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

Week 2: Wednesday January 30th, 2019

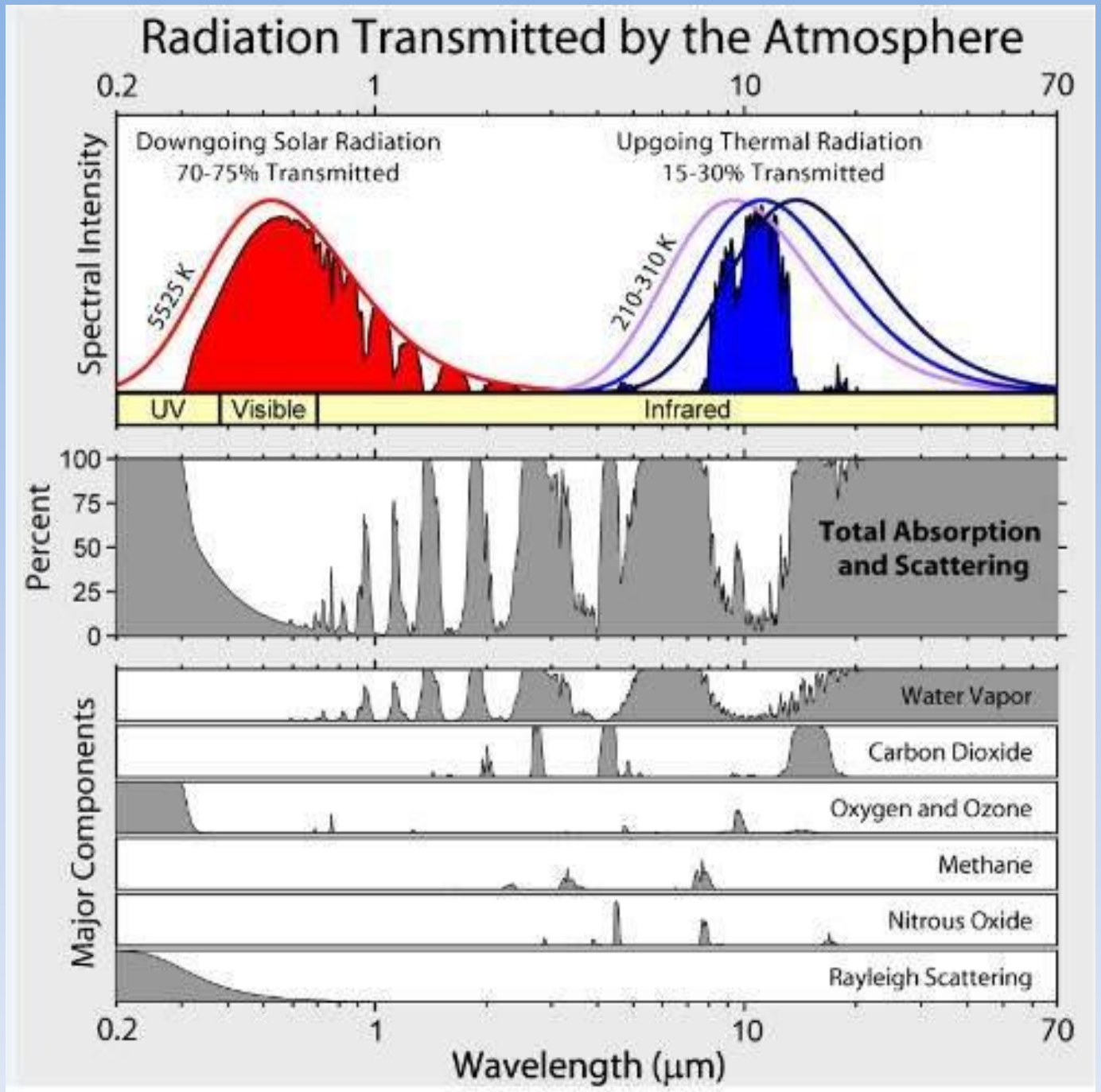
Paul Belanger

Earth's past climate history and what caused those changes

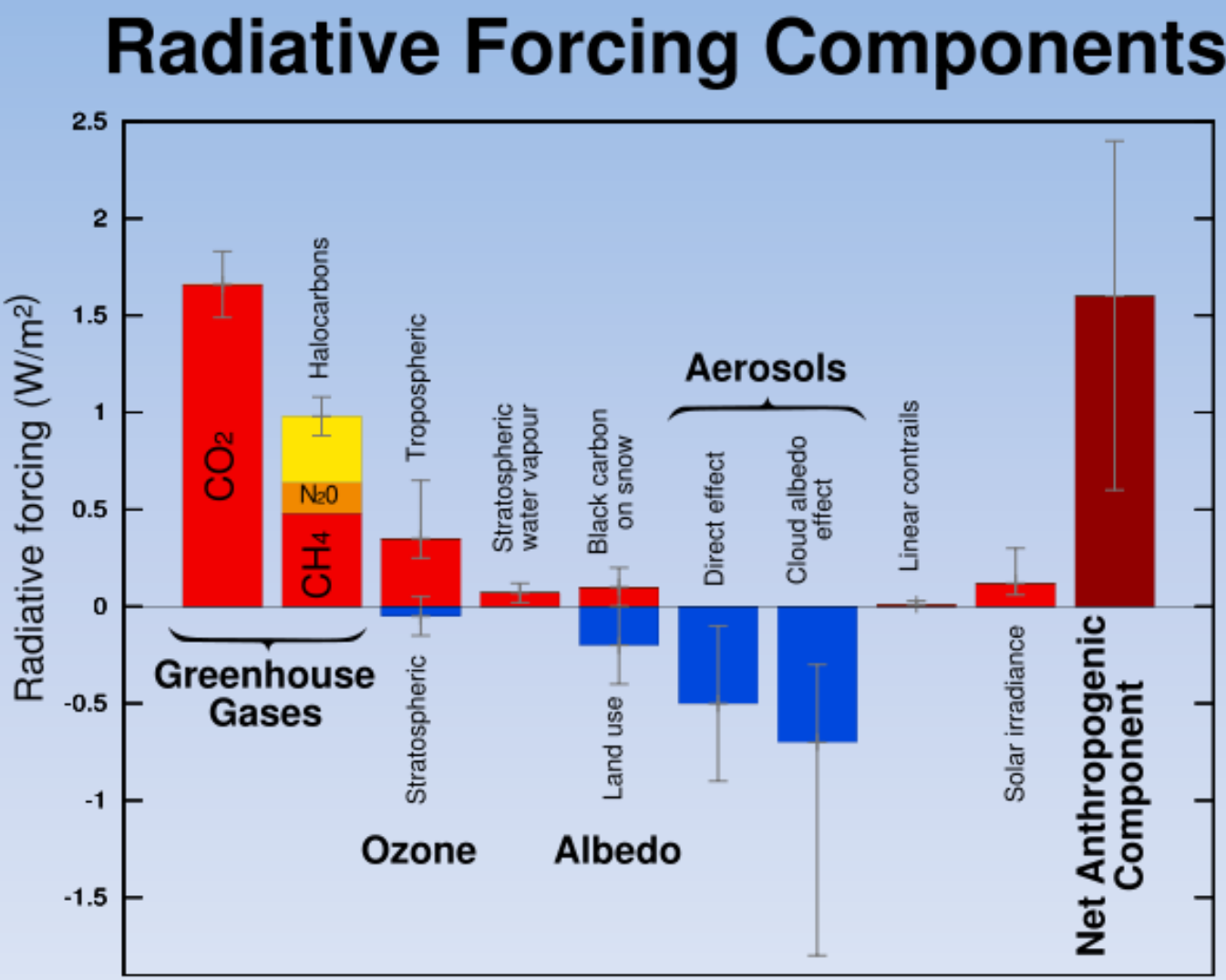
1. 4,500 to 600 million years: Earth's deep past before the Cambrian (600 MaBP): hot and cold
2. 600 to 65 million years: mostly hot-house Earth; 100s parts per million (ppm)
3. 65 million to 1 million years: long continuous drop with notable exceptions; CO_2 levels were possibly as high as 3600 ppm to recent times as low as 200 ppm.
4. 1 million to present: 180-280 part per million from ice core data
5. Today: 412 ppm and growing ~3ppm/year

But first

- Finishing slides from last week; slide # 58 onward in a cursory fashion
- If you have further questions please email me, raise your hand, etc.
- To do that I have to review this slide next:


Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

GLOBAL WARMING CONCERNS



Incoming Solar irradiance: 342 W/m^2

IPCC, 2007

How GHGs Blanket the Earth

Blanket Earth:

- **NASA –Global Climate Change Cause:** http://climate.nasa.gov/causes/

Denial 101x - Video includes First handout Global warming:

- https://www.youtube.com/watch?v=aqkGoCglp_U&feature=youtu.be

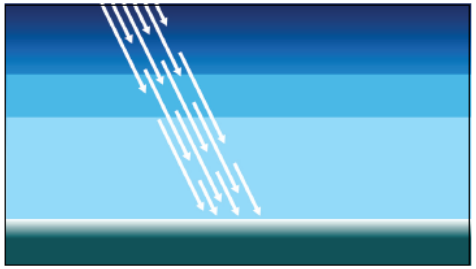
Denial 101x - Second handout – Increasing Greenhouse Effect:

- https://www.youtube.com/watch?v=we8VXwa83FQ

Increasing GHGs 1 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

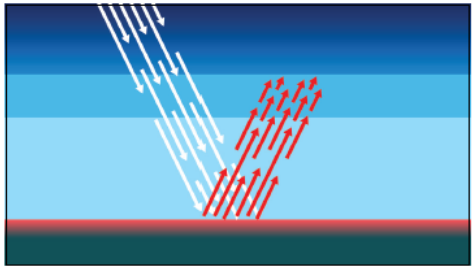
1 — 5 sec



Voice Over:
Greenhouse gases let sunlight through to warm the surface.

Visual: White arrows continually move into the Earth's surface. Earths surface glows white.

2 — 3 sec



Voice Over:
The surface then glows with infrared light.

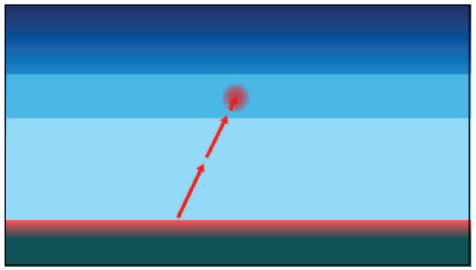
Visual:
Earths surface glows red. Red arrows move away from the ground reducing in speed as they move through the greenhouse gas.

3 — 4 sec

Voice Over:
Our eyes aren't tuned to its frequency so it's invisible to us.

Visual:
All arrows and glows disappear.

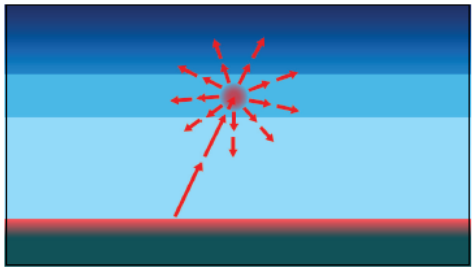
4 — 7 sec



Voice Over:
But greenhouse gases absorb some of this infrared. At the same time, they glow with their own infrared.

Visual:
Glow reappears and a single arrow continually moves up from the ground in the greenhouse gas. The a small section of the greenhouse gas glows where the arrow collides.

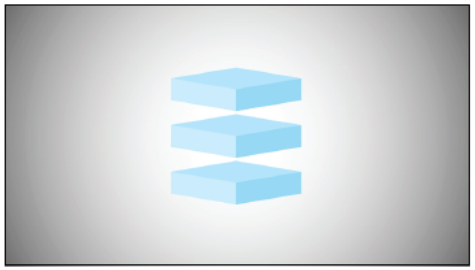
5 — 8 sec



Voice Over:
They glow in all directions, and the part of the glow that goes up can be absorbed by greenhouse gases further up in the atmosphere.

Visual:
Arrows are emitted from the glow in the greenhouse gas.

6 — 3 sec



Voice Over:
It's useful to think of the atmosphere as layers.

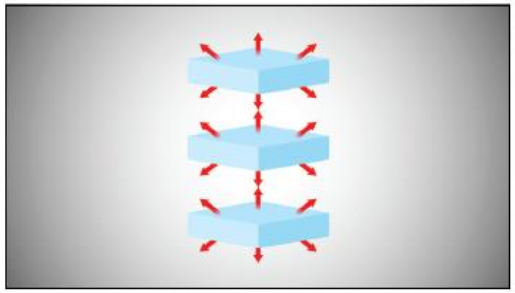
Visual:
Cut to new scene showing layers of atmosphere.

animation by Daniel Greenup, University of Queensland for Denial101x

Increasing GHGs 2 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

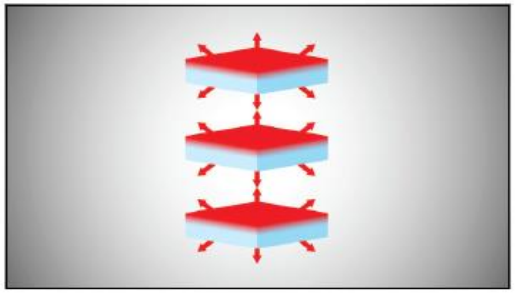
7 **4 sec**



Voice Over:
Each layer of the atmosphere has a greenhouse glow in every direction.

Visual:
Layers separate more and arrows are emitted.

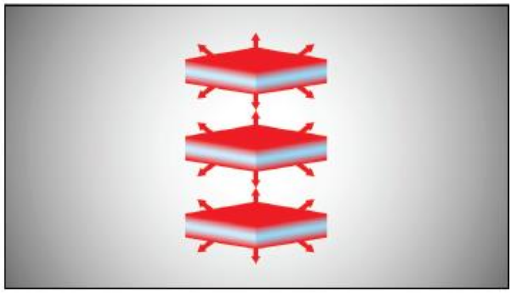
8 **5 sec**



Voice Over:
Meanwhile, each layer absorbs some of the infrared glow that comes from the layer above,

Visual:
Top of layers glow.

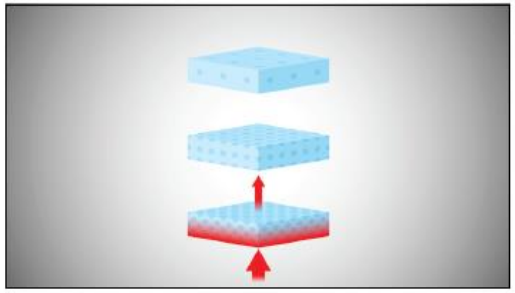
9 **3 sec**



Voice Over:
and some from the layer below.

Visual:
Bottoms of layers start glowing.

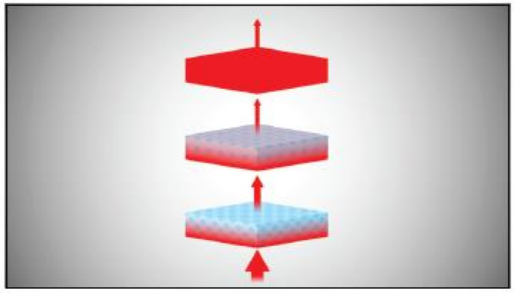
10 **9 sec**



Voice Over:
Low down in the atmosphere, the air is thicker than higher up. Each layer has enough greenhouse gas to absorb much of the infrared going through it.

Visual:
Glow and arrows are removed. Dots appear in layers to indicate air thickness. A new arrows moves through the bottom layer and reduce in size. The bottom of the layer glows.

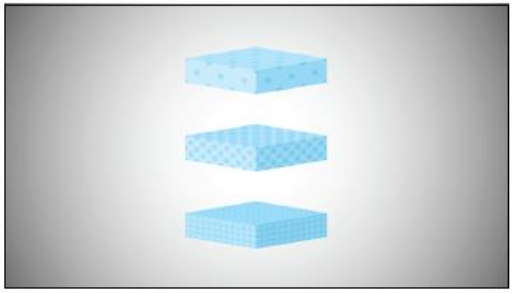
11 **11 sec**



Voice Over:
Higher up in the atmosphere, the air gets thinner. That's why it's harder to breathe at the top of a mountain. Each layer doesn't have enough greenhouse gas to fully trap passing infrared.

Visual:
Arrows move through all of the layers reducing in size.

12 **9 sec**



Voice Over:
Burning coal, oil and gas releases carbon dioxide, a greenhouse gas. Stirred by the winds, it mixes through the atmosphere.

Visual:
Arrows and glows are removed and extra dots appear in each layer.

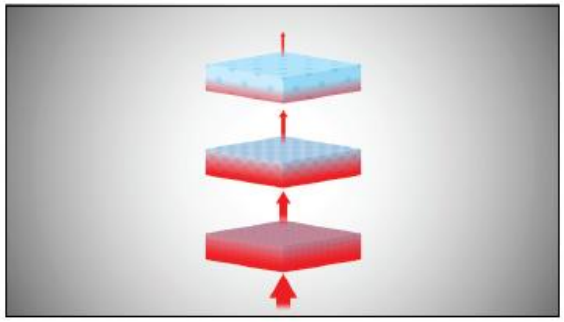
animation by Daniel Greenup, University of Queensland for Denial101x

Increasing GHGs 3 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

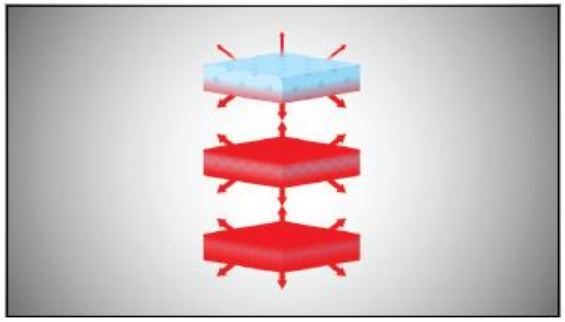
3 of 3

13 10 sec



Voice Over:
The biggest effect is high up where the air is thinner. This is where infrared previously escaped to space. Adding more greenhouse gases captures this infrared.

14 9 sec

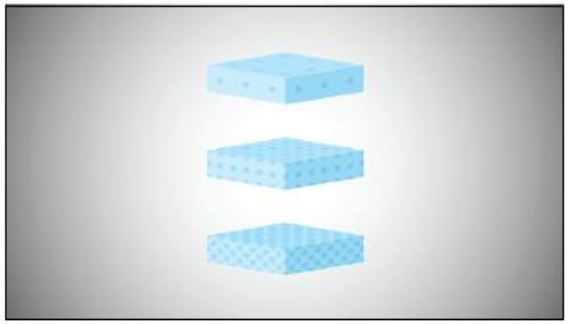


Voice Over:
This upper layer now glows a little more brightly. A little more heat is recycled back into the atmosphere. This is how adding more greenhouse gases makes us warmer.

DENIAL101x - 3.3.2.1 - Animation 2 v2

1 of 1

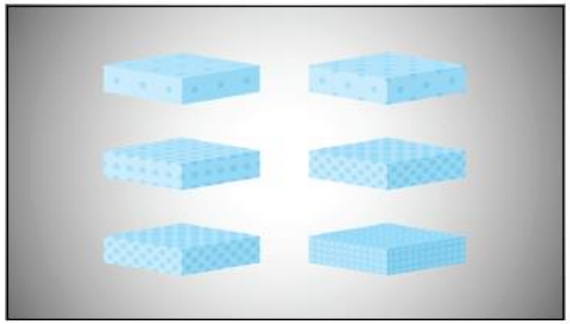
1 9 sec



Voice Over:
In the upper layers of the atmosphere, the greenhouse effect isn't saturated. The concentration of greenhouse gases is a lot less than in Angstrom's tube.

Visual:
Layers of atmosphere appear.

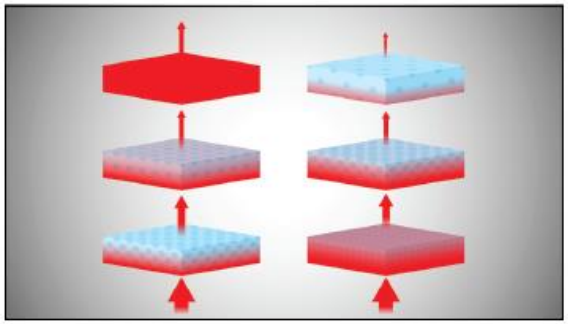
2 6 sec



Voice Over:
Adding greenhouse gases blocks the infrared's escape path to space.

Visual:
Layers of atmosphere and greenhouse gases appear.

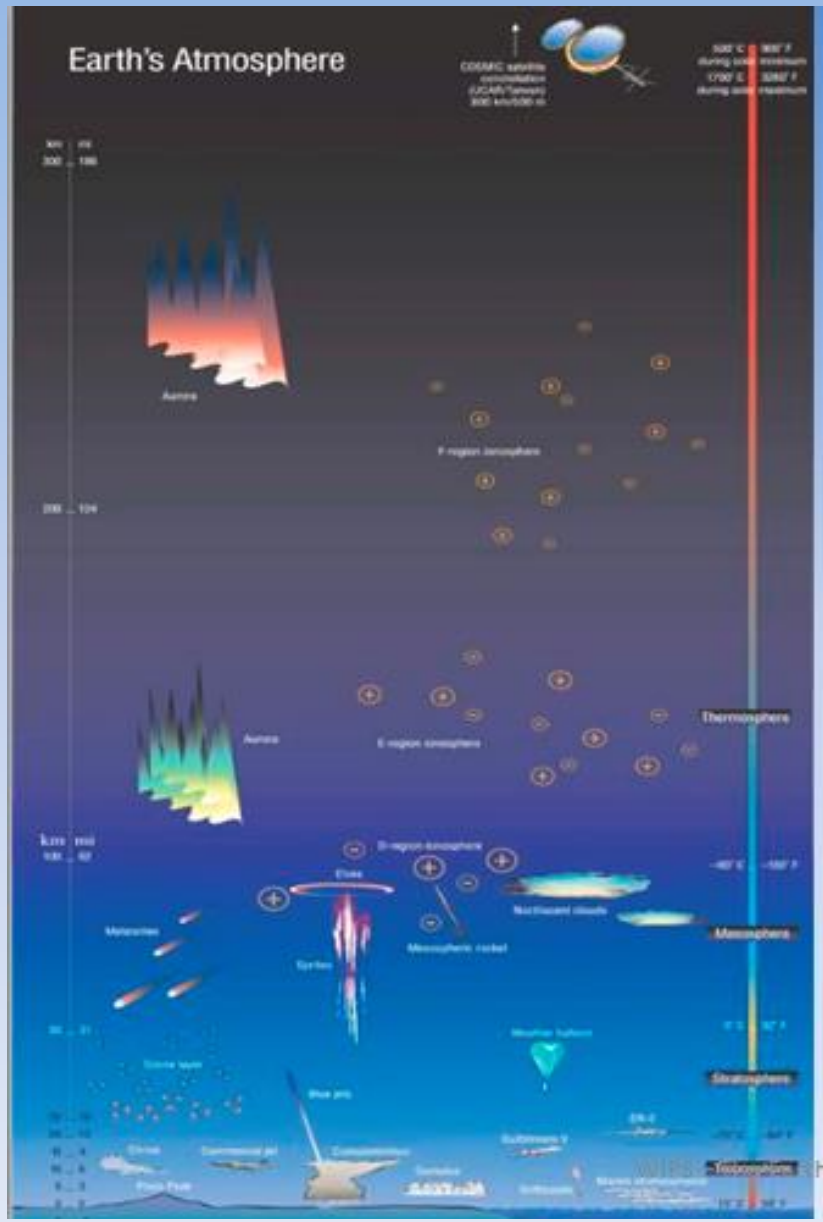
3 8 sec



Voice Over:
Some of the infrared that used to escape to space has now been trapped. The layer's greenhouse glow sends some of it back down to warm us up.

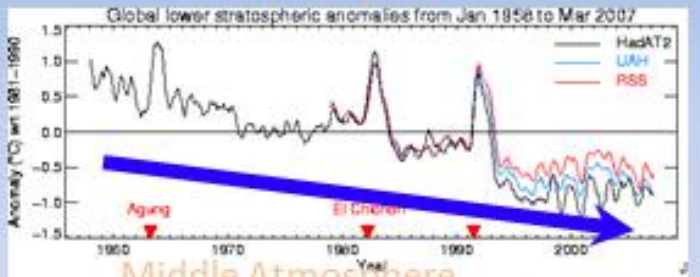
Visual:
Arrows move through layers.

5: SURFACE TO STRATOSPHERE CHANGES

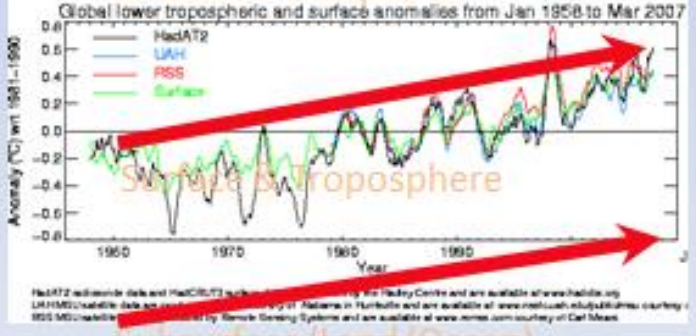


Greenhouse Fingerprint

Middle Atmosphere



Middle Atmosphere

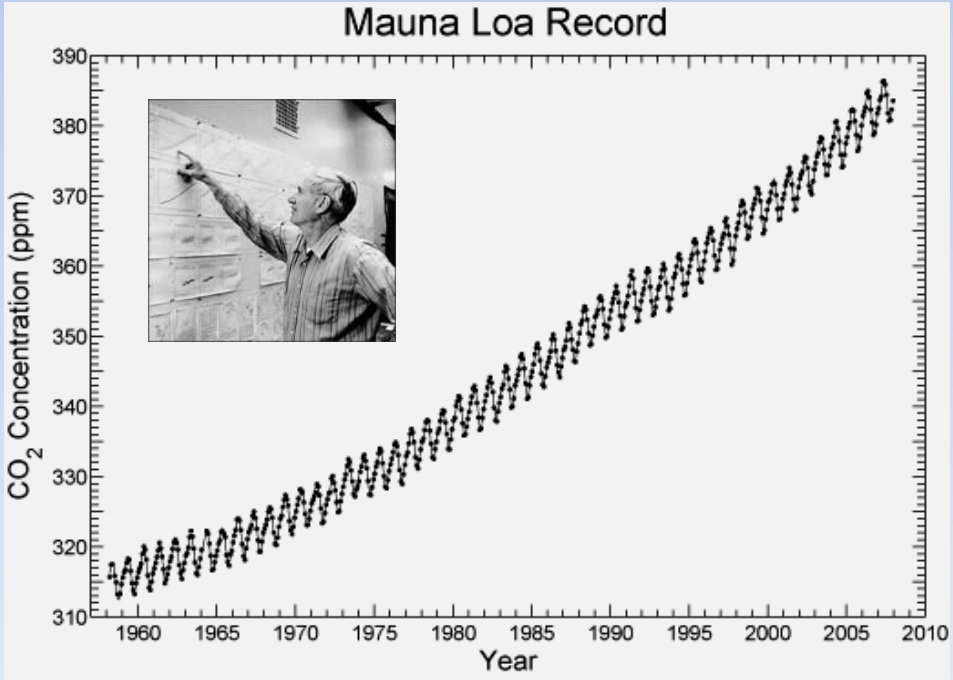


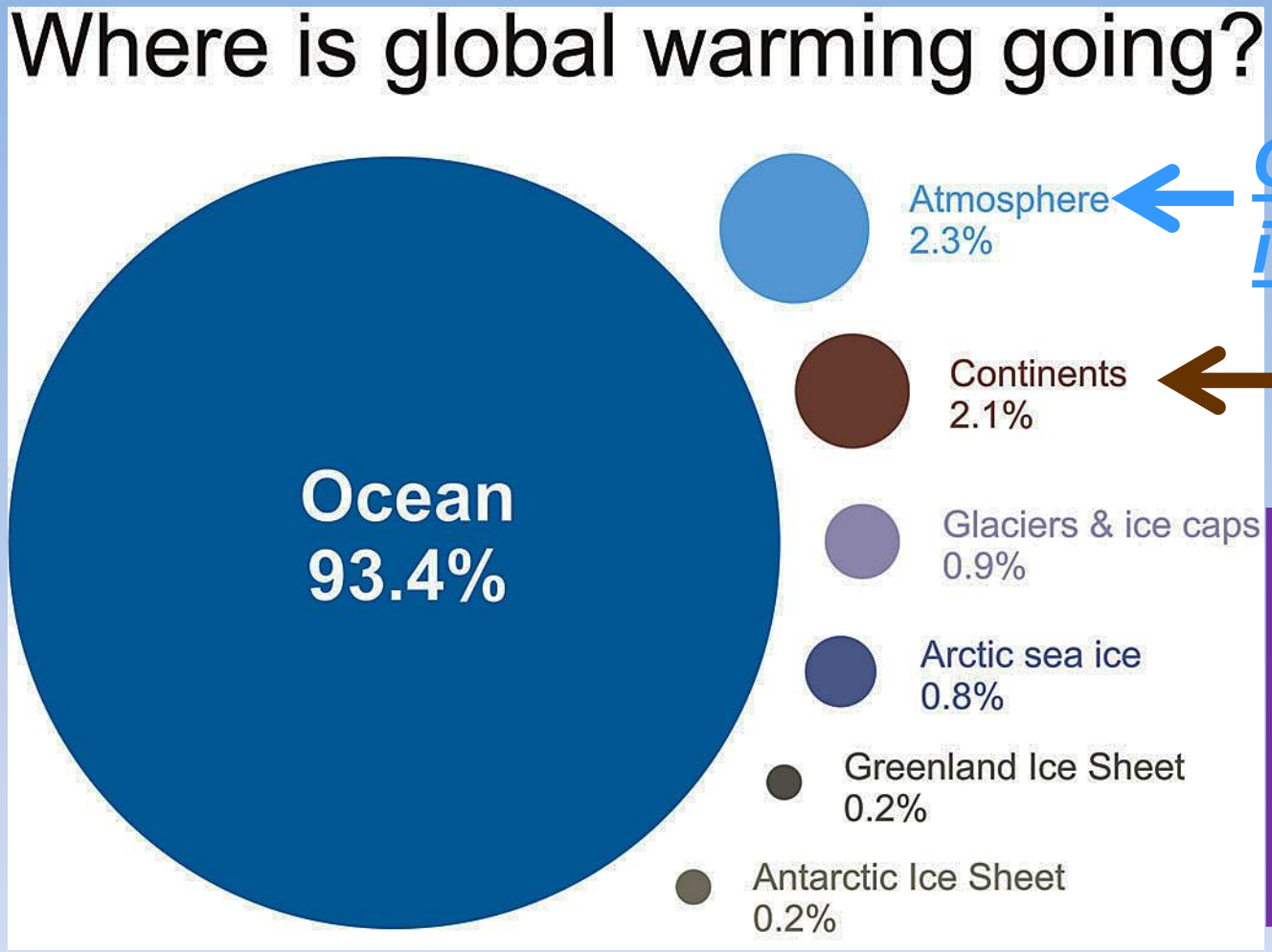
Surface & Troposphere

Subsurface (Land/Ocean)

3: EMISSIONS FROM HUMAN ACTIVITIES LARGELY TO BLAME

- 40% increase in CO_2
- Dead carbon altering atmospheric C^{14}
- That Carbon is more negative/enriched in C^{12}





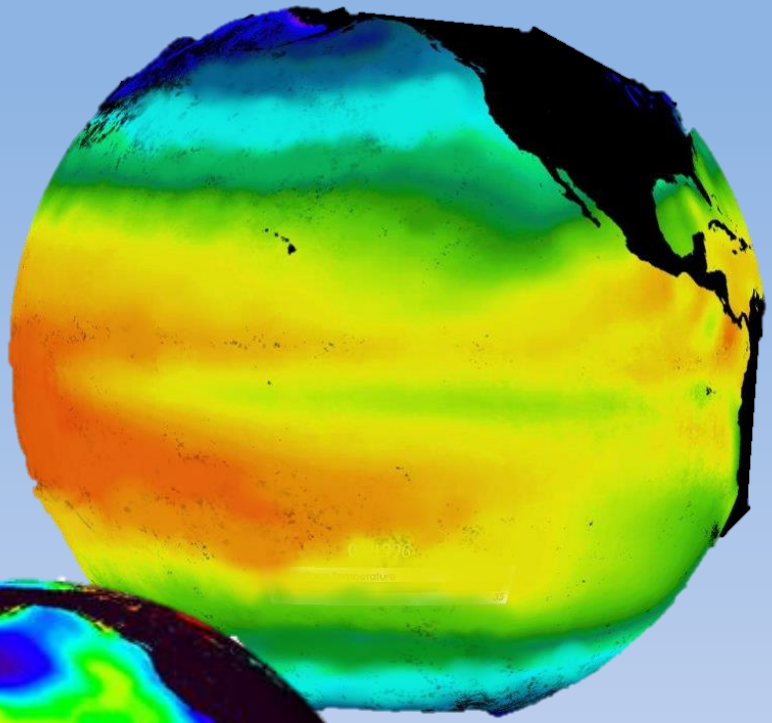
Only ~2% stays in atmosphere

~2% warms the land

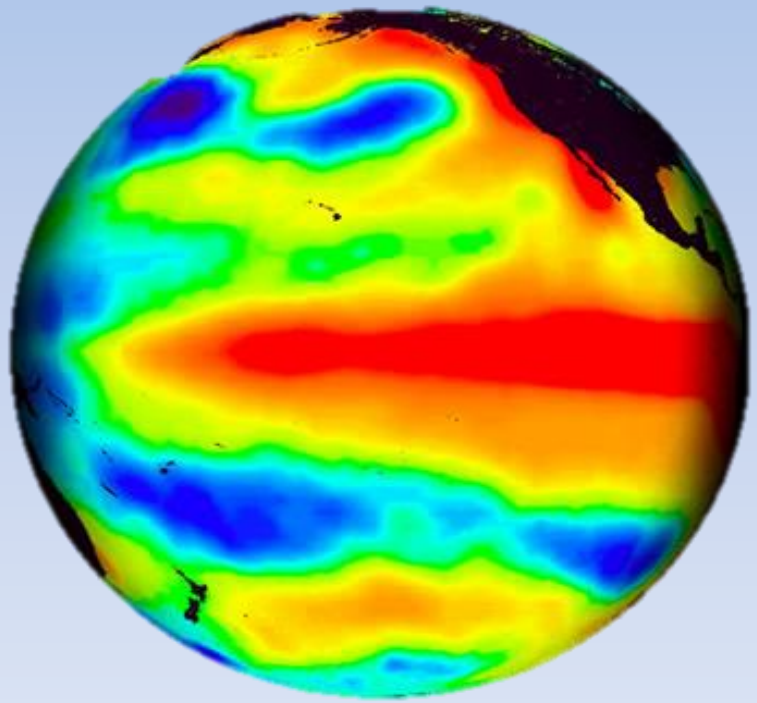
Melting ice absorbs ~2%

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

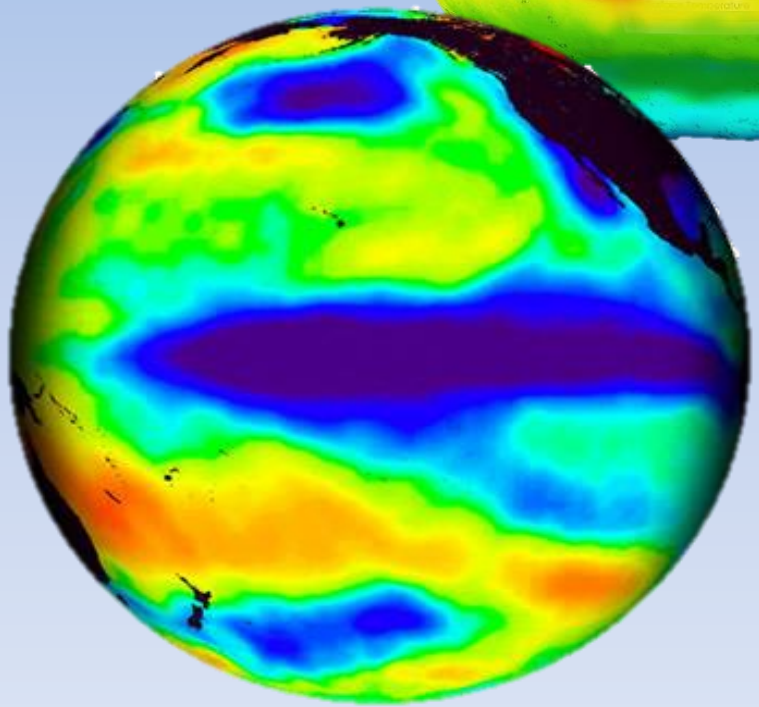
The Pacific – ‘normal condition’



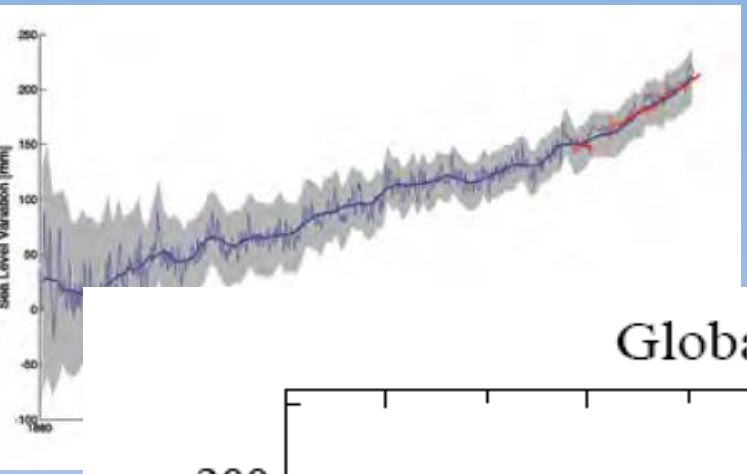
El Niño



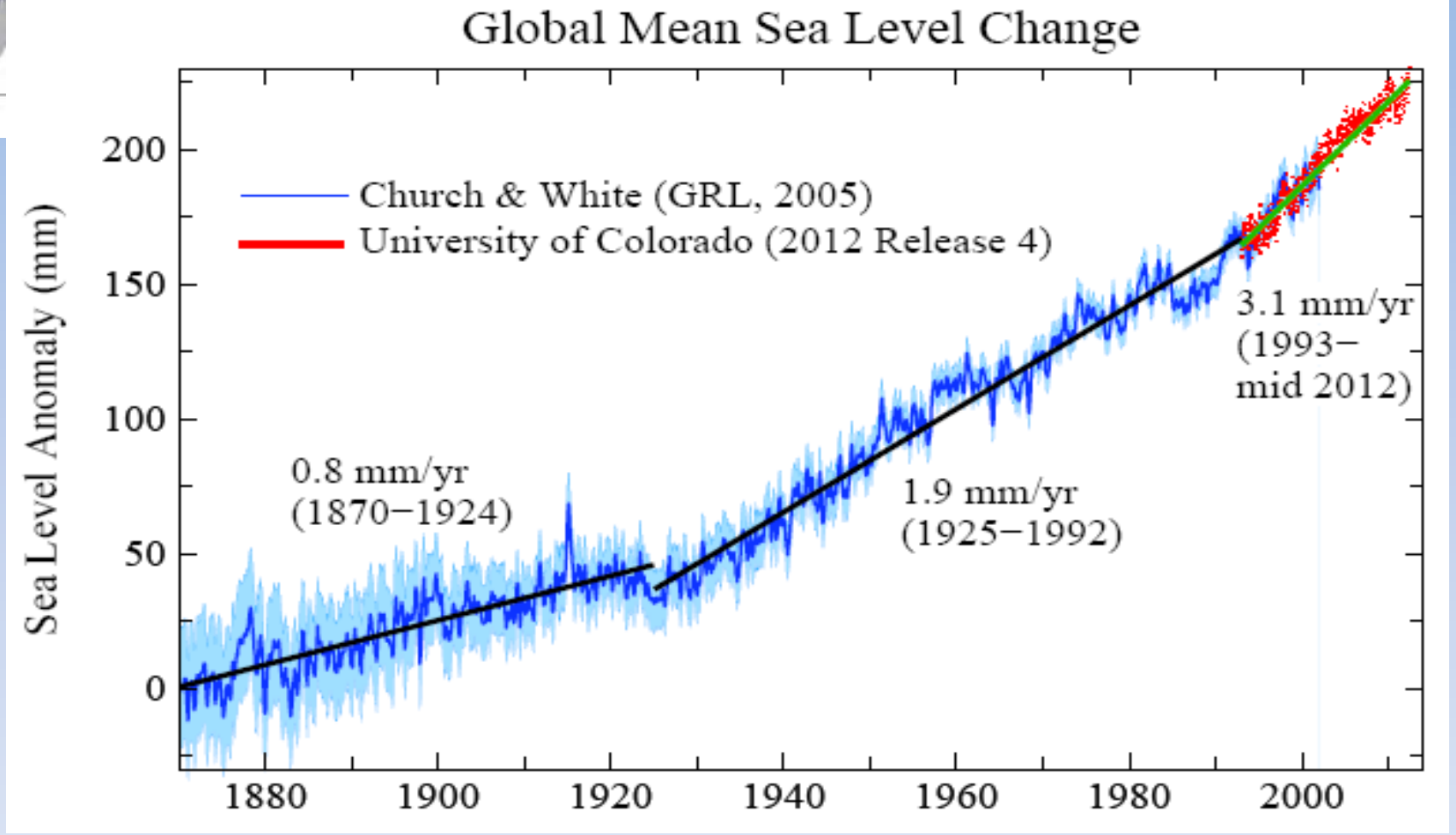
La Niña



Temperature Anomaly °C



14: HOW FAST IS SEA LEVEL RISING?

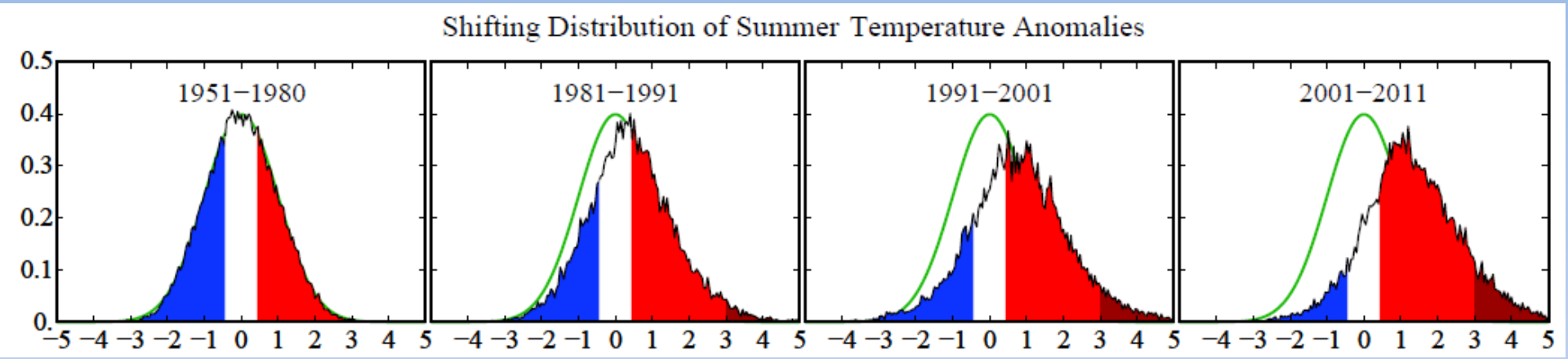


Blue: Sea level change from tide-gauge data *(Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602)*
Red: Univ. Colorado sea level analyses in satellite era *(http://www.columbia.edu/~mhs119/SeaLevel/)*.

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.

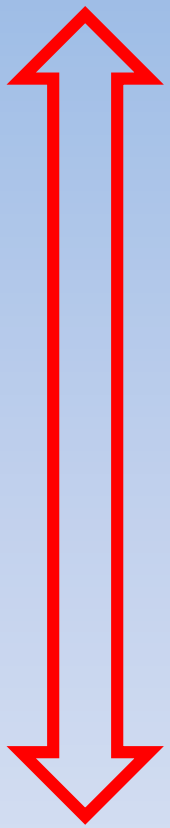
Resume week 2

Past Earth History Objectives:

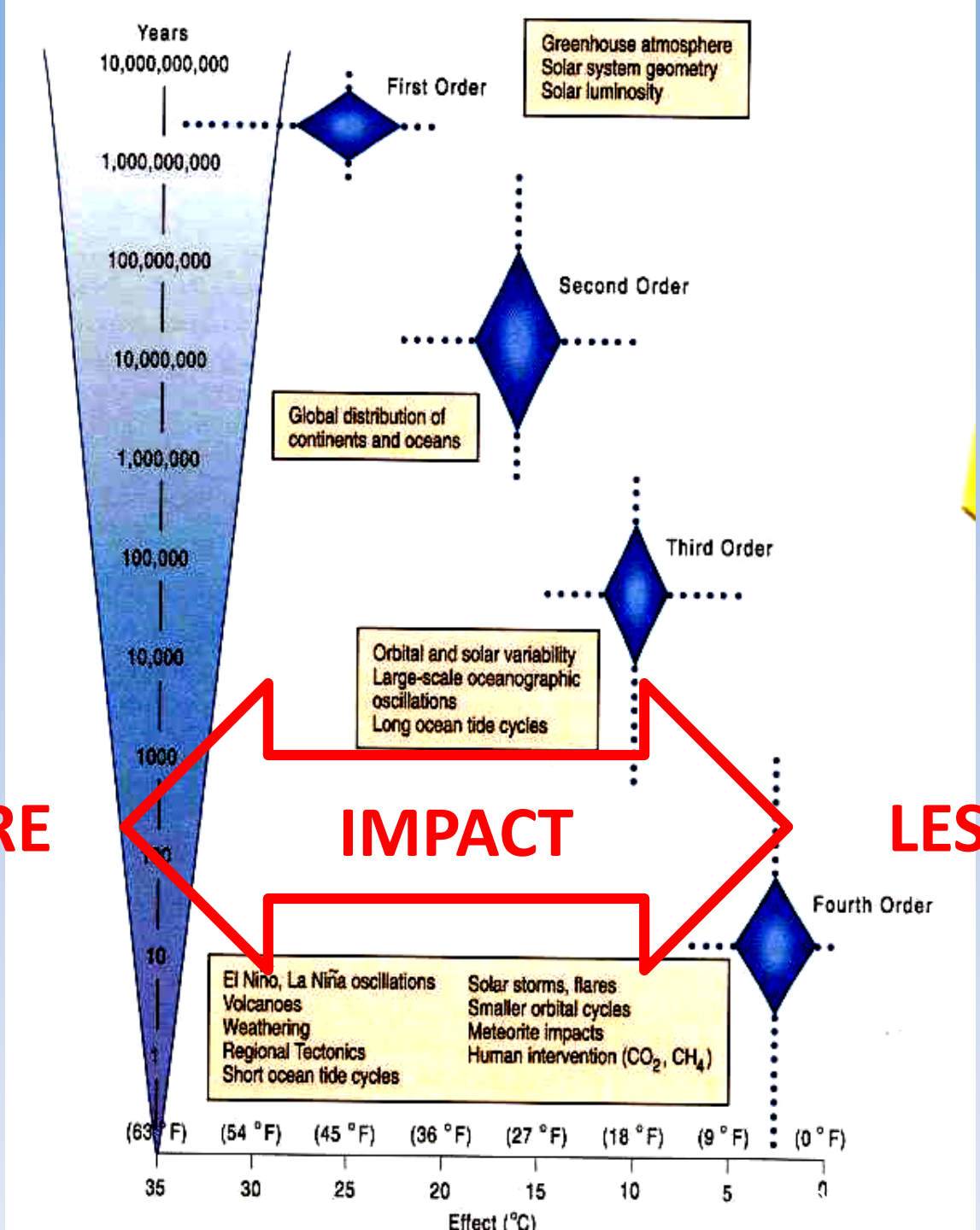
1. **Present you with the geologic evidence; Earth's past**
2. **Educate / That the science is sound**
3. **Understand the denial movement and how to counter it**
4. **Motivate you**
5. **Give you hope / look at potential game changers**

- SO –
WHAT CONTROLS CLIMATE

Billions of years



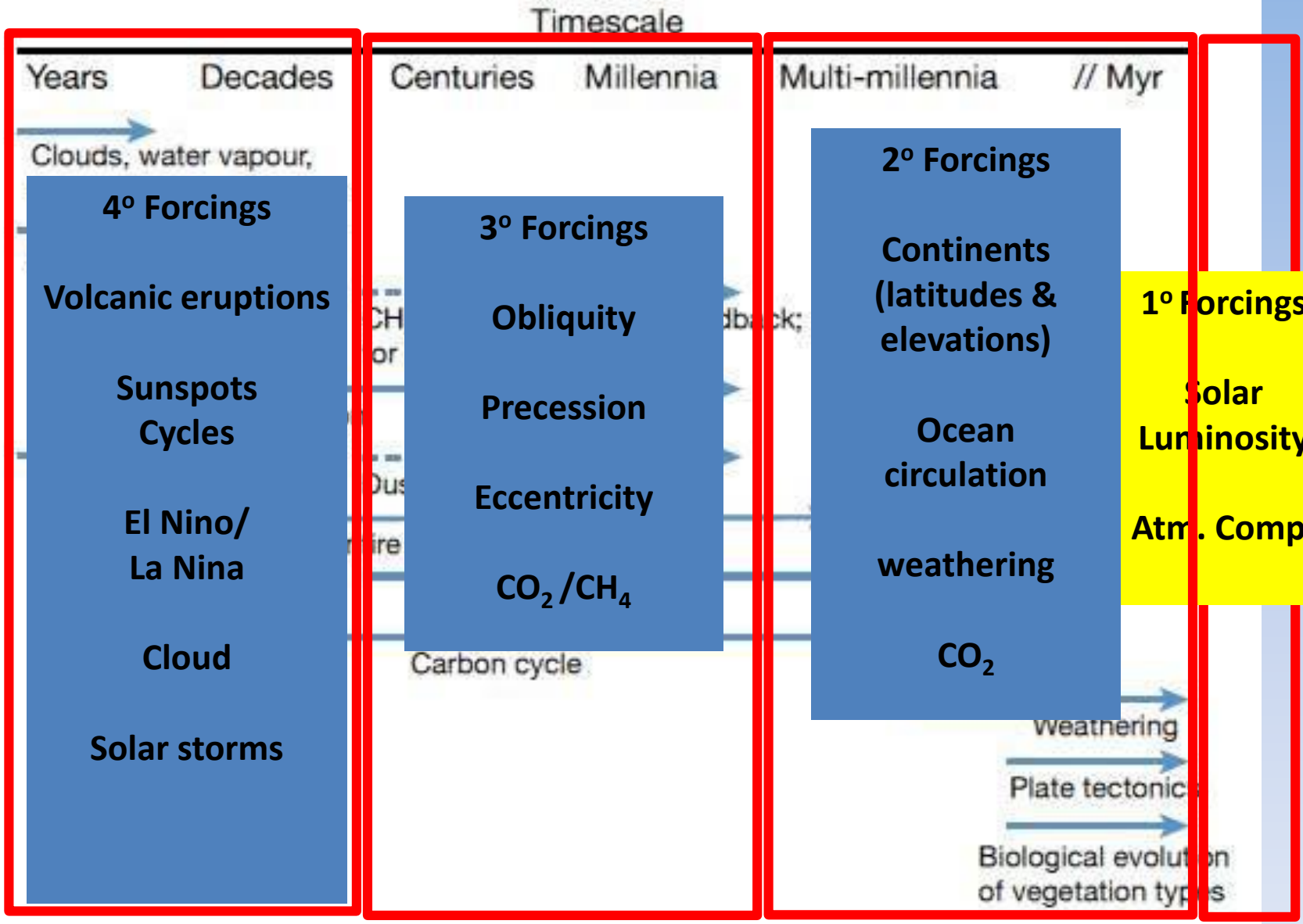
Just a few years



MORE IMPACT LESS

al., 2001

FEEDBACKS



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

Earth's past climate – CO_2 Levels

1. 4,500 to 600 million years: Earth's deep past before the Cambrian (600 MaBP): hot and cold
2. 600 million to 65 million years : mostly hot-house Earth; 100s parts per million (ppm)
3. 65 to 1 million years: Climate trend in the Cenozoic – the last 65 million years; proxy data from 3600ppm to <200 ppm.
4. Last Million years: 180-280 ppm; how do we know – empirical data – ice core data
5. Today (last 100 years): 40% increase to 412 ppm and growing

Earth's past climate 1 of 2

Earth's deep past hot and cold

- Scientific American article – see your email

- 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/
- 3-4 minutes each

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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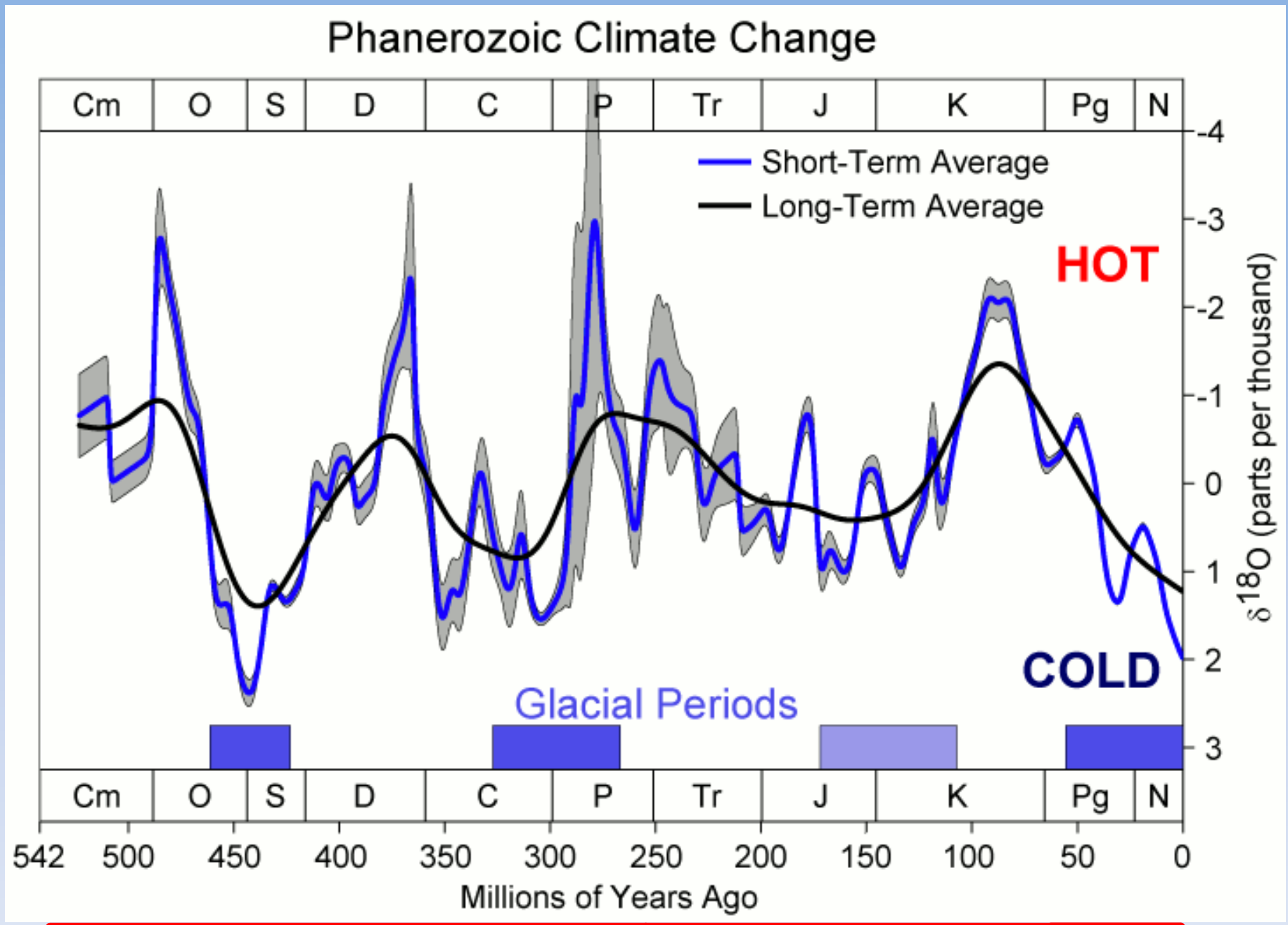
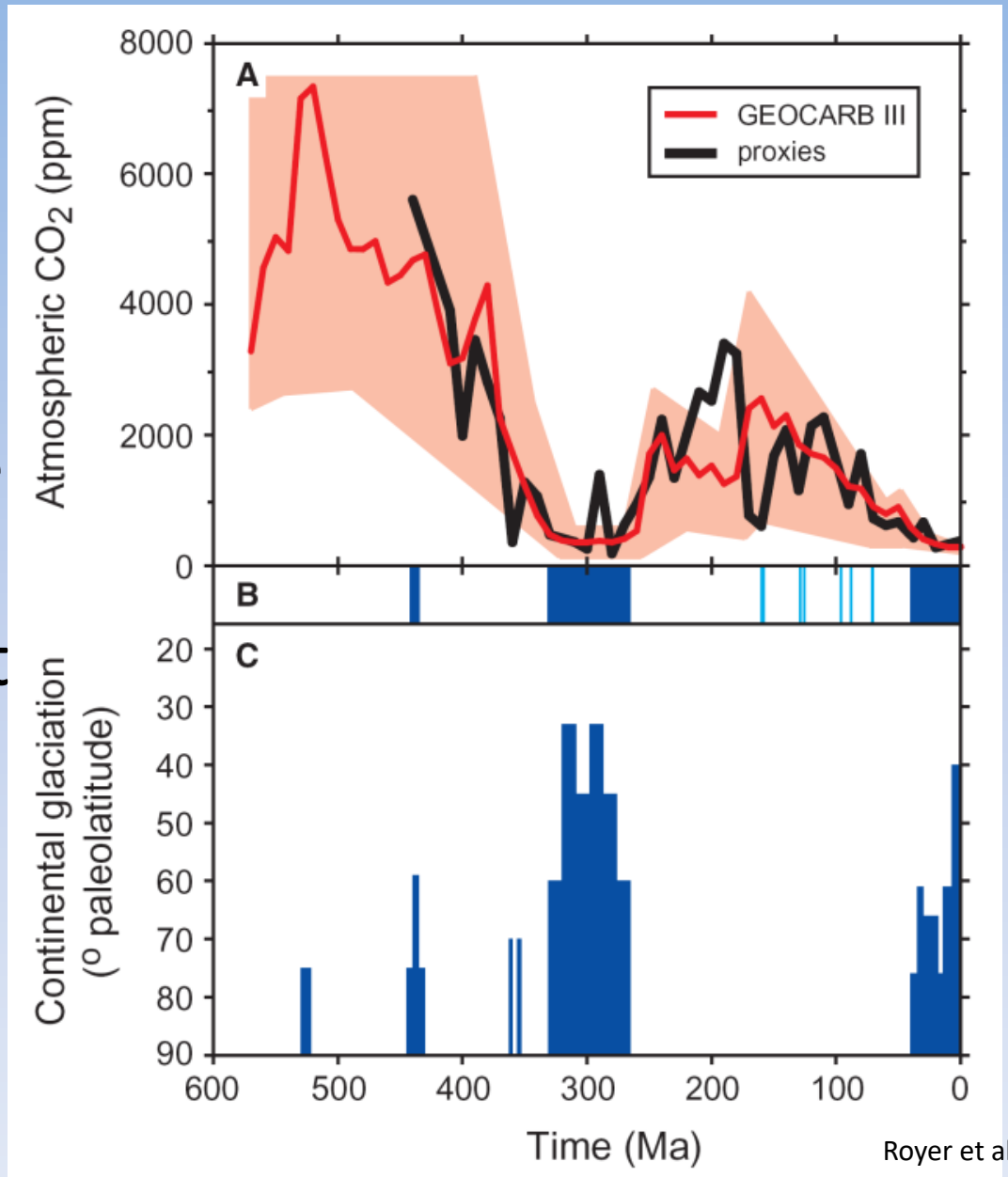


PALEOZOIC	MESOZOIC	CENOZ.

Alternating Greenhouse Earth / Ice-house Earth

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



Royer et al., 2003

Earth's past climate – CO_2 Levels

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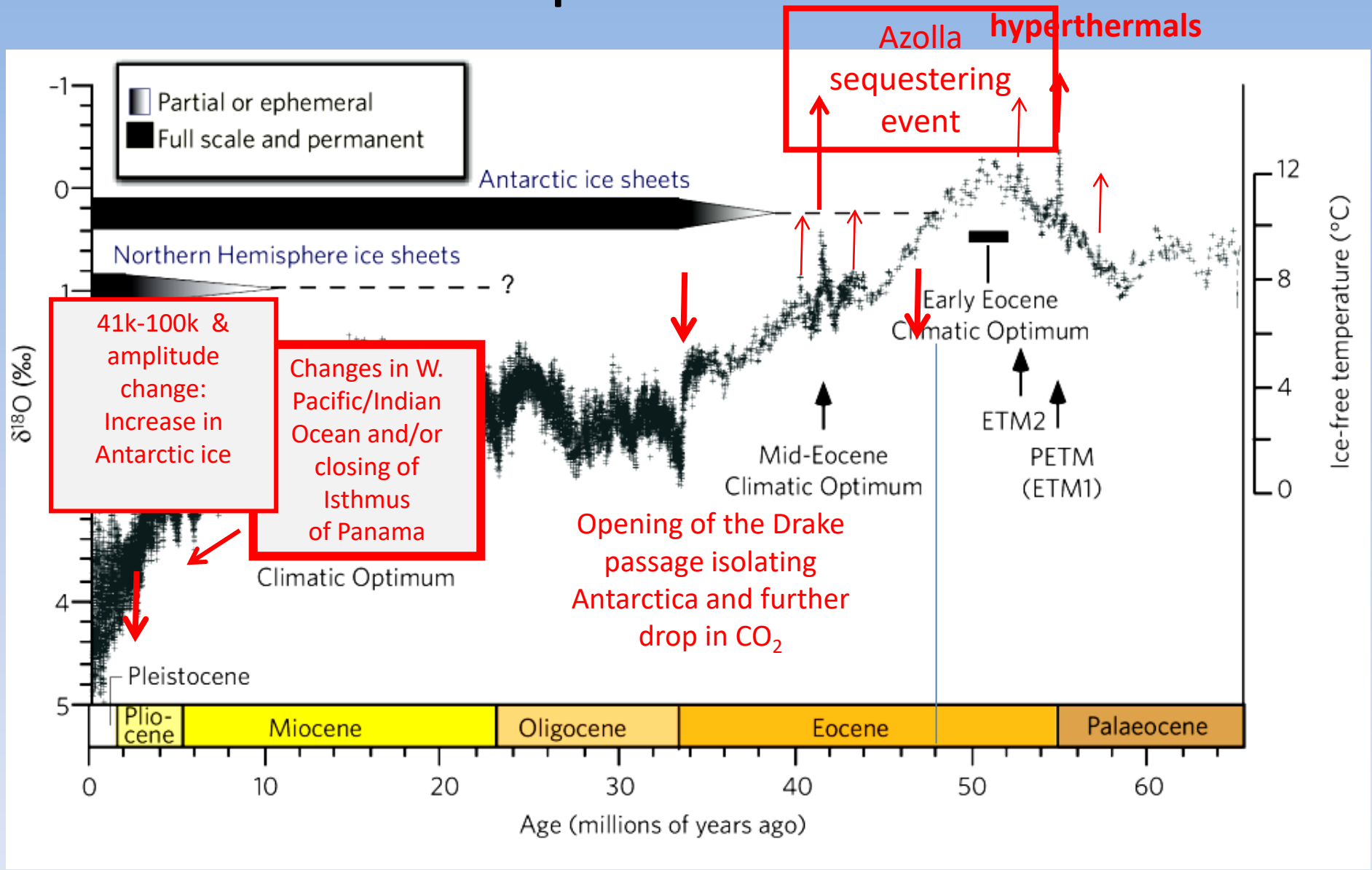
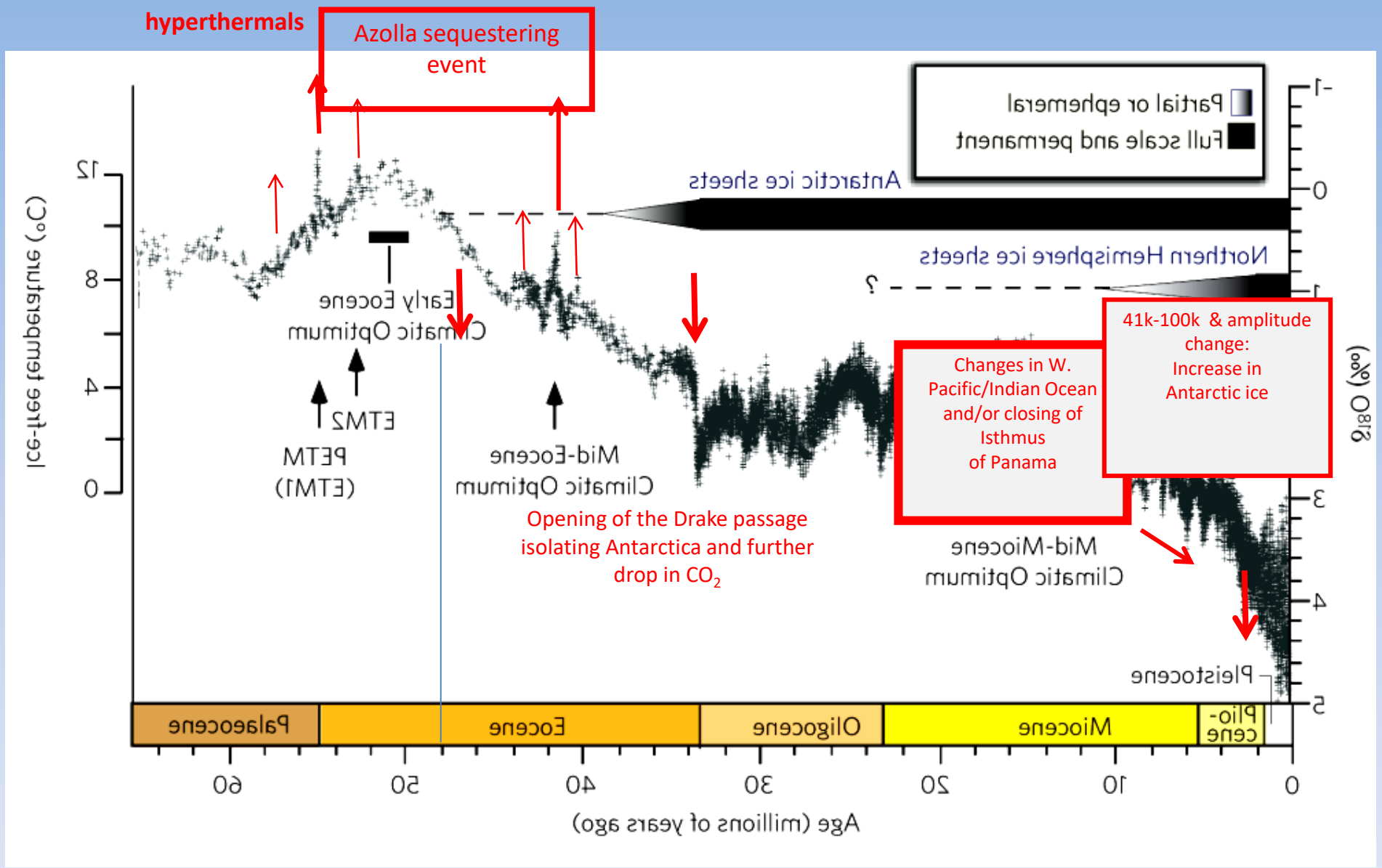
Cenozoic Deep Sea Climate Record



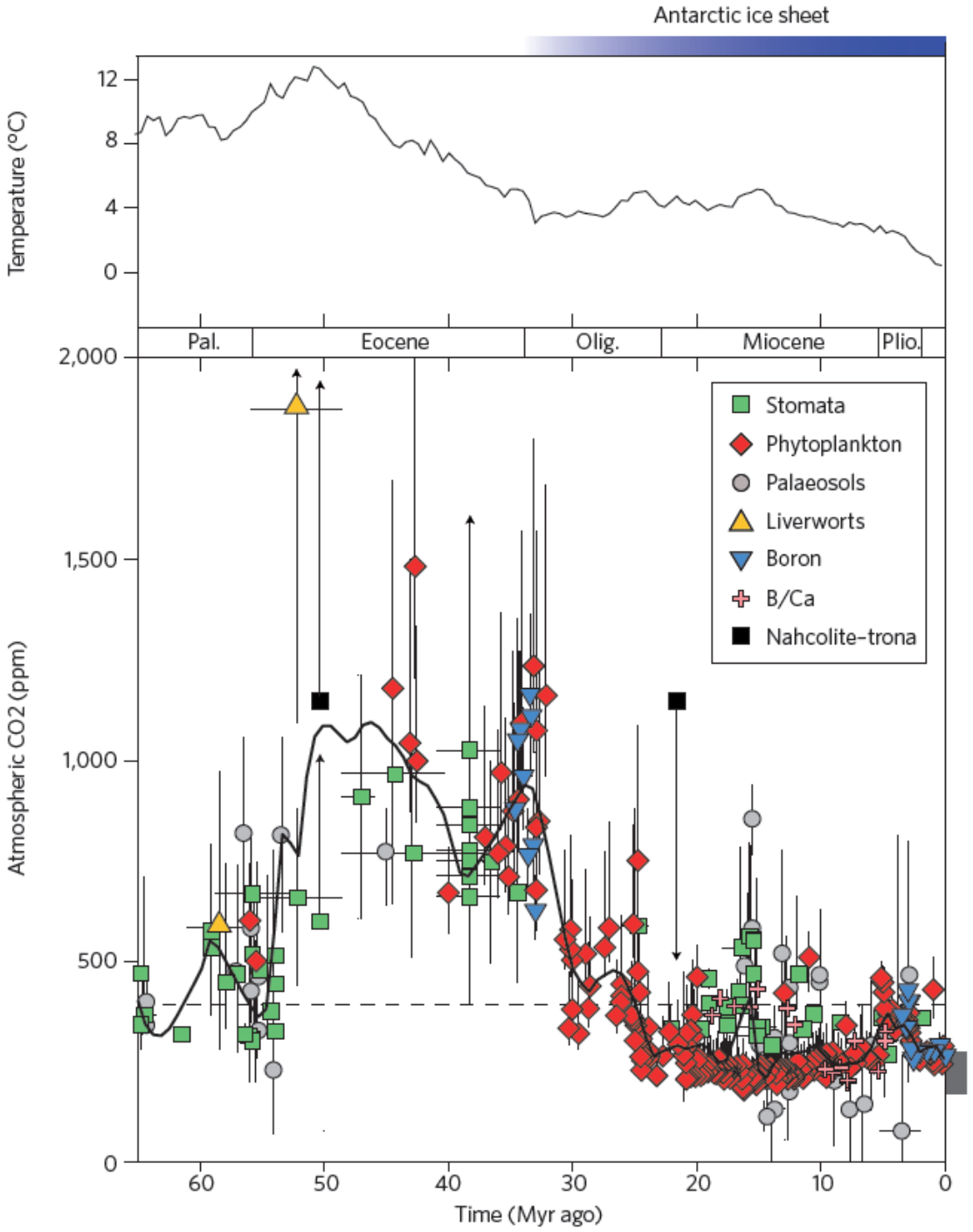
Zachos et al. 2008

Cenozoic Deep Sea Climate Record

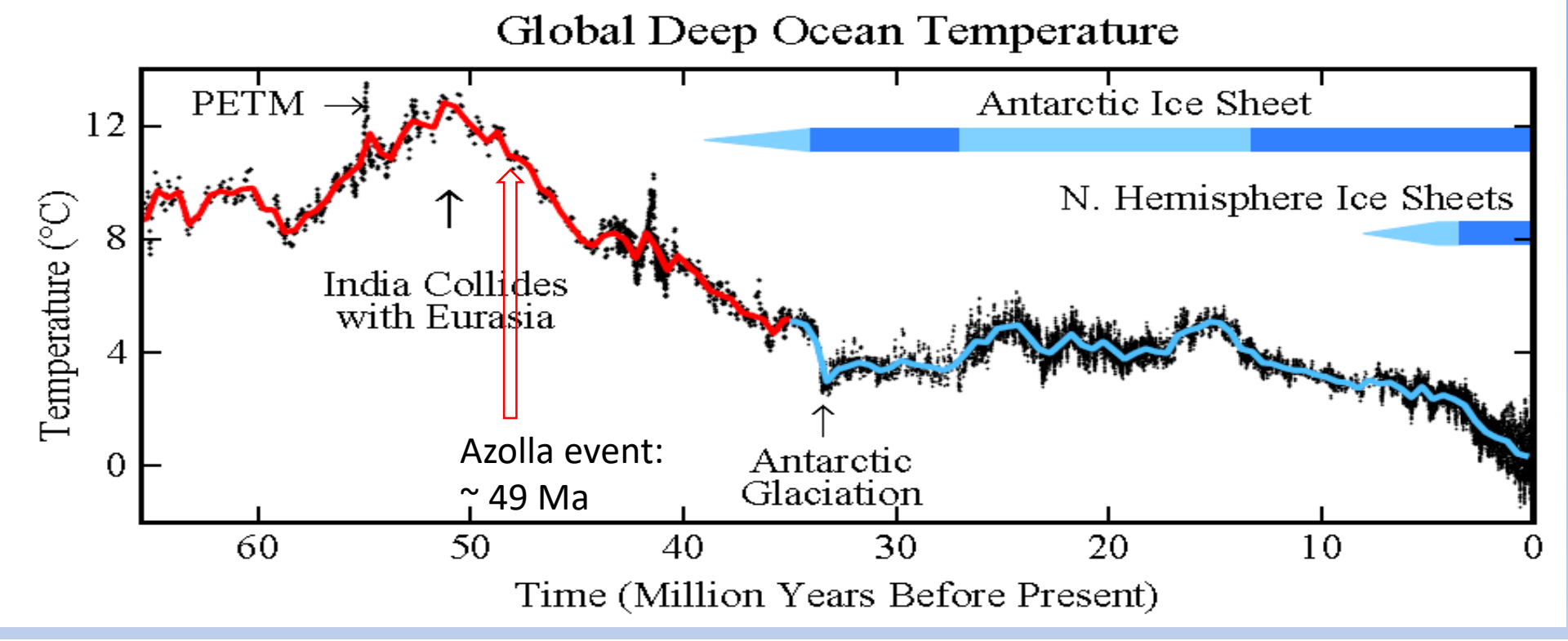


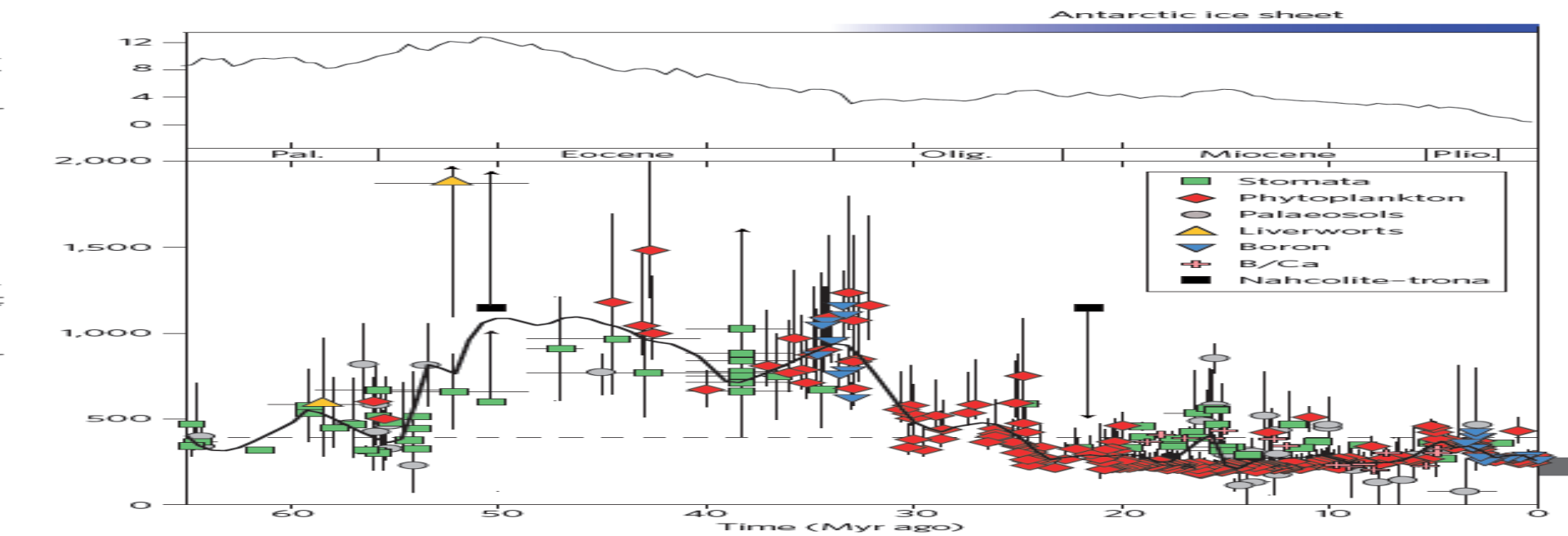
Zachos et al. 2008

Correlation of CO_2 and temperature over last 65 million years

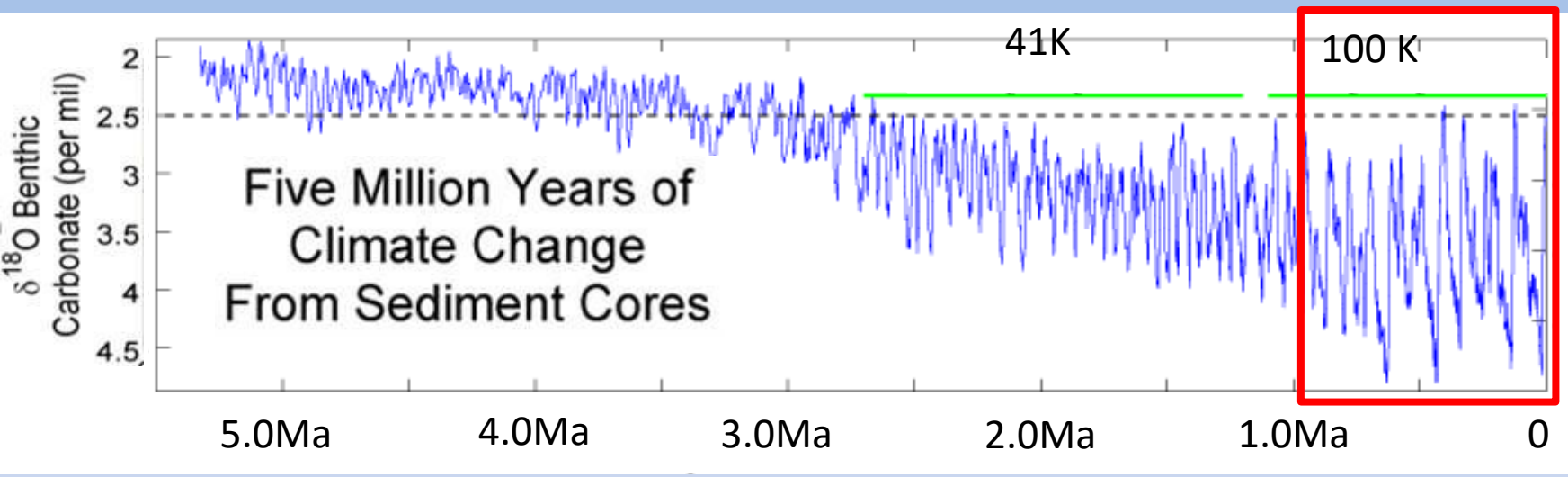


Beerling and Royer, Nature 2011

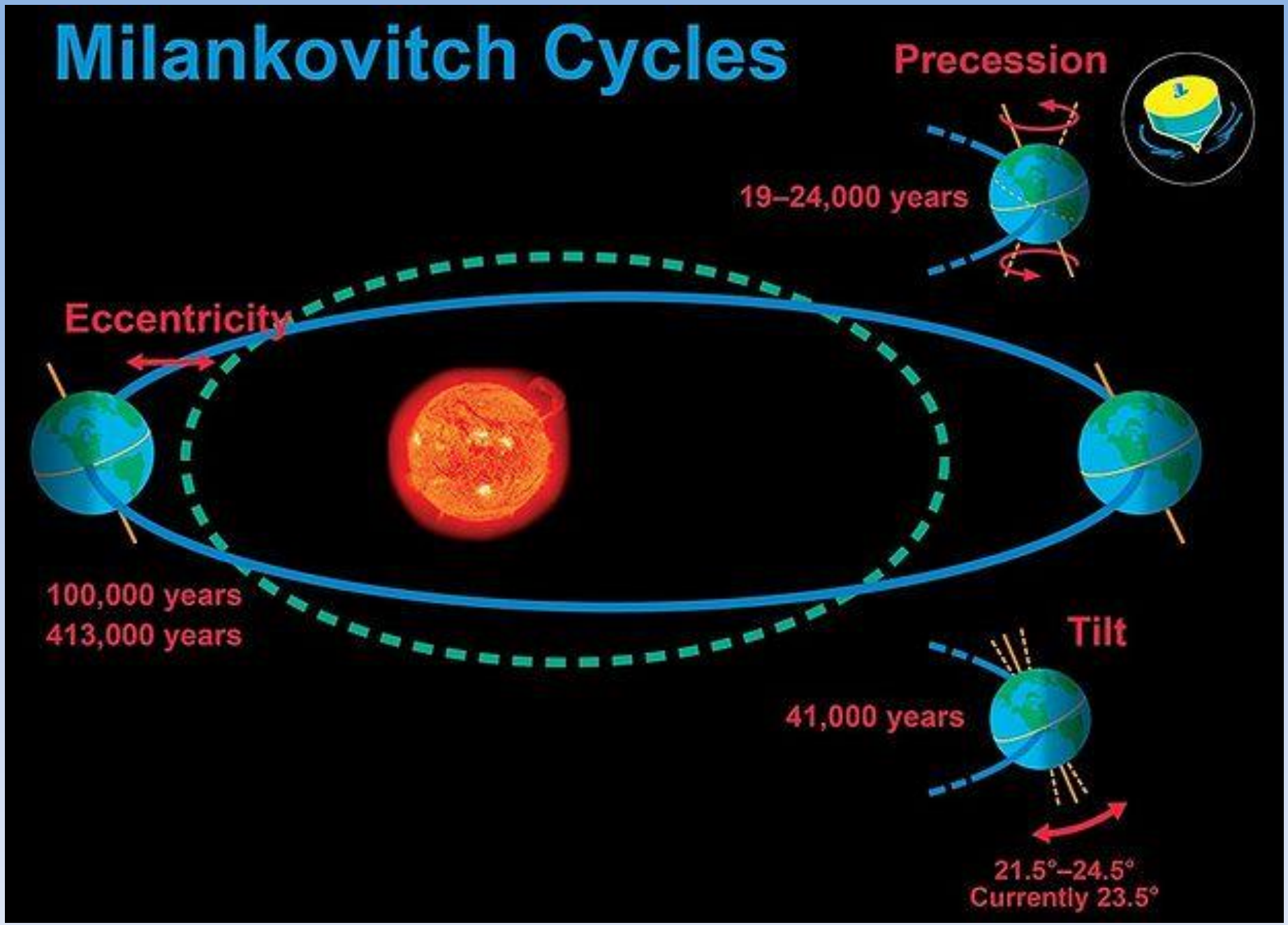

Global Deep Ocean Temperature
PETM
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Azolla event:
~ 49 Ma
Antarctic Glaciation
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (Million Years Before Present)


Antarctic ice sheet
12
8
4
0
Pal.
Eocene
Olig.
Miocene
Plio.
2,000
1,500
1,000
500
0
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

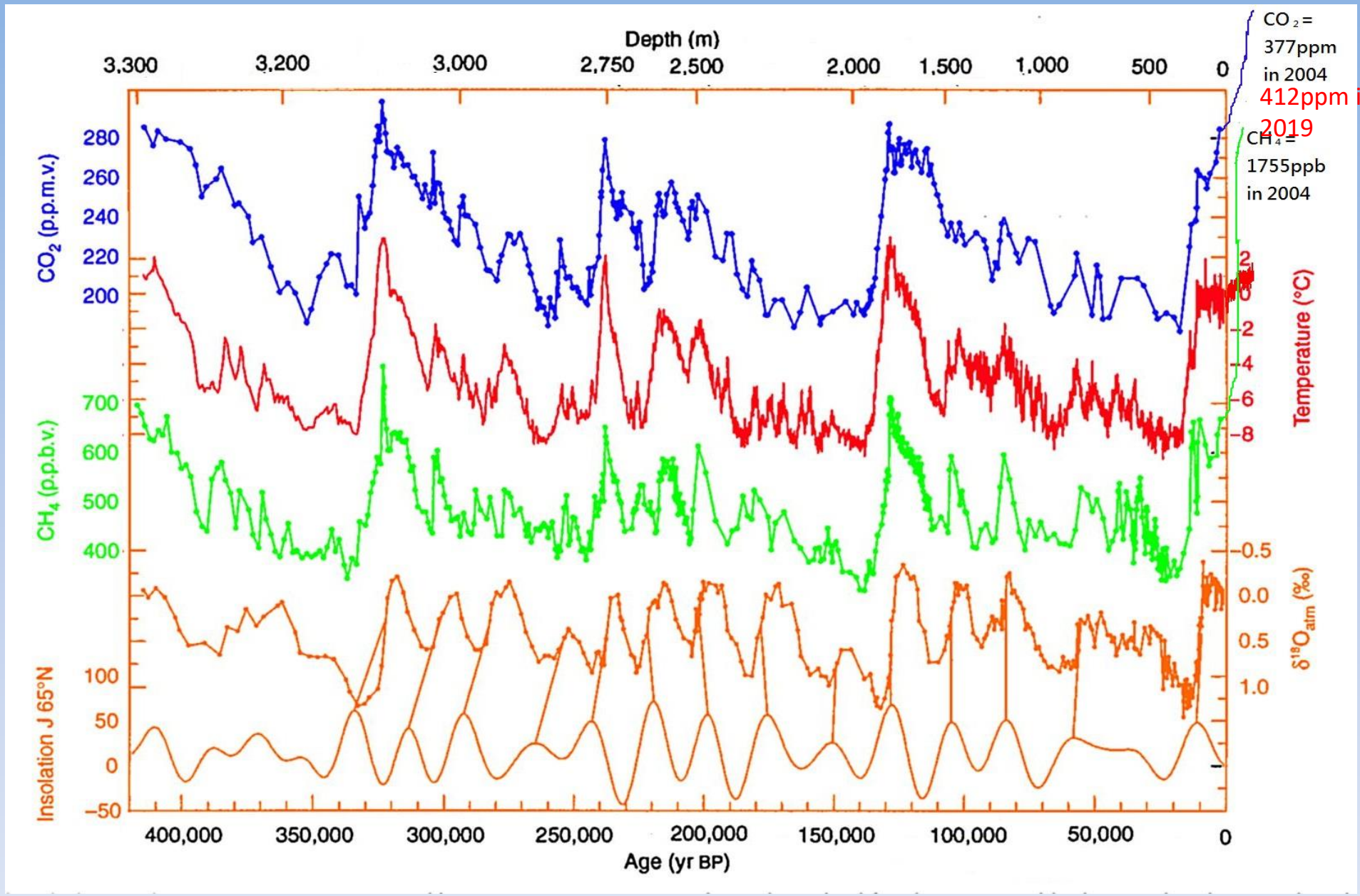
Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



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

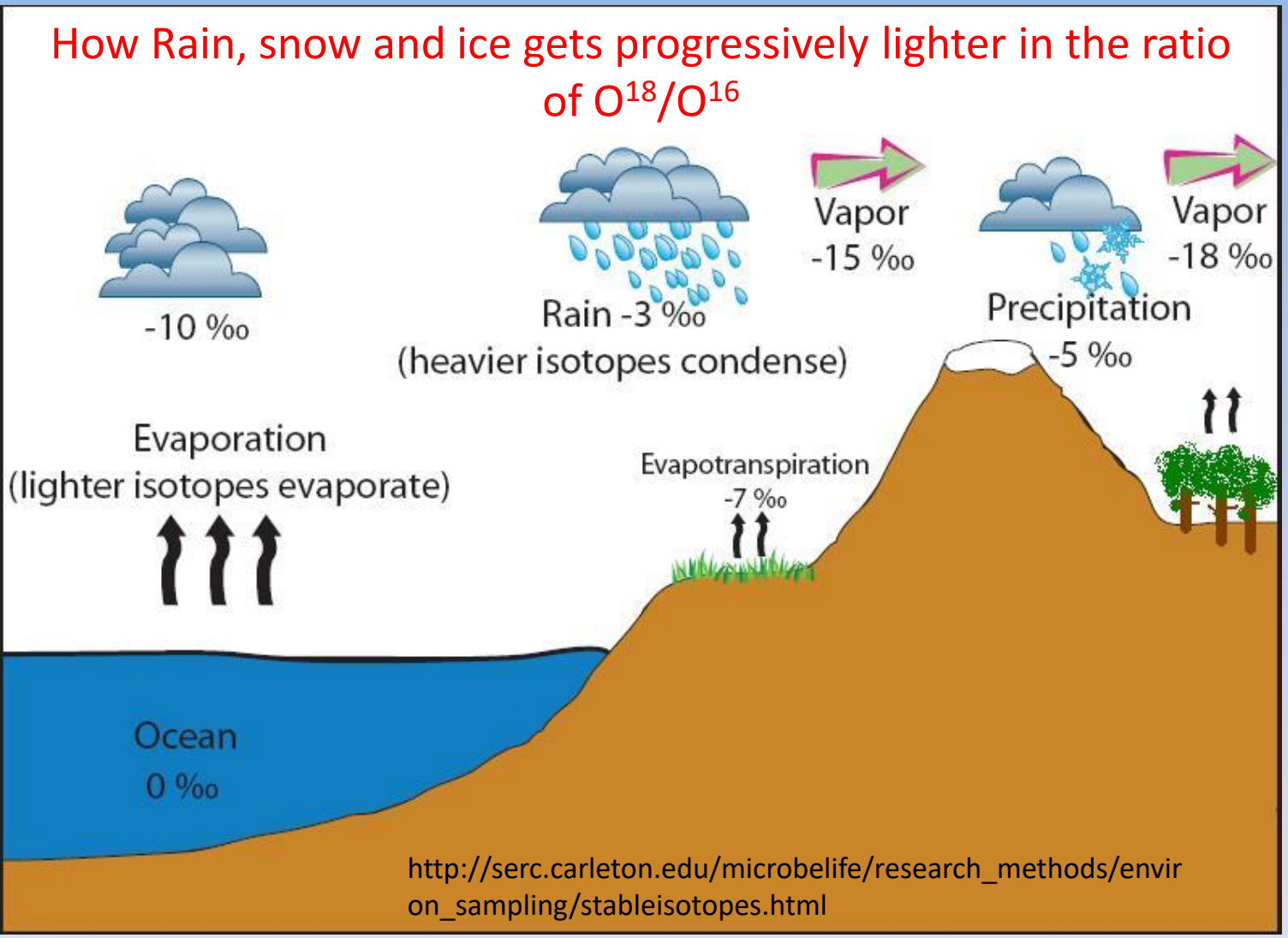


http://cnx.org/content/m38572/1.5/



http://www.antarcticglaciers.org/climate-change/

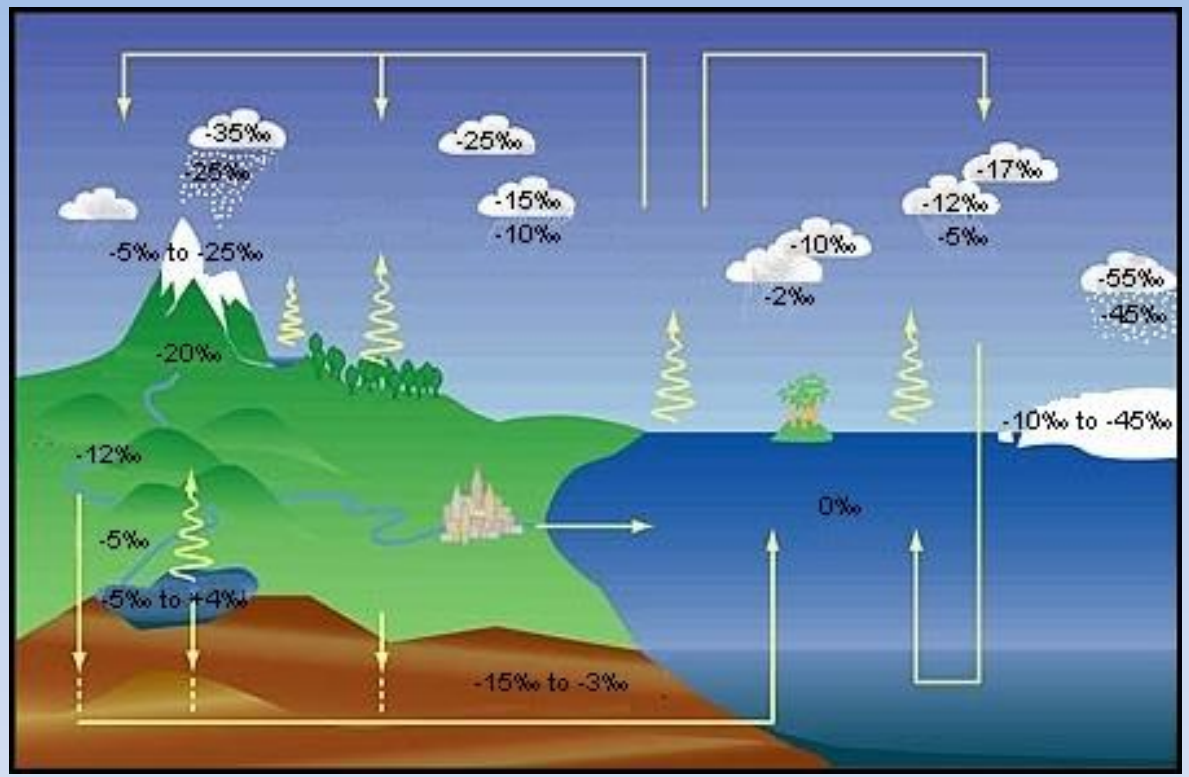
How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



http://serc.carleton.edu/microbelife/research_methods/environ_sampling/stableisotopes.html

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}

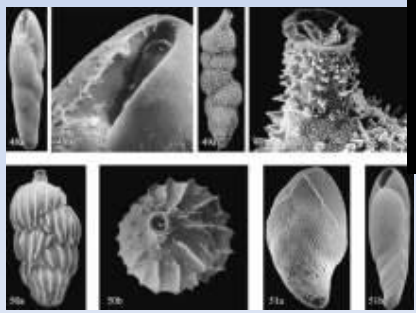


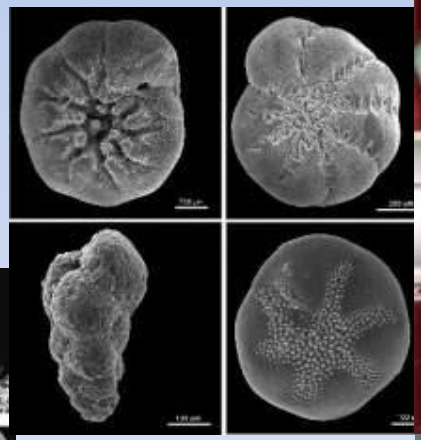
http://atoc.colorado.edu/~dcn/SWING/overview.php

Earth's past climate – CO_2 Levels

1. 4,500 to 600 million years: Earth's deep past before the Cambrian (600 MaBP): hot and cold
2. 600 million to 65 million years : mostly hot-house Earth; 100s parts per million (ppm)
3. 65 to 1 million years: Climate trend in the Cenozoic – the last 65 million years; proxy data from 3600ppm to <200 ppm.
4. Last Million years: 180-280 ppm; how do we know – empirical data – ice core data
5. Today (last 100 years): 40% increase to 412 ppm and growing

Scientific History of Climate change – PROXY DATA





Long-term Carbon Cycle: rocks

Two generalized reactions…

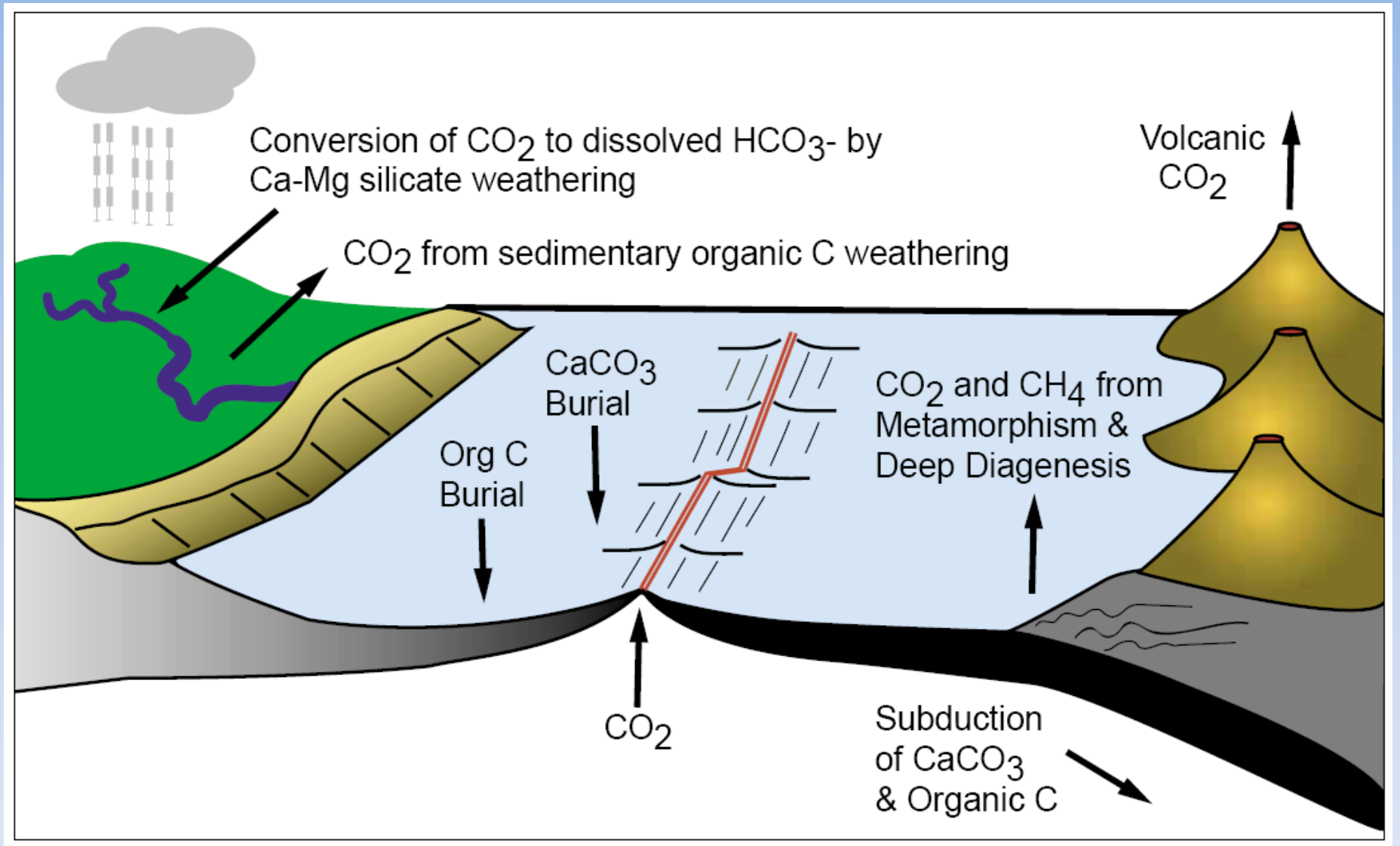
Photosynthesis/Respiration

$$CO_2 + H_20 \leftrightarrow CH_2O + O_2$$

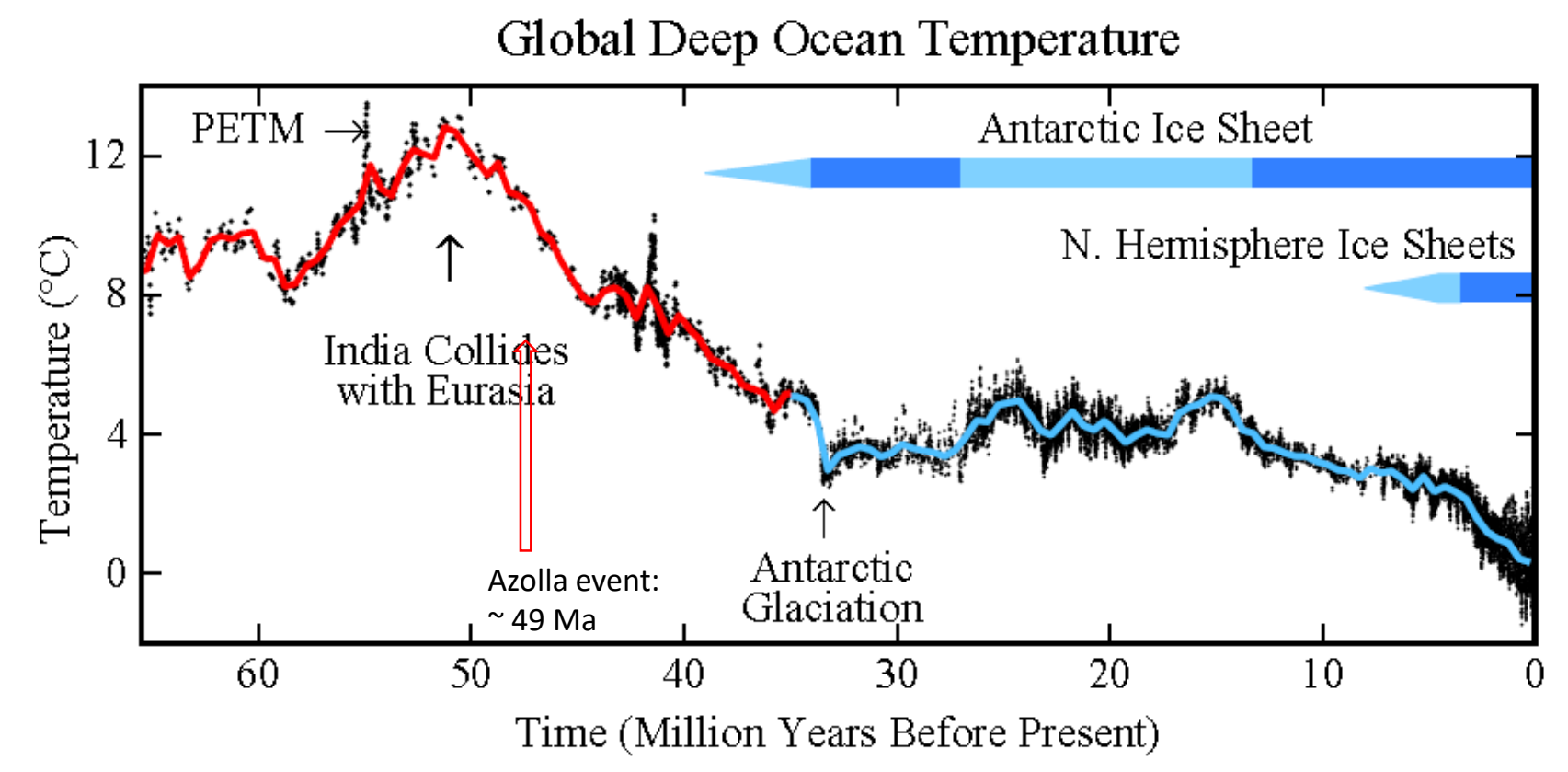
Weathering/Precipitation

$$CO_2 + CaSiO_3 \leftrightarrow CaCO_3 + SiO_2$$

Long-term carbon cycle: *rocks*



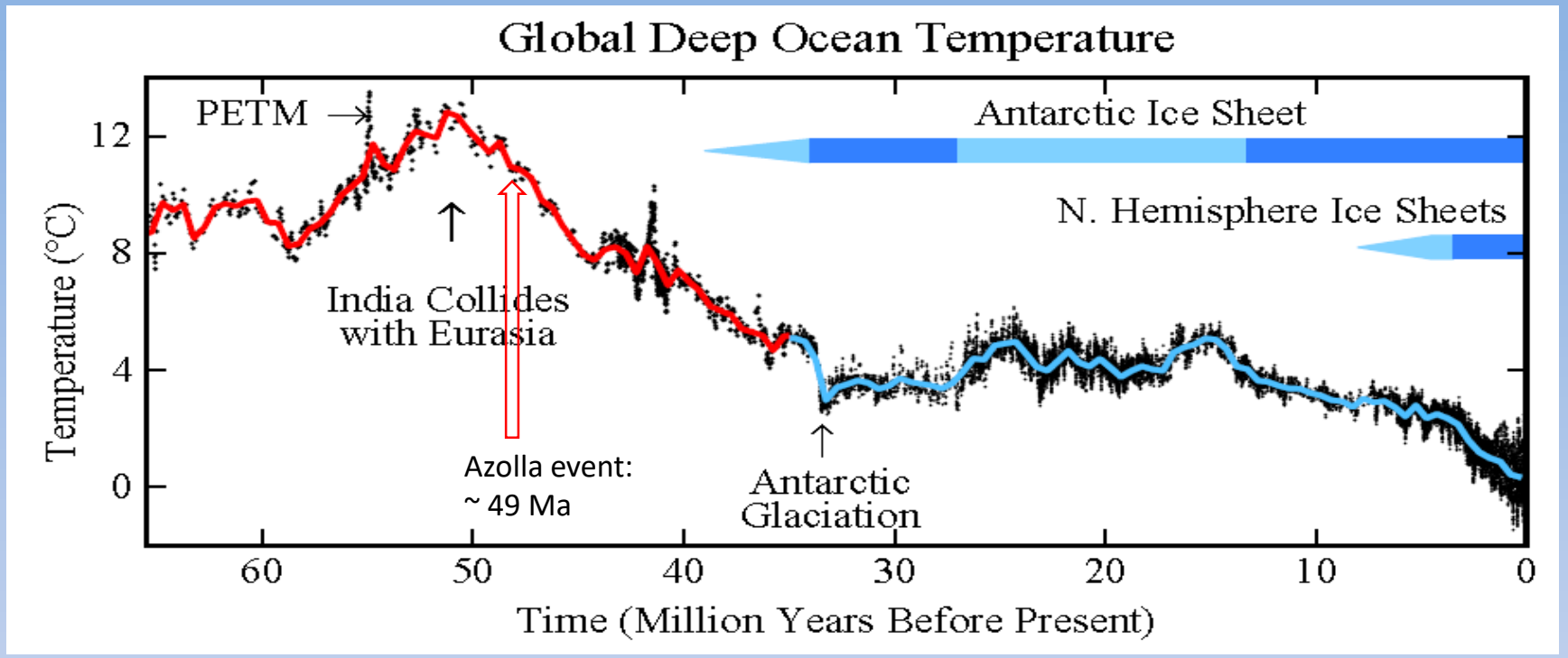
Berner, 2001

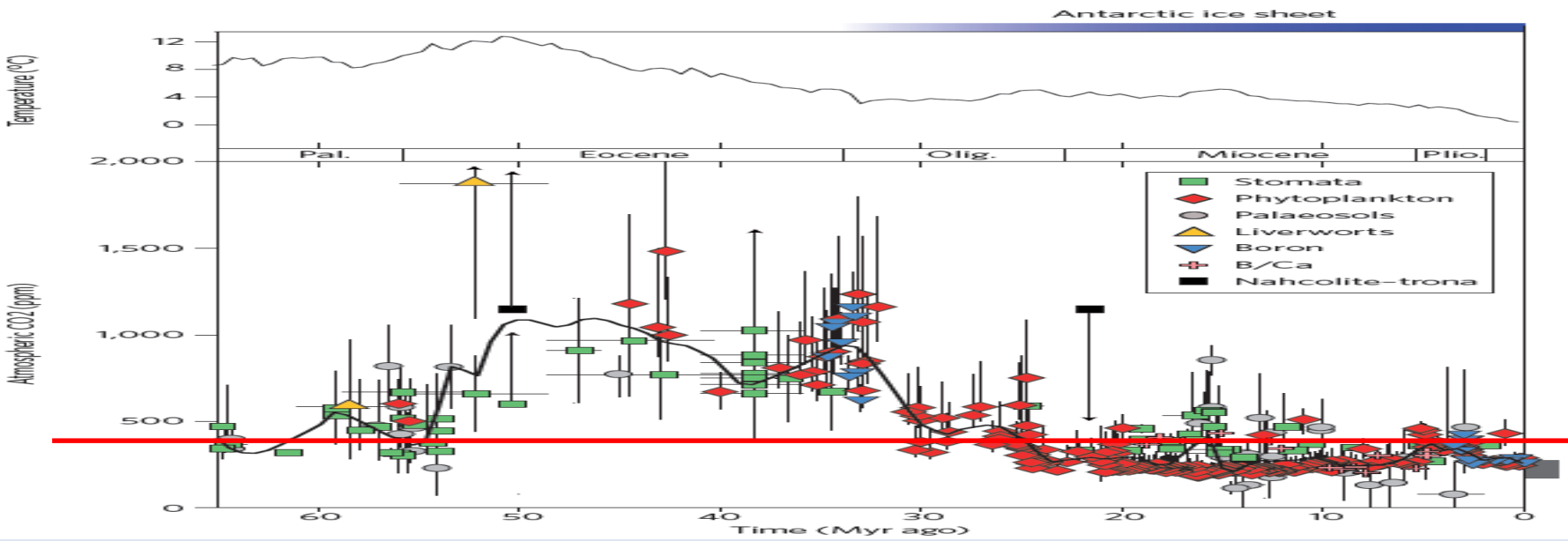


50 million years ago (50 MYA) Earth was ice-free.

Atmospheric CO_2 amount was of the order of 1000 ppm 50 MYA.

Atmospheric CO_2 imbalance due to plate tectonics ~ 10^{-4} ppm per year.


Global Deep Ocean Temperature
PETM
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Azolla event: ~ 49 Ma
Antarctic Glaciation
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (Million Years Before Present)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2,000
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Atmospheric CO2 (ppm)
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

So – what changed?

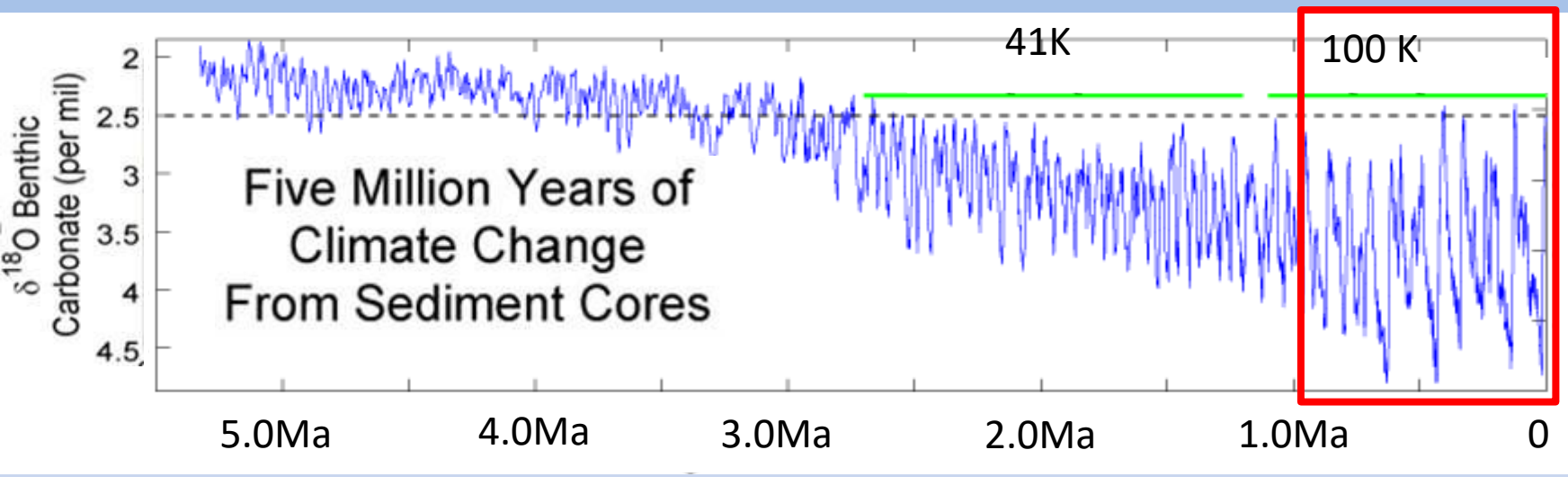
Volcanism decreased; some slowing of spreading rates: less CO_2 emitted by volcanoes

Weathering/Precipitation increased; India colliding into Asia/Himalayans

Earth's past climate

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: 412 ppm and growing

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



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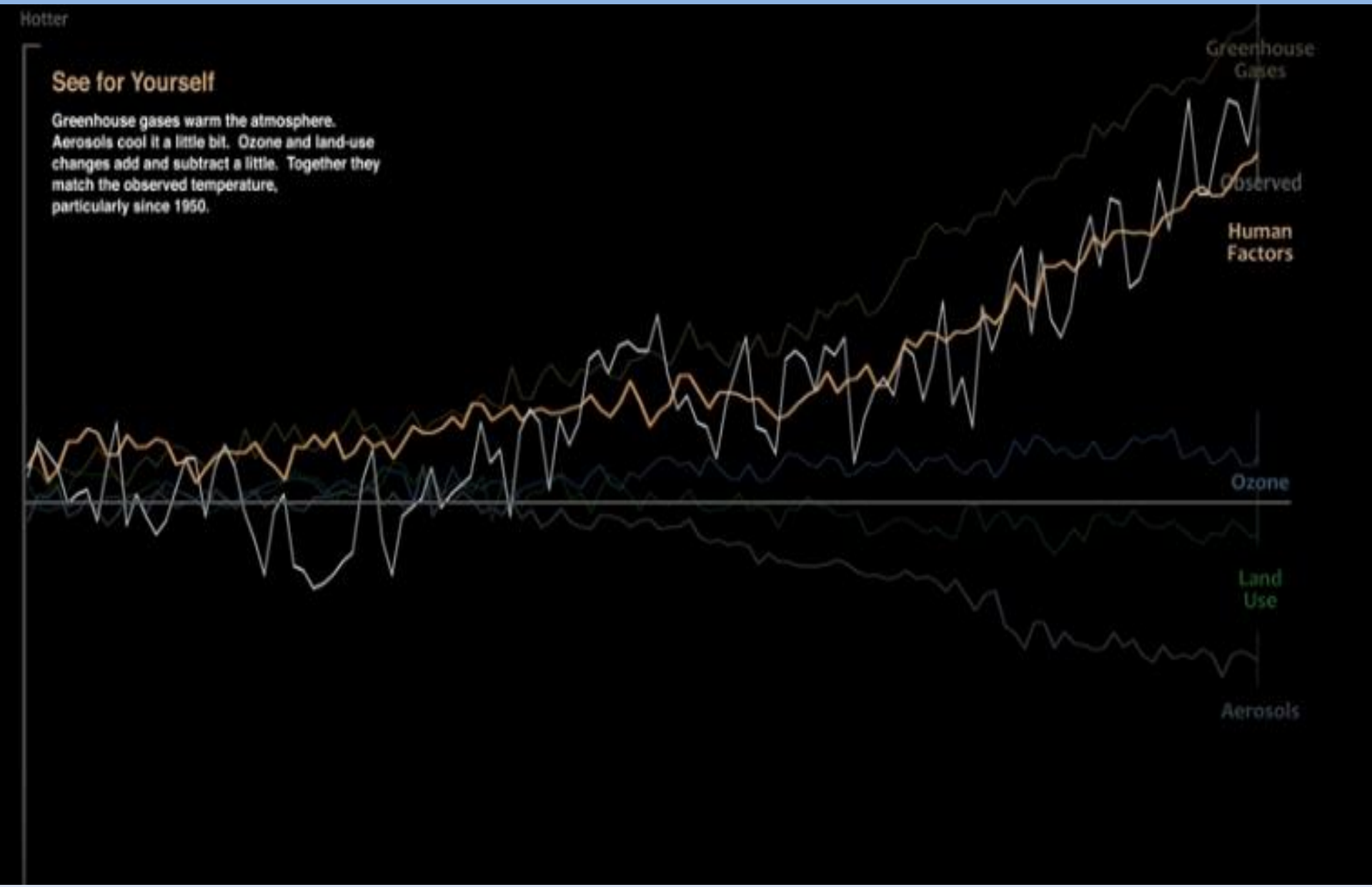
5. **Today: 412 in 2019 ppm and growing**

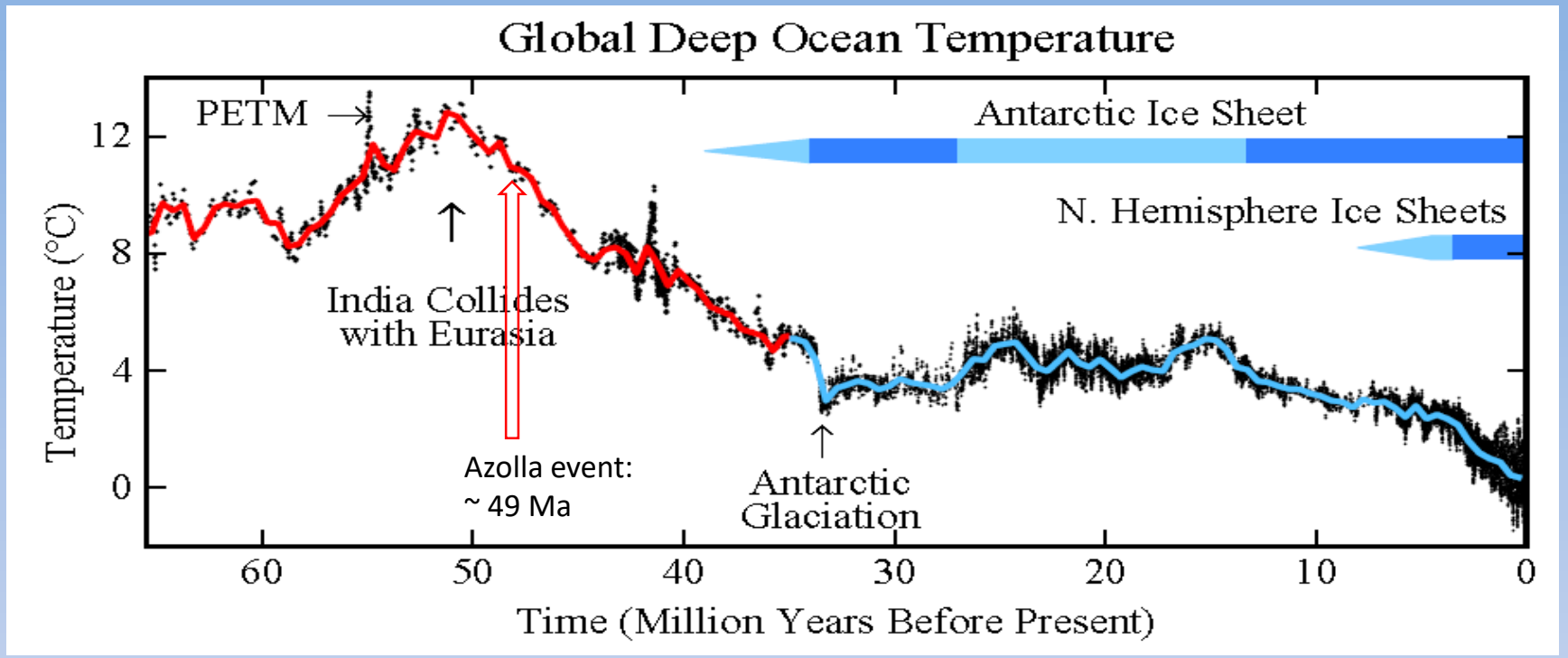
LINKS

- 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 on next page: 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.
Greenhouse Gases
Observed
Human Factors
Ozone
Land Use
Aerosols

End of week 2
EXTRAS FOLLOW

Paleocene/Eocene Thermal Maximum
PETM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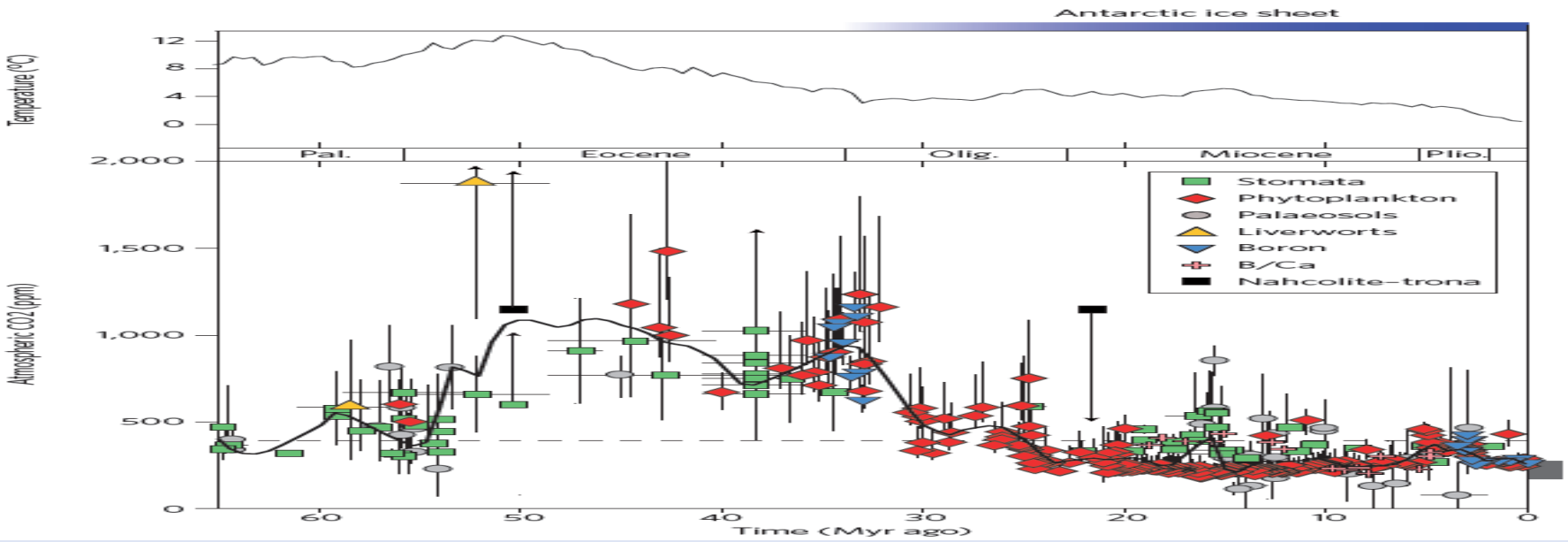
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Temperature (°C)
12
8
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Pal.
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Atmospheric CO2 (ppm)
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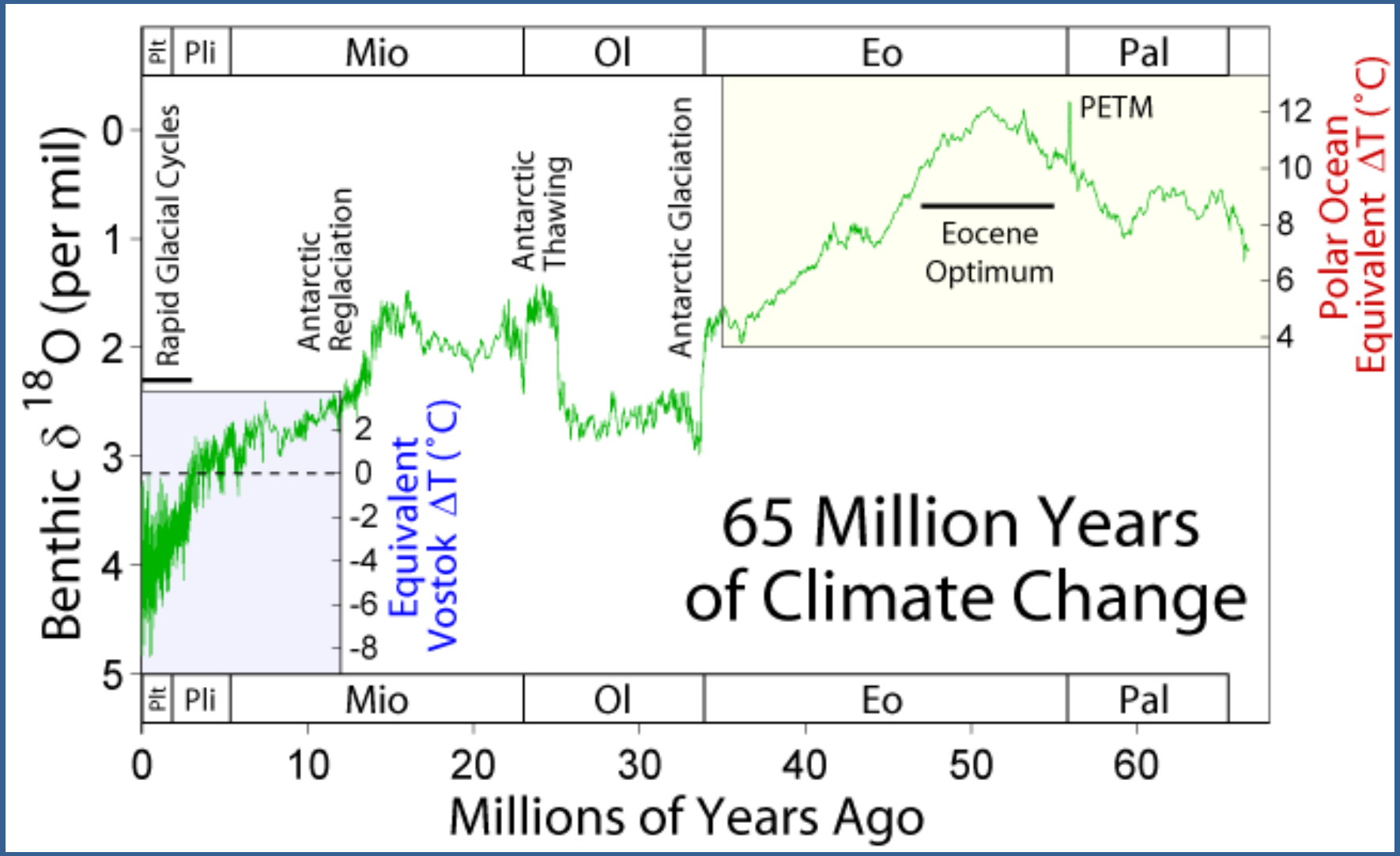
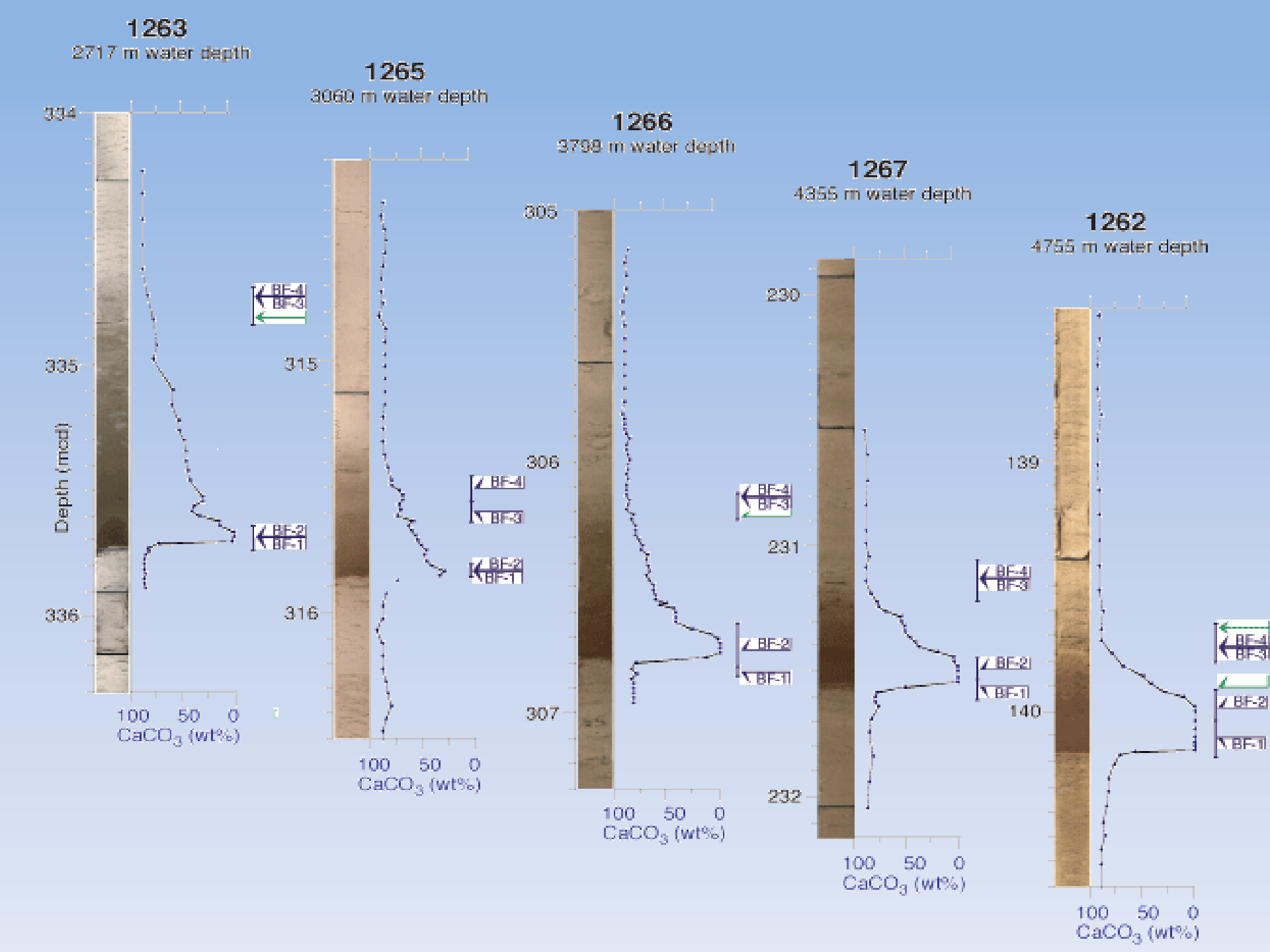
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

Proxy data: stable isotopes



Wikipedia


4 45 46 47 48 49 50 51 52
PMAG
4 55 56 5


1263
2717 m water depth
334
335
336
Depth (mcd)
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)
1265
3060 m water depth
315
316
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)
1266
3798 m water depth
305
306
307
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)
1267
4355 m water depth
230
231
232
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)
1262
4755 m water depth
139
140
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)

PETM - THE LAND RECORD

Bighorn Basin

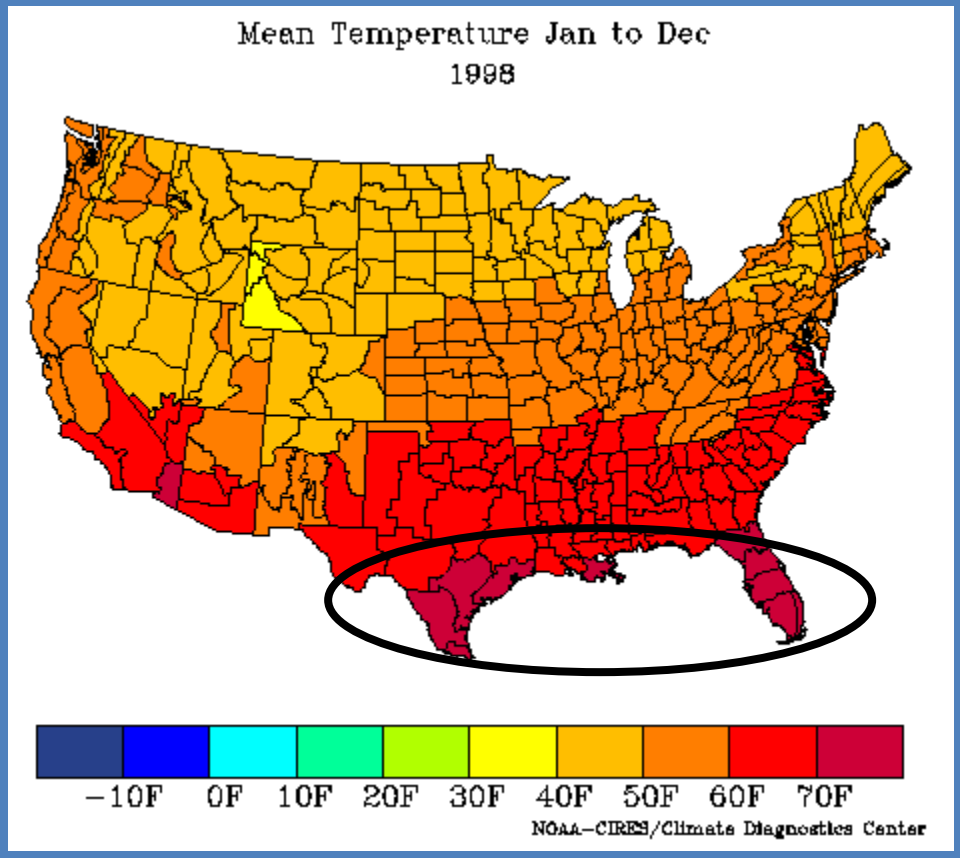
- PETM interval in fluvial deposits with excellent alluvial paleosols - seen as color bands, which are soil horizons
- Found in Willwood Fm
- Reds, purples due to iron oxides in B horizons

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

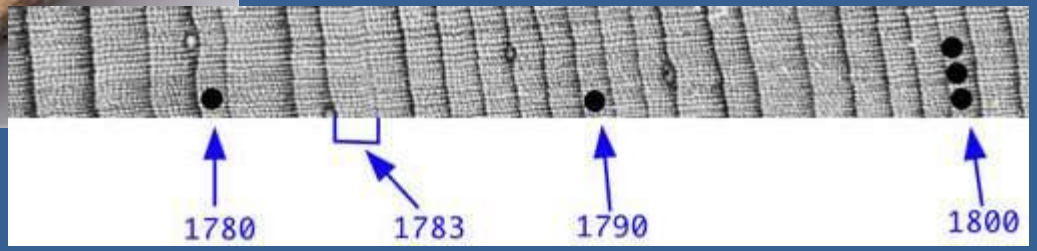
Born	May 28, 1807 Haut-Vully, Switzerland
Died	December 14, 1873 (aged 66) Cambridge, Massachusetts
Fields	Paleontology, Glaciology, Geology, Natural History
Alma mater	University of Erlangen-Nuremberg

- **Jean Louis R. Agassiz**
- **"Father" of Glaciology**
- 1807-1873
- Paleontologist
- Glaciologist

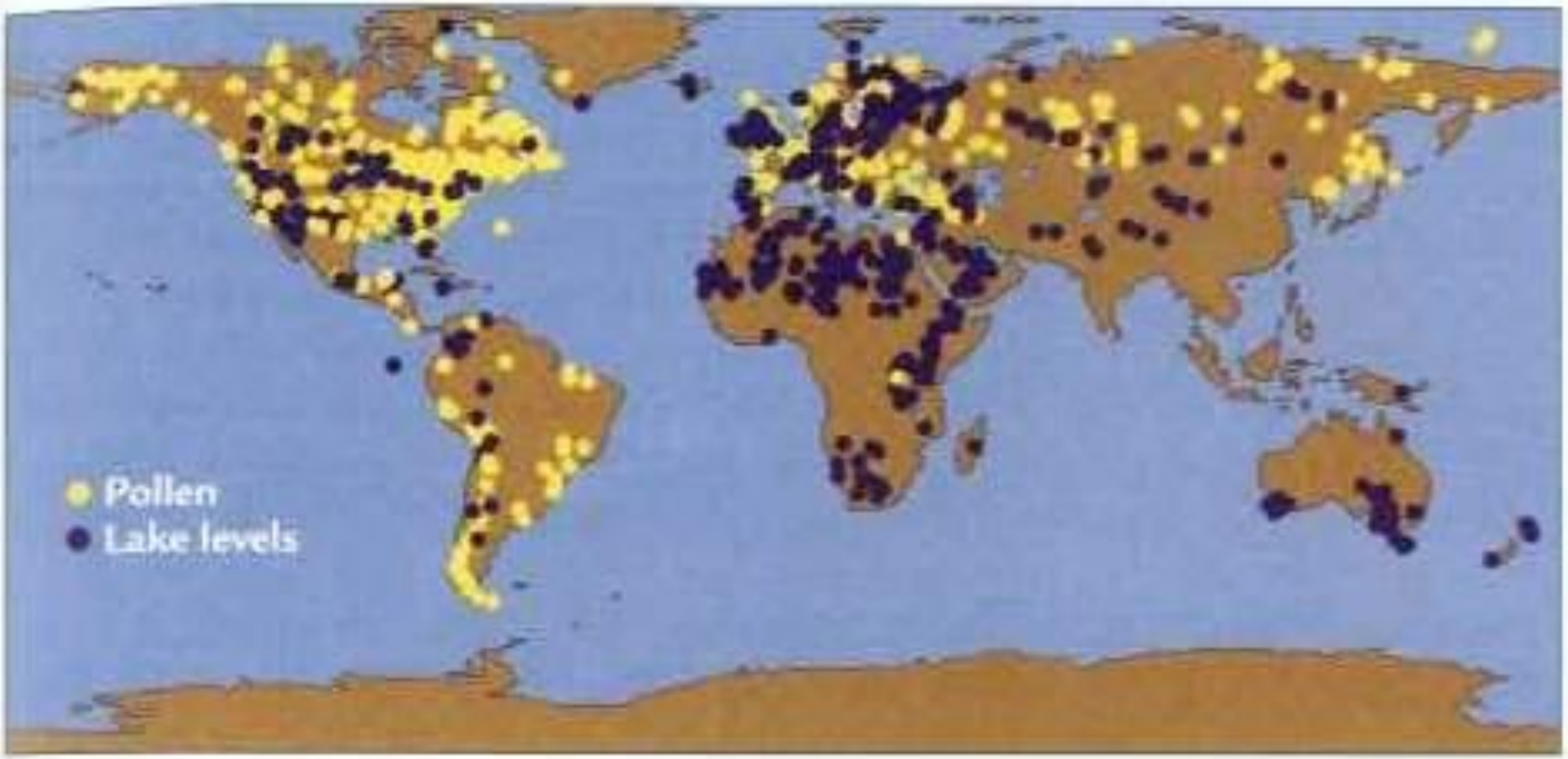
Photographic proxy data/evidence

Ruddiman, 2008

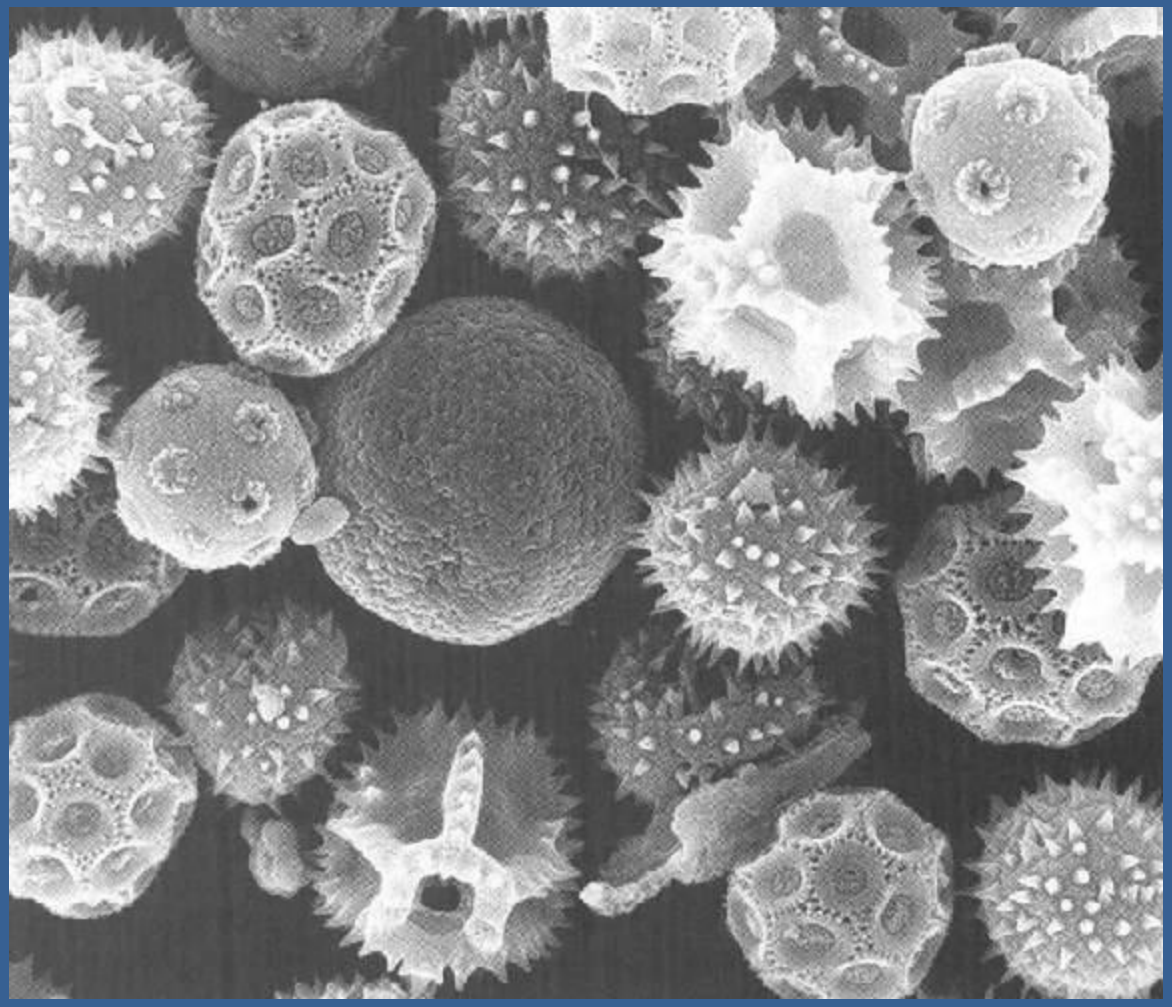
EARLY PROXY DATA: TREE RINGS



Pollen & Lake core data



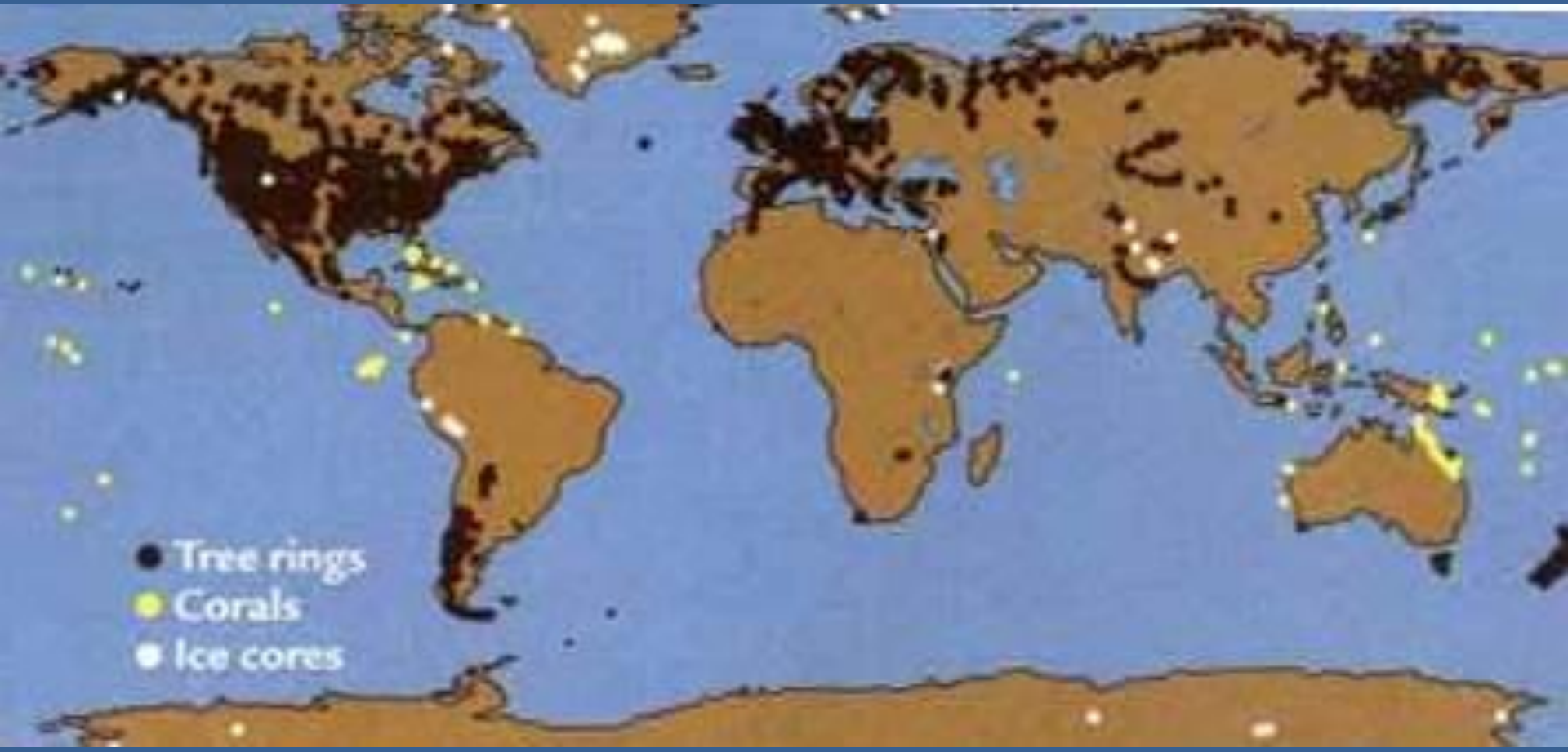
Ruddiman, 2008



PROXY DATA: POLLEN DATA

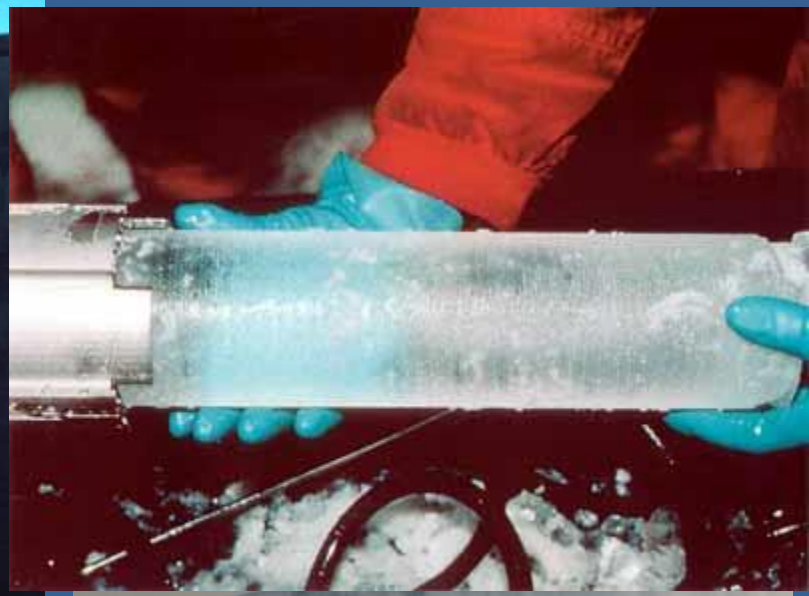
PROXY DATA: LEAVES

Tree rings, corals, ice cores



Ruddiman, 2008

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 Emilani:

Paleontologist, Chemist

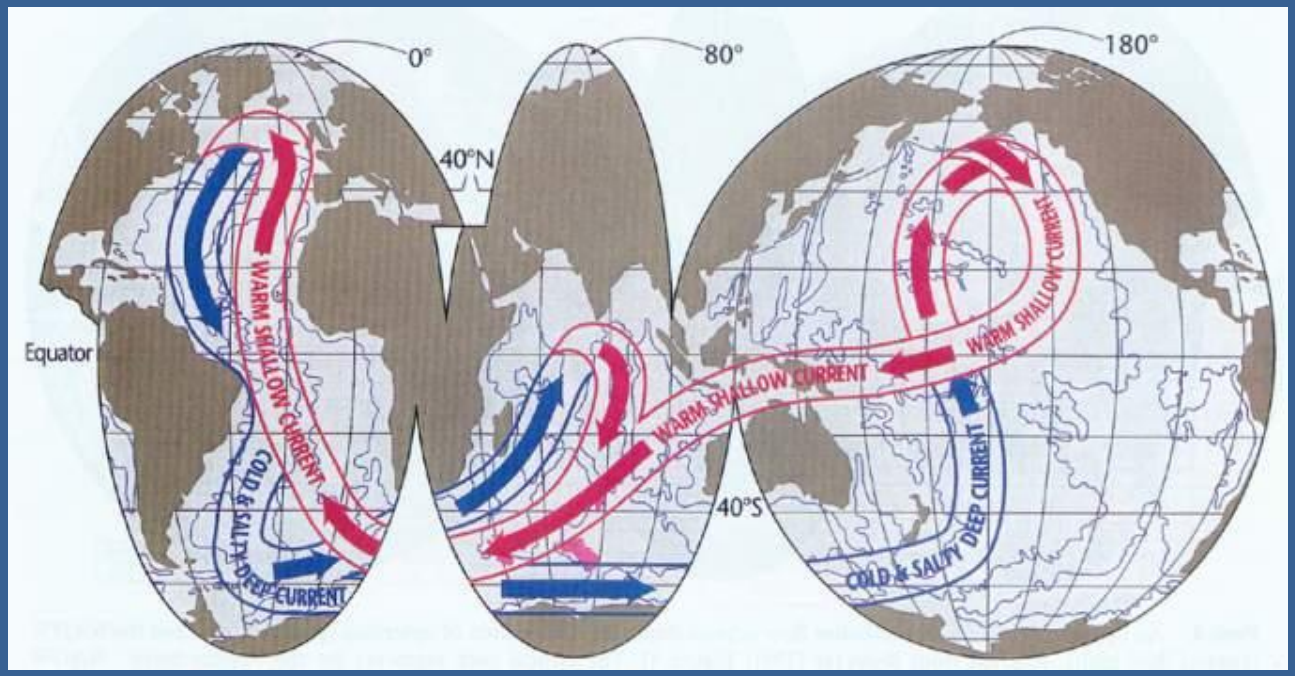
Father of Paleoceanography

Other Paleoceanographers

Wally Broecker

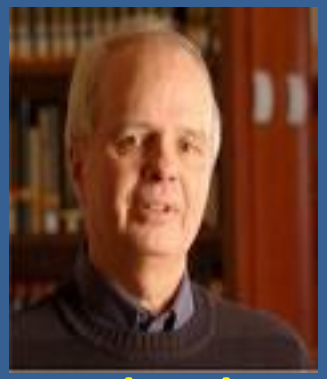
Thermal-haline

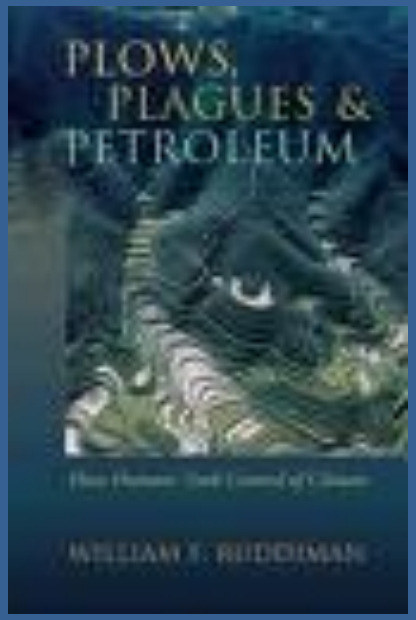
"conveyor" belt of circulation



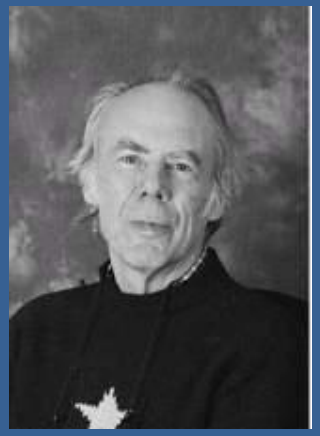
Other Paleoceanographers

Bill Ruddiman



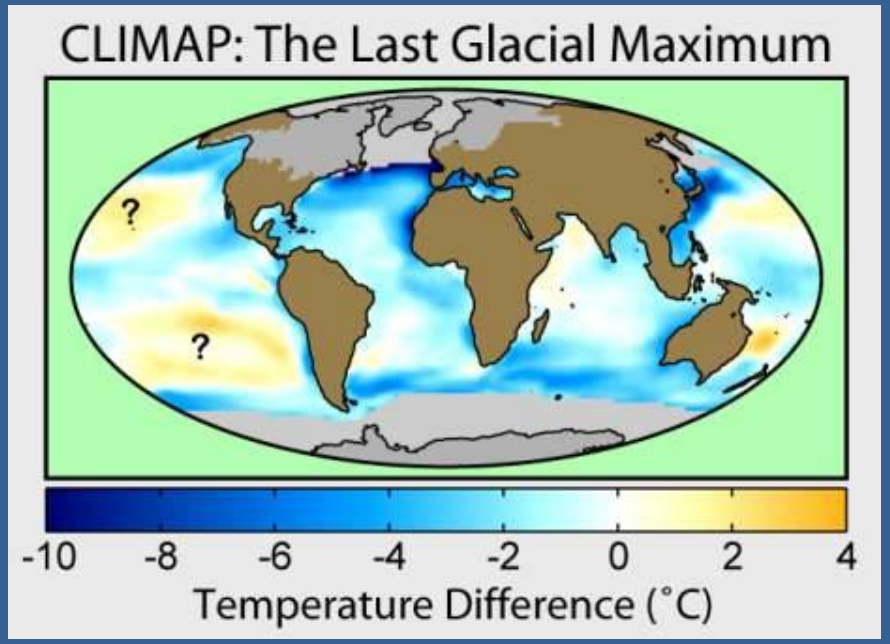


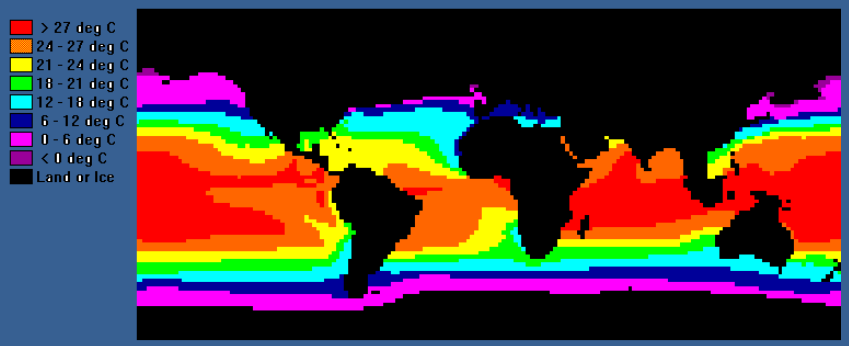
Nick Shackleton

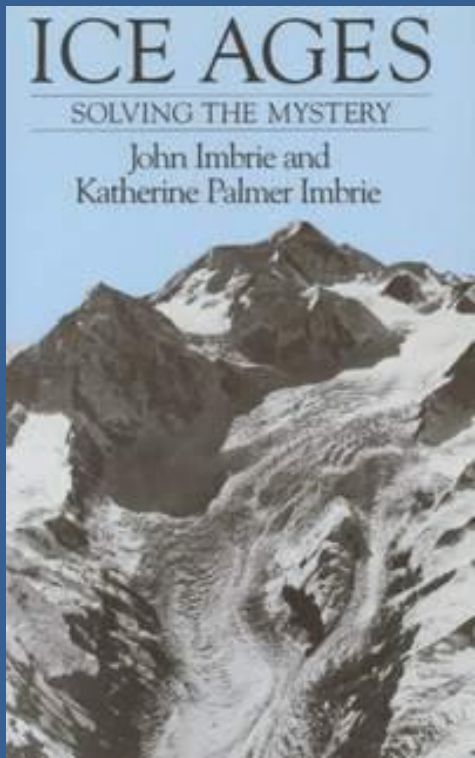


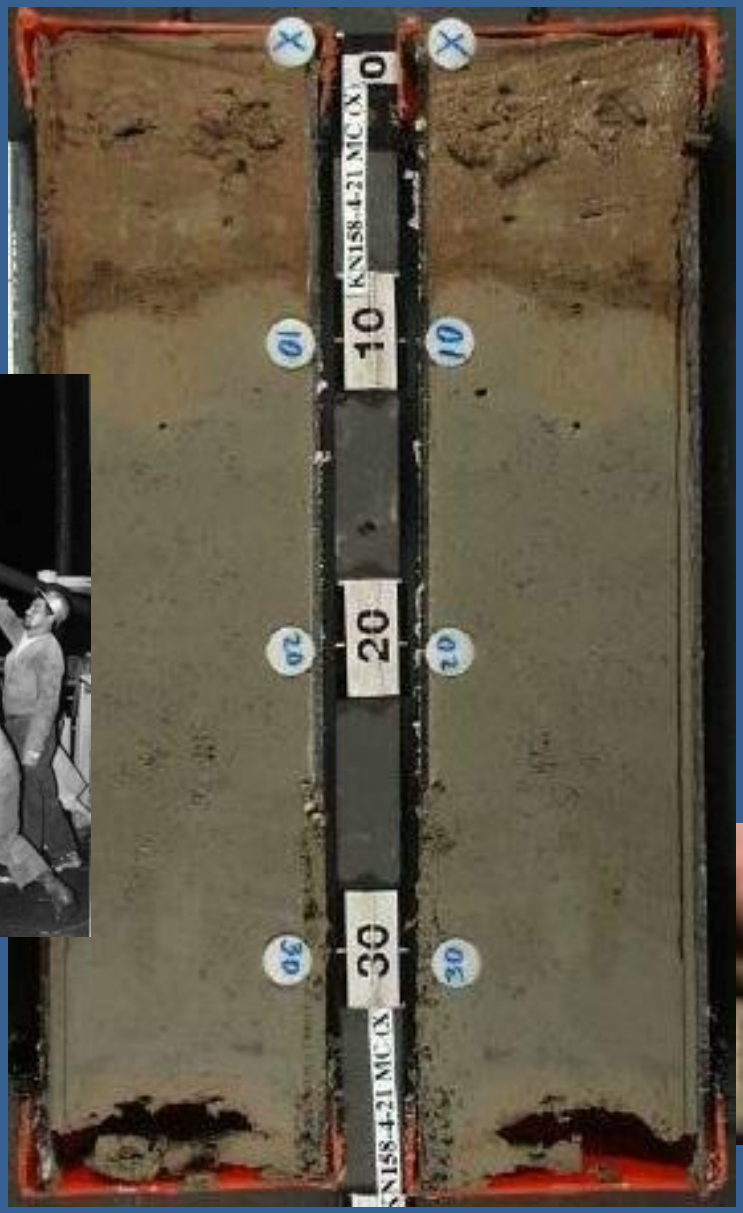
Other Paleoceanographers

John Imbrie:
CLIMAP



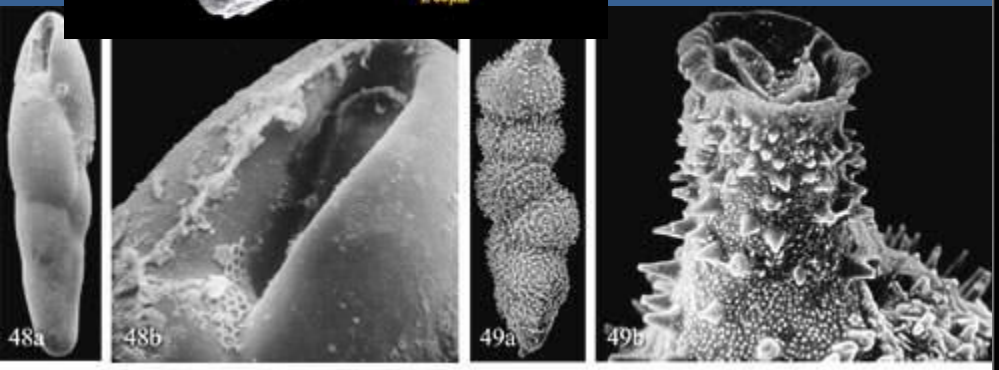


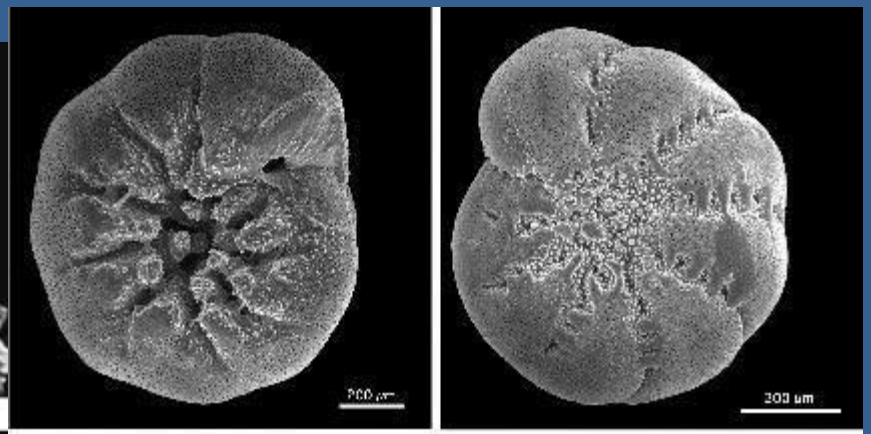


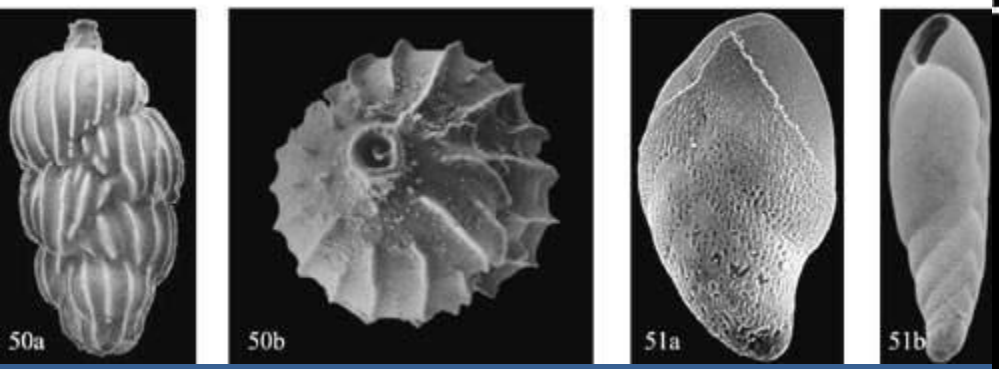


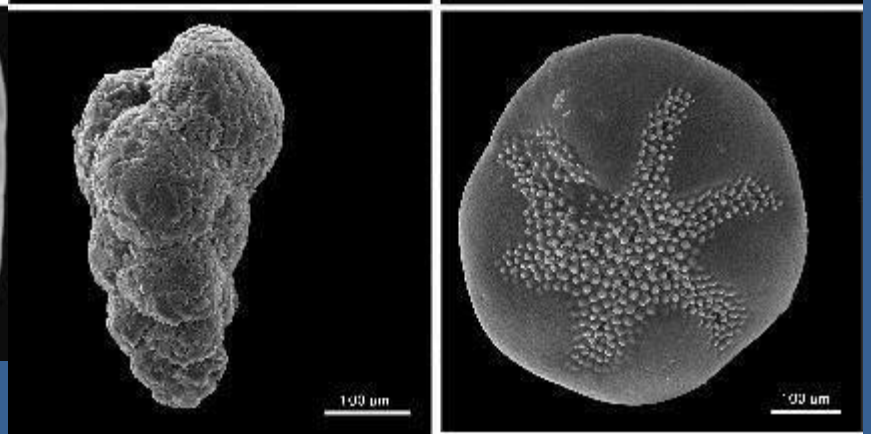
PROXY DATA: CORE DATA

PROXY DATA: BENTHIC FORAMS









PROXY DATA: PLANKTONIC FORAMS

Deep Sea Coring

Ruddiman, 2008

The Azolla event

Precipitation (sink):

$$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$$

GUESS WHAT:

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

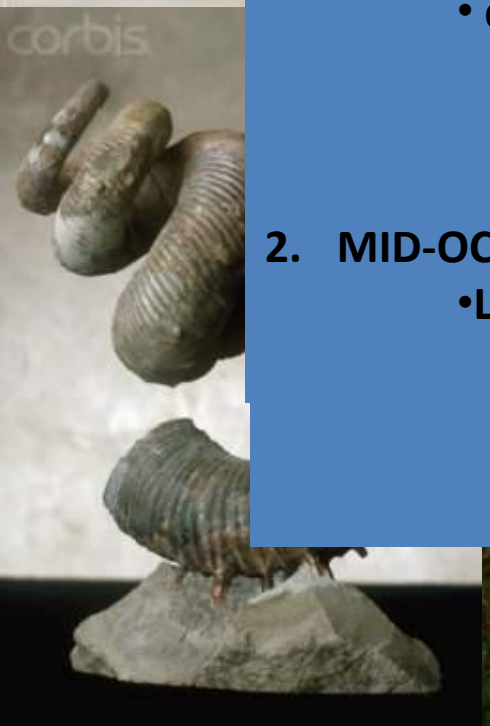
1. **GREATER MECHANICAL WEATHERING OF SILICATES:**
   - **increasing sequestration of CO_2 in sediments**
   - **decreasing the amount in the atmosphere**

ADDITIONALLY in the Cenozoic:

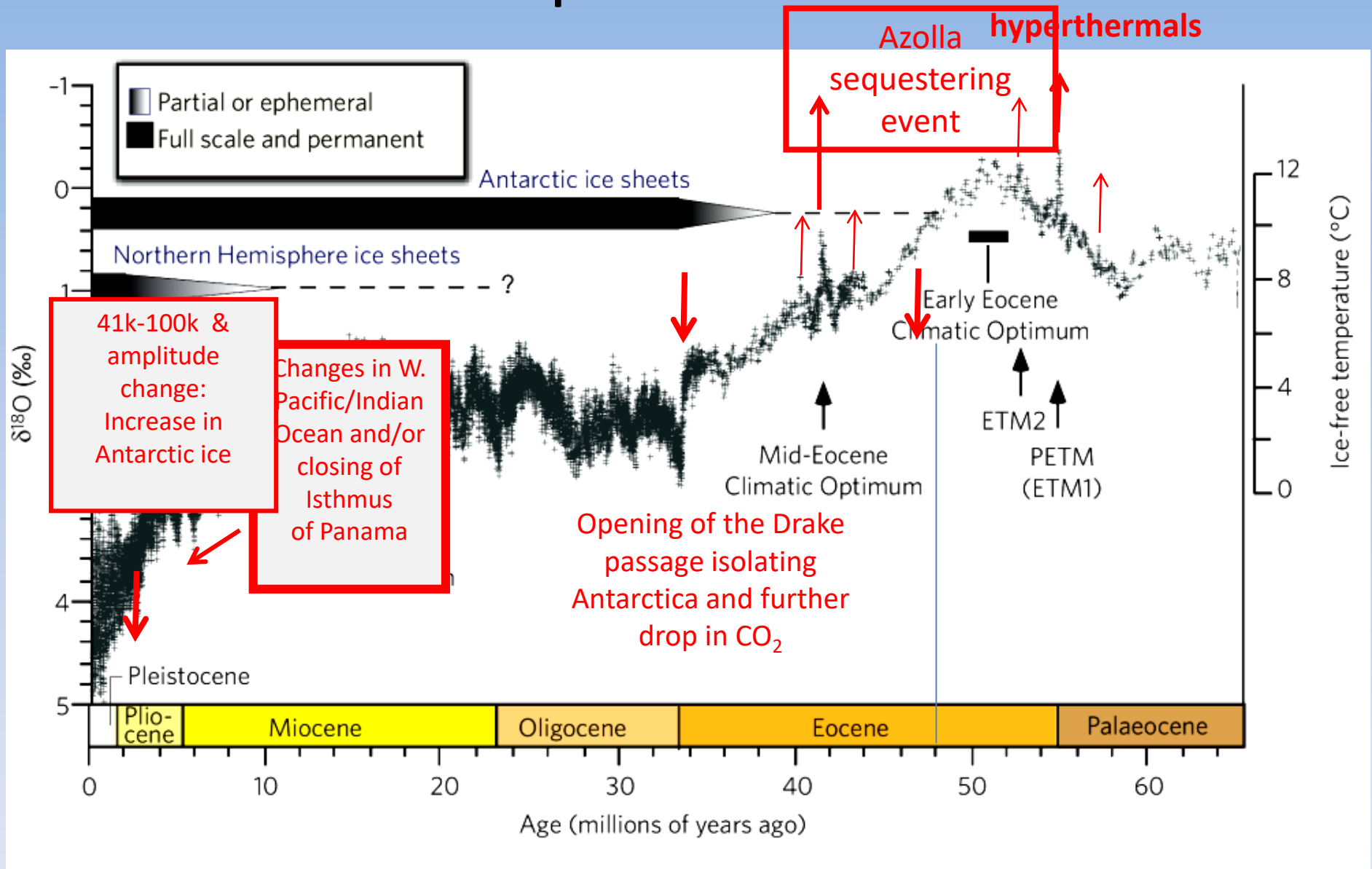
2. **MID-OCEAN SPREADING RATES SLOW DOWN**
   - **Less CO_2 into the atmosphere for volcanoes**

=

CO_2 DRAW DOWN THROUGH TIME!

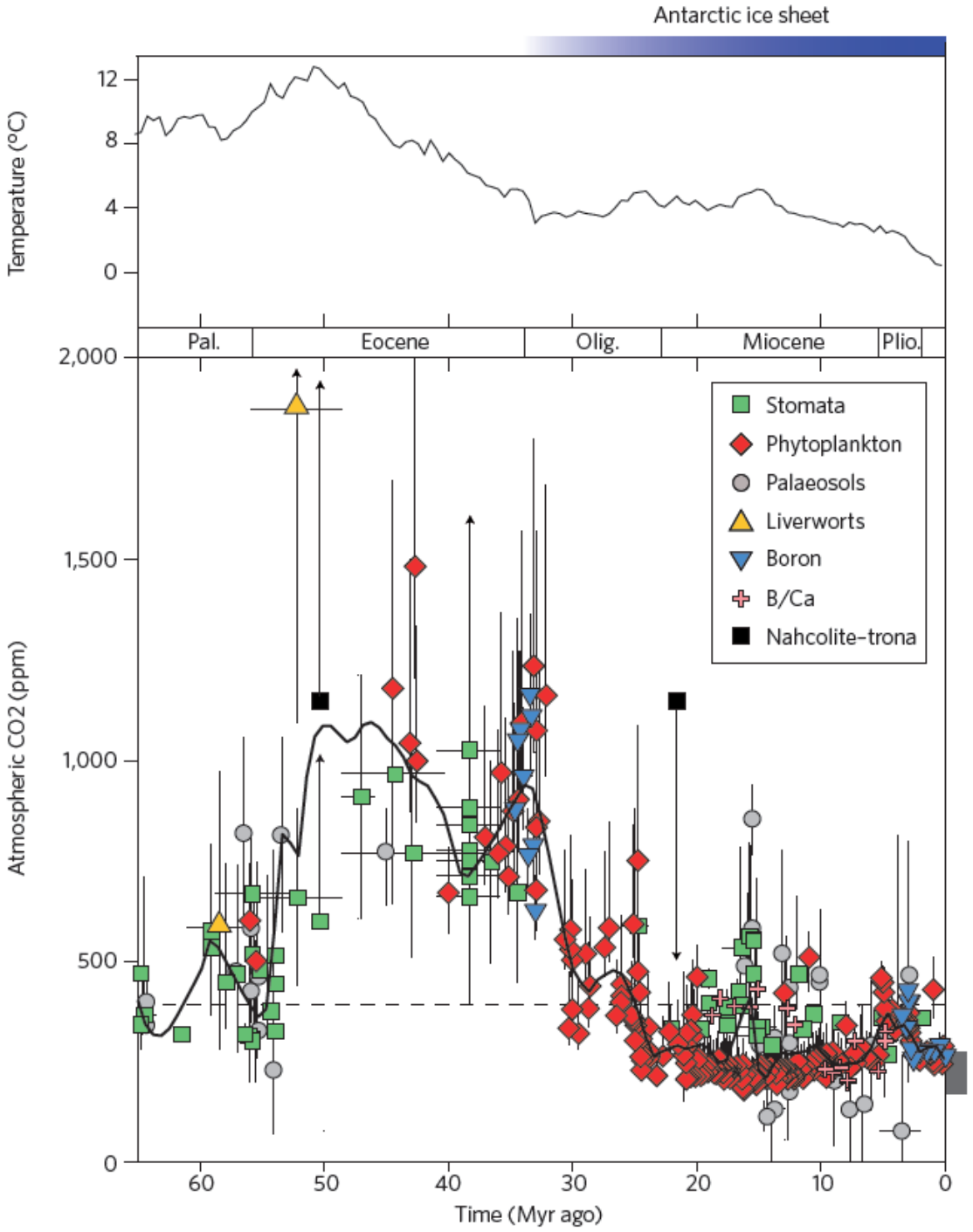


Cenozoic Deep Sea Climate Record



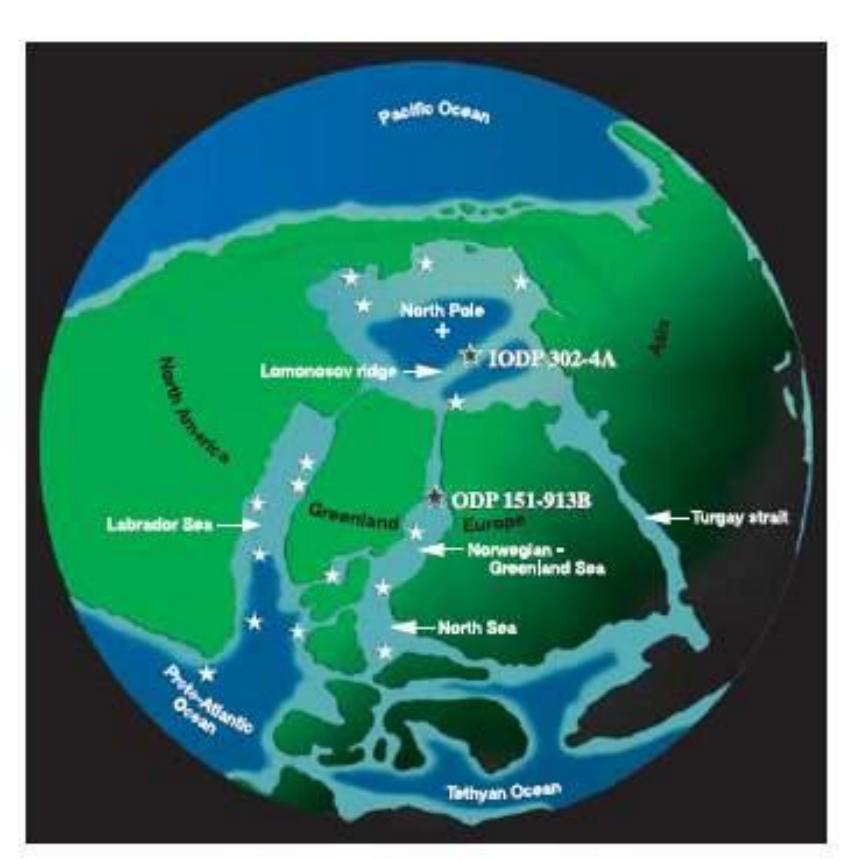
Zachos et al. 2008

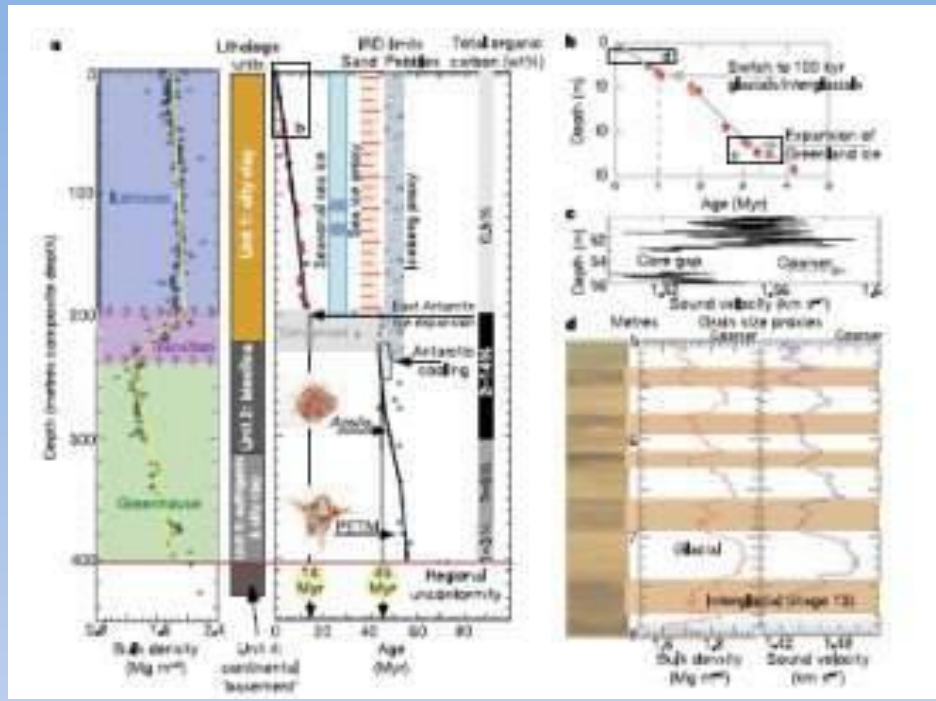
Correlation of CO_2 and temperature over last 65 million years

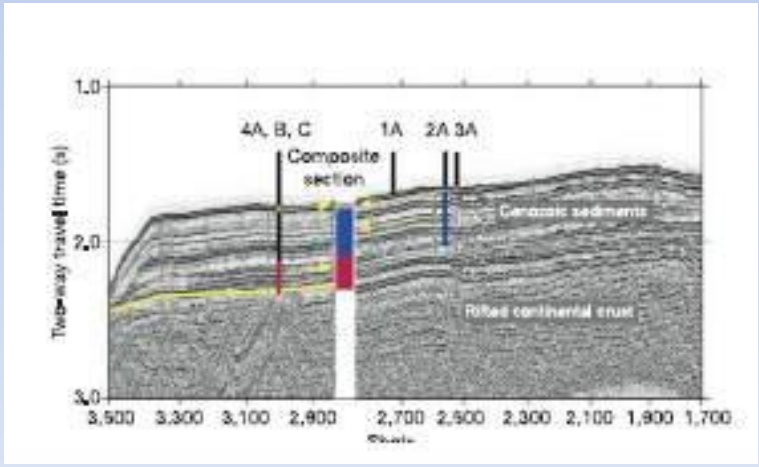


Beerling and Royer, Nature 2011

ARCTIC EVENTS





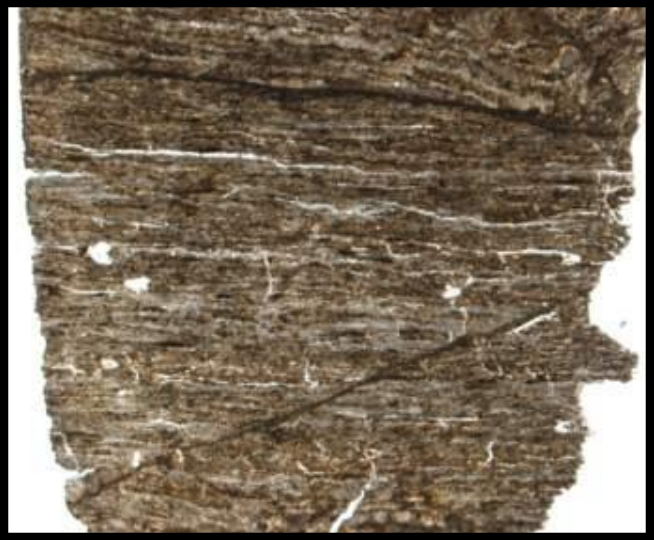


Brinkhuis et al,, 2006
Moran et al., 2006

The Arctic Sea 50 million years ago

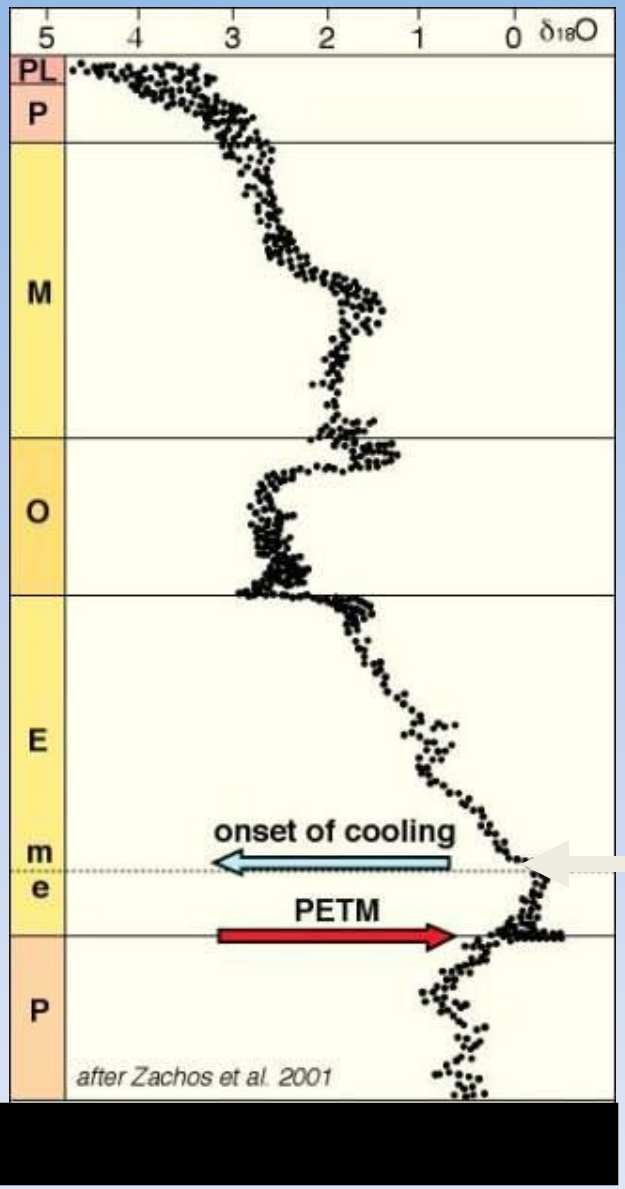
ACEX Azolla core

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

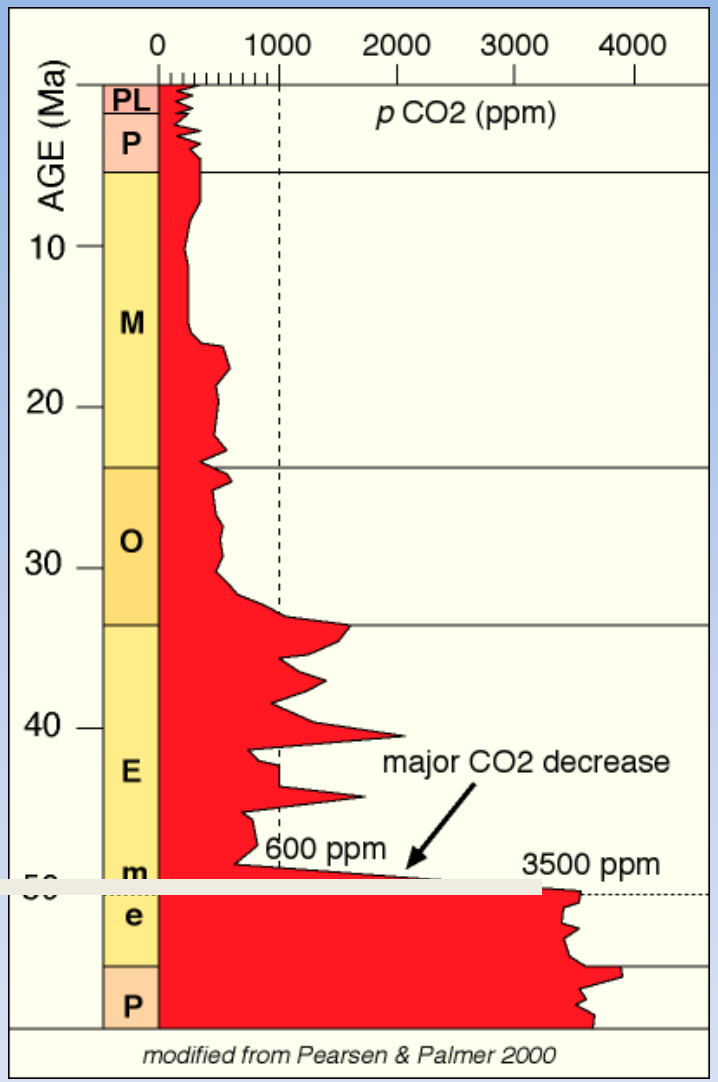


Bujak, pers. Comm.

UNPRECEDENTED DROP IN CO_2

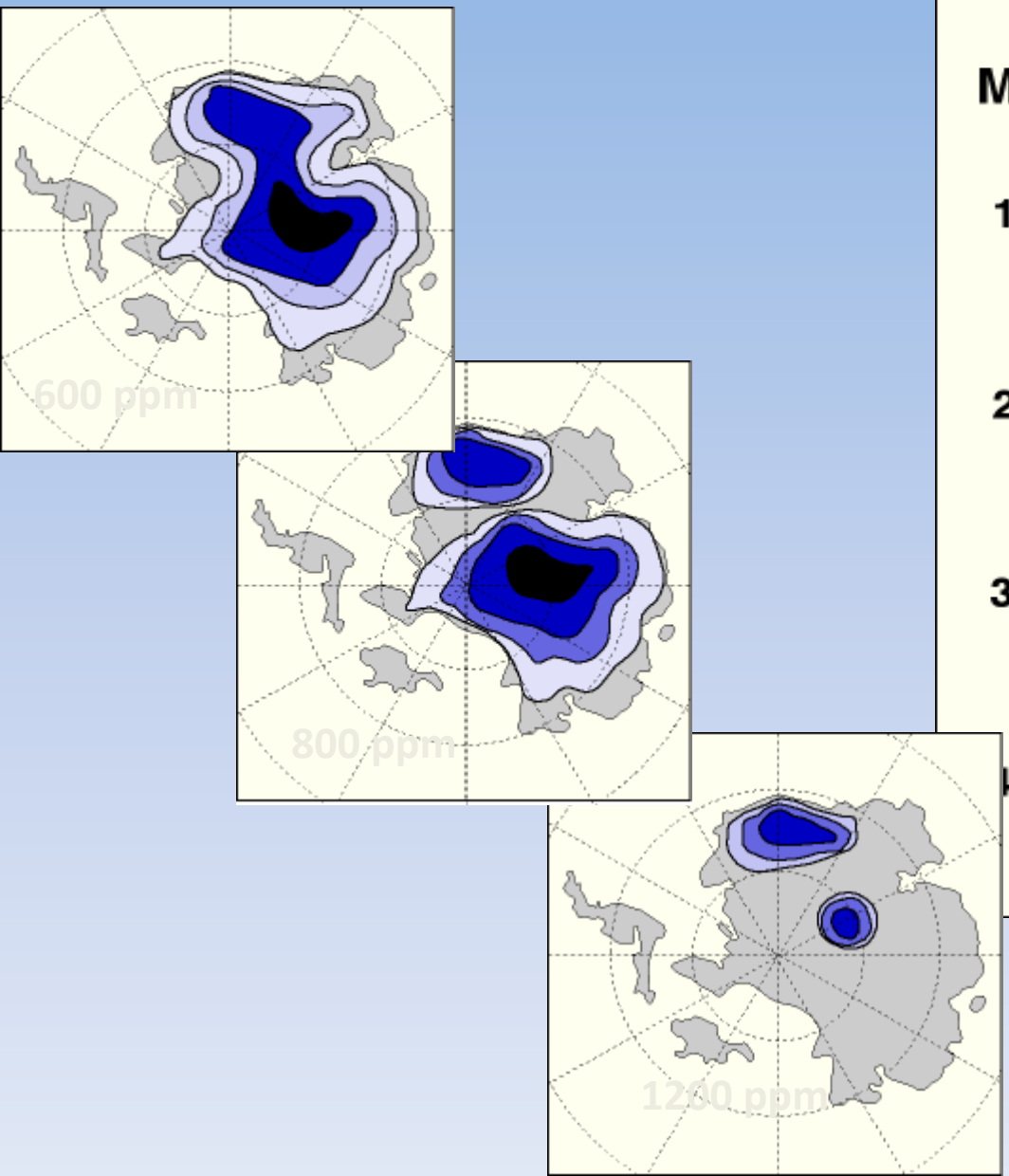


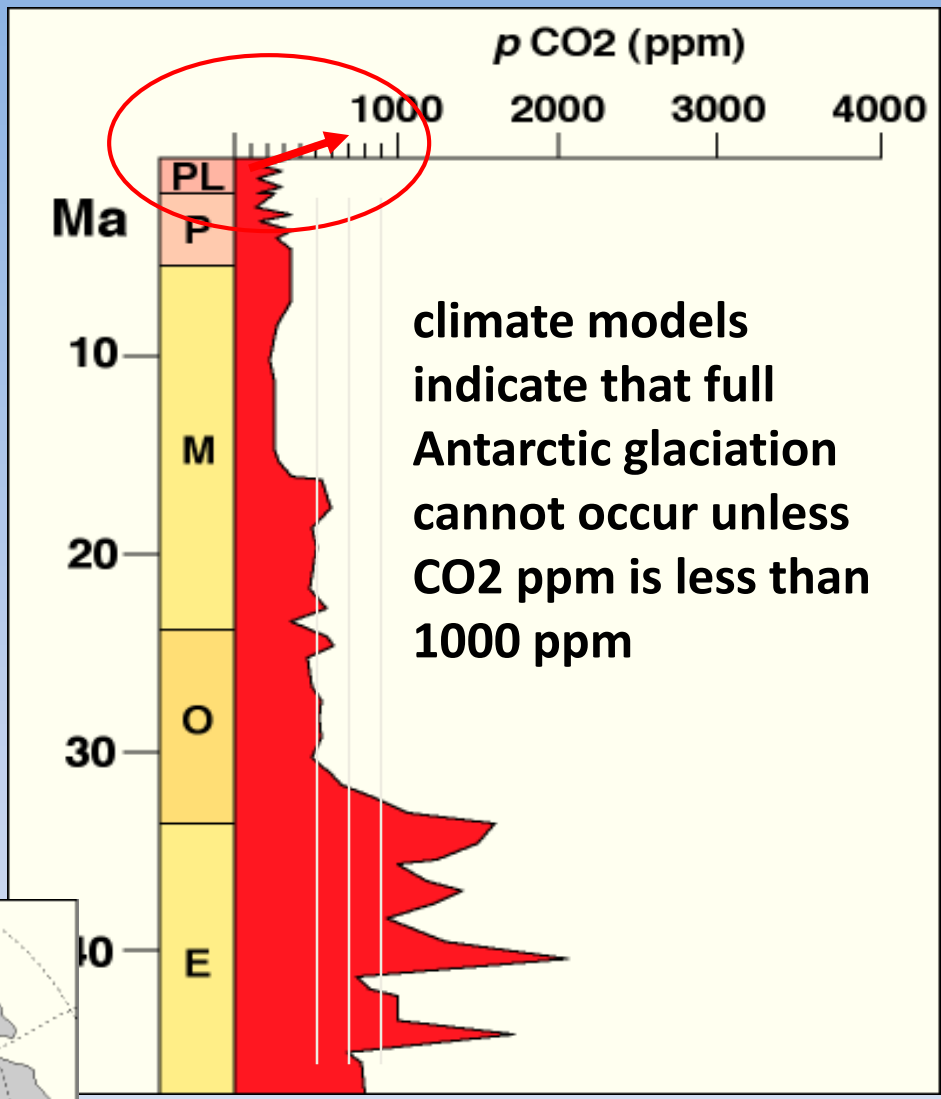
the massive decrease in atmospheric CO_2?



Bujak, pers. Comm.

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





Bujak, pers. Comm.