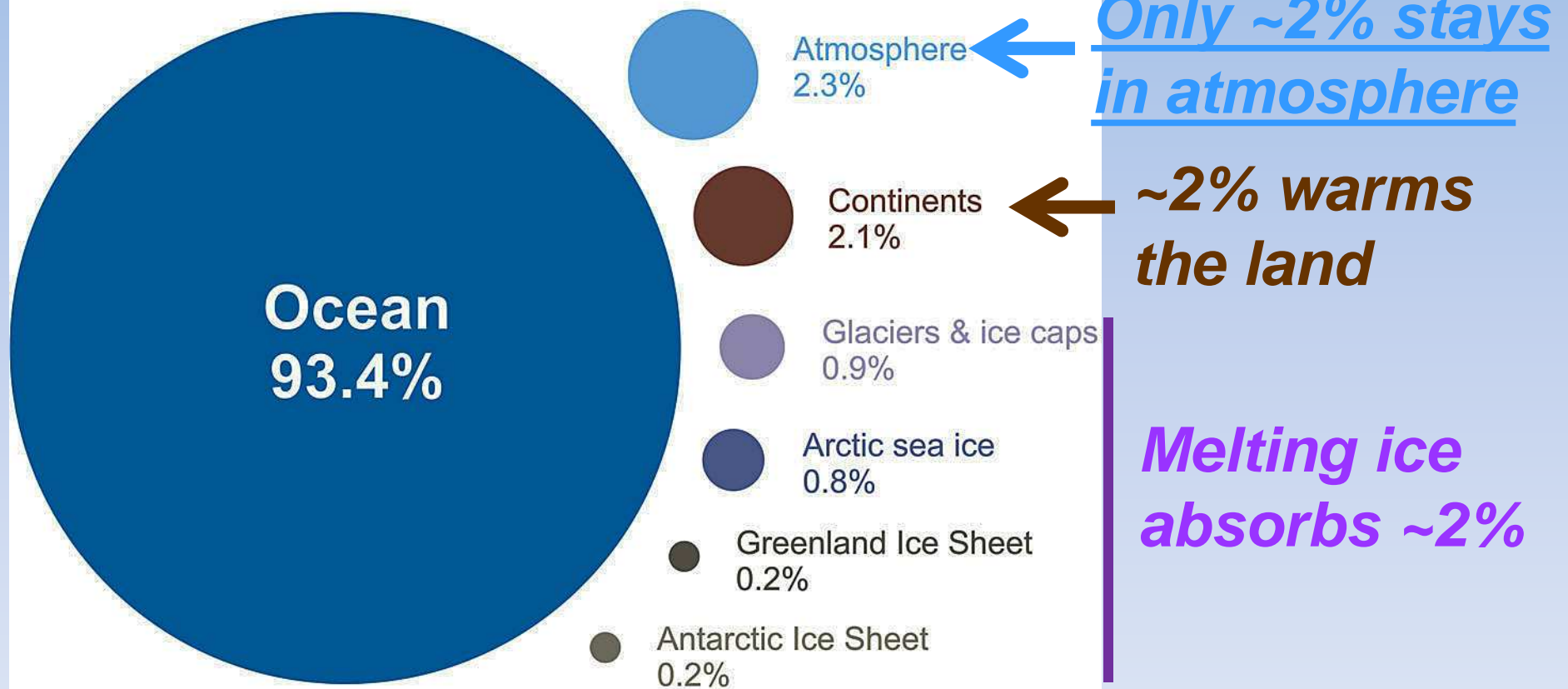
84 + 20 + 56 = 160
which = ~ incoming 161 shortwave

How GHGs Blanket the Earth

- **Blanket Earth:**
- <http://climate.nasa.gov/causes/>
- https://www.youtube.com/watch?v=aqkGoCglp_U&feature=youtu.be
- <https://www.youtube.com/watch?v=we8VXwa83FQ>

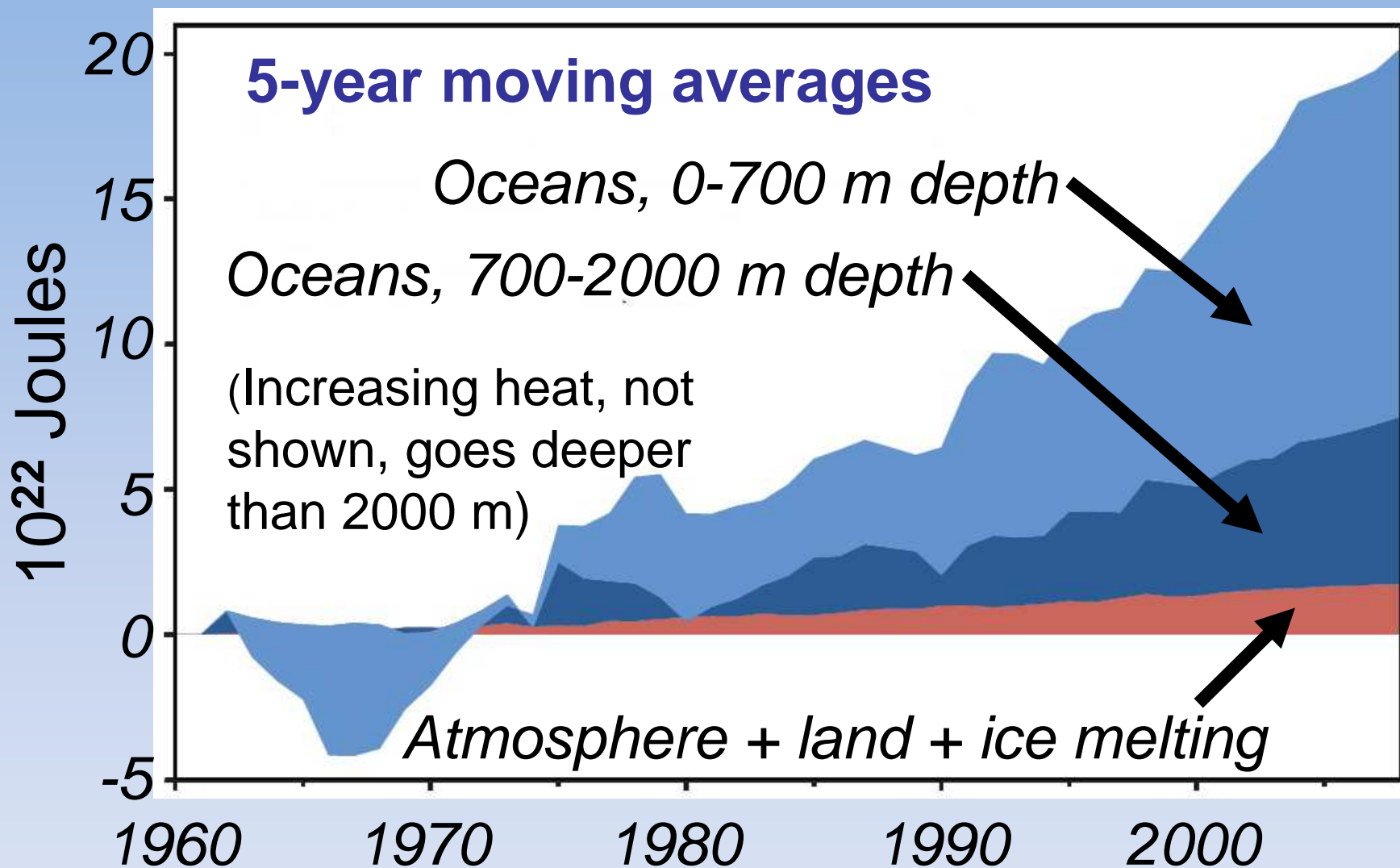
Where's the Heat Going

Where is global warming going?



John Cook, from IGPP 2007 data; ~93% to oceans continues (NOAA/NODC, 2012)

Change in heat content, 1958-2011

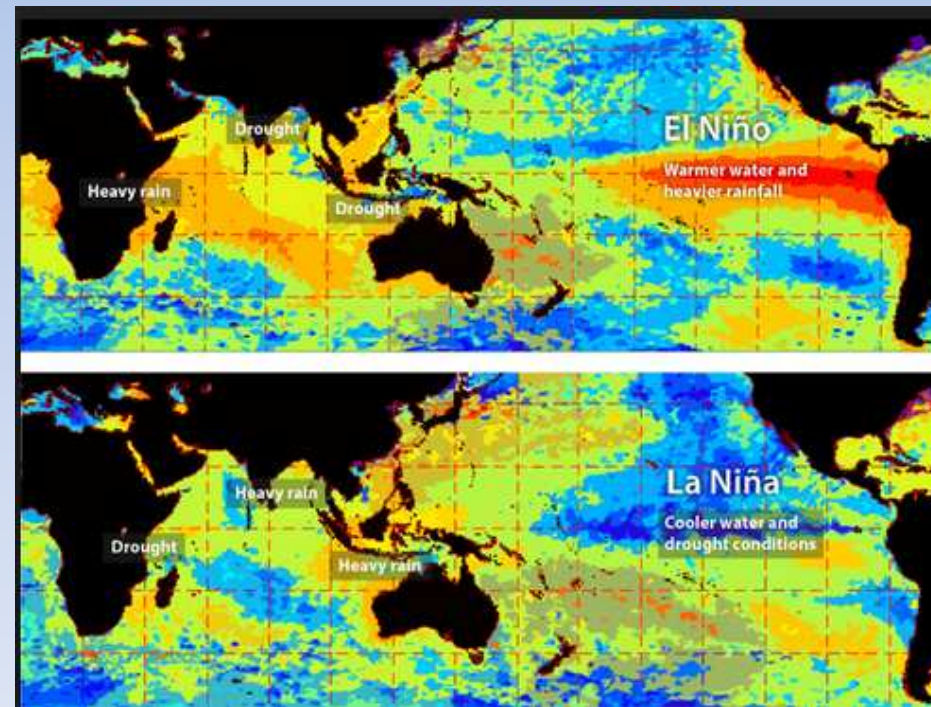
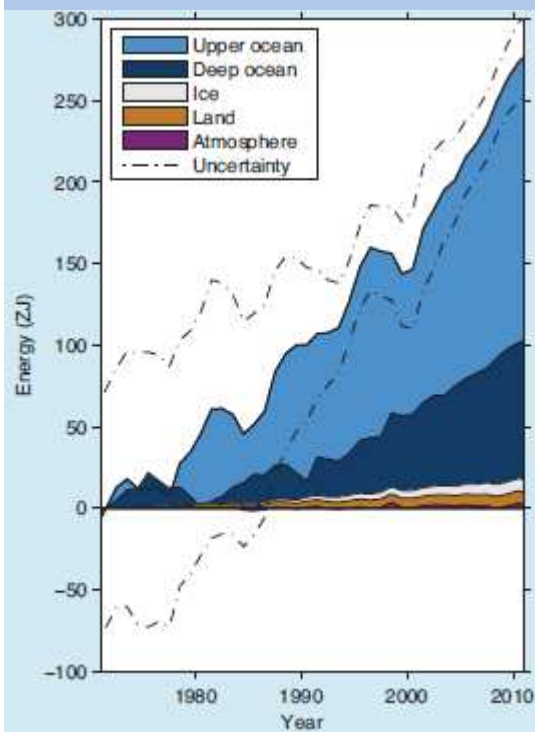
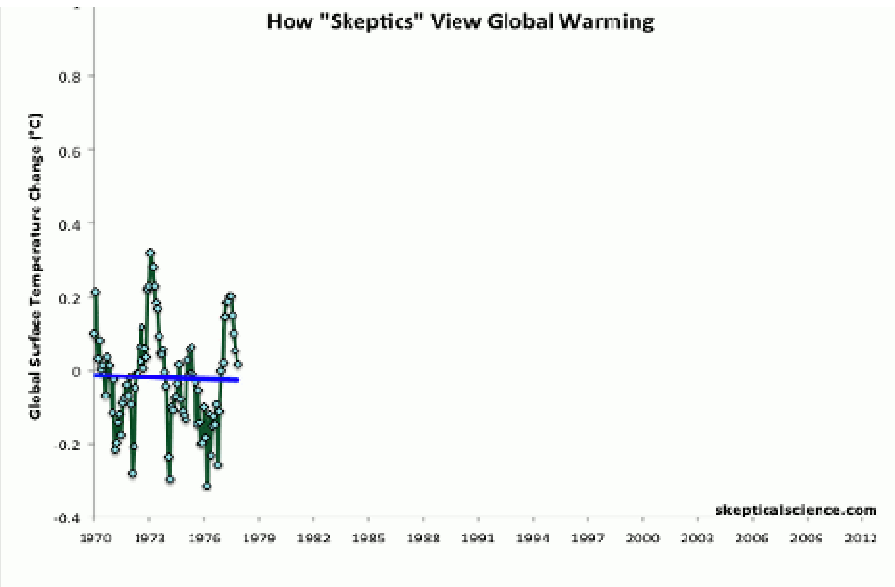
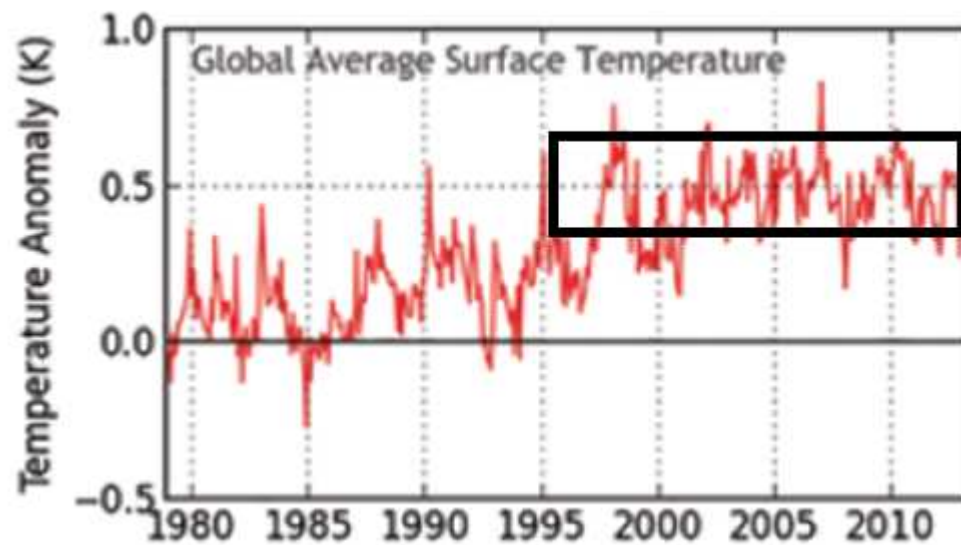


(NOAA 2012 data, Nuccitelli et al. 2012 plot)

Where's the CO₂ Going

The “Missing Sink”

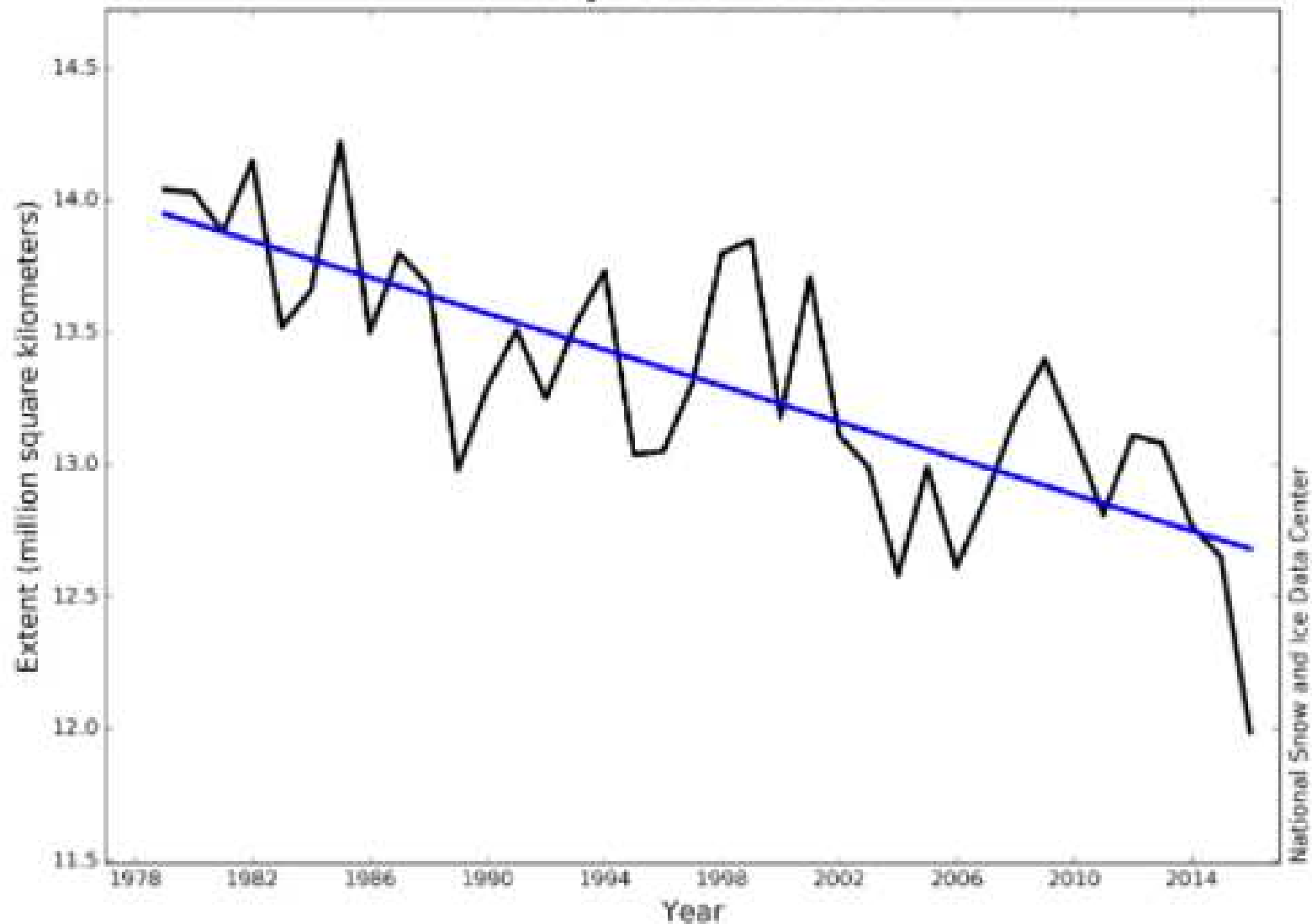
+	Fossil Fuel Burning	100%	Commercial Records
-	Atmospheric Increase	50%	Direct Measurement
-	Ocean Uptake	25%	Bomb ¹⁴ C
=	“Missing Sink”	25%	Arithmetic



Box 3.1, Figure 1 | Plot of energy accumulation in ZJ ($1 \text{ ZJ} = 10^{21} \text{ J}$) with

<http://www.skepticalscience.com/graphics.php?g=47>

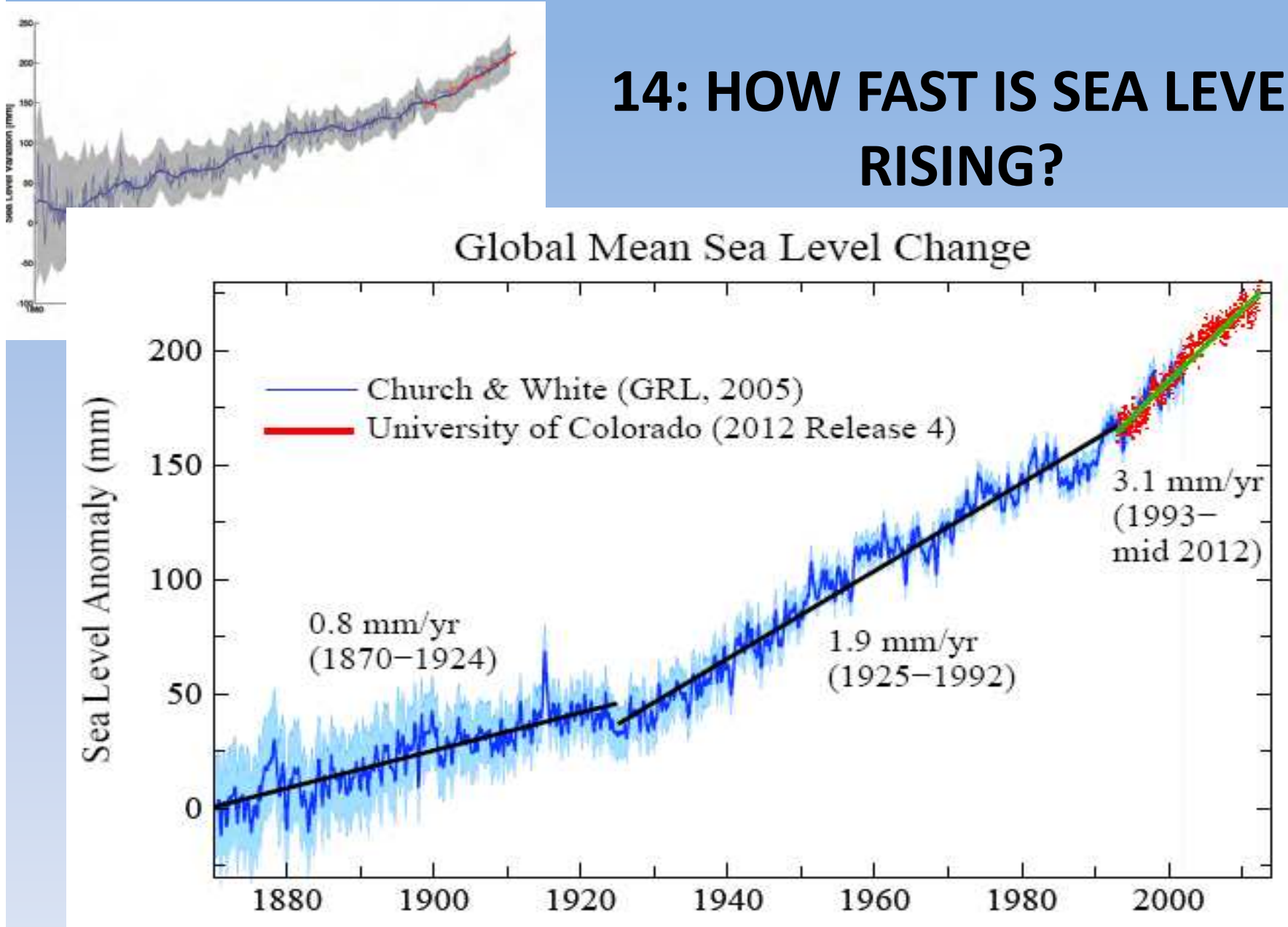
Average Monthly Arctic Sea Ice Extent May 1979 - 2016



For more see: <http://www.skepticalscience.com/melting-ice-global-warming.htm>

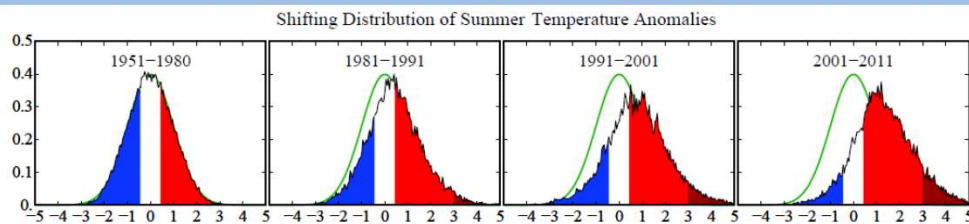
<http://nsidc.org/arcticseaicenews/2016/06/>

14: HOW FAST IS SEA LEVEL RISING?



Blue: Sea level change from tide-gauge data (*Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602*)
Red: Univ. Colorado sea level analyses in satellite era (<http://www.columbia.edu/~mhs119/SeaLevel/>).

Loaded Climate Dice: global warming is increasing extreme weather events.
Extreme summer heat anomalies now cover about 10% of land area, up from 0.2%.
This is based on observations, not models.



Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis). Temperature anomalies in the period 1951-1980 match closely the normal distribution ("bell curve", shown in green), which is used to define cold (blue), typical (white) and hot (red) seasons, each with probability 33.3%. The distribution of anomalies has shifted to the right as a consequence of the global warming of the past three decades such that cool summers now cover only half of one side of a six-sided die, white covers one side, red covers four sides, and an extremely hot (red-brown) anomaly covers half of one side.

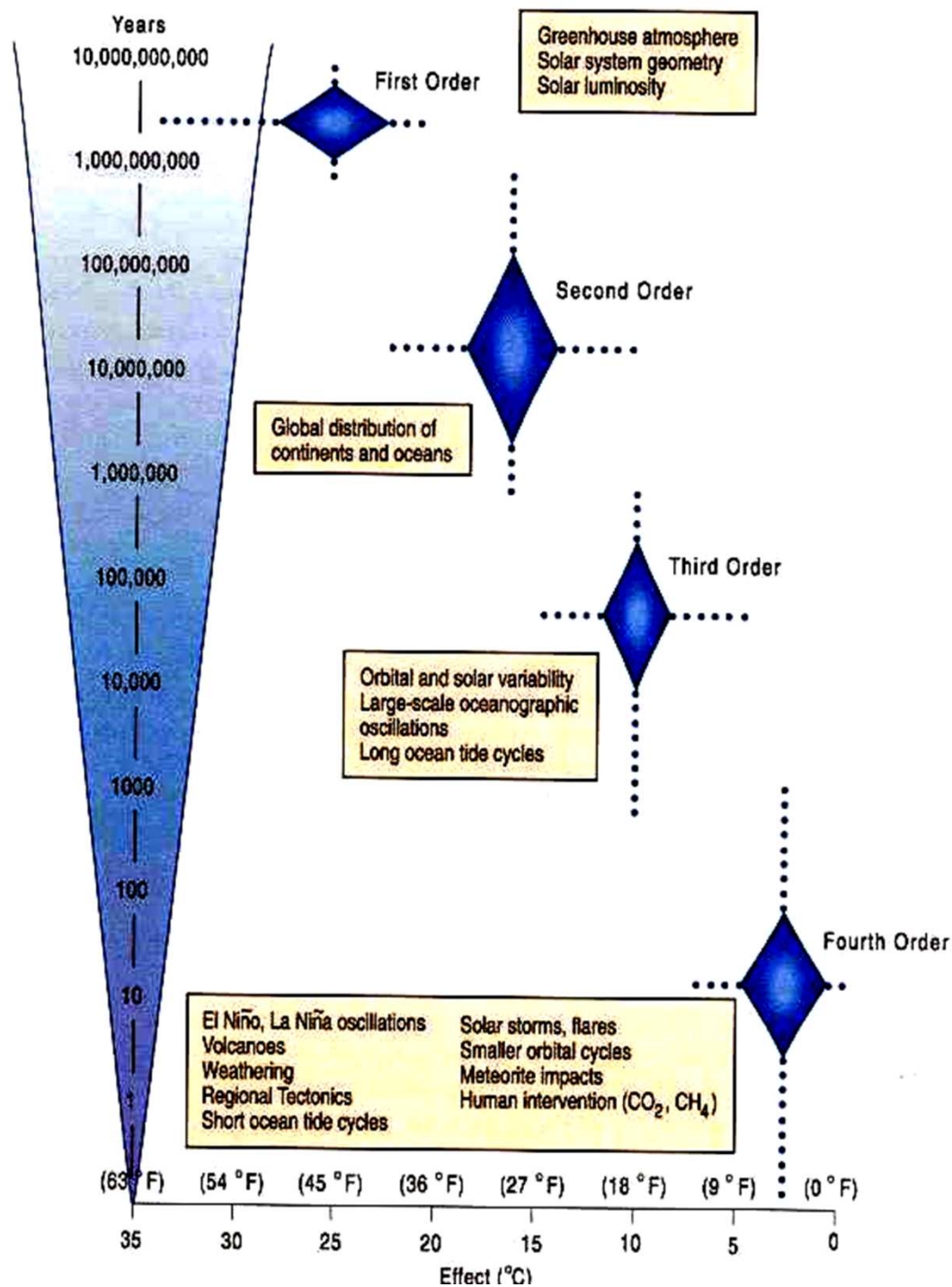
Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.

Resume week 2

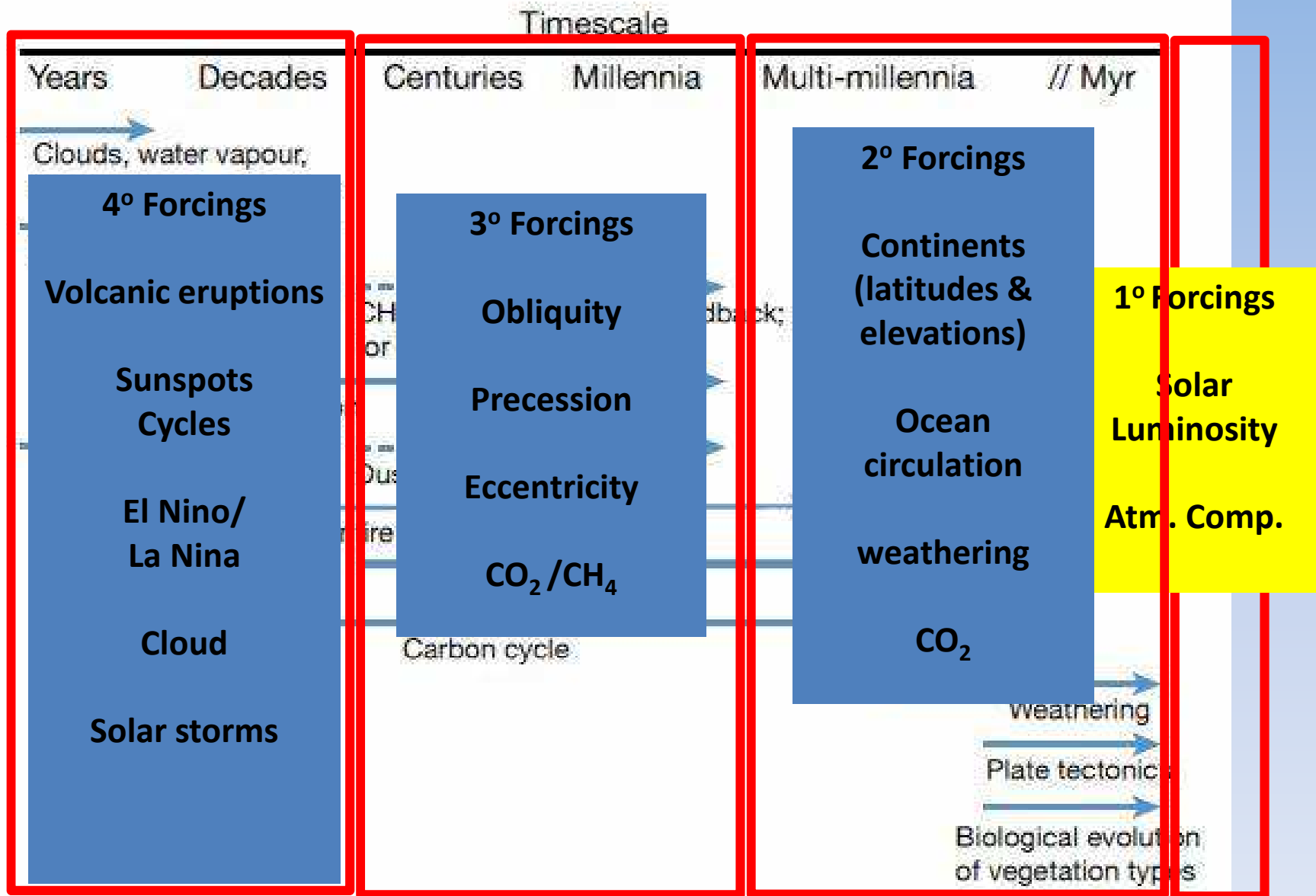
Past Earth History Objectives:

- 1. Present you with the geologic evidence; Earth's past**
- 2. Educate / That the science is sound**
- 3. Understand the denial movement and how to counter it**
- 4. Motivate you**
- 5. Give you hope / look at potential game changers**

**- SO –
WHAT CONTROLS
CLIMATE**



FEEDBACKS



Rohling, et al., (PALAEOSENS Project mbrs), 2012

Earth's past climate

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Earth's past climate 1 of 2

Earth's deep past and early atmosphere before the Cambrian (600 MaBP): hot and cold

- Earth self regulates 2.1 -2.3 Tim Lenton video – 9 minute overview and BBC article:
[http://www.bbc.co.uk/nature/ancient_earth/Snowball Earth](http://www.bbc.co.uk/nature/ancient_earth/Snowball_Earth)
- Nat geographic – not terribly good – but at 2:30 describe dropstones - evidence
- <https://www.youtube.com/watch?v=mX3pHD7NH58> but at Better description of cause:
<http://www.sciencechannel.com/tv-shows/how-the-universe-works/videos/snowball-earth/>

Earth's past climate 2 of 2

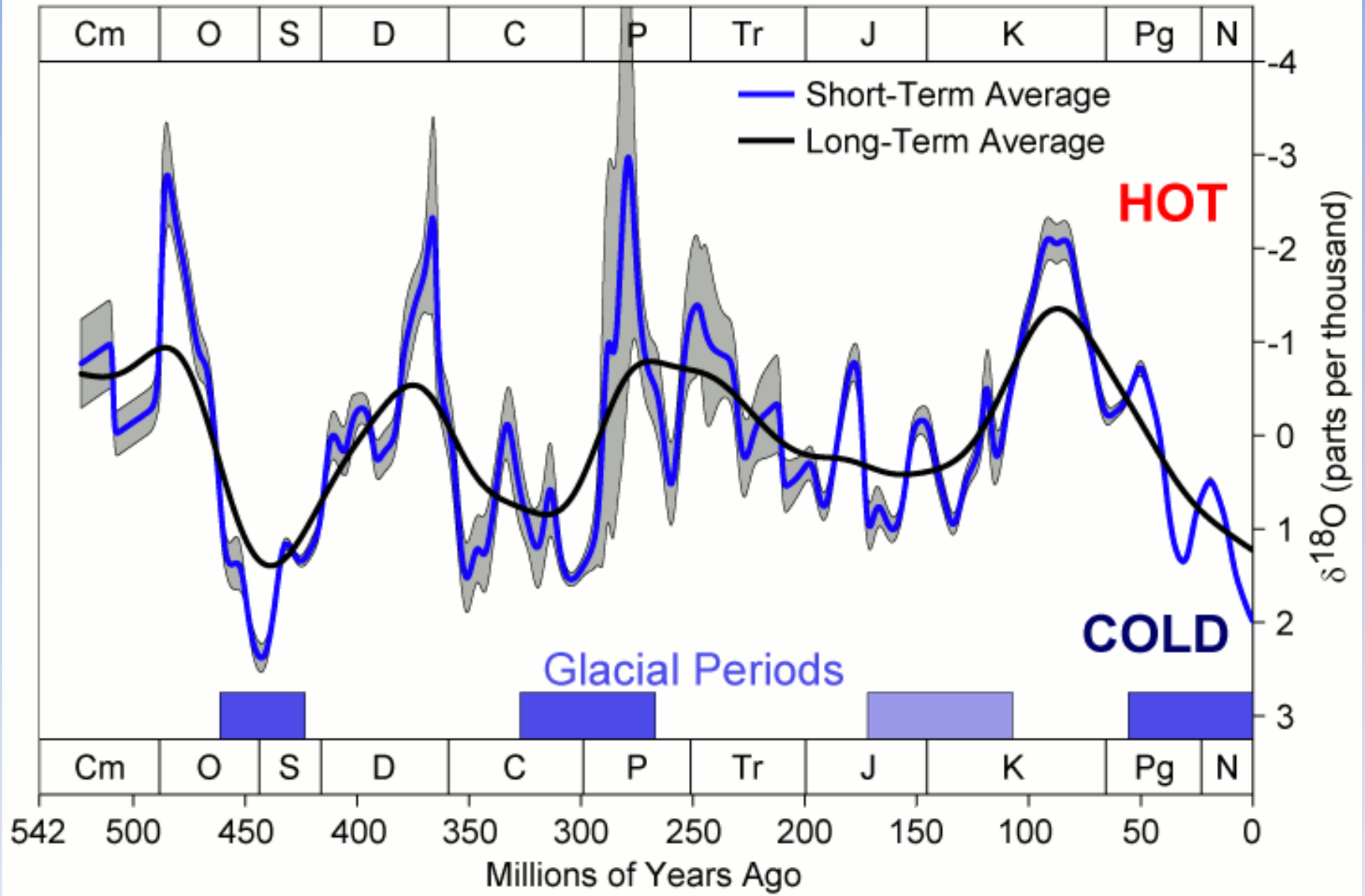
Earth's deep past and early atmosphere before the Cambrian (600 MaBP): hot and cold

- 48 minutes
<https://www.youtube.com/watch?v=YOLbE8frMrM>
- WIKI: https://en.wikipedia.org/wiki/Snowball_Earth
- Article Link: BBC Nature --- video is not currently working
9/20/2015 and 4/5/16 at
http://www.bbc.co.uk/nature/ancient_earth/Snowball_Earth
but here's a link about the video including a link to the transcript:
<http://www.bbc.co.uk/science/horizon/2000/snowballearth.shtml>
- You Tube – leaving for you to watch on your own:
https://www.youtube.com/results?search_query=snow+ball+earth – various links

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Phanerozoic Climate Change



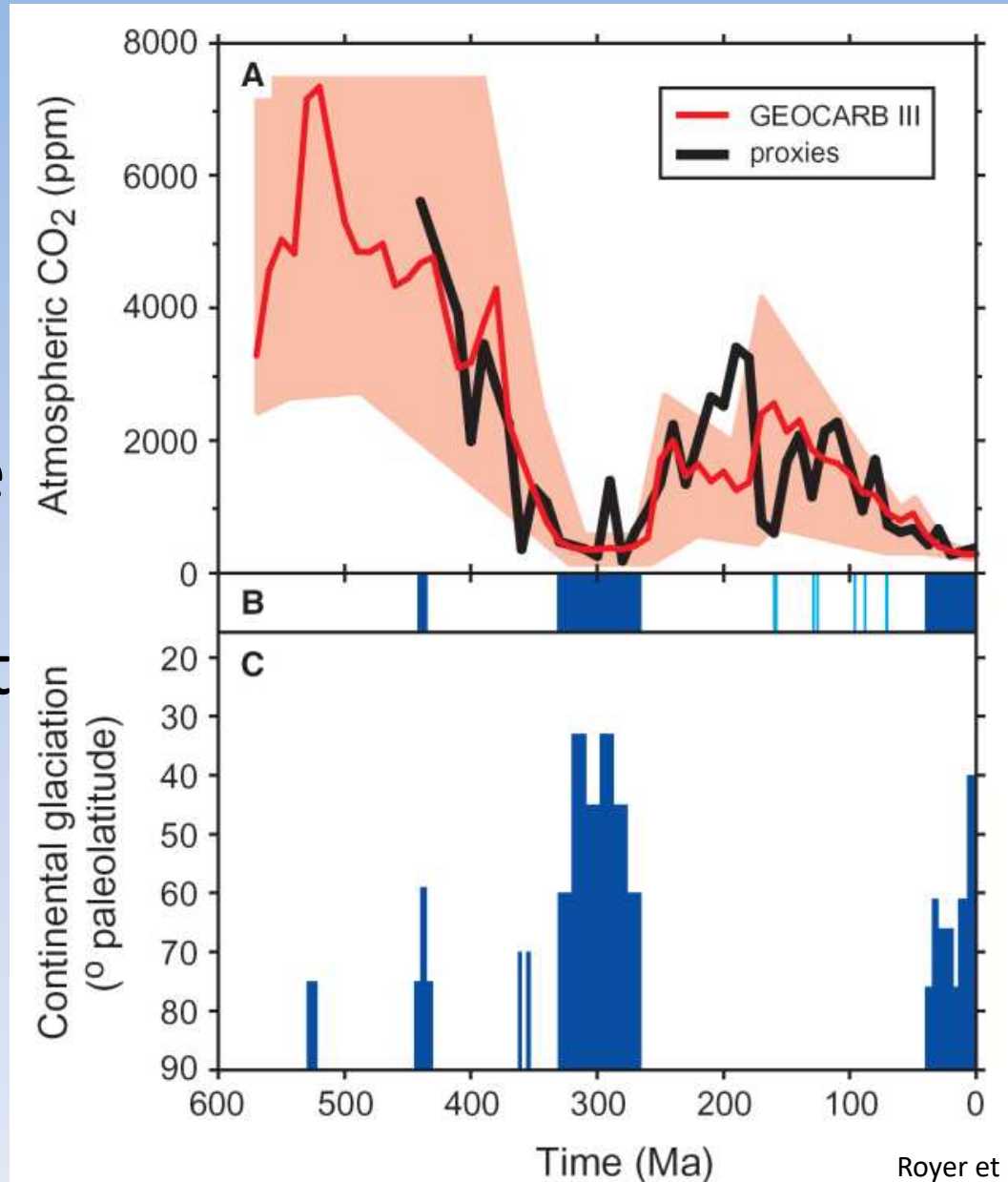
PALEOZOIC

MESOZOIC

CENOZ.

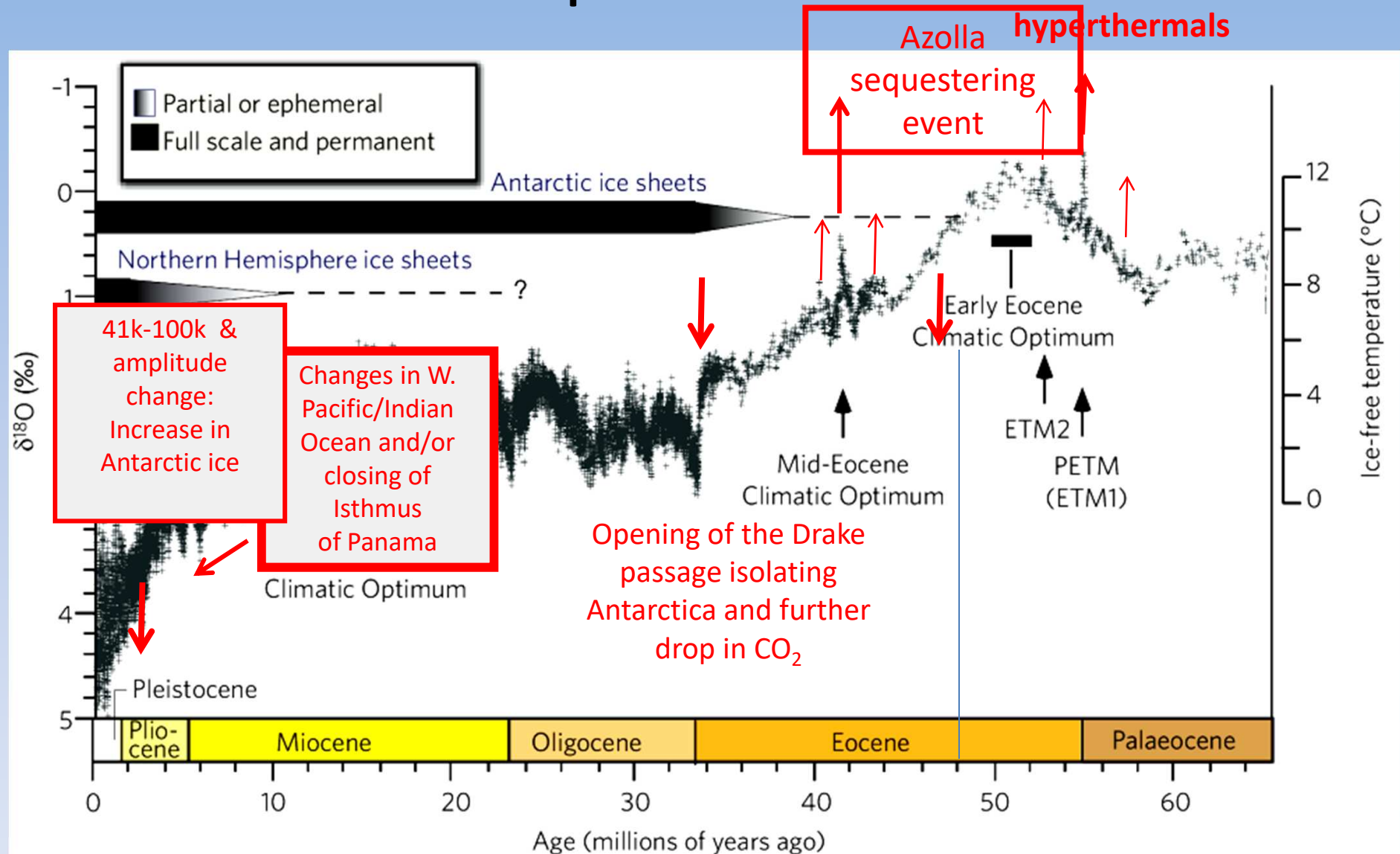
Alternating Greenhouse Earth / Ice-house Earth

Geologic cycles:
Climate through the
Phanerozoic:
Carbon is the culprit

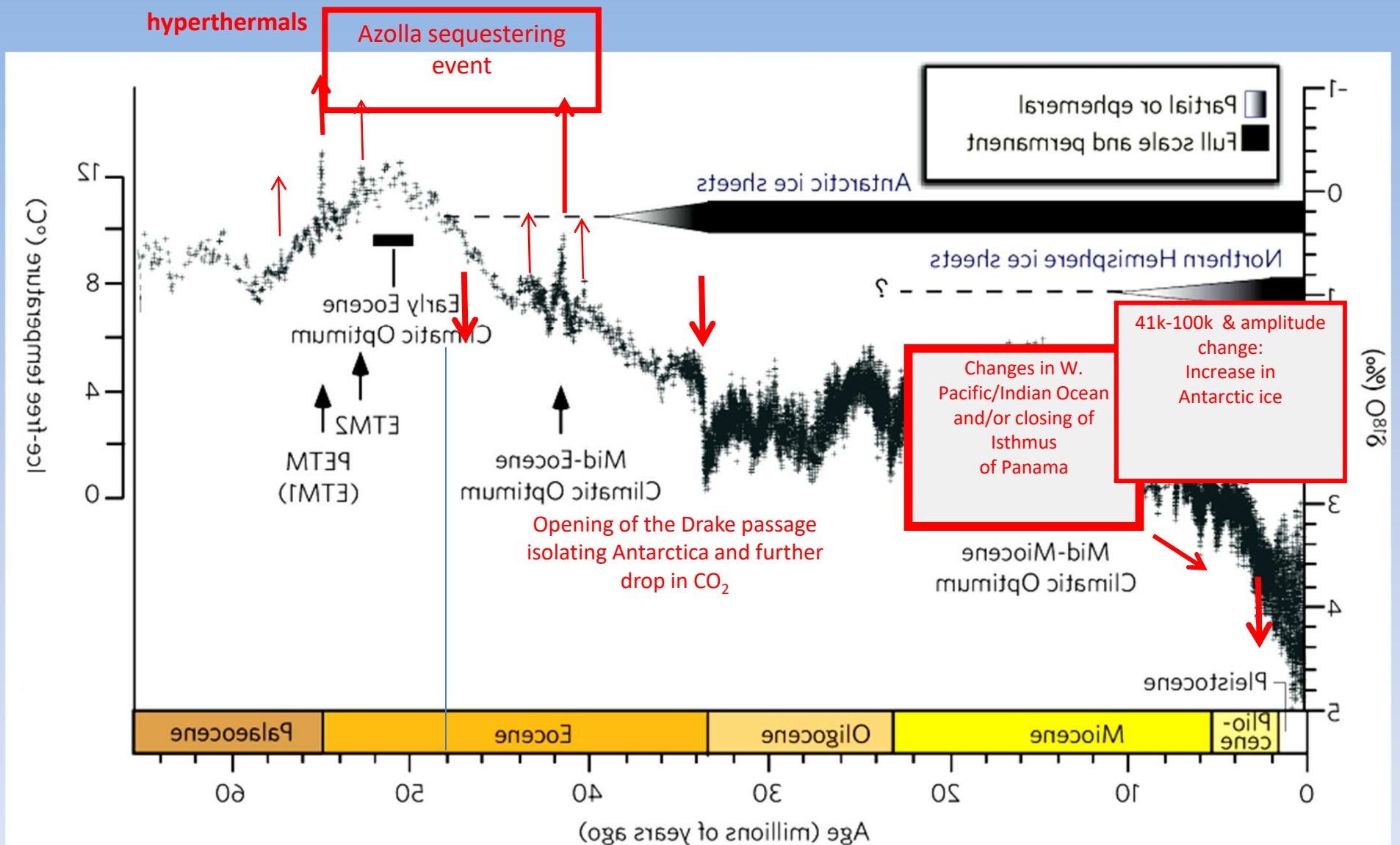


Royer et al., 2003

Cenozoic Deep Sea Climate Record

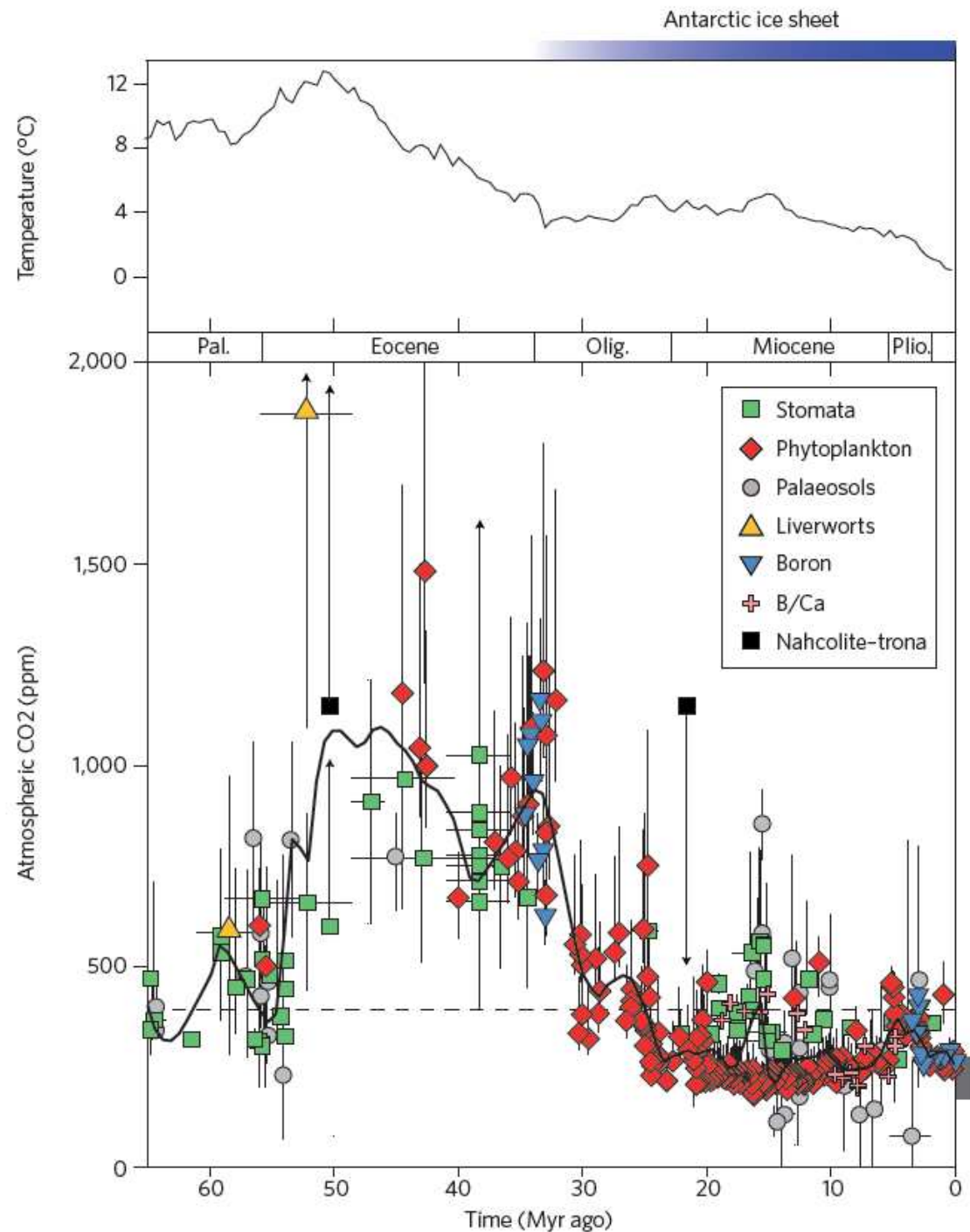


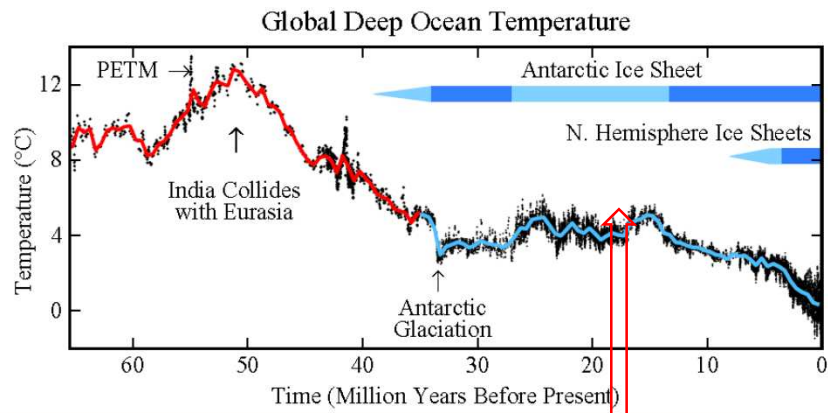
Cenozoic Deep Sea Climate Record



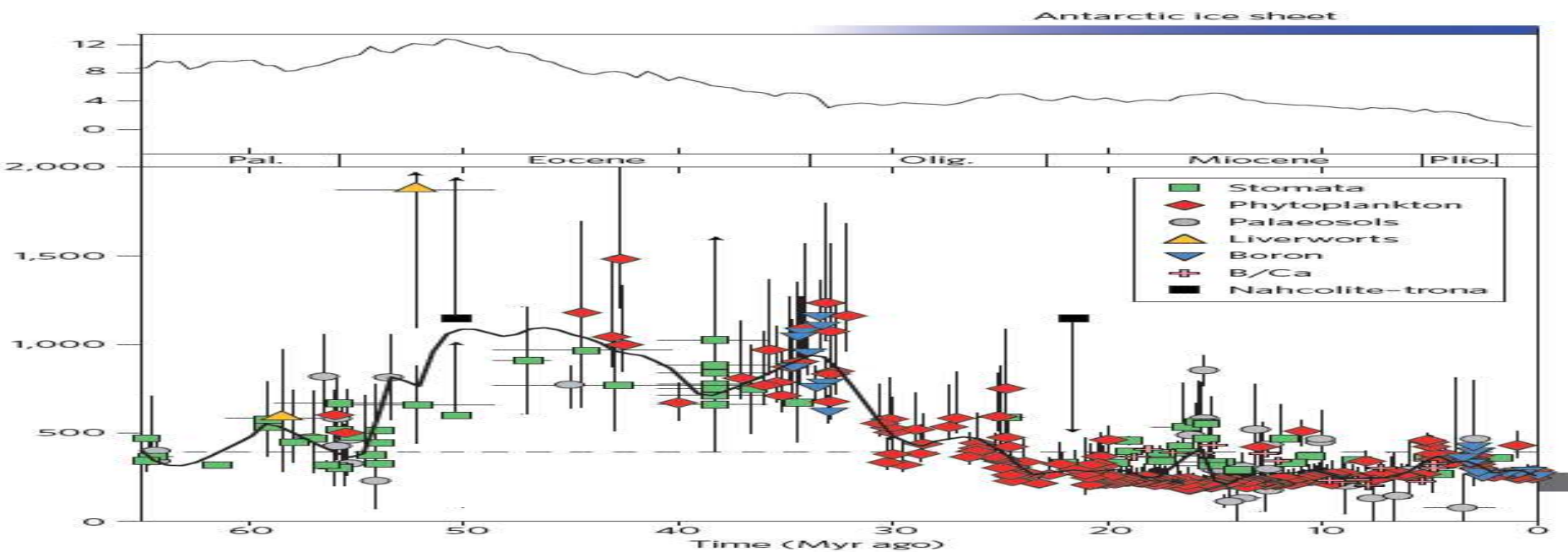
Correlation of CO₂ and temperature over last 65 million years

Beerling and Royer, Nature 2011

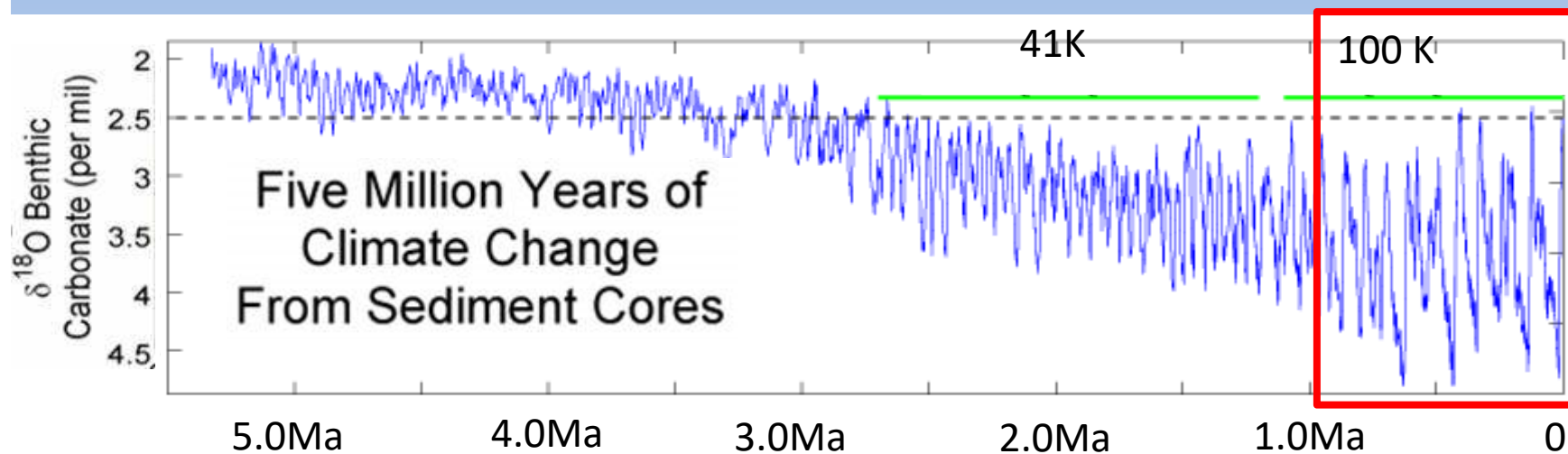




Azolla event:
~ 49 Ma



Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



When CO_2 levels get below ~400-600 ppm Orbital parameters become more important than CO_2

Milankovitch Cycles

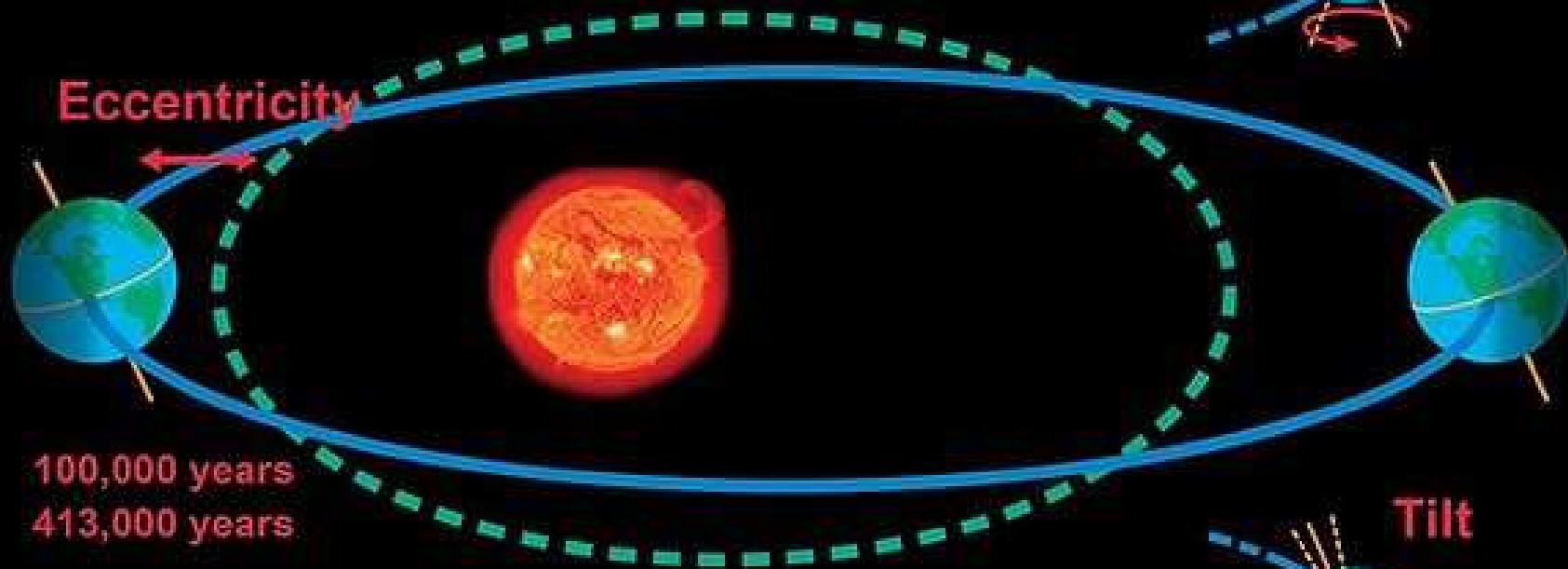
Precession

19–24,000 years



Eccentricity

100,000 years
413,000 years

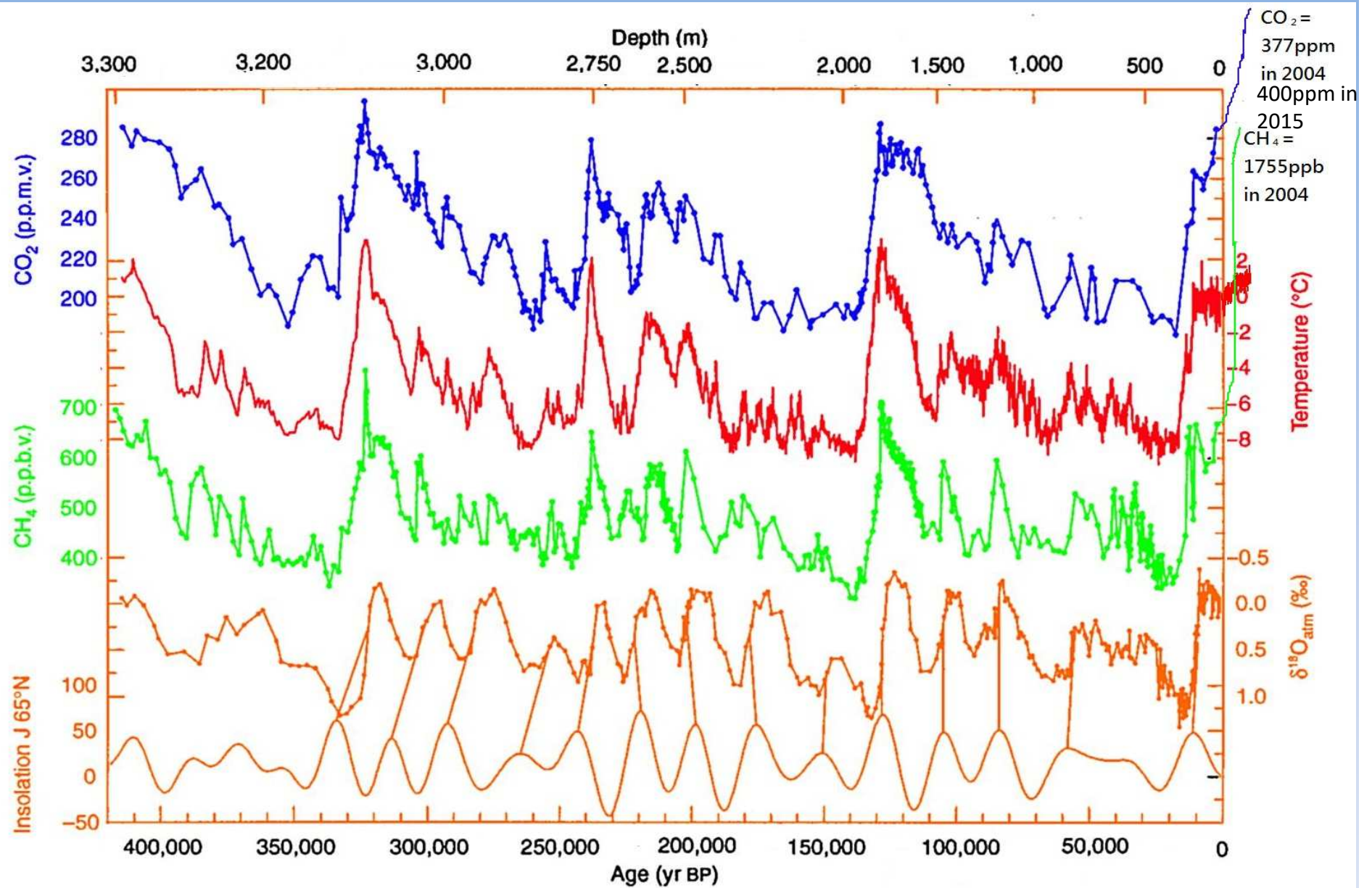


Tilt

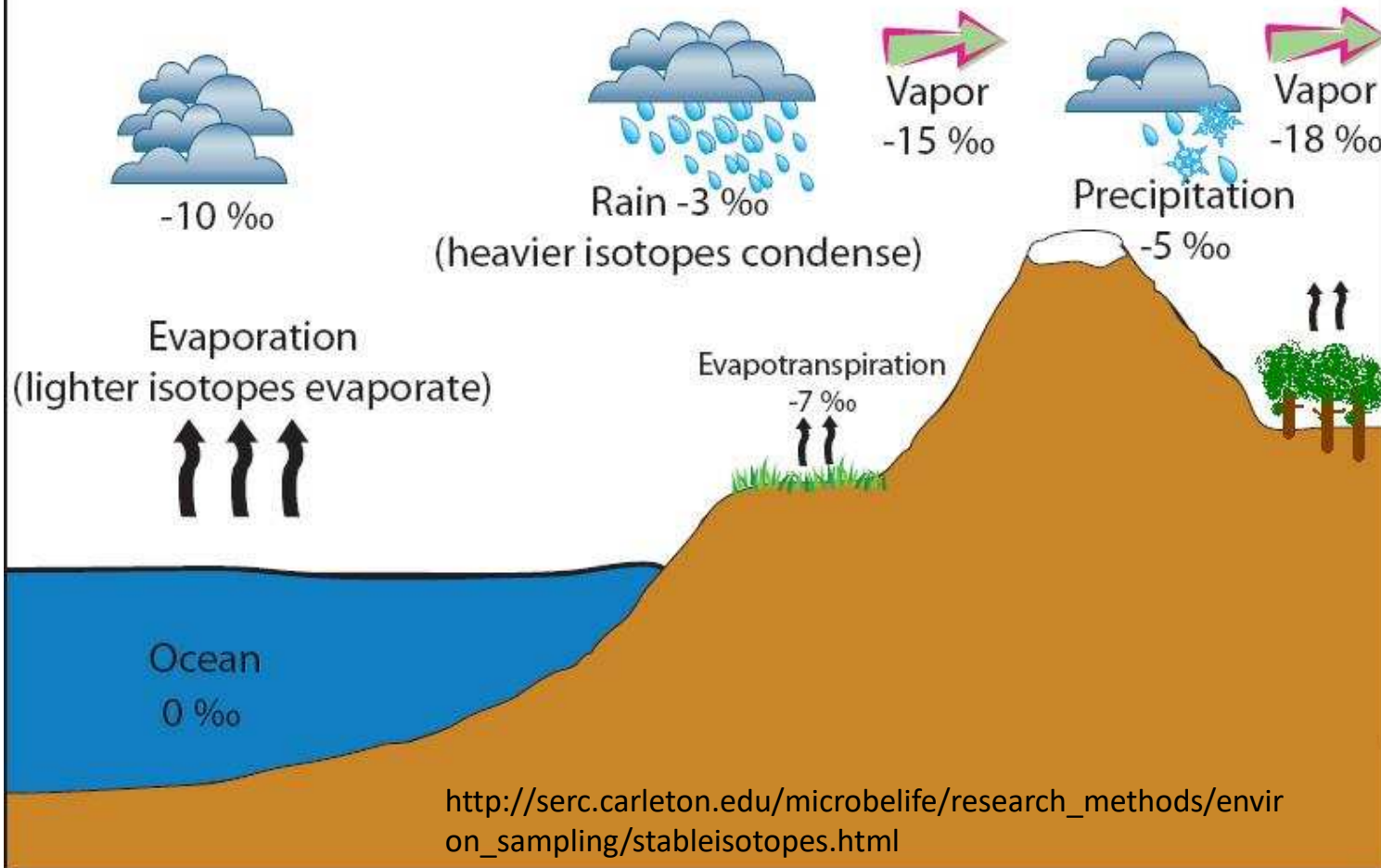
41,000 years

21.5°–24.5°
Currently 23.5°



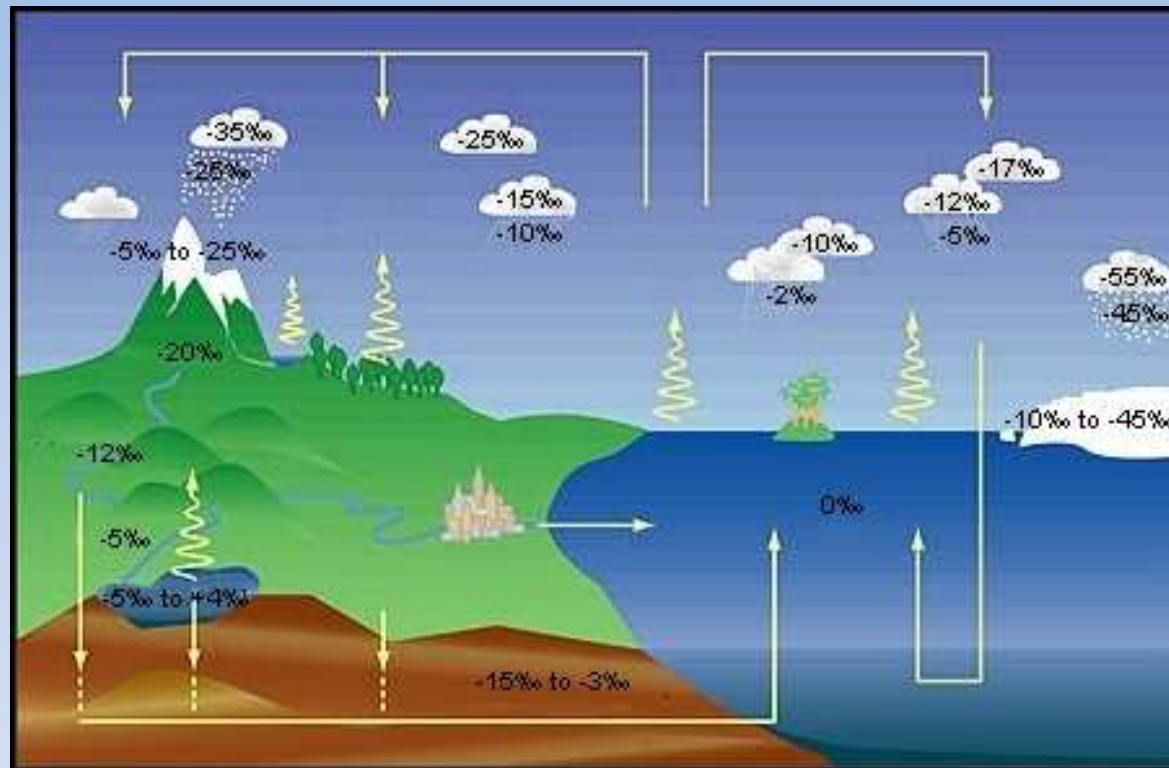


How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



Normal Oxygen has 8 protons and 8 neutrons referred to as O^{16} . The rarer stable isotope of oxygen has 2 extra neutrons and is referred to as O^{18} .

How Rain, snow and ice gets progressively lighter in the ratio
of O^{18}/O^{16}

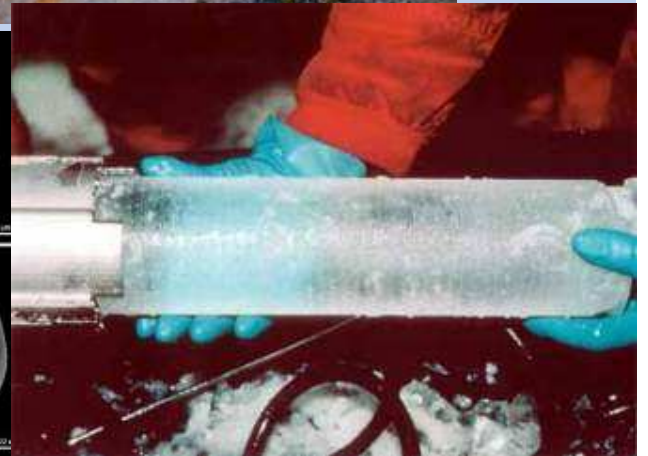
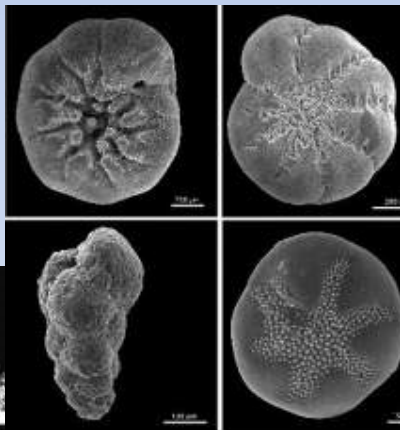
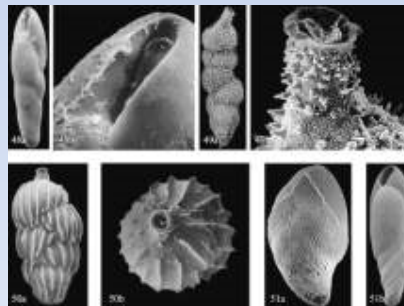


<http://atoc.colorado.edu/~dcn/SWING/overview.php>

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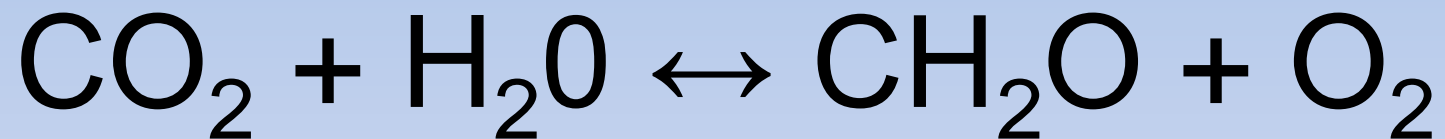
Scientific History of Climate change – PROXY DATA



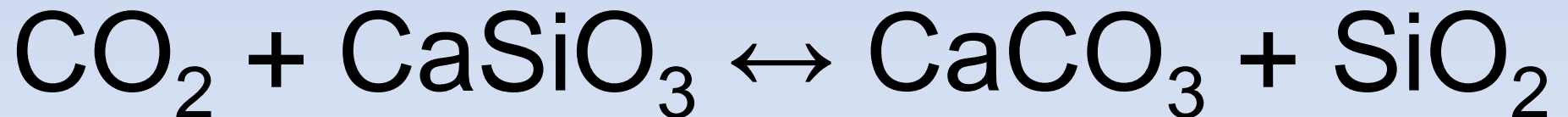
Long-term Carbon Cycle: rocks

Two generalized reactions...

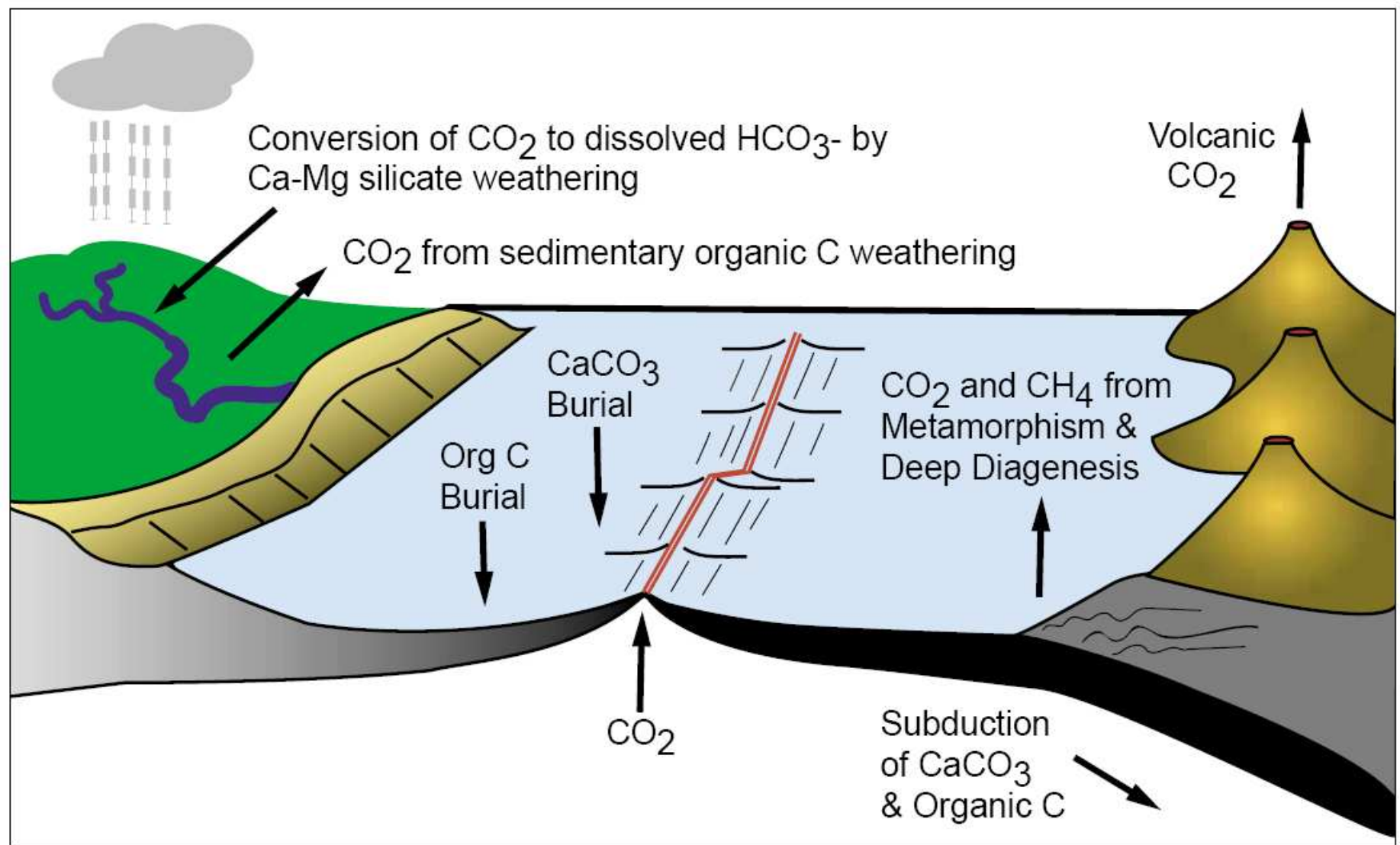
Photosynthesis/Respiration

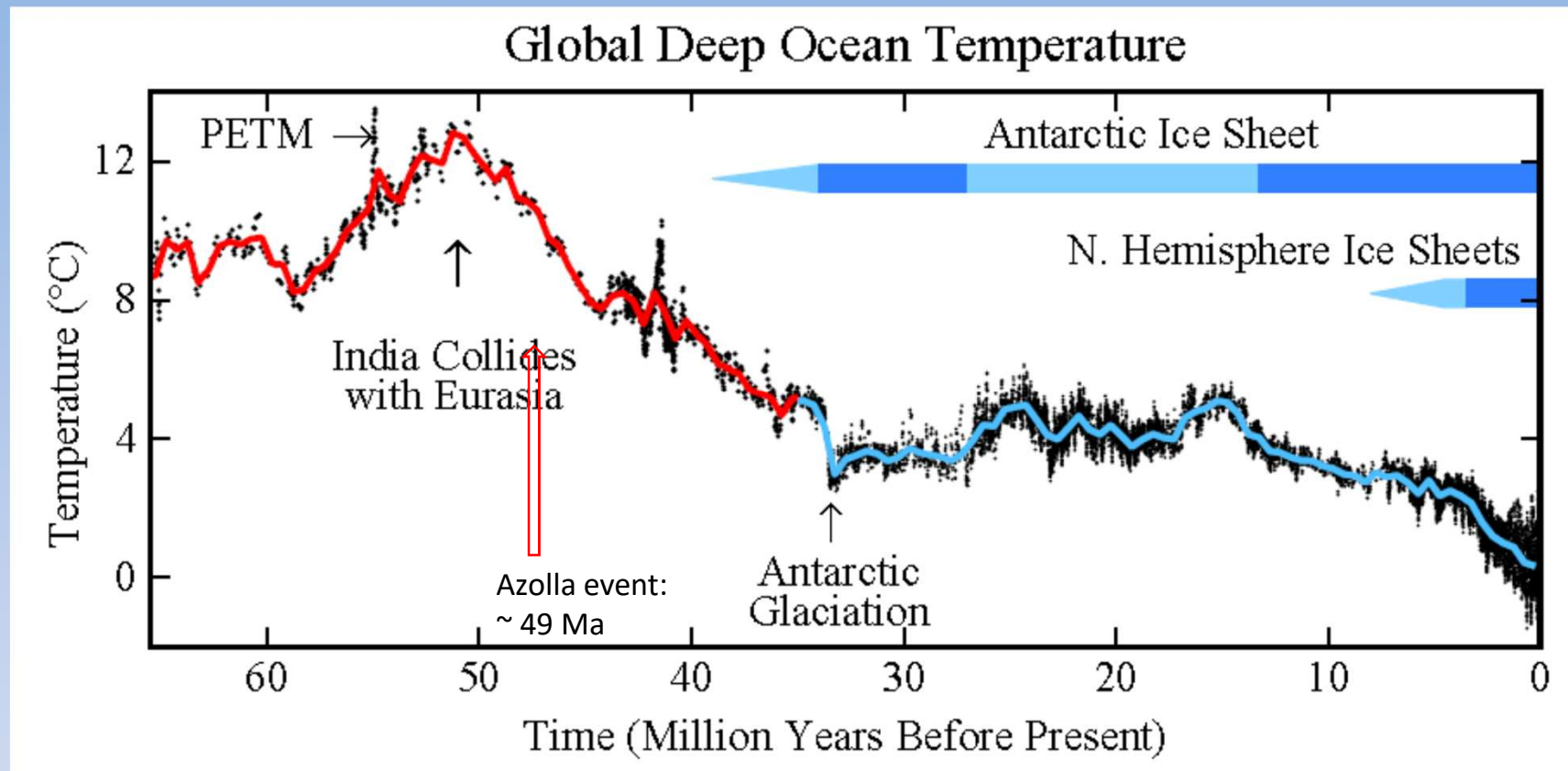


Weathering/Precipitation



Long-term carbon cycle: *rocks*



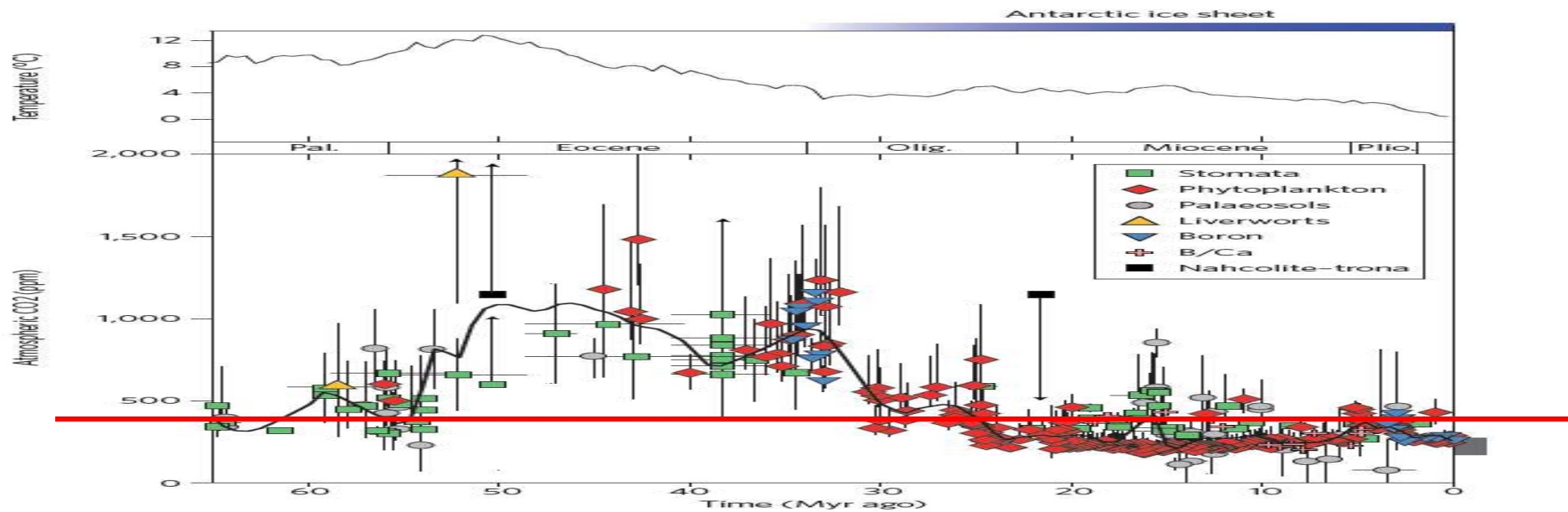
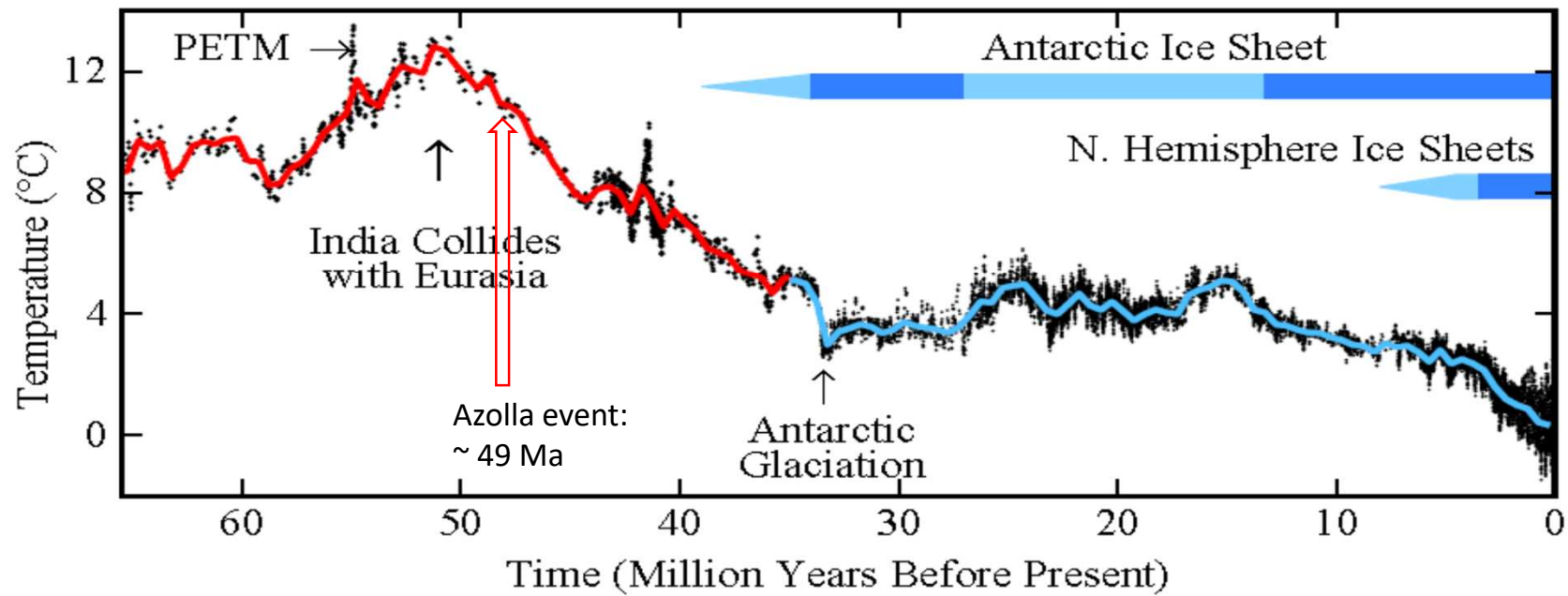


50 million years ago (50 MYA) Earth was ice-free.

Atmospheric CO₂ amount was of the order of 1000 ppm 50 MYA.

Atmospheric CO₂ imbalance due to plate tectonics $\sim 10^{-4}$ ppm per year.

Global Deep Ocean Temperature



So – what changed?

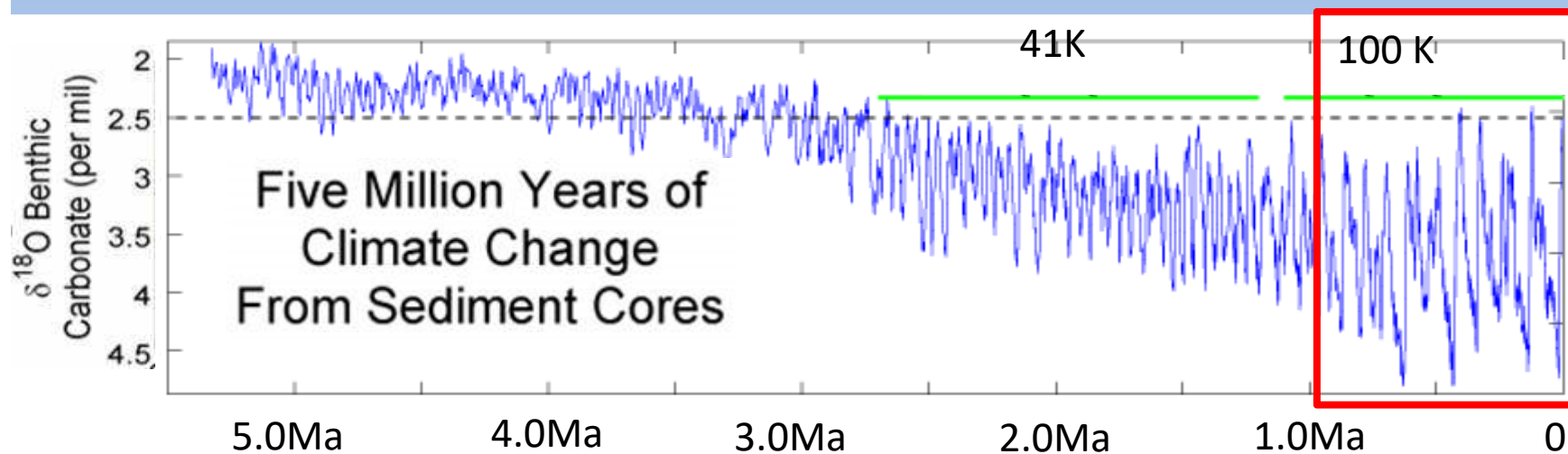
Volcanism decreased; some
slowing of spreading rates: less
CO₂ emitted by volcanoes

Weathering/Precipitation
increased; India colliding into
Asia/Himalayans

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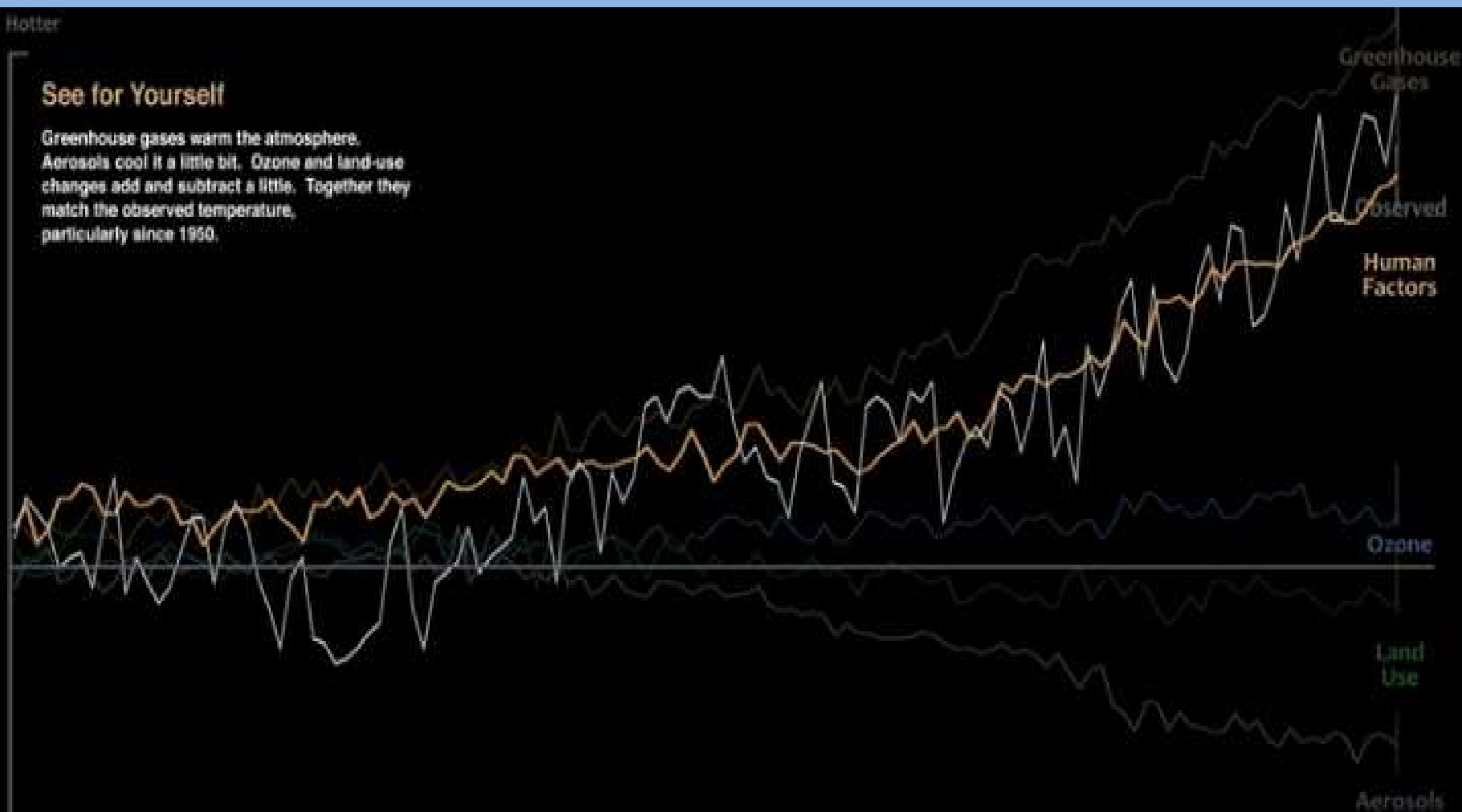
LINKS in email 4/6/2017

- This is the video I showed – see <https://www.youtube.com/channel/UCH4BNi0-FOK2dMXoFtViWHw> for all his videos – pretty good:
- **Why People Don't Believe In Climate Science**
<https://www.youtube.com/watch?v=y2euBvdP28c>
- **This one is really funny – to the point – and I'll show again in 2 or 3 weeks**
<https://www.youtube.com/watch?v=OWXoRSIxyIU&feature=youtu.be>
- Have a look here too: 5:56 minutes: from <https://skepticalscience.com/>
- UQx DENIAL101x 4.4.4.1 Climate science in the 1970s
<https://www.youtube.com/watch?v=F6bq0l18Ng>
-
- **On snowball earth:**
 - This one helps explain the balance of weathering/volcanoes and early earth
<https://www.youtube.com/watch?v=YKuoPBbh58Y>
 - Others? https://www.youtube.com/results?search_query=snow+ball+earth
-
- **Screen capture:** <https://www.youtube.com/watch?v=-gHUHoqBn-Y>
- SEE NEXT PAGE

Hotter

See for Yourself

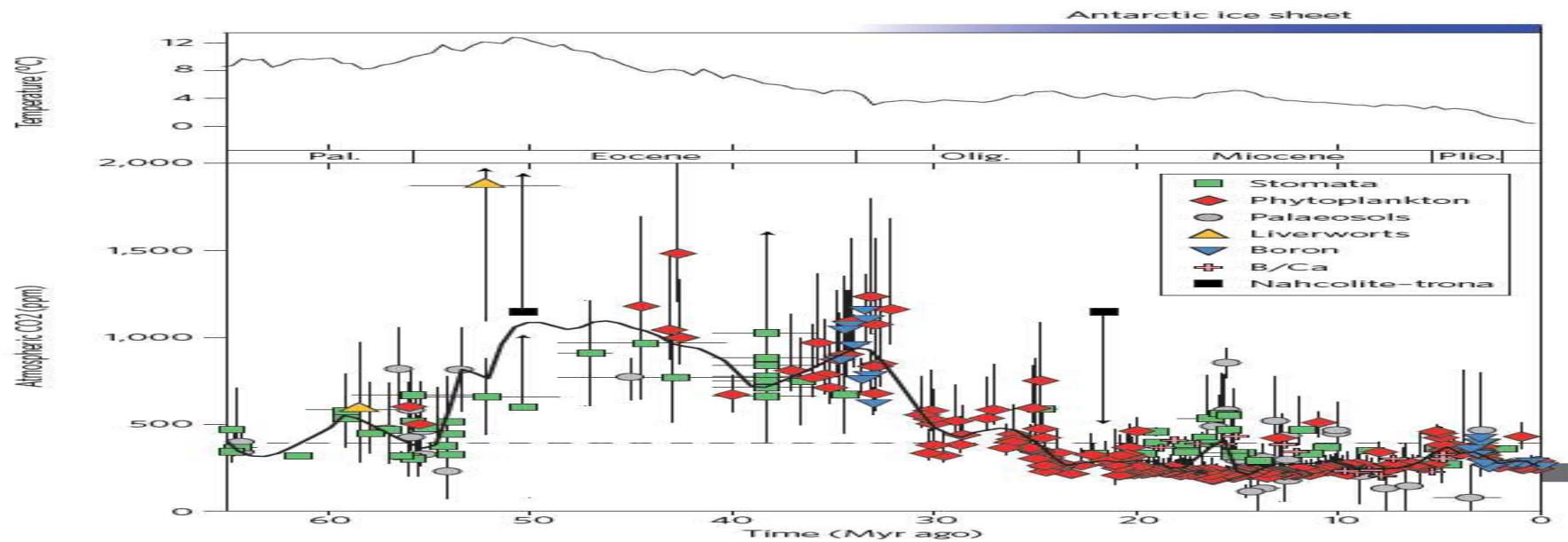
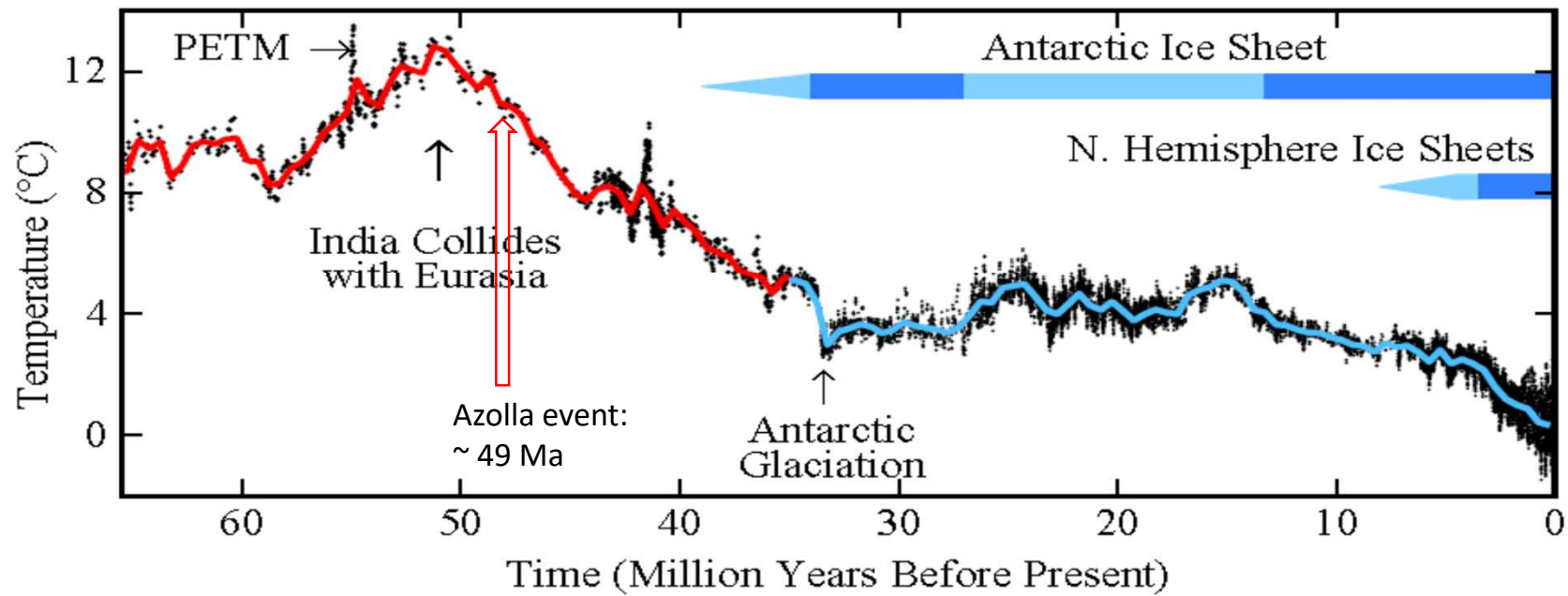
Greenhouse gases warm the atmosphere. Aerosols cool it a little bit. Ozone and land-use changes add and subtract a little. Together they match the observed temperature, particularly since 1950.



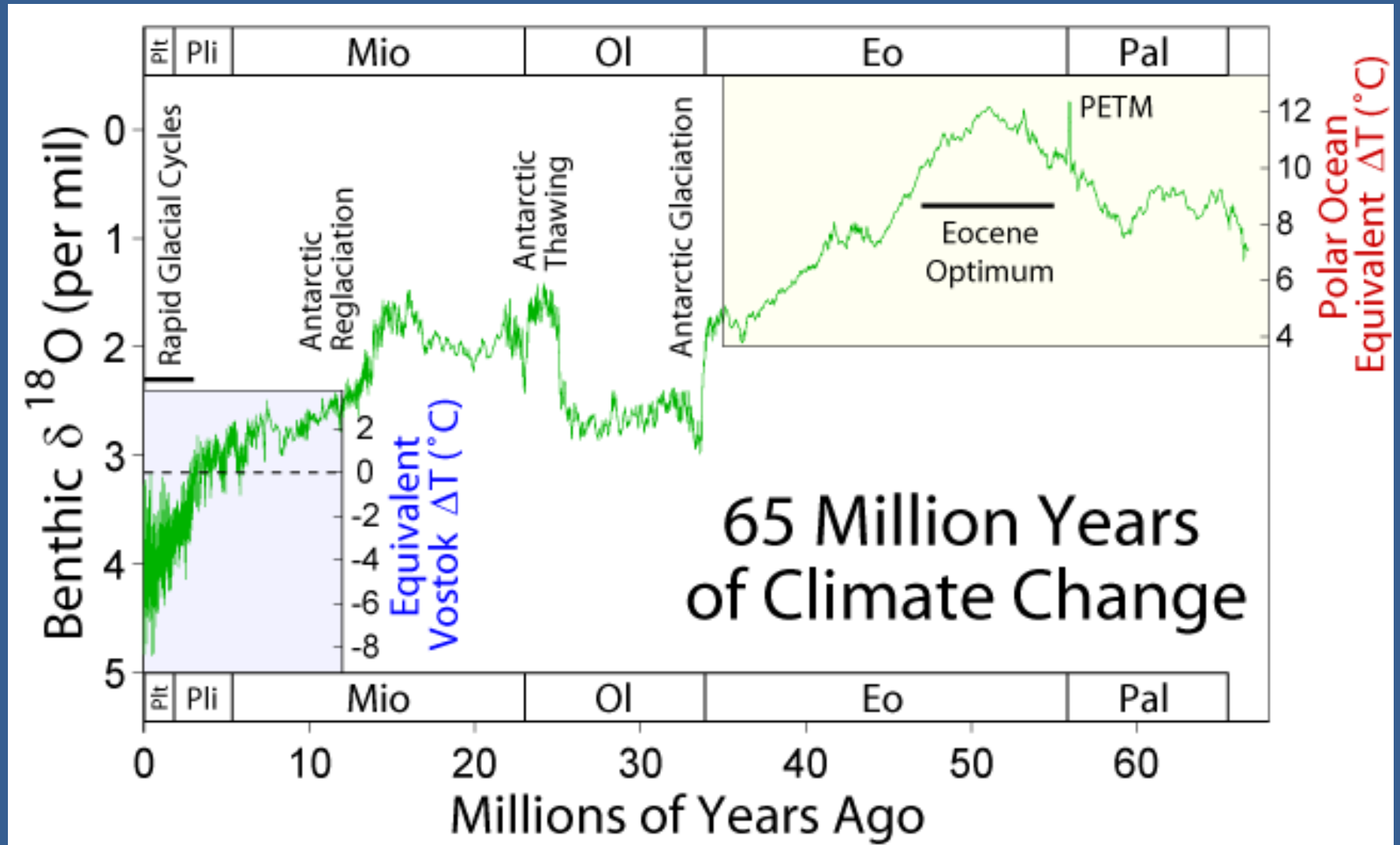
End of week 2
EXTRAS FOLLOW

Paleocene/Eocene Thermal Maximum PETM

Global Deep Ocean Temperature



Proxy data: stable isotopes





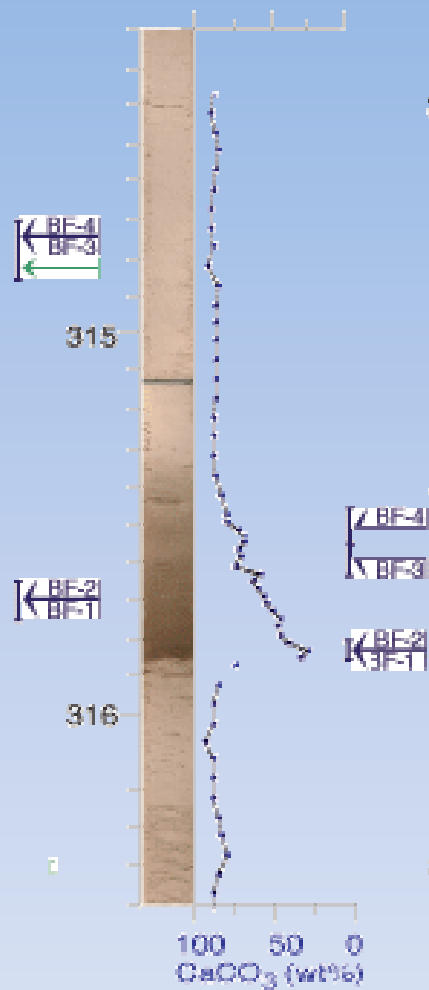
1263

2717 m water depth



1265

3060 m water depth



1266

3738 m water depth



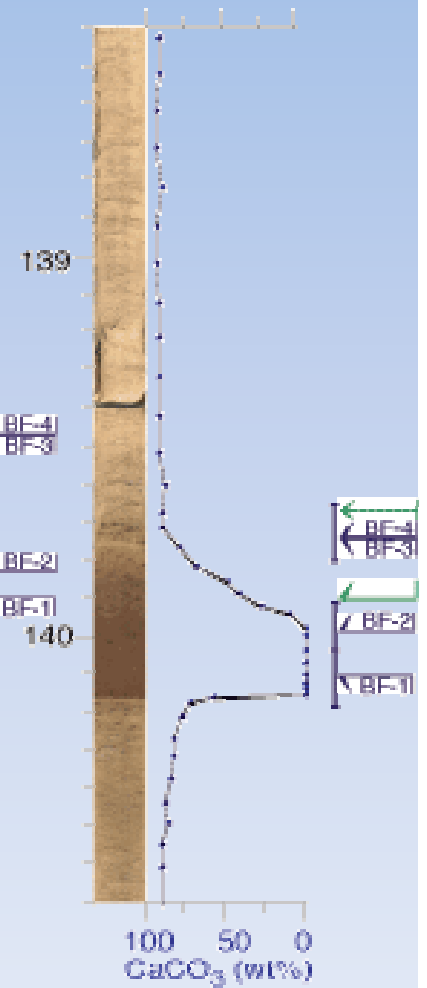
1267

4355 m water depth



1262

4755 m water depth





PETM - THE LAND RECORD

Bighorn Basin

- PETM interval in fluvial deposits with excellent alluvial paleosols - seen as color bands, which are soil horizons
- Found in Willwood Fm
- Reds, purples due to iron oxides in B horizons



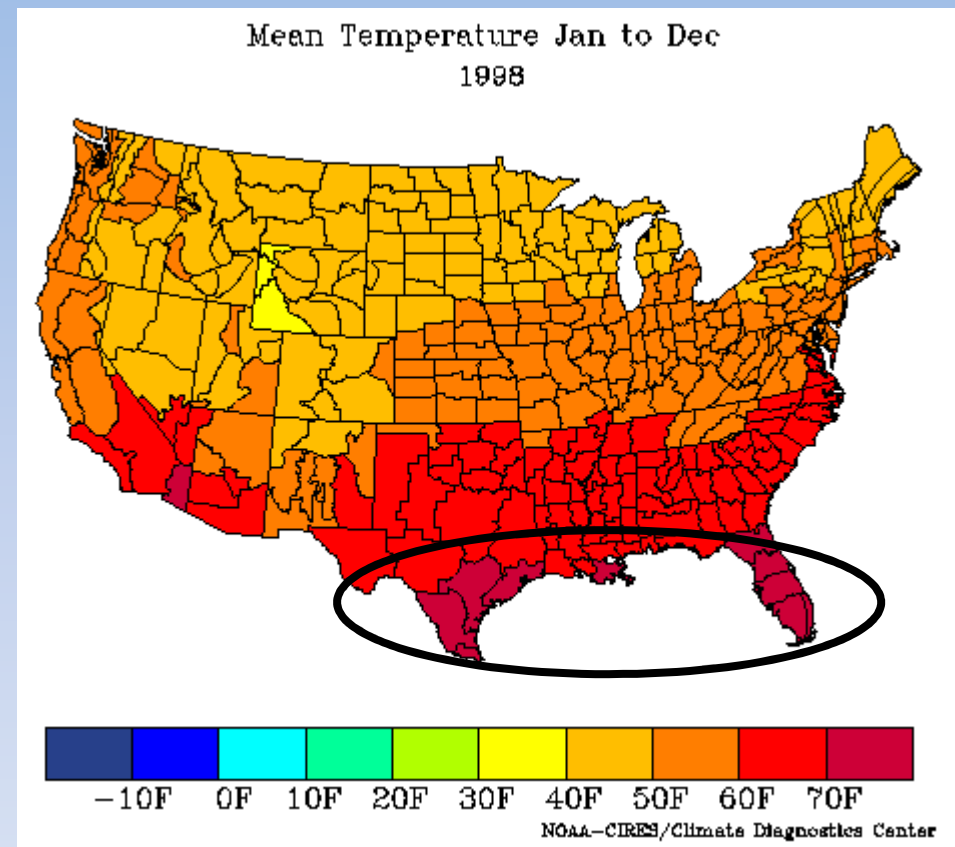
Paleosol Density



Bighorn Basin Climate

■ Plant fossils and isotopes show Mean Annual Temperature of 20° to 25° C or 68 to 77° F

■ Similar to Gulf Coast region today



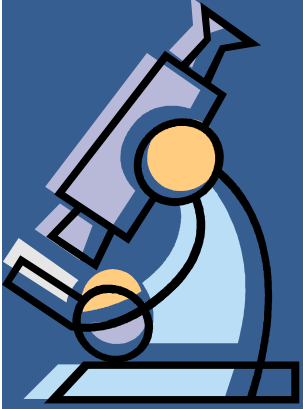
PROXY DATA-EXTRAS



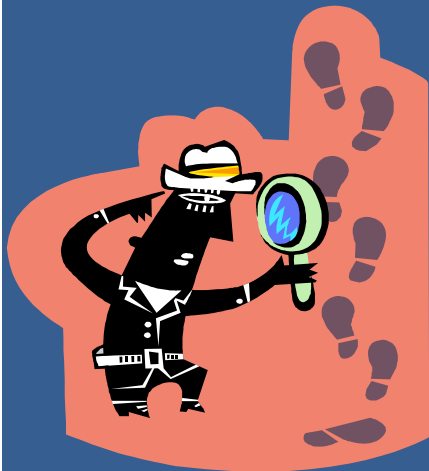
FROM CSI TO GSI: GEOLOGICAL SAMPLE INVESTIGATION

LET THE **EVIDENCE** SPEAK
FOR ITSELF





WE CALL THIS EVIDENCE “PROXY” DATA



SOME OF THE EARLIEST PROXY DATA WAS FROM TERRESTRIAL DEPOSITS



- Strandlines/shorelines
- Moraines
- Till
- Kettle lakes, etc.



We may know what caused these today, but imagine back then?

IT'S THE INTERPRETATION THAT'S NOT ALWAYS CORRECT

Darwin observed ancient Alpine shorelines:
interpreted as ocean shoreline

Agassiz – later correctly interpreted as ice-
dammed lake-shore strandlines/shoreline

Louis Agassiz



Louis Agassiz

Born	May 28, 1807 Haut-Vully, Switzerland
Died	December 14, 1873 (aged 66) Cambridge, Massachusetts
Fields	Paleontology, Glaciology, Geology, Natural History
Alma mater	University of Erlangen-Nuremberg

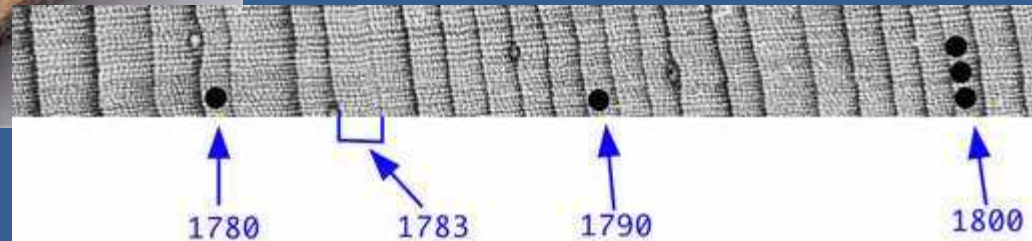
- Jean Louis R. Agassiz
- “Father” of Glaciology
- 1807-1873
- Paleontologist
- Glaciologist

Photographic proxy data/evidence

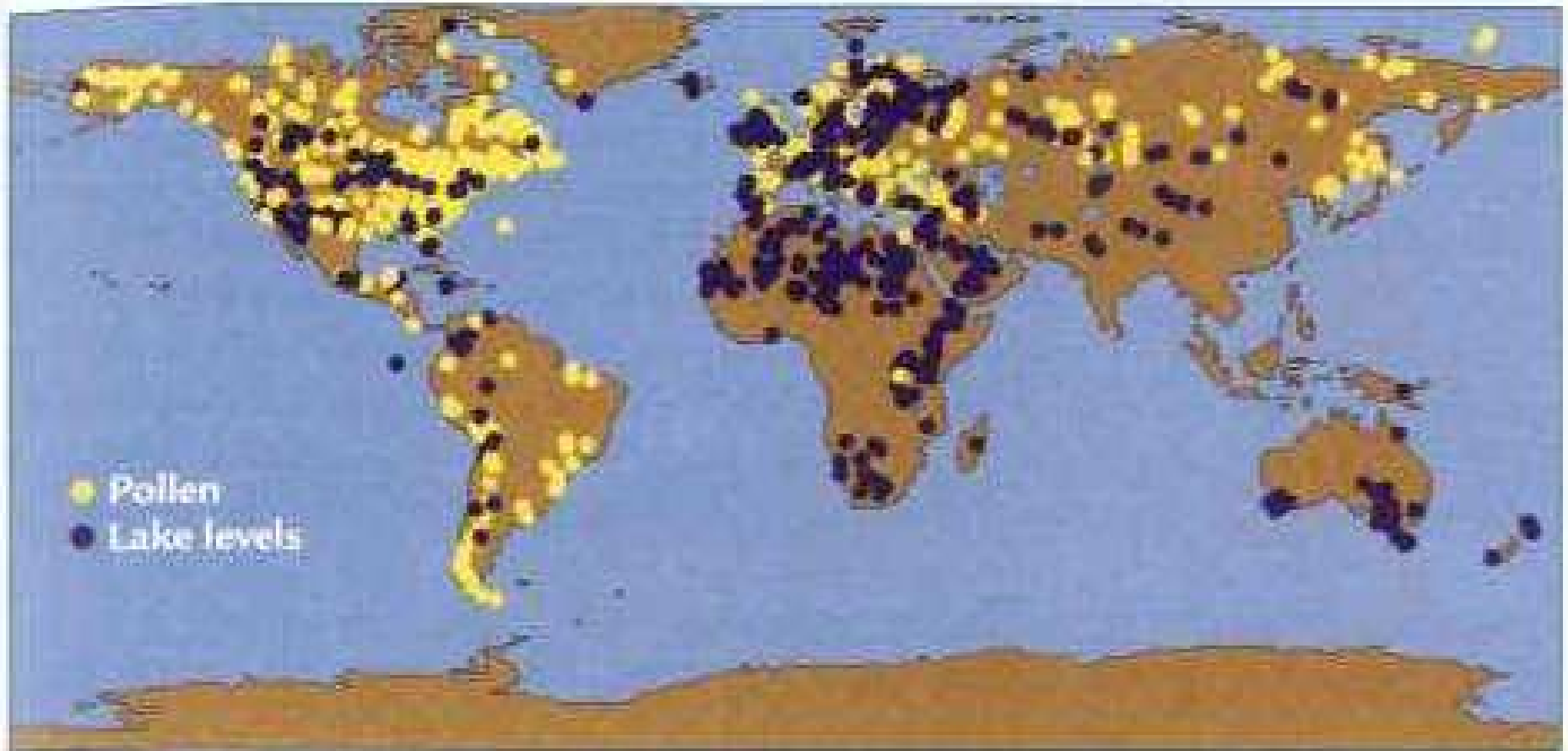




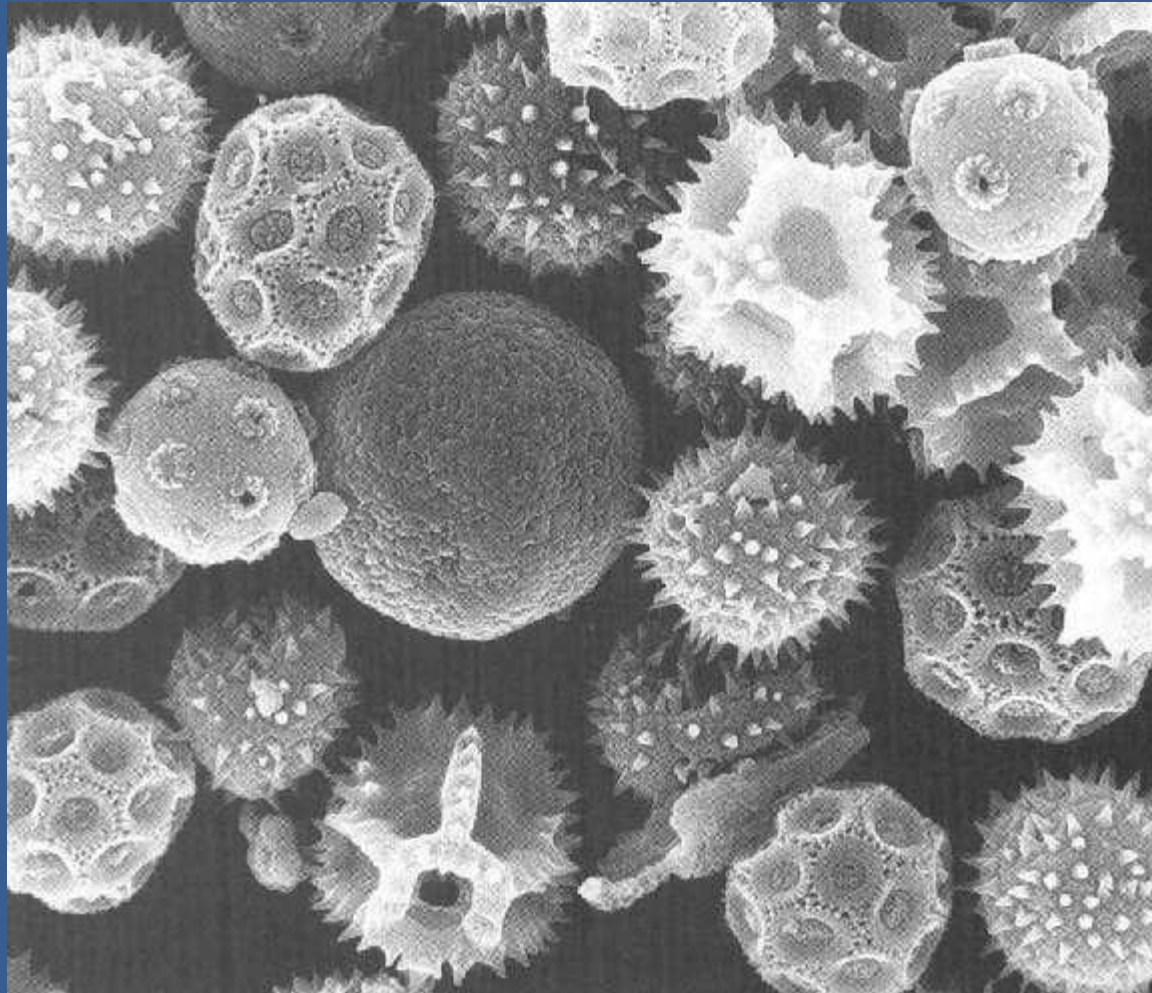
EARLY PROXY DATA: TREE RINGS



Pollen & Lake core data

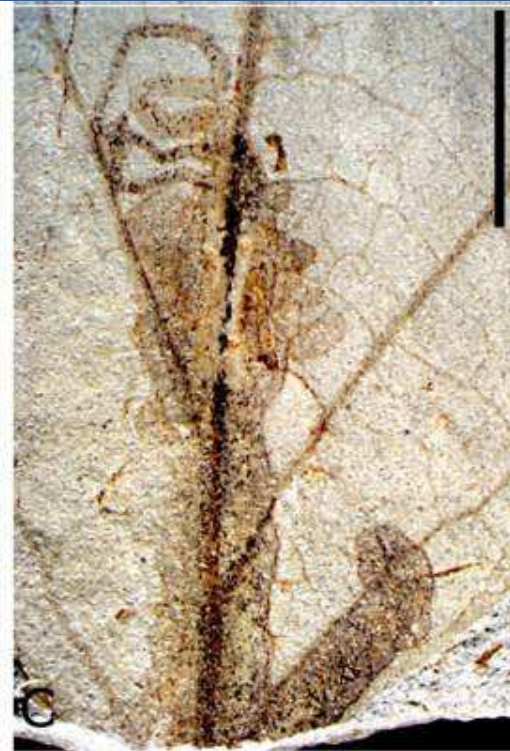


Ruddiman, 2008



PROXY DATA: POLLEN DATA

PROXY DATA: LEAVES



Tree rings, corals, ice cores



PROXY DATA: ICE CORES



TERRESTRIAL DATA

North American:

Wisconsin

Illinoian

Kansan

Nebraskan

European:

Wurm

Riss

Mindel

Gunz

**LATER EVIDENCE CAME FROM
THE MARINE RECORD**

**NOT WITHOUT IT'S PROBLEMS,
BUT MORE COMPLETE**



Cesare Emiliani in the early 1950s when he was doing his pioneering research at the University of Chicago (Photo from the Archives of the Rosenstiel School of Marine and Atmospheric Science, University of Miami).

Cesare
Emiliani:

Paleontologist,
Chemist

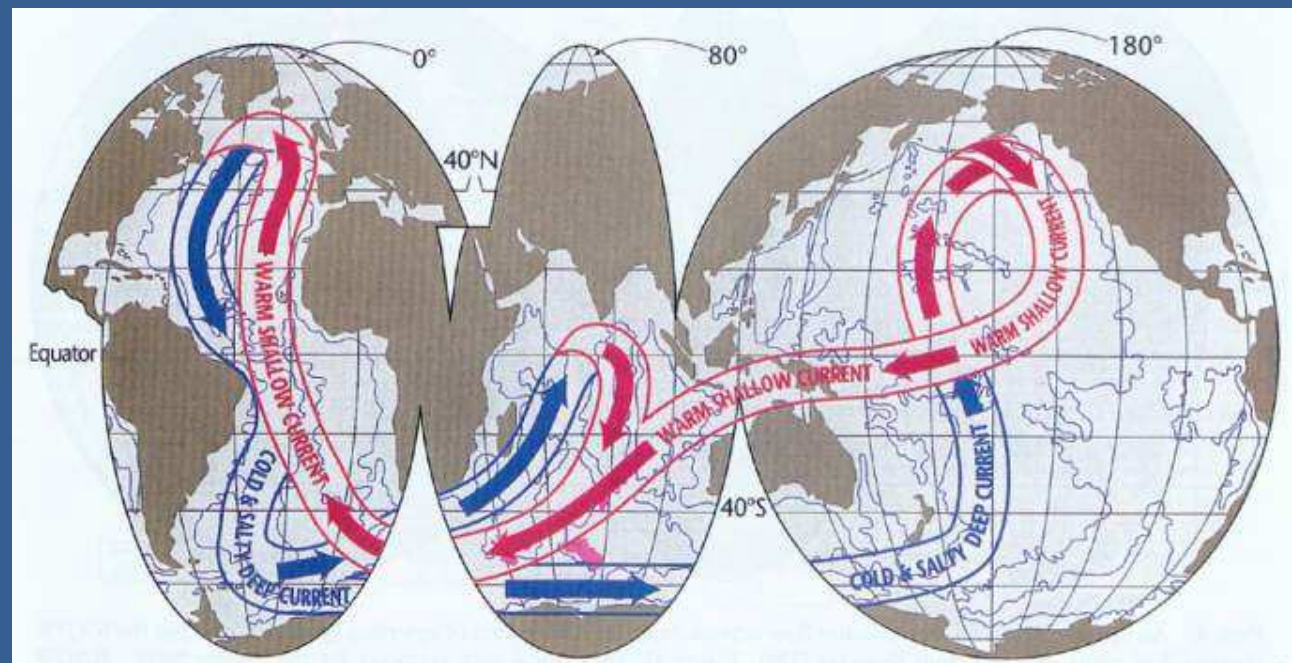
Father of
Paleoceanography

Other Paleoceanographers

Wally Broecker

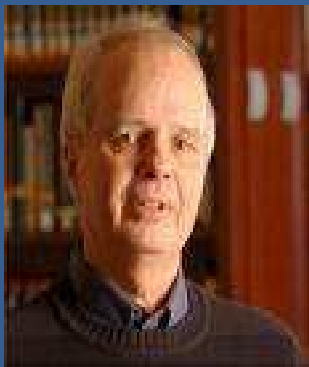
Thermal-haline

“conveyor” belt of circulation

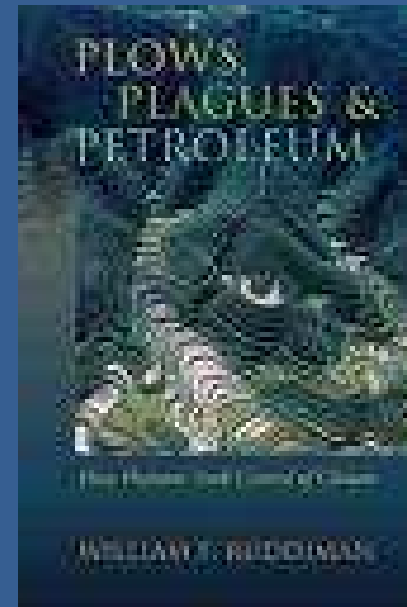
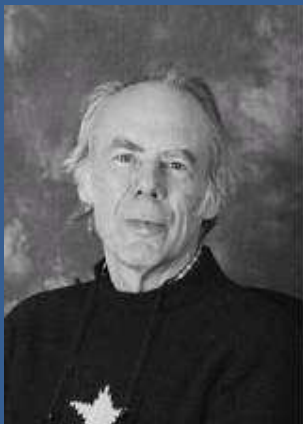


Other Paleooceanographers

Bill Ruddiman

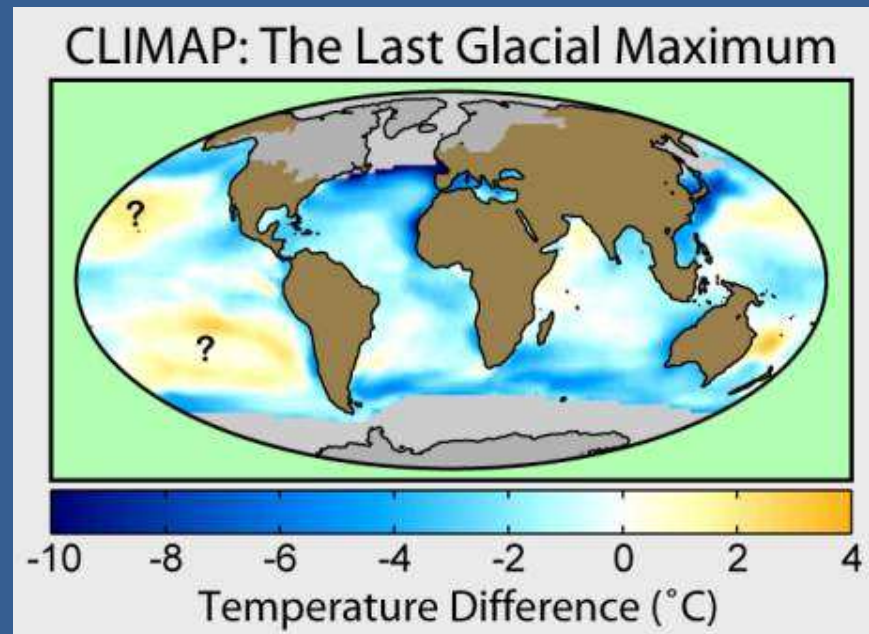


Nick Shackleton

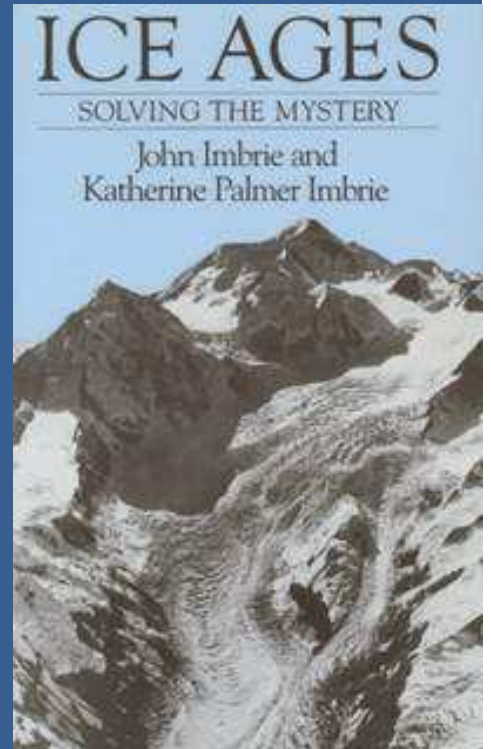
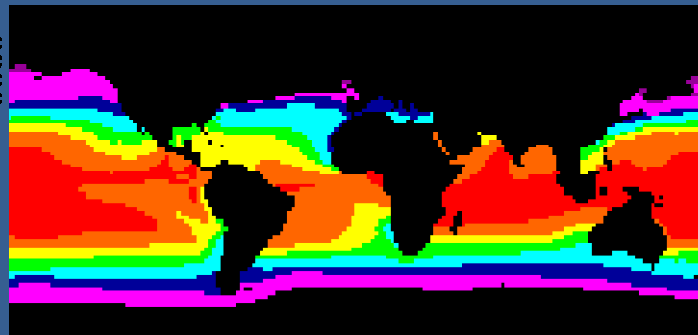


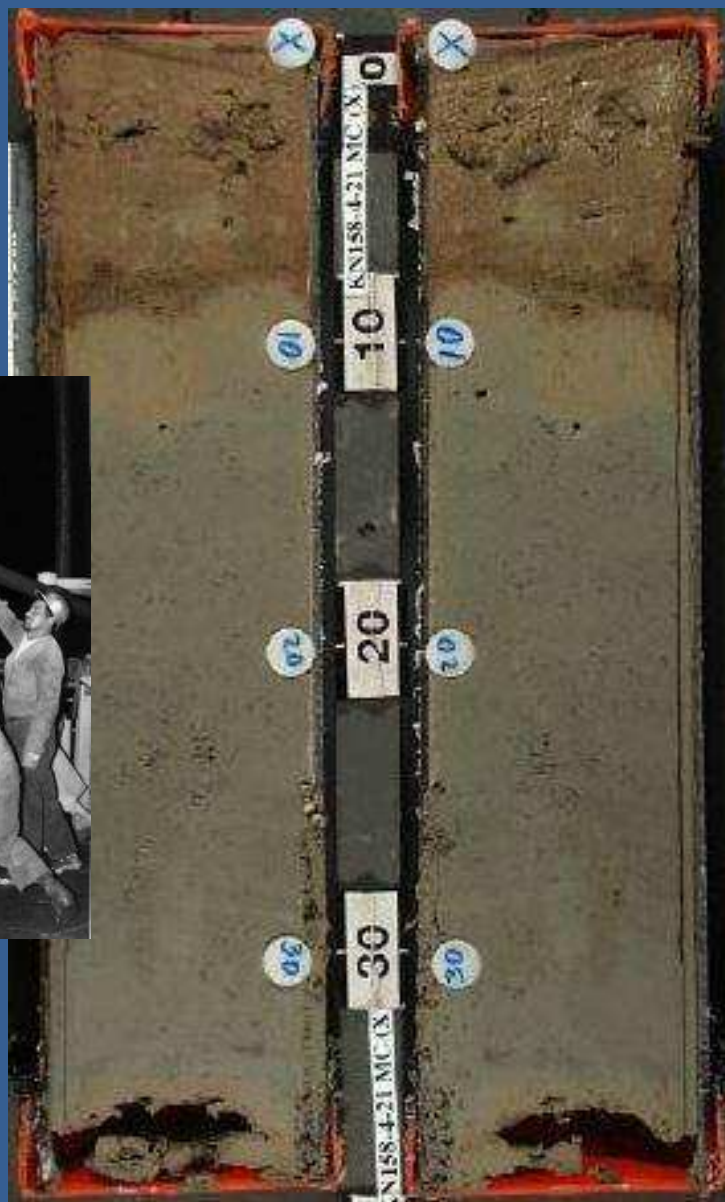
Other Paleooceanographers

John Imbrie:
CLIMAP

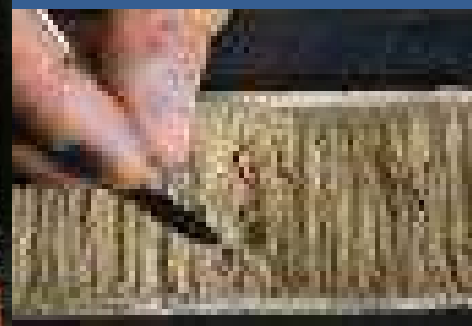


> 27 deg C
24 - 27 deg C
21 - 24 deg C
18 - 21 deg C
12 - 10 deg C
6 - 12 deg C
0 - 6 deg C
< 0 deg C
Land or Ice

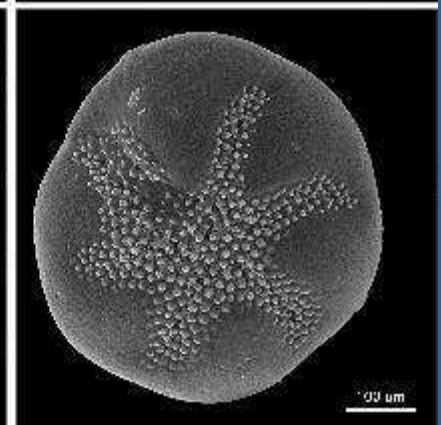
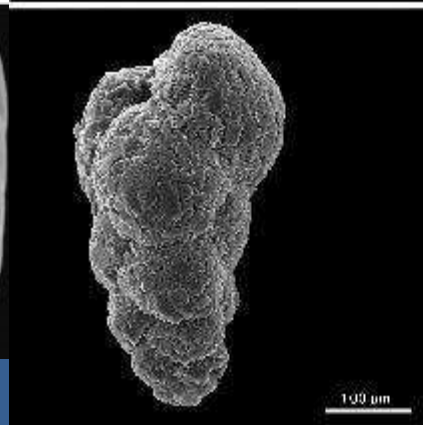
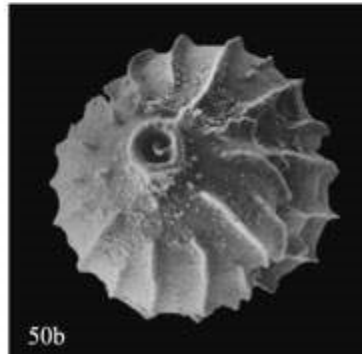
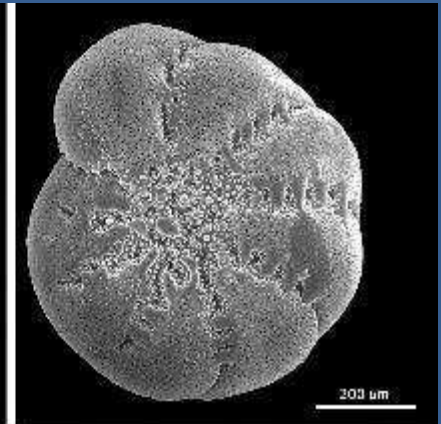
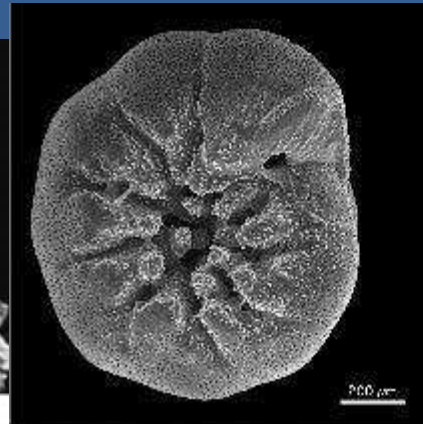
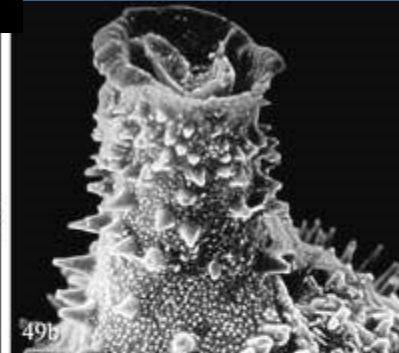
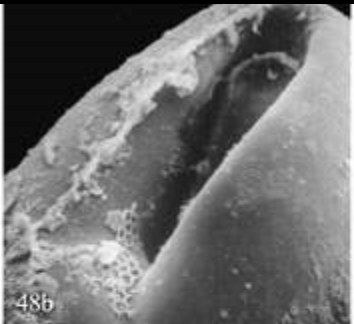




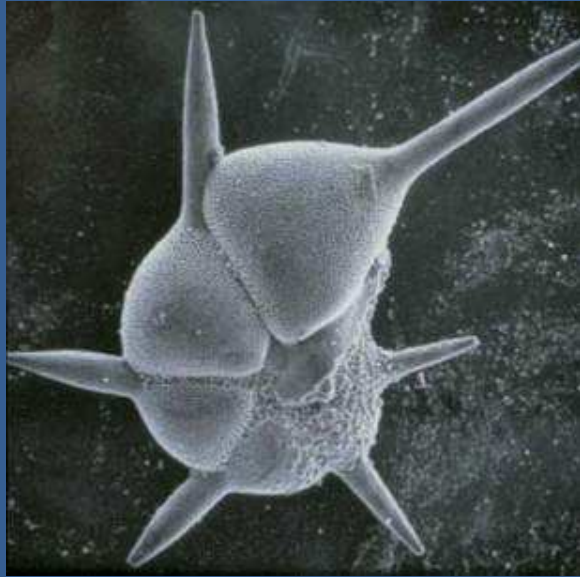
**PROXY DATA:
CORE DATA**



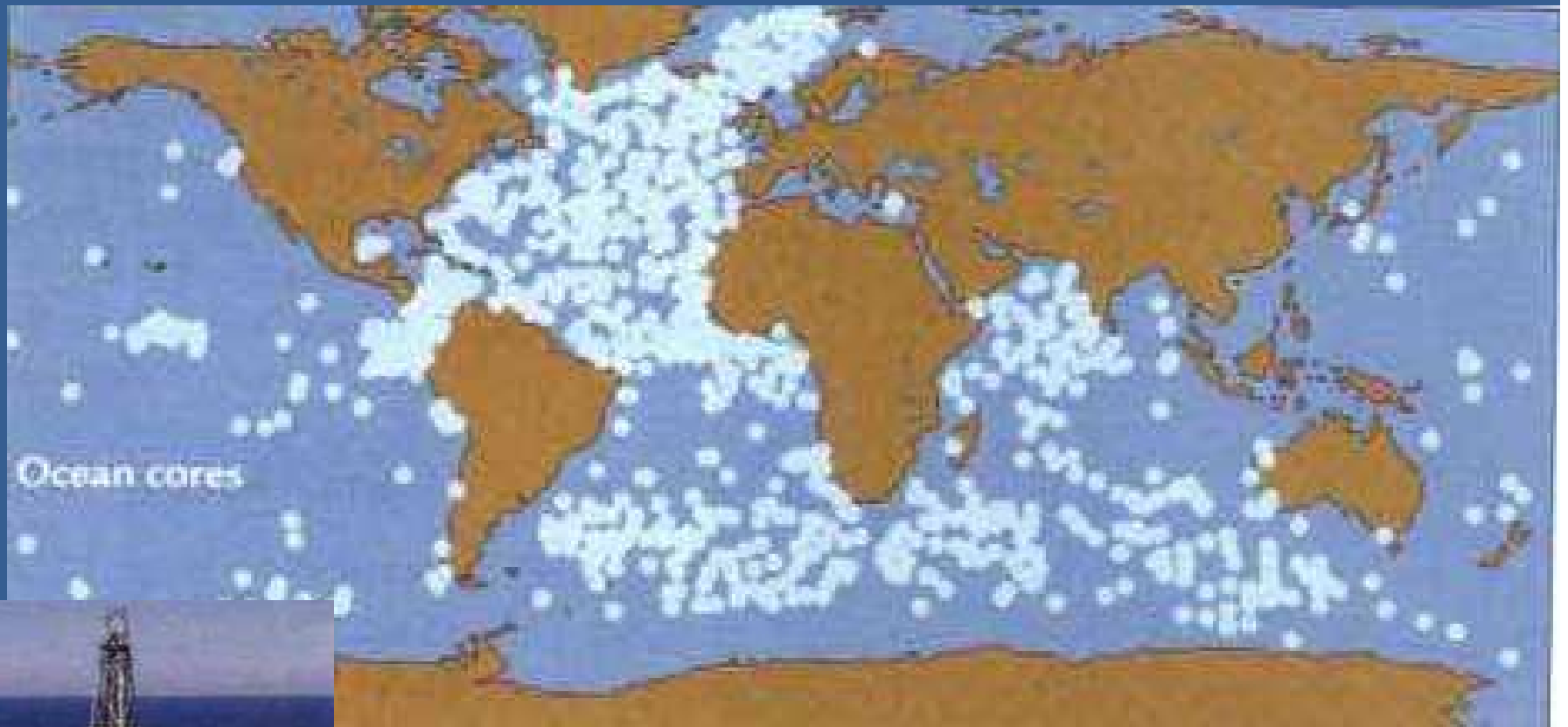
PROXY DATA: BENTHIC FORAMS



PROXY DATA: PLANKTONIC FORAMS

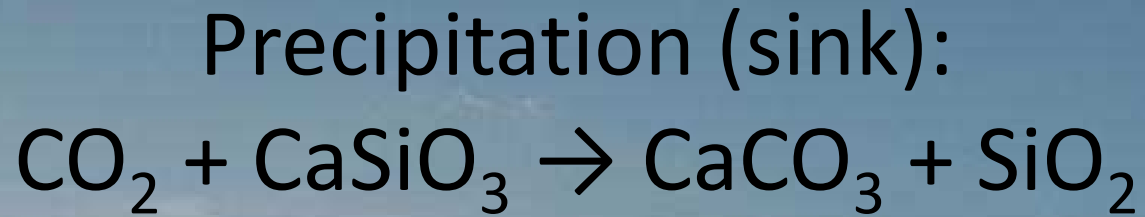


Deep Sea Coring



Ruddiman, 2008

The Azolla event



GUESS WHAT:

AS CONTINENTS DRIFT TO HIGH LATITUDES AND HIGHER ELEVATIONS AND BECOME GLACIATED IT LEADS TO:

- 1. GREATER MECHANICAL WEATHERING OF SILICATES:**
 - increasing sequestration of CO_2 in sediments
 - decreasing the amount in the atmosphere

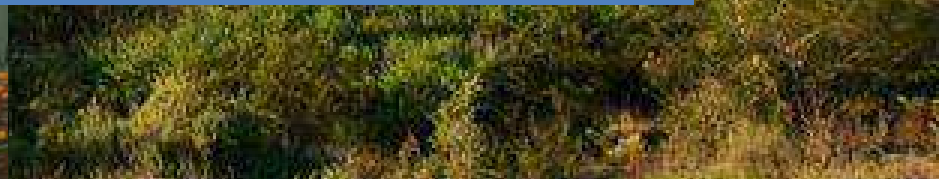
ADDITIONALLY in the Cenozoic:

- 2. MID-OCEAN SPREADING RATES SLOW DOWN**
 - Less CO_2 into the atmosphere for volcanoes

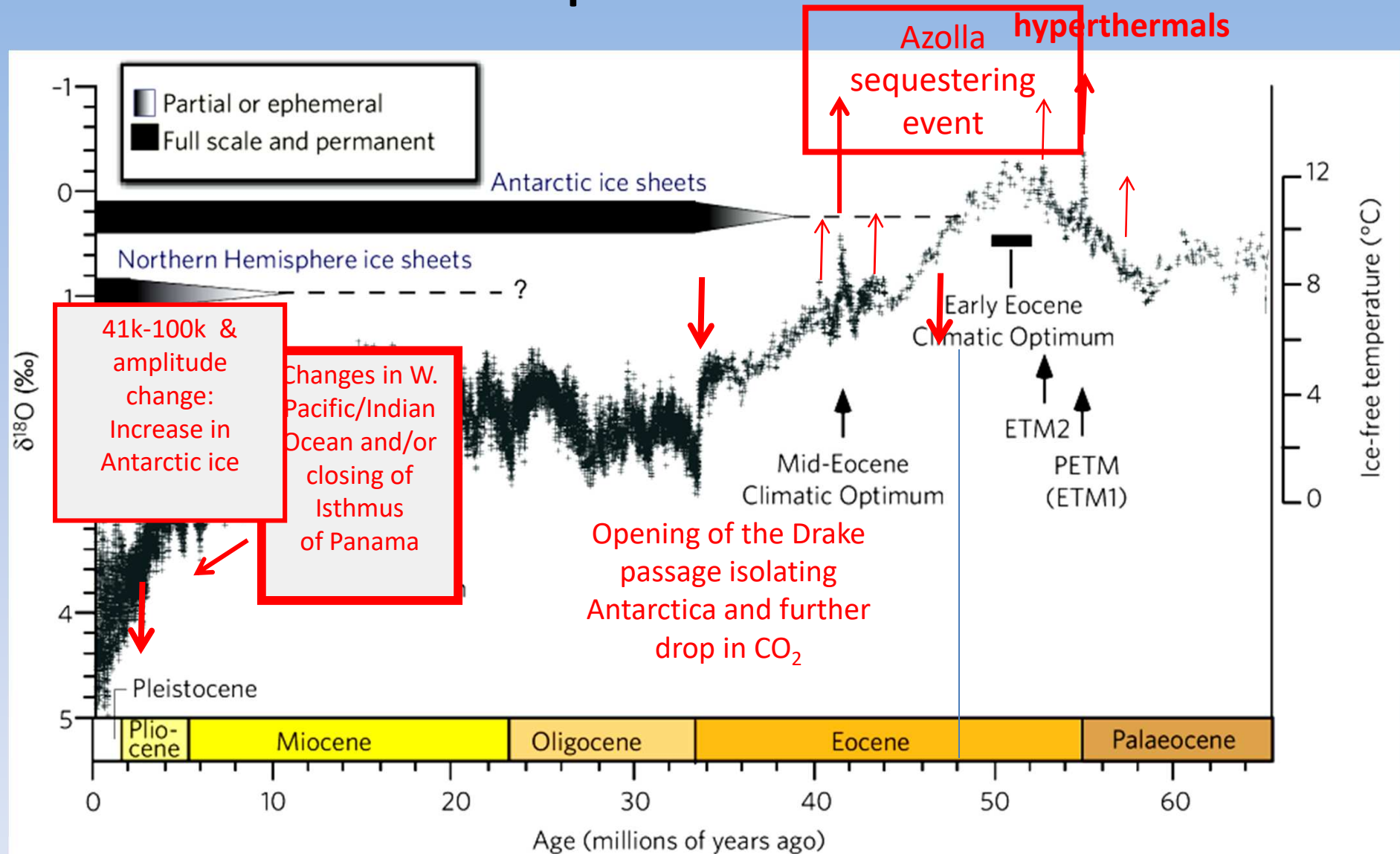
=

CO_2 DRAW DOWN THROUGH TIME!

corbis

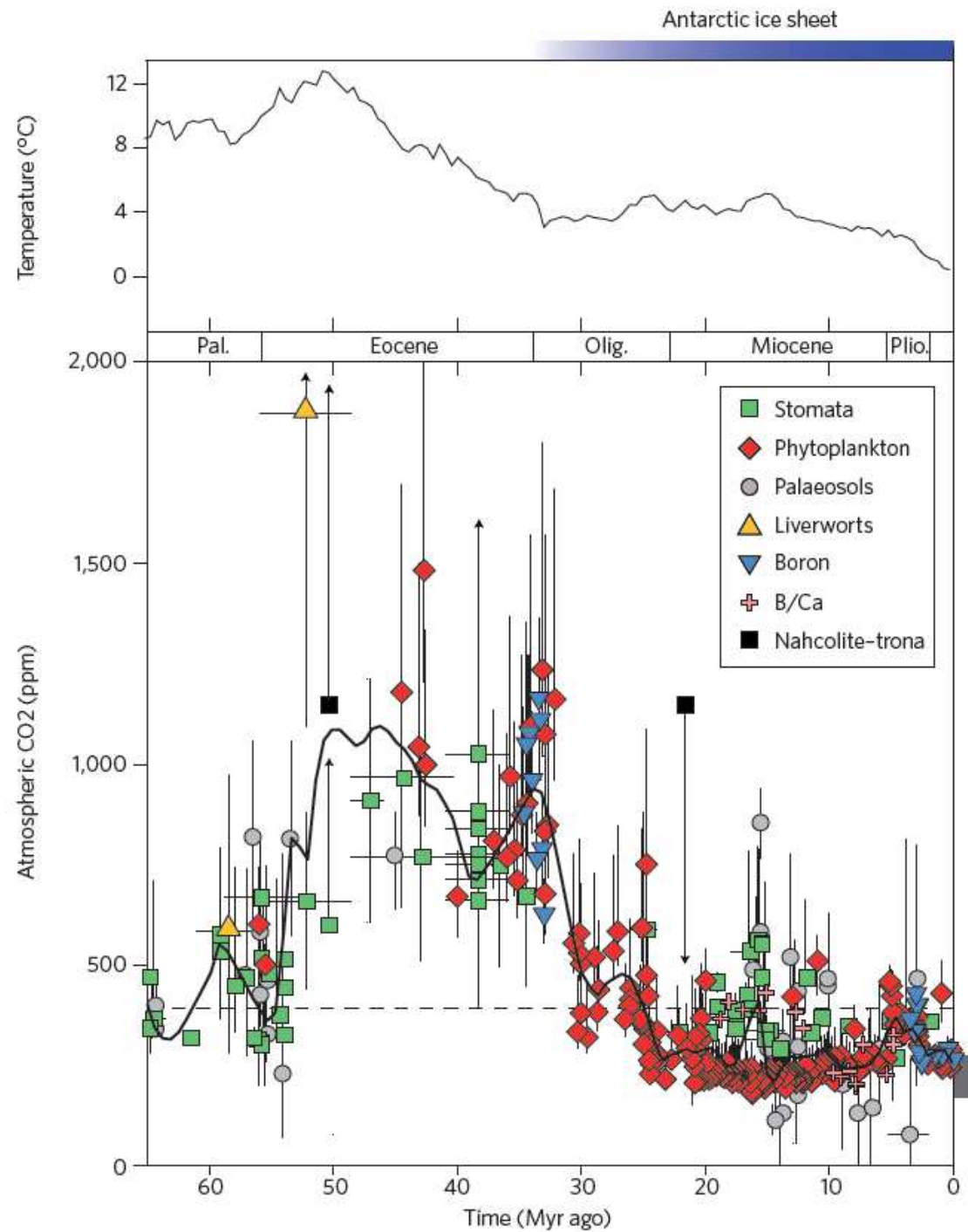


Cenozoic Deep Sea Climate Record

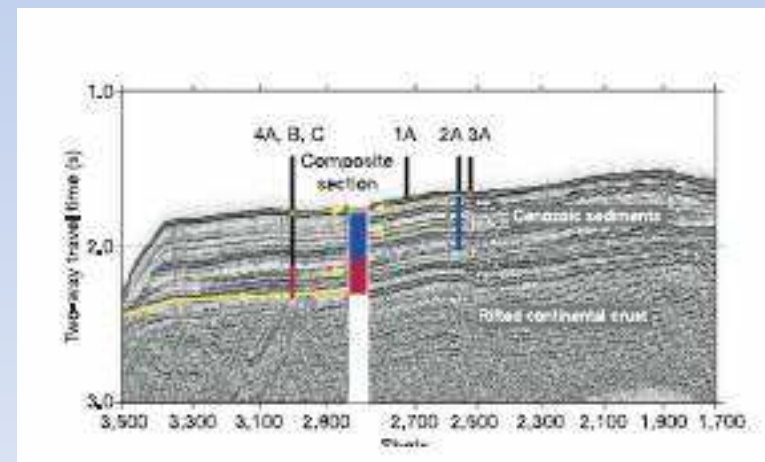
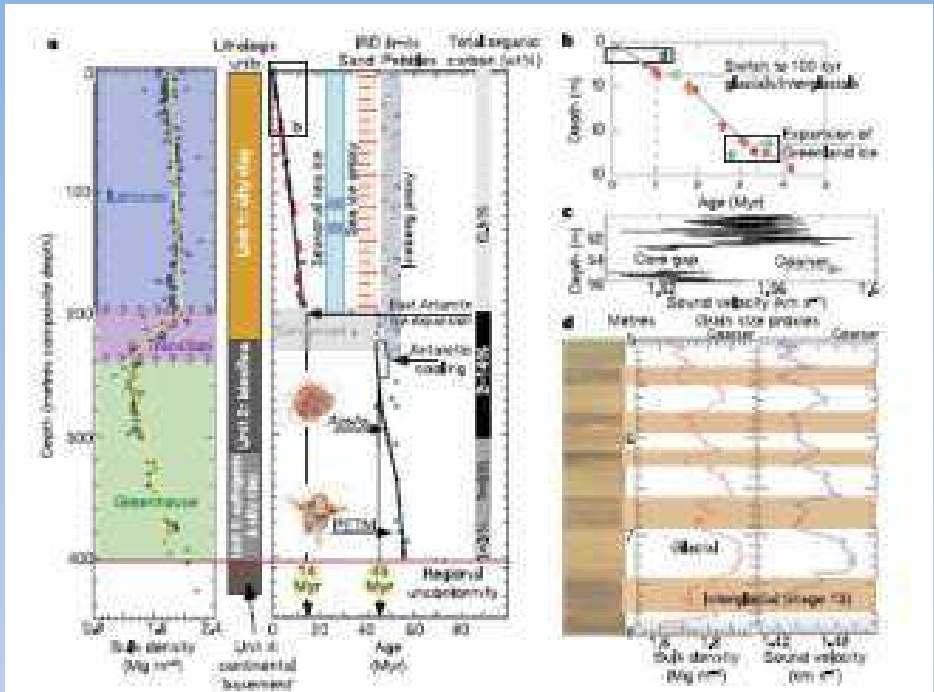
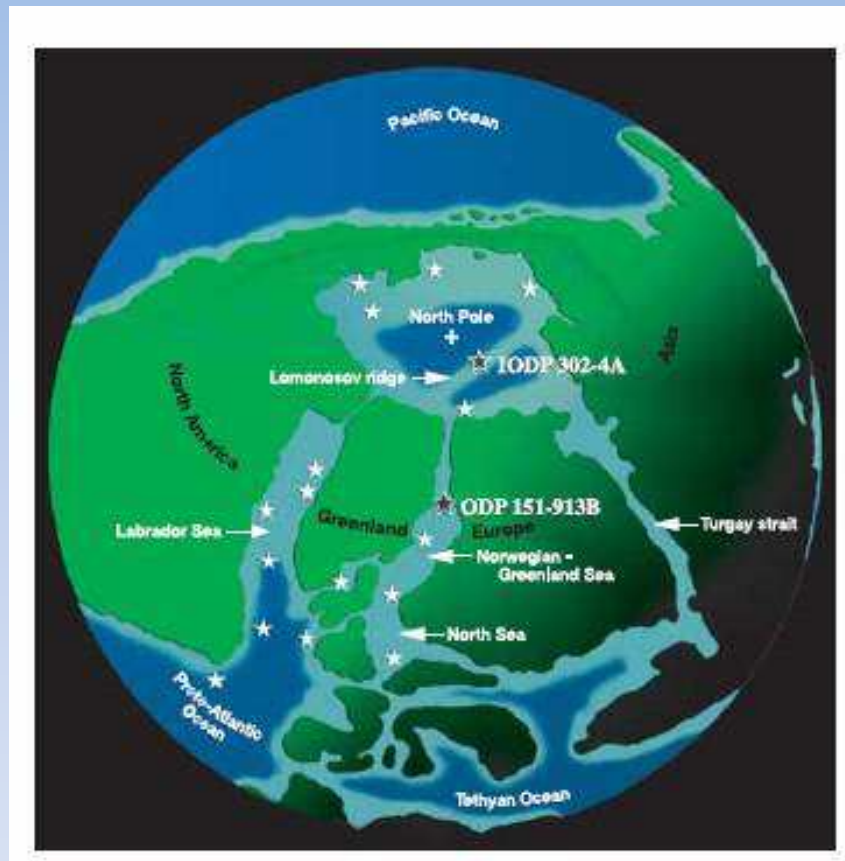


Correlation of CO₂ and temperature over last 65 million years

Beerling and Royer, Nature 2011

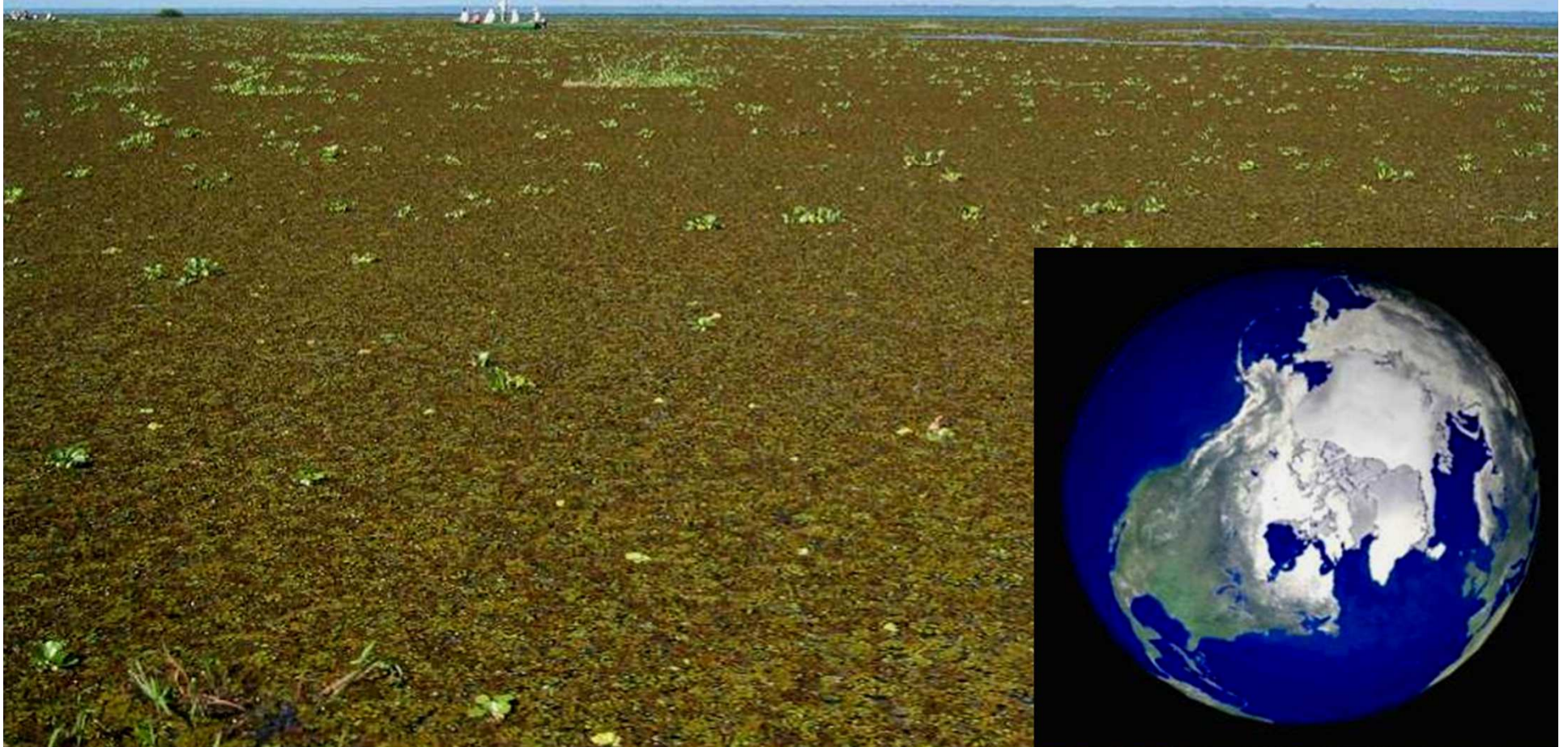


ARCTIC EVENTS



Brinkhuis et al., 2006
Moran et al., 2006

The Arctic Sea 50 million years ago

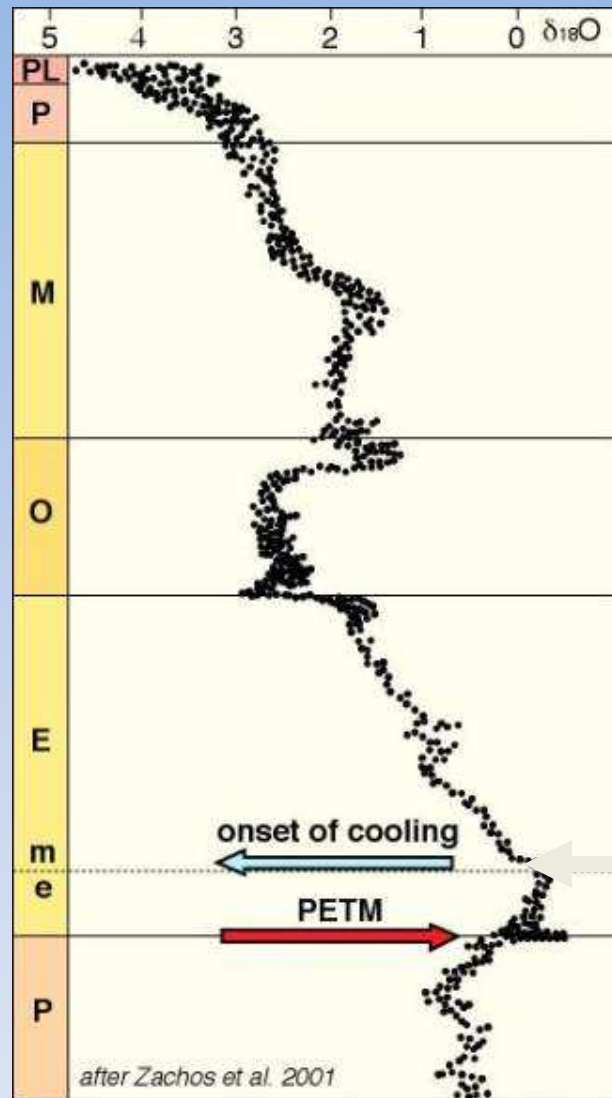


ACEX Azolla core

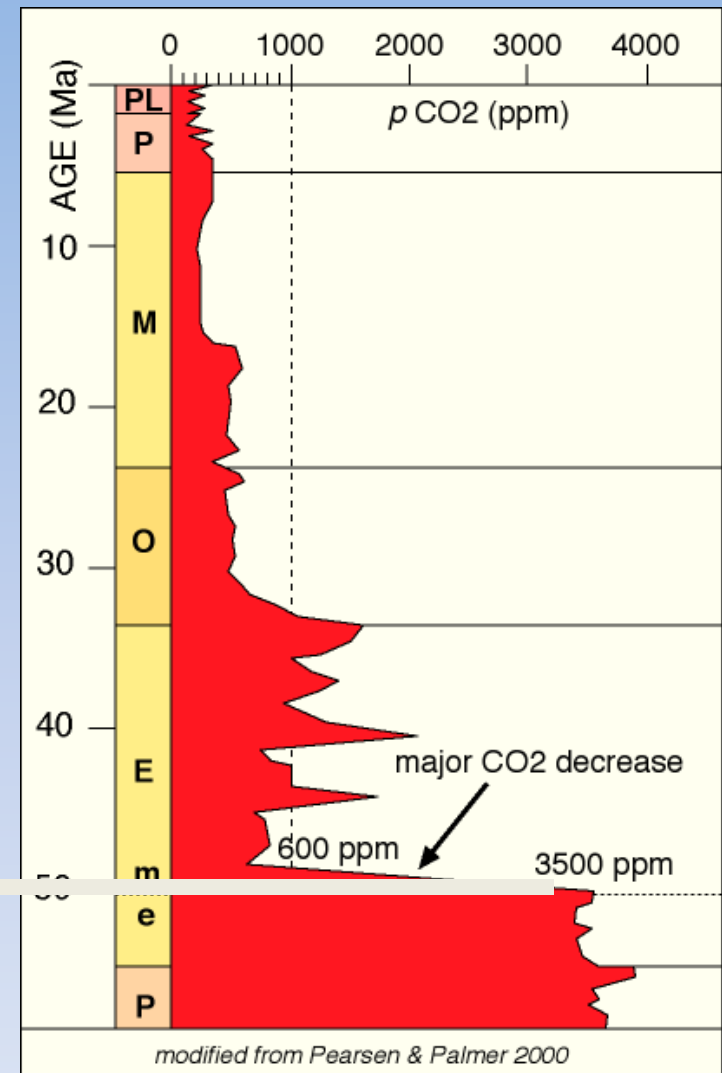
- >8 meter ACEX core with 90% Azolla
- Azolla occurs as laminated layers
- indicates Azolla deposited in situ
- bottom-water anoxia at ACEX site



UNPRECEDENTED DROP IN CO₂



the massive
decrease in
atmospheric
CO₂?



can this be used to predict the effect of future increases in CO₂ ?

