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

Week 4: Wednesday April 20, 2016

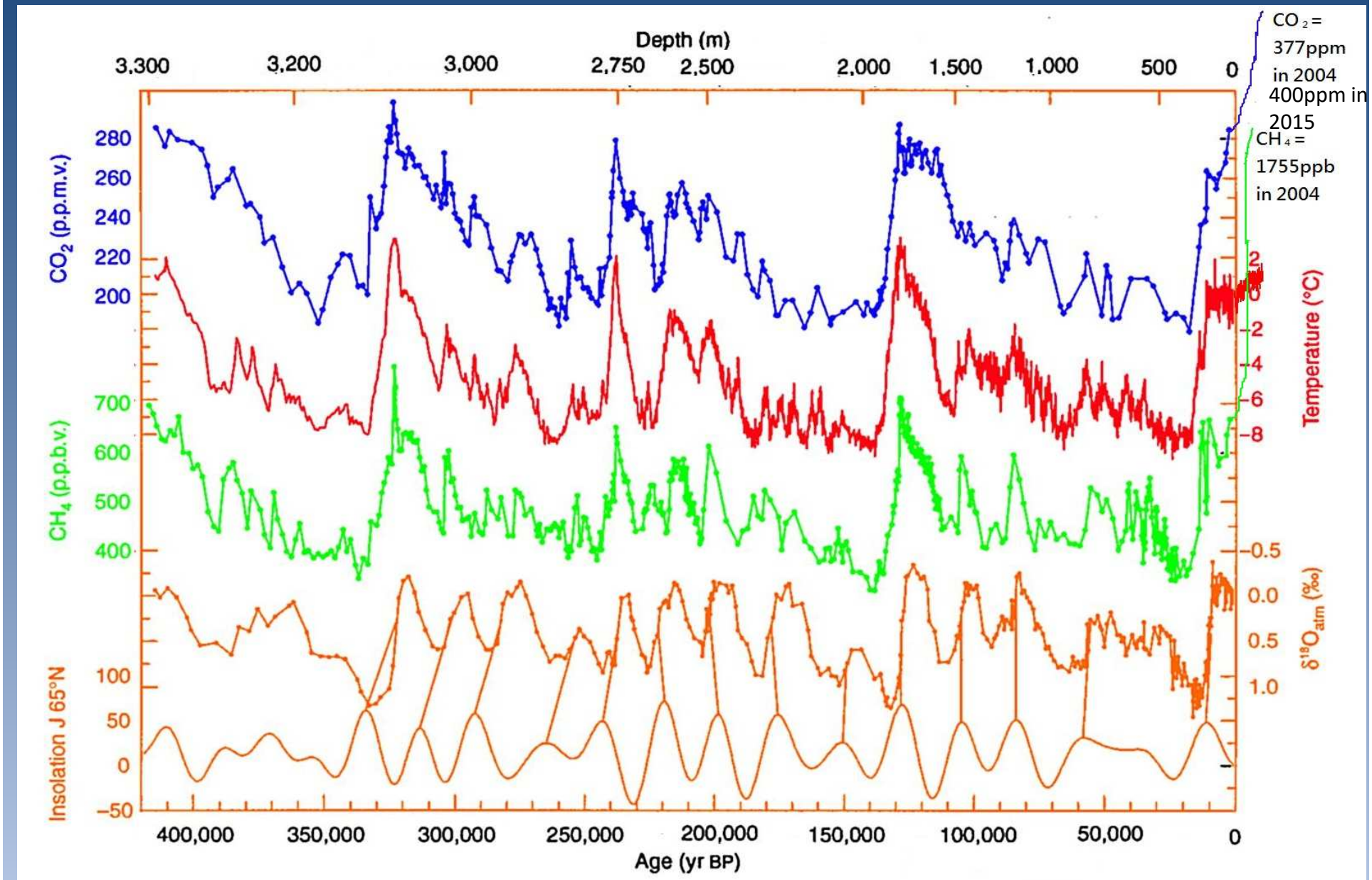
Paul Belanger

Concerns: Rates of change, Ocean acidification, modeling

1. Recap of climate variables and past records
2. Rates of change
3. Proxies that tell us of climate records
4. Ocean Acidification
5. Climate Modeling

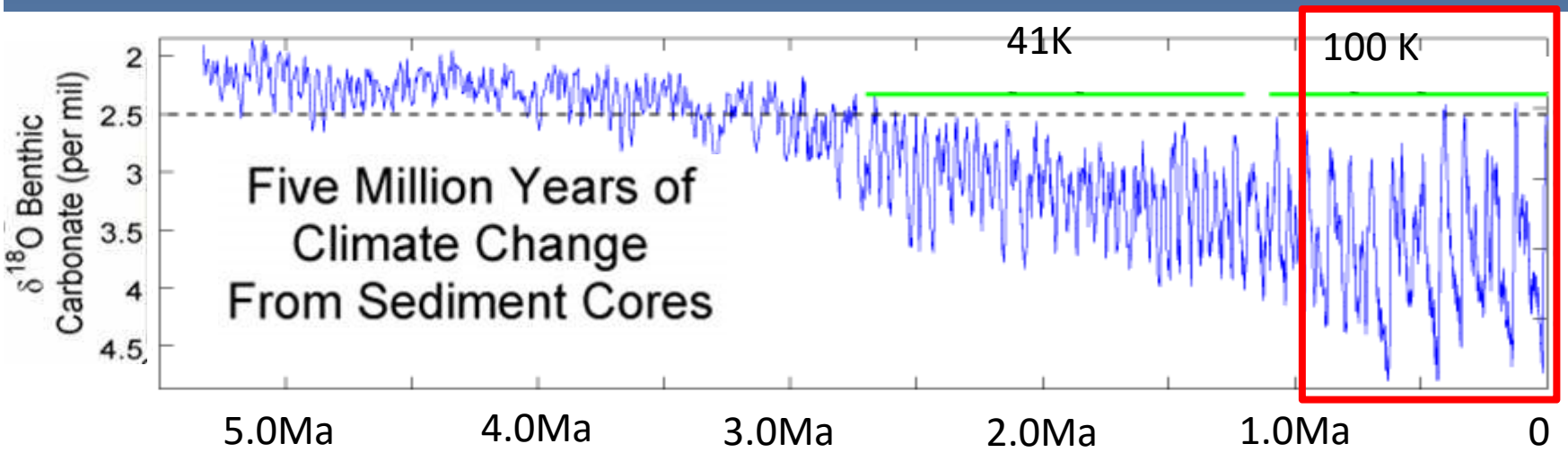
- Week 2's slide set http://denverclimatestudygroup.com/?page_id=1796
- Week 3's slides and video links http://denverclimatestudygroup.com/?page_id=1798

1. Recap of climate variables and past records

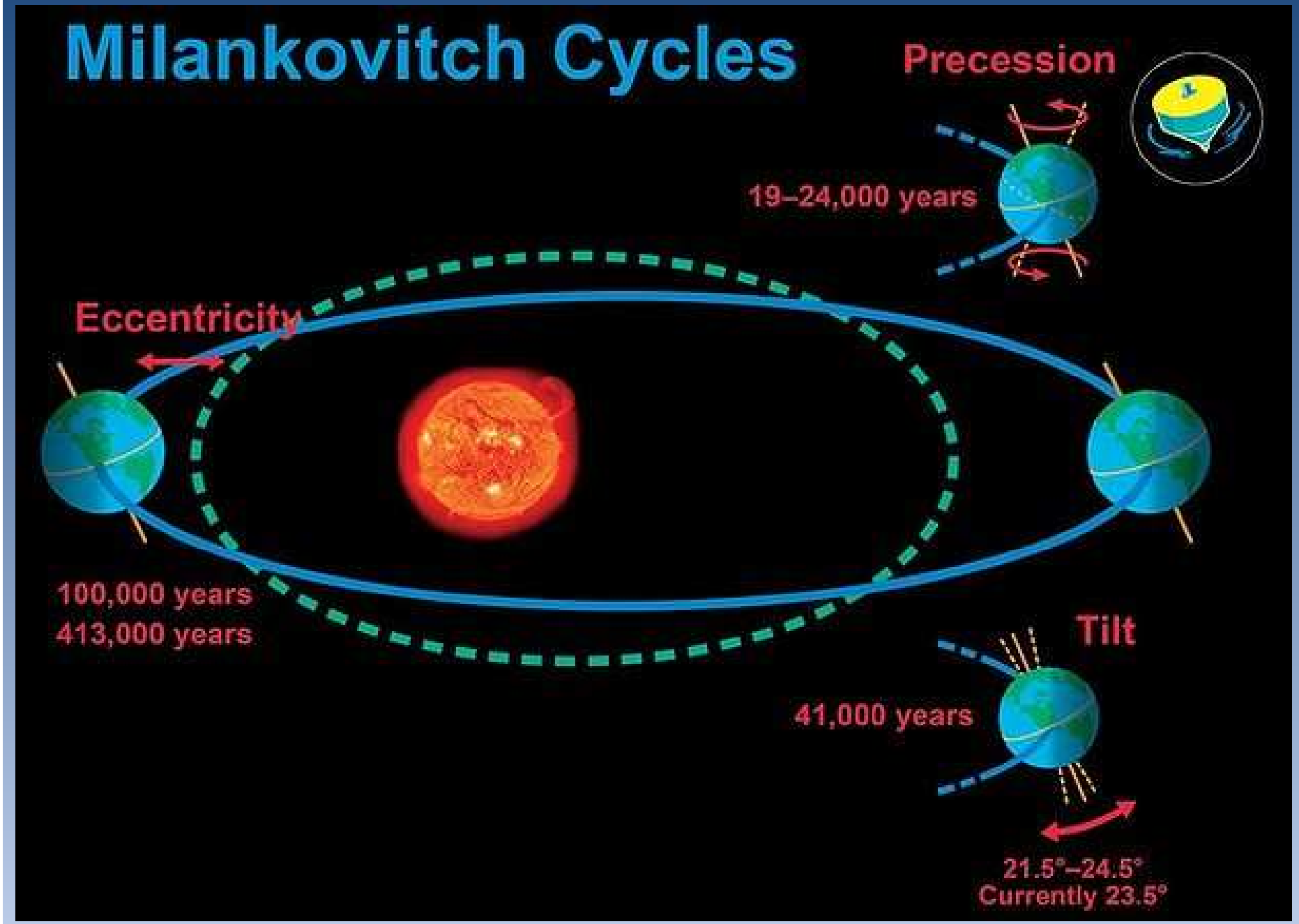


http://www.antarcticglaciers.org/climate-change/

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



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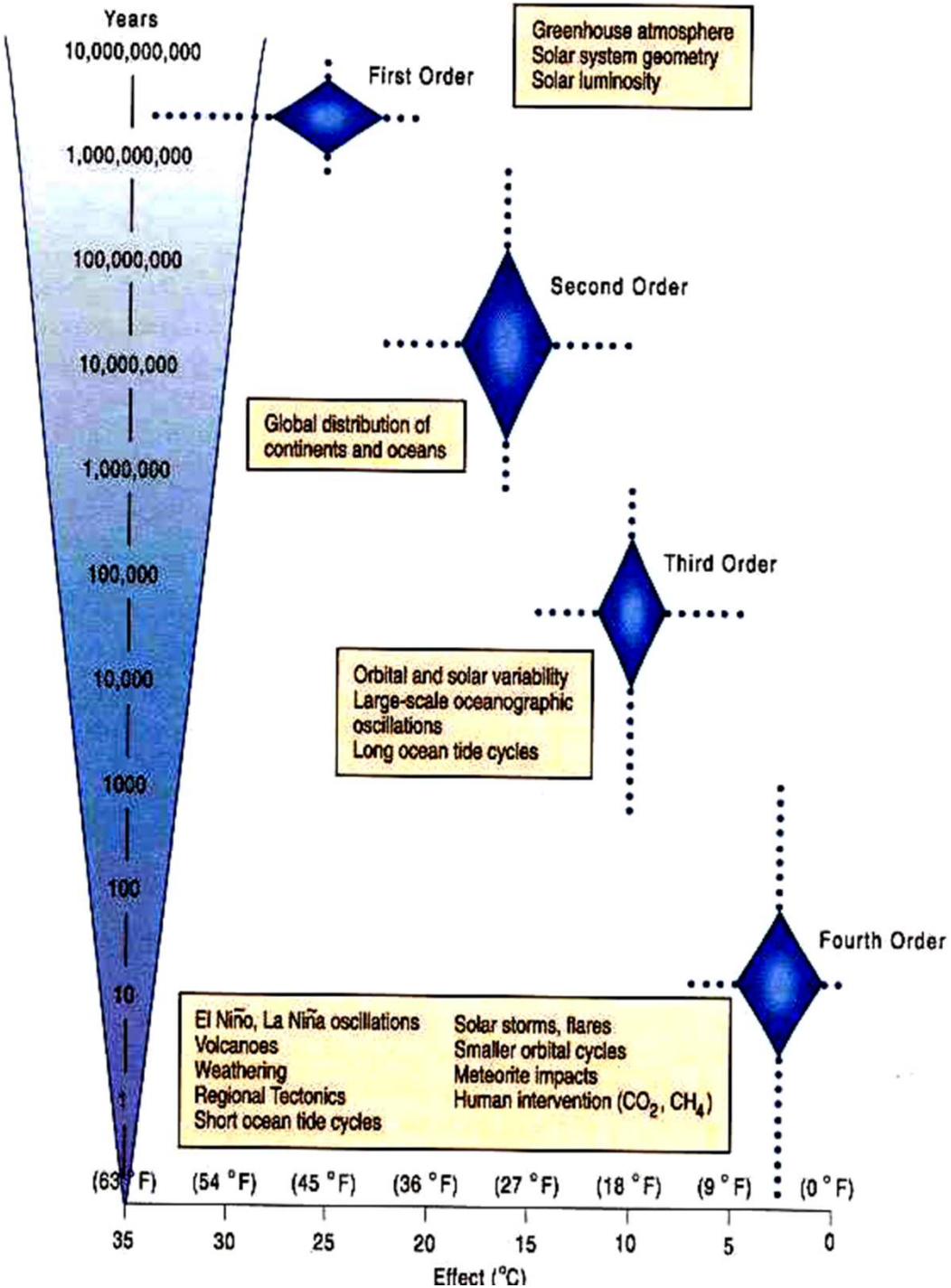
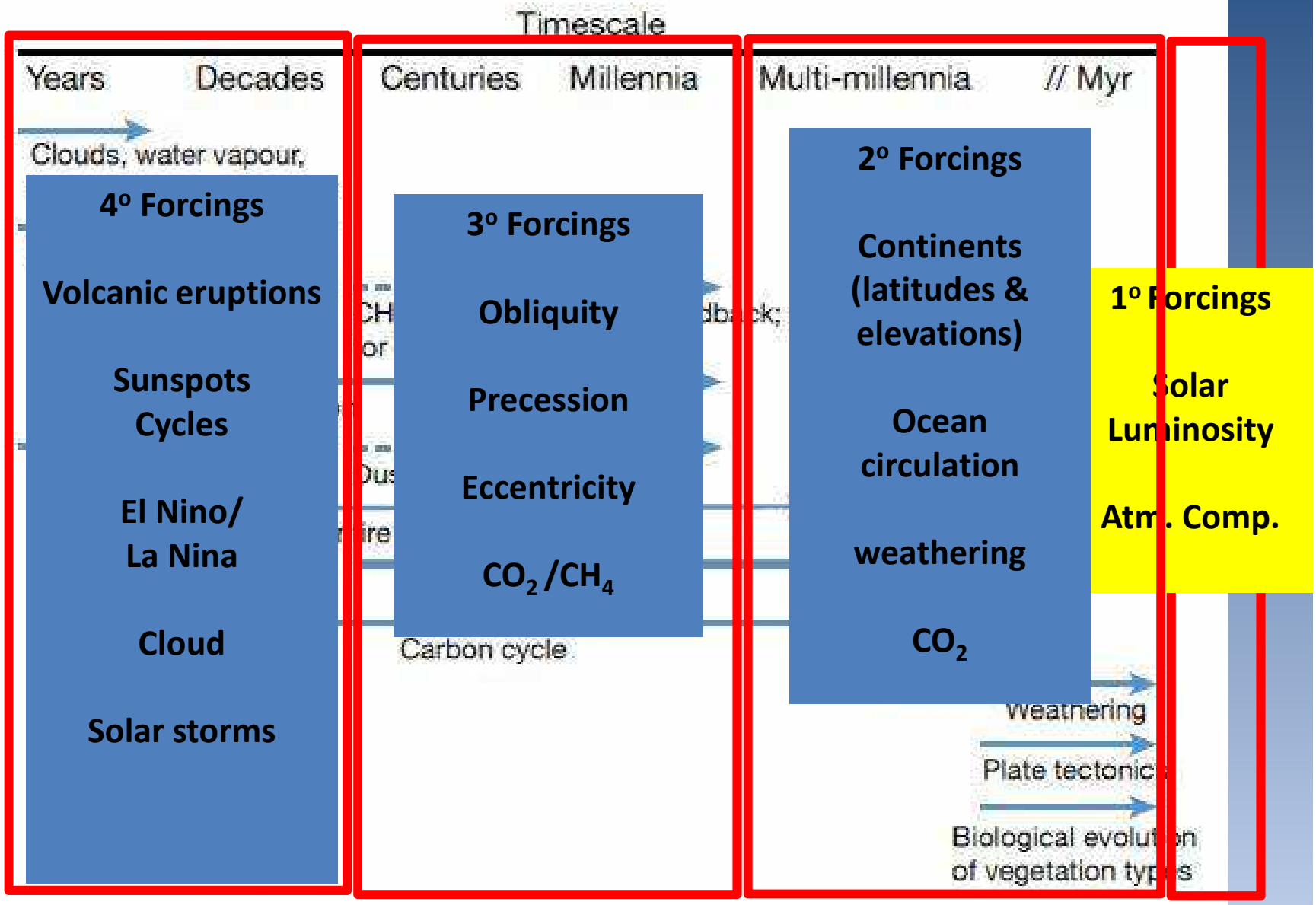
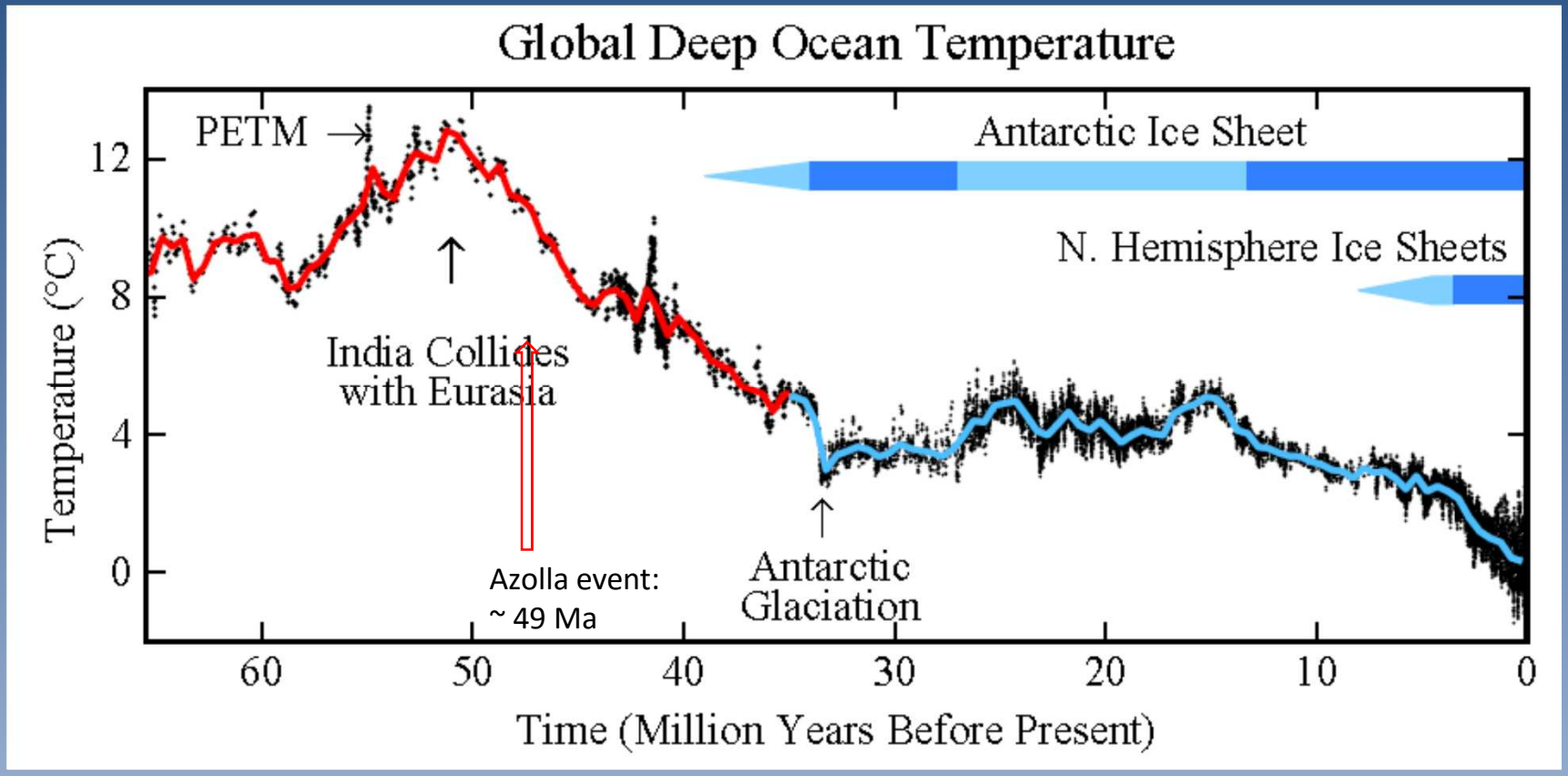


Gerhard et al., 2001

FEEDBACKS



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



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

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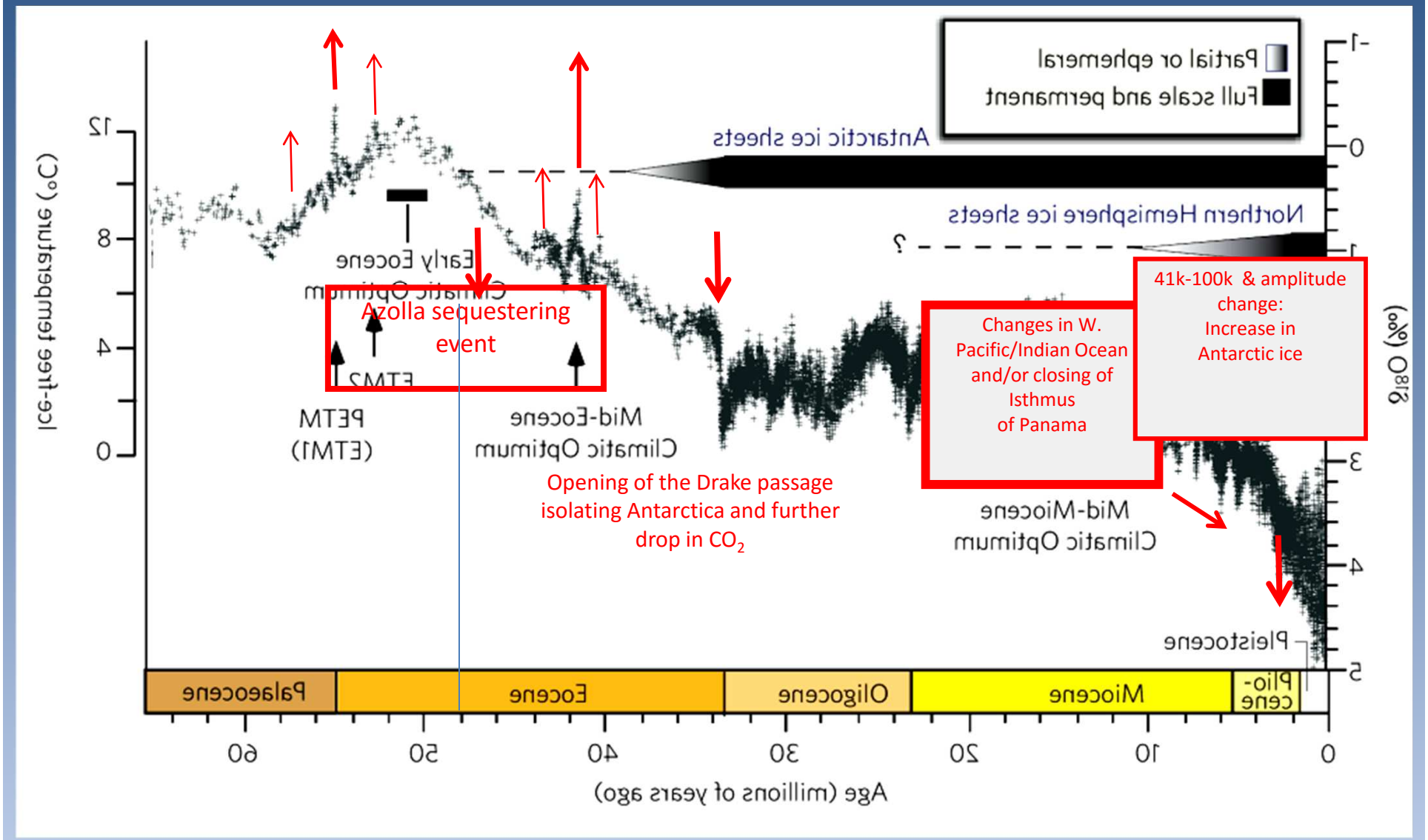
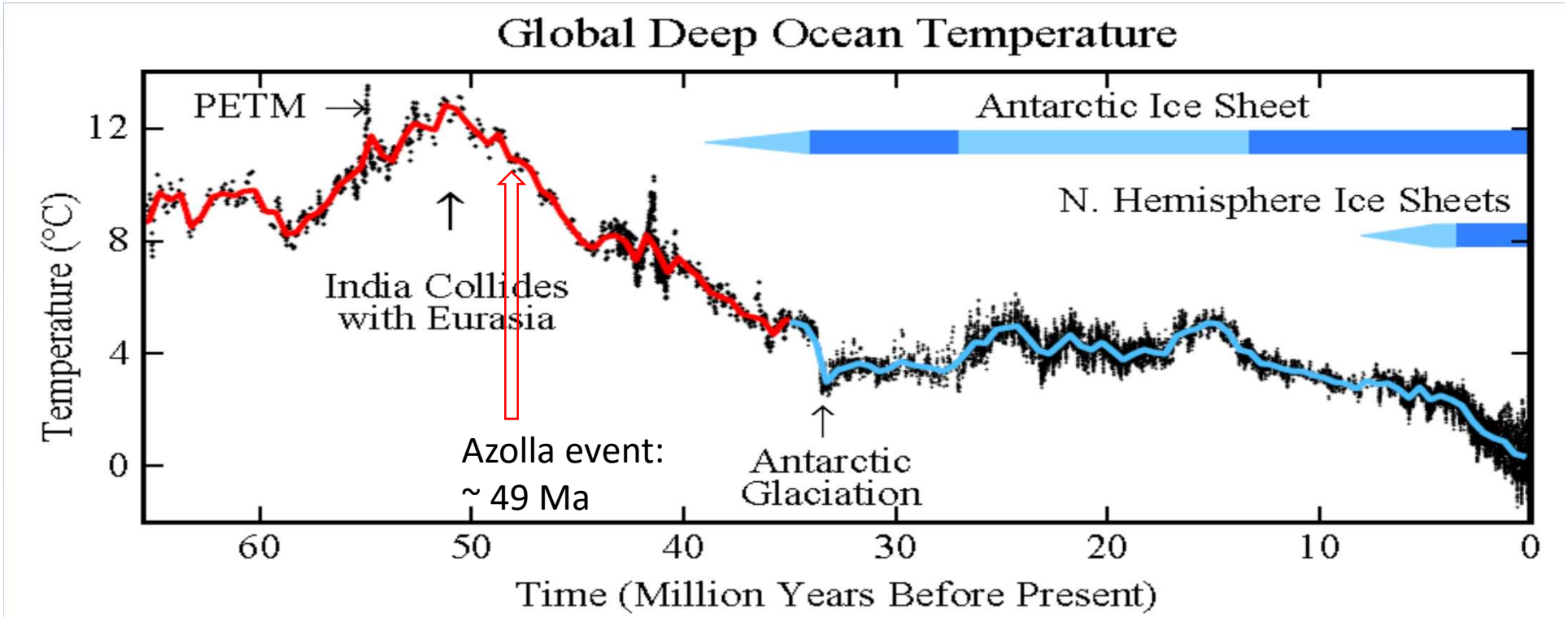
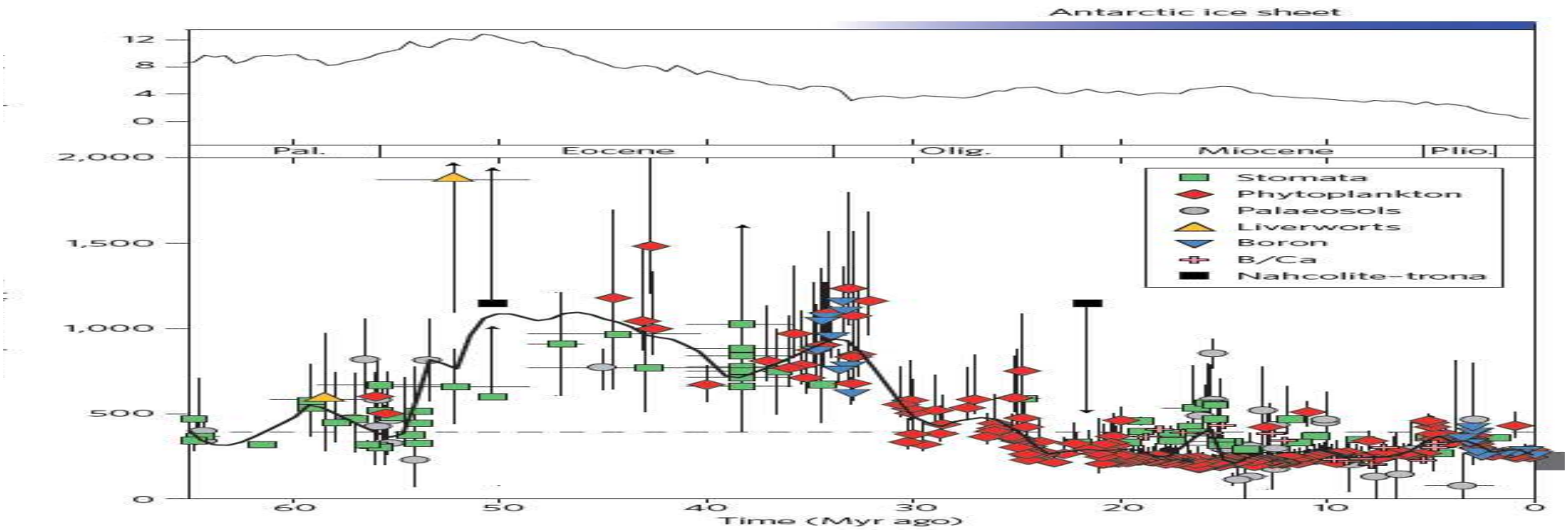
Atmospheric CO_2 imbalance due to plate tectonics ~ 10^{-4} ppm per year.

Cenozoic Deep Sea Climate Record



Zachos et al. 2008


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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60
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Time (Myr ago)

Long-term Carbon Cycle: rocks

Two generalized reactions…

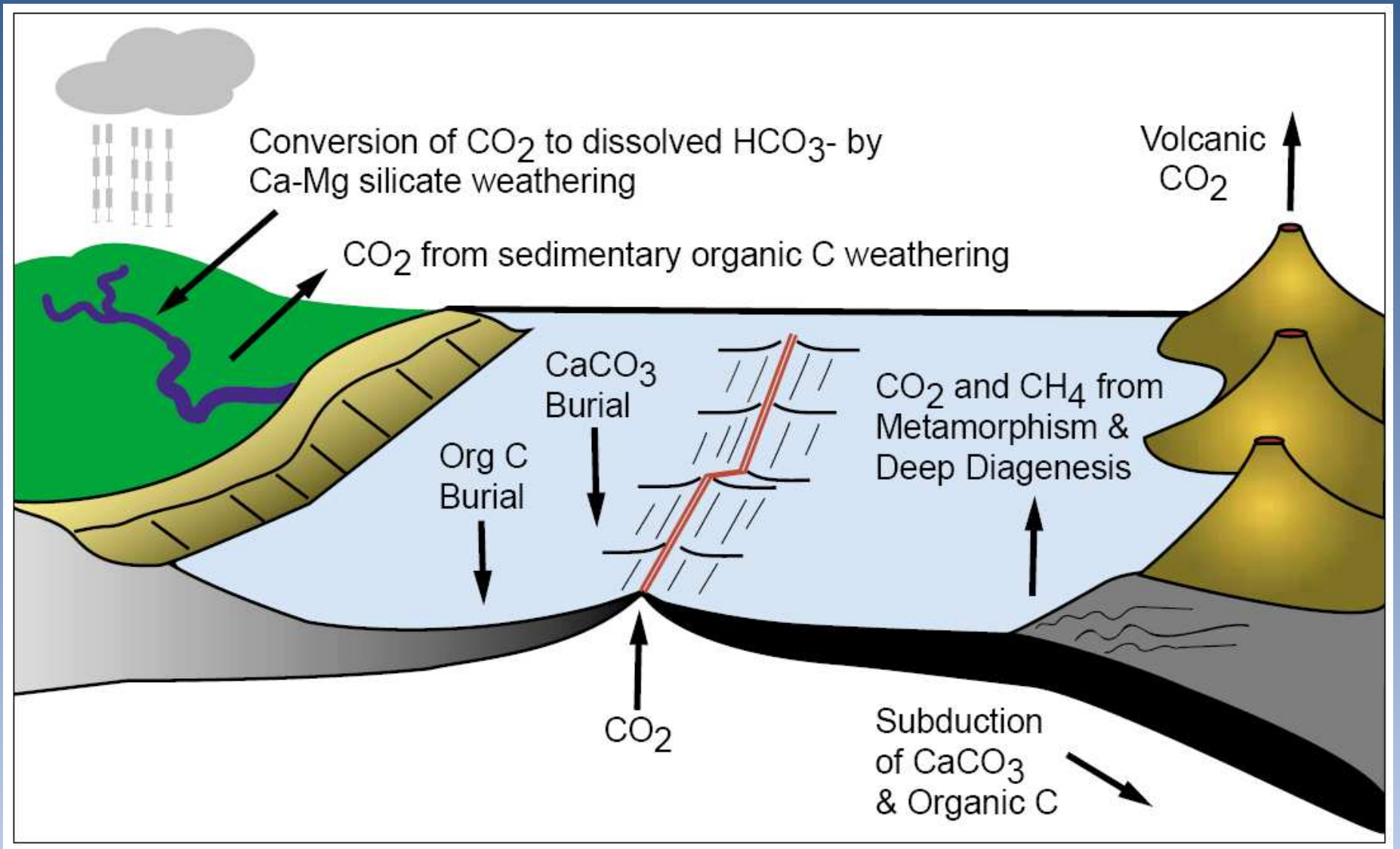
Photosynthesis/Respiration

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

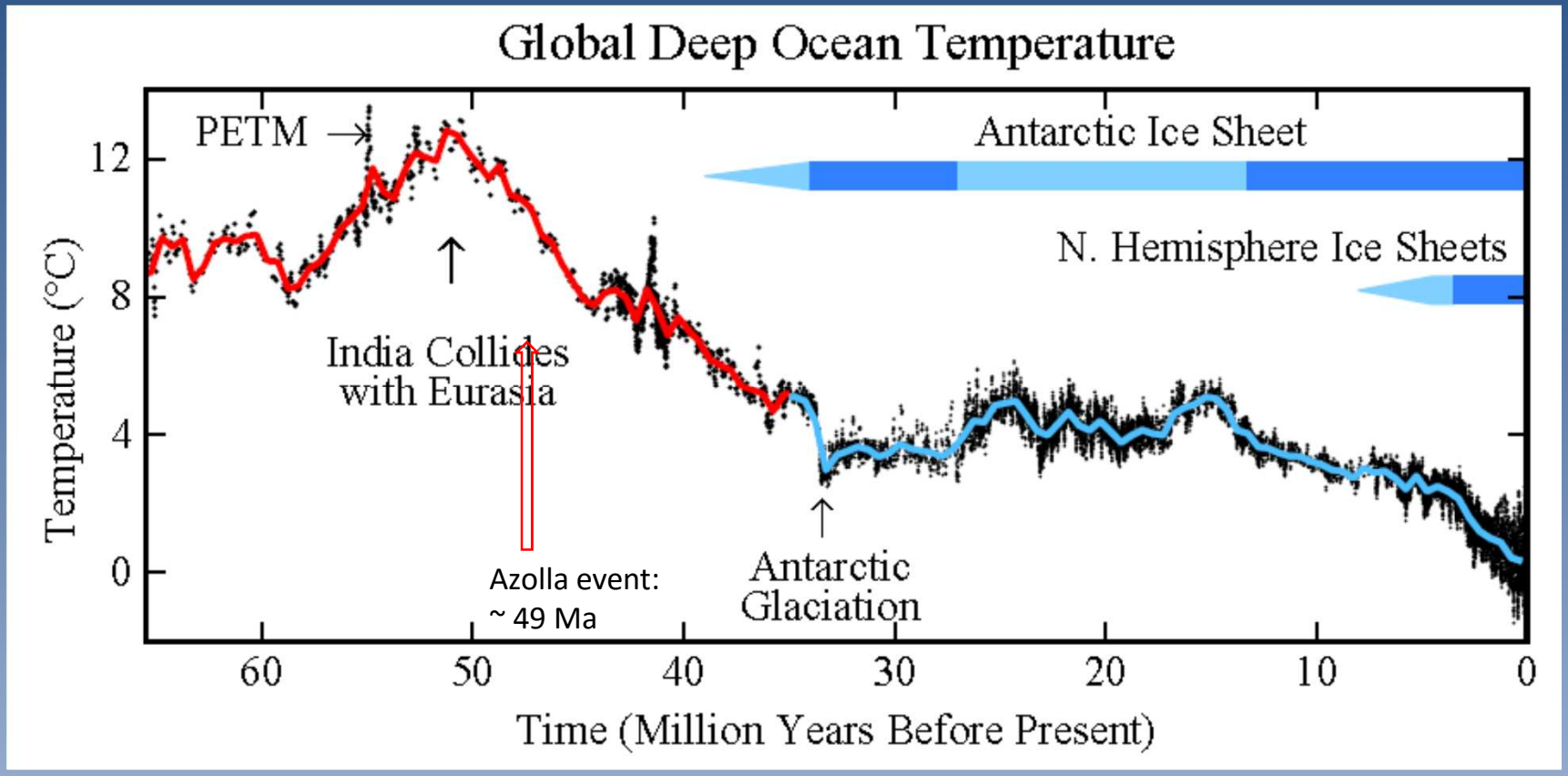
Weathering/Precipitation

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

Long-term carbon cycle: *rocks*



Berner, 2001



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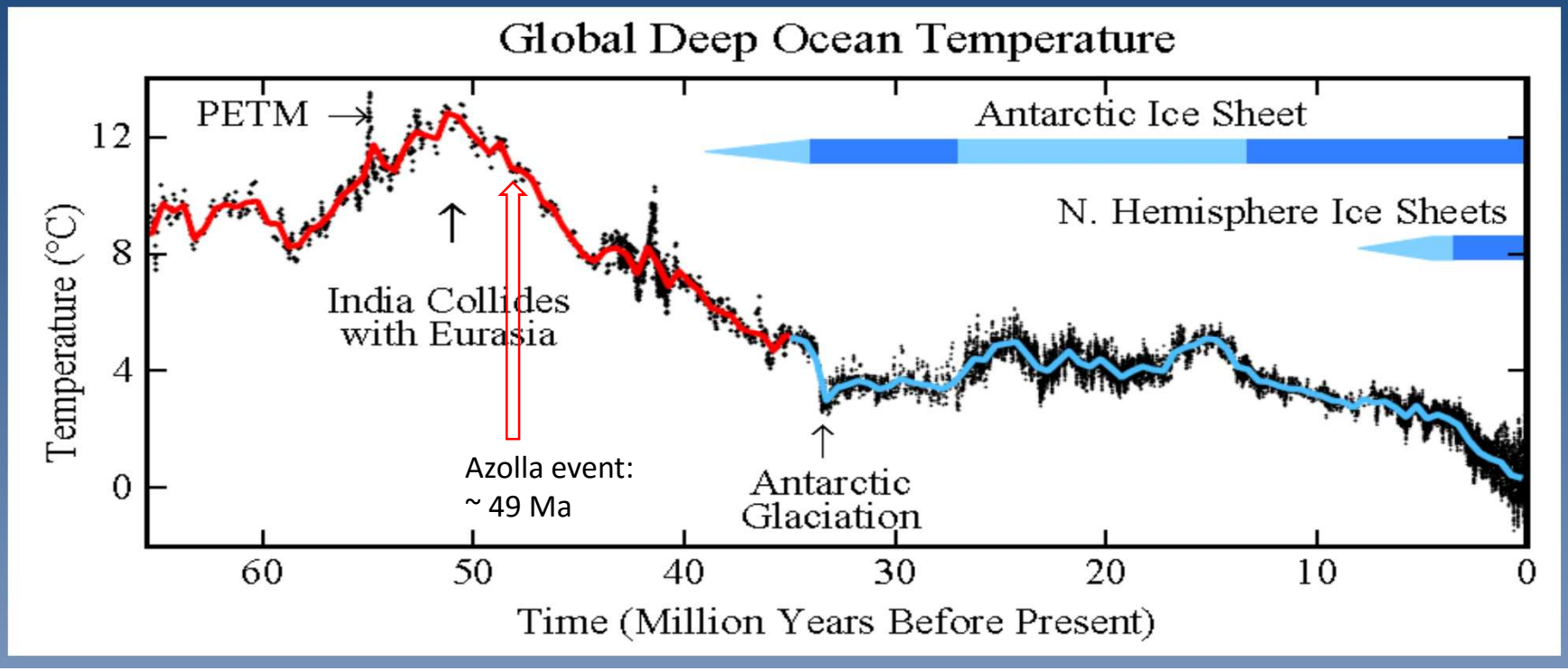
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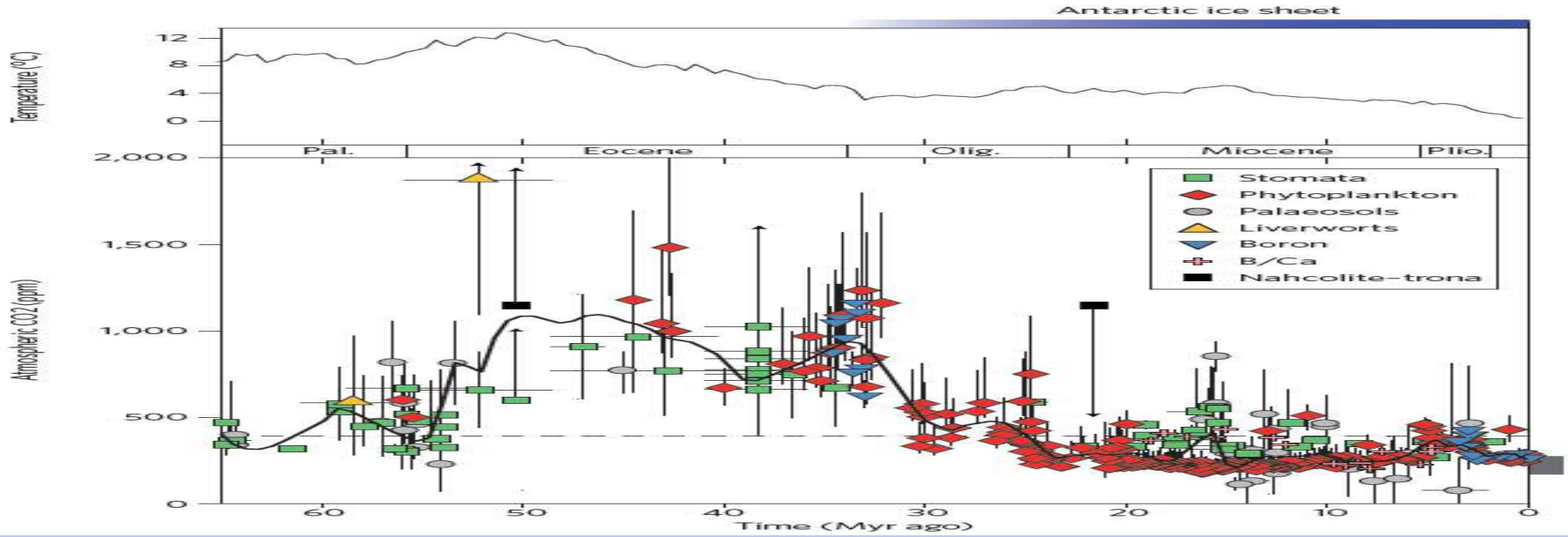
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Time (Myr ago)

So – what changed?

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:

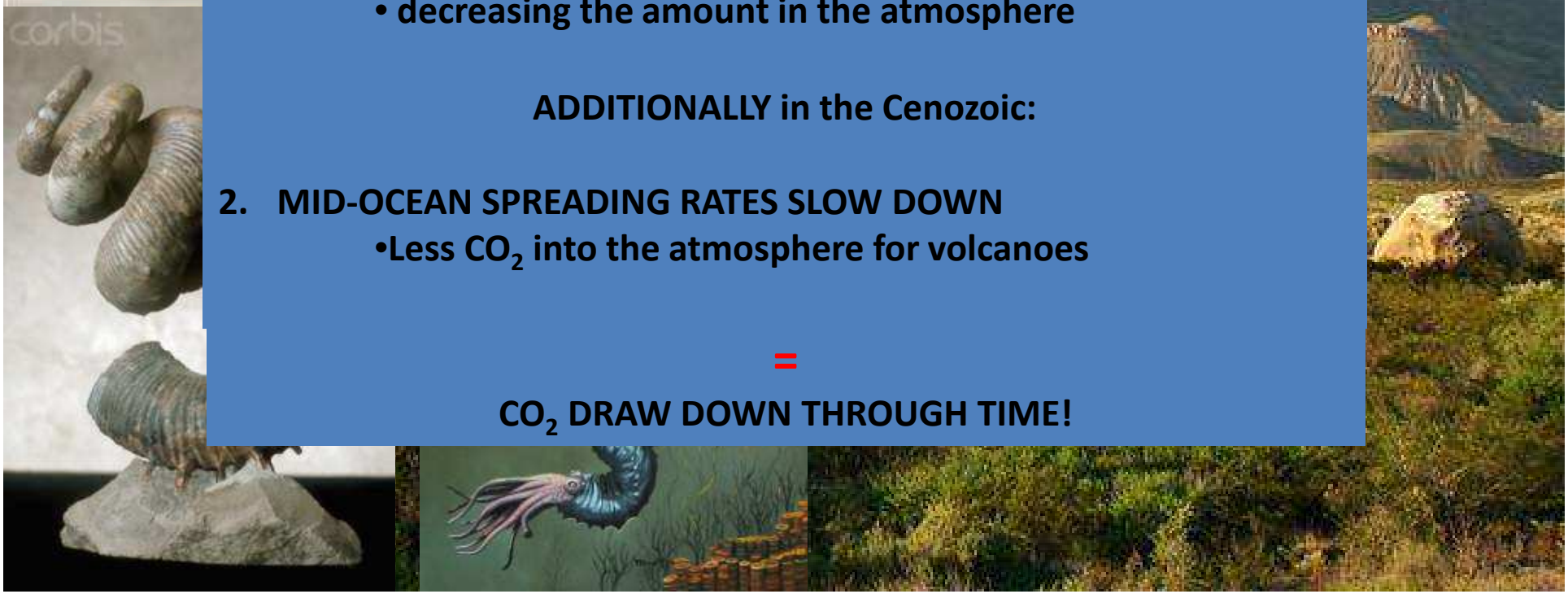
1. **GREATER MECHANICAL WEATHERING OF SILICATES:**
   - **increasing sequestration of CO_2 in sediments**
   - **decreasing the amount in the atmosphere**

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!



2. Rates of change

Unprecedented rates of change

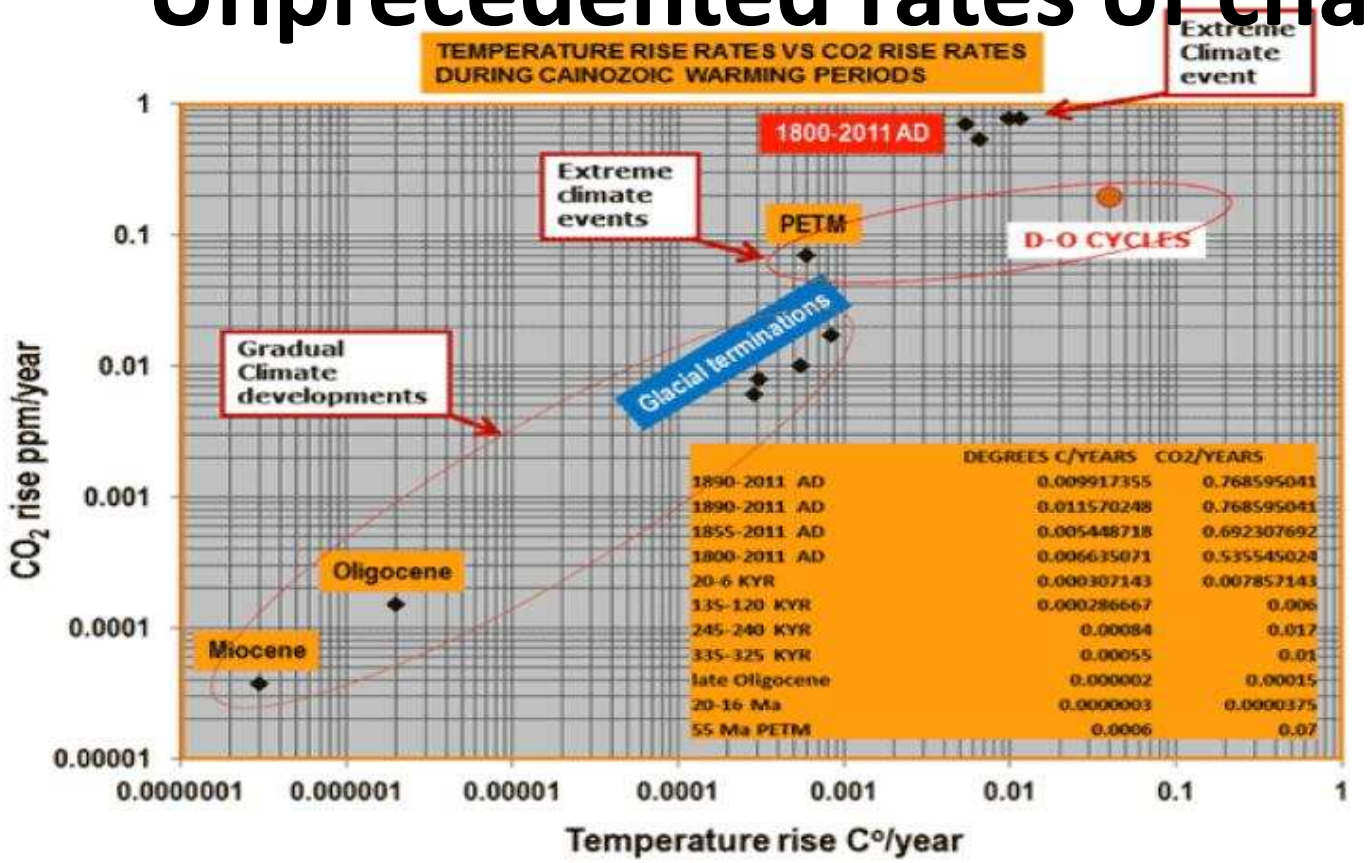
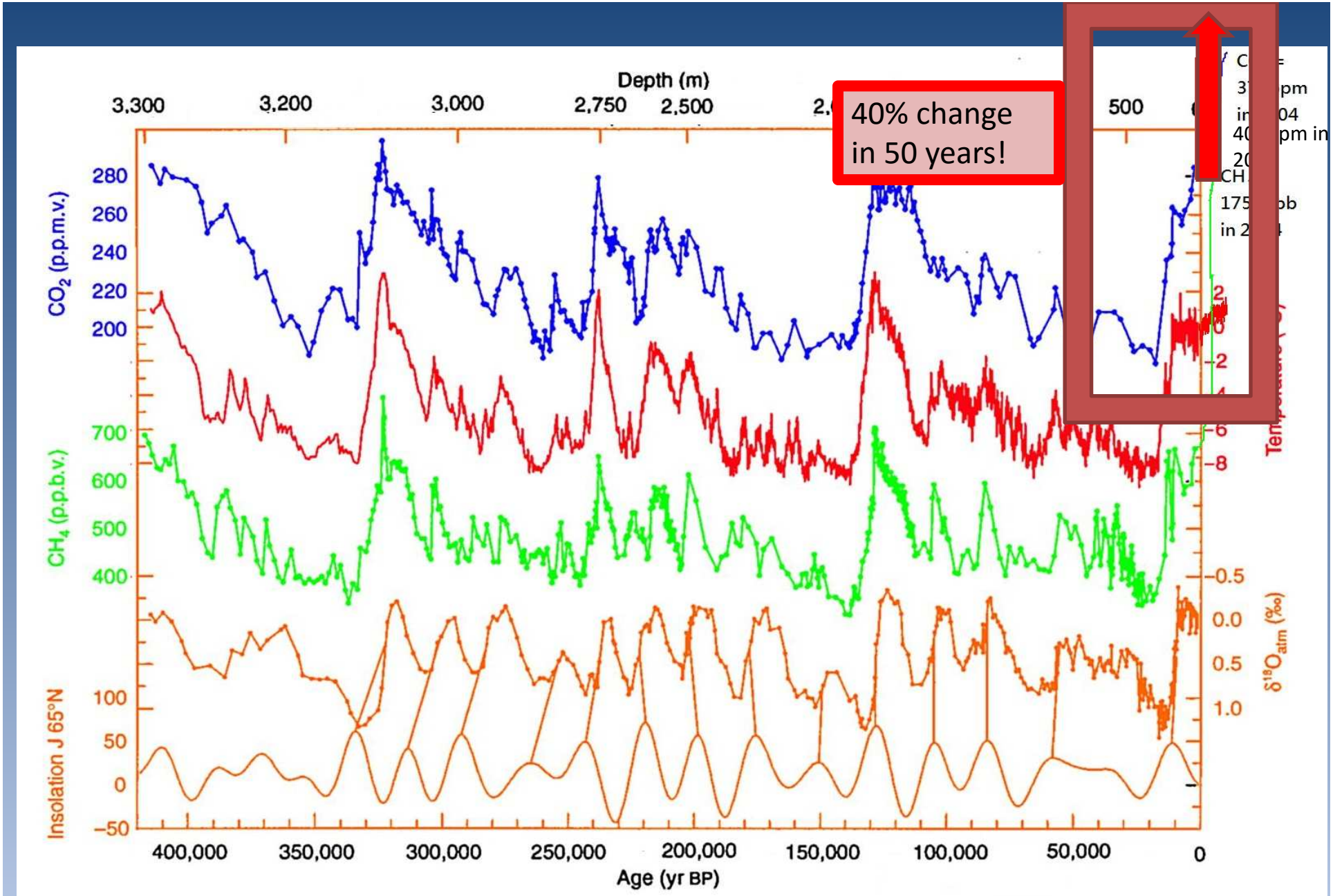


Figure 2: Relations between CO_2 rise rates and mean global temperature rise rates during warming periods, including the Paleocene-Eocene Thermal Maximum, Oligocene, Miocene, glacial terminations, Dansgaard-Oeschger cycles and the post-1750 period.



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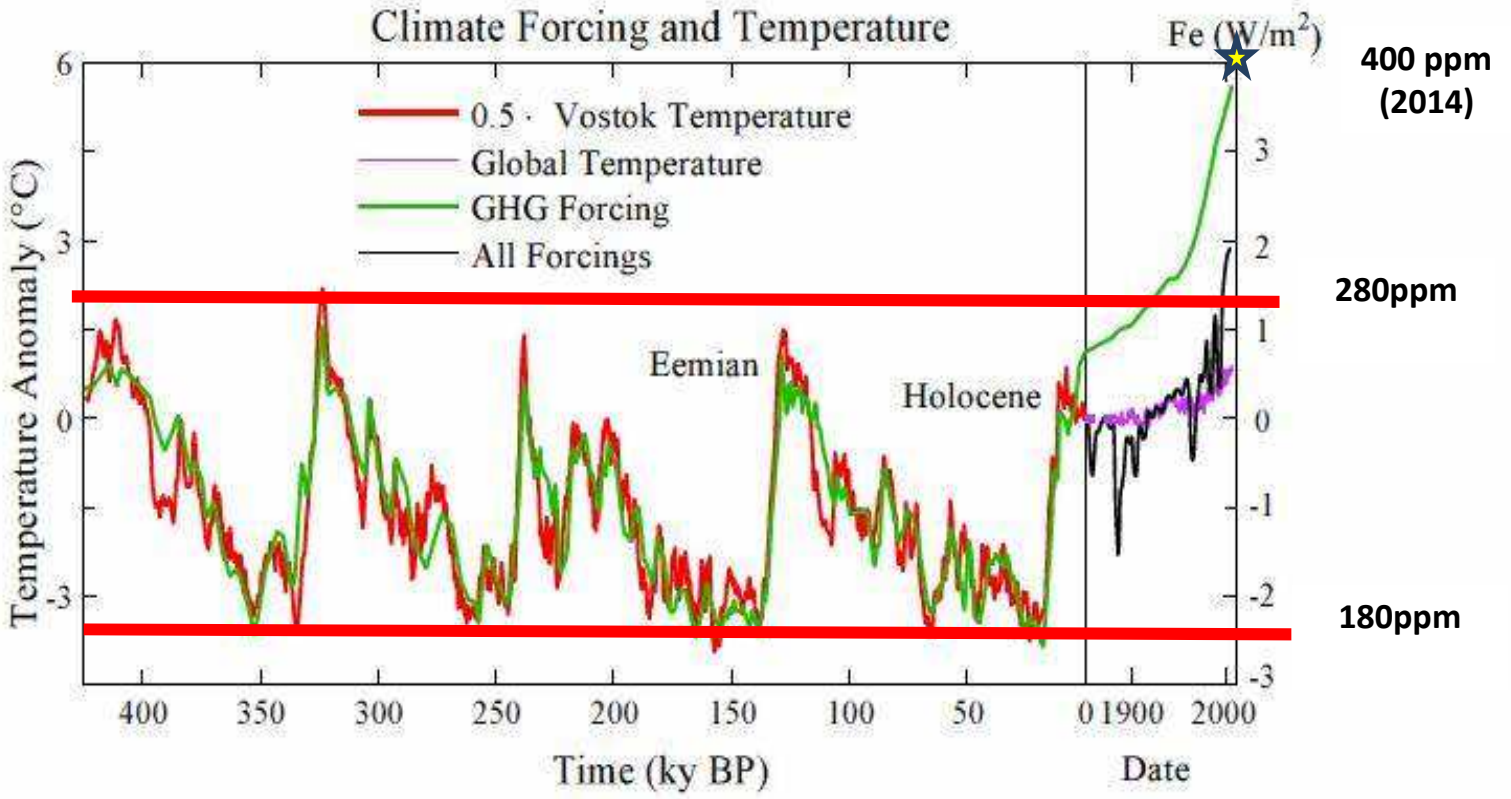
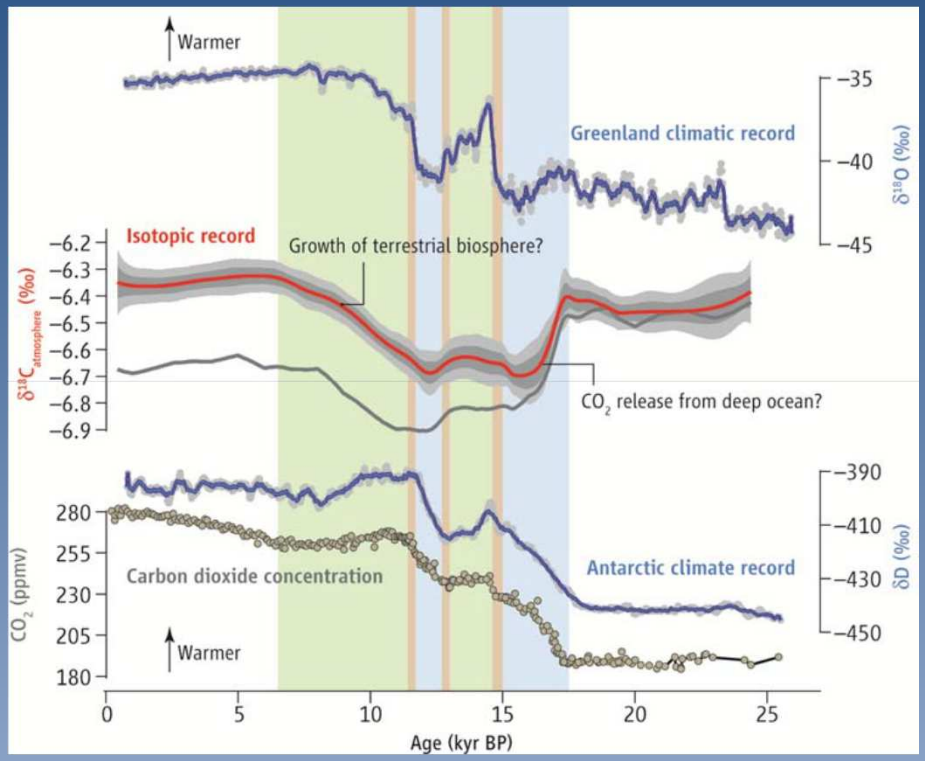


400 ppm (2014)

280ppm

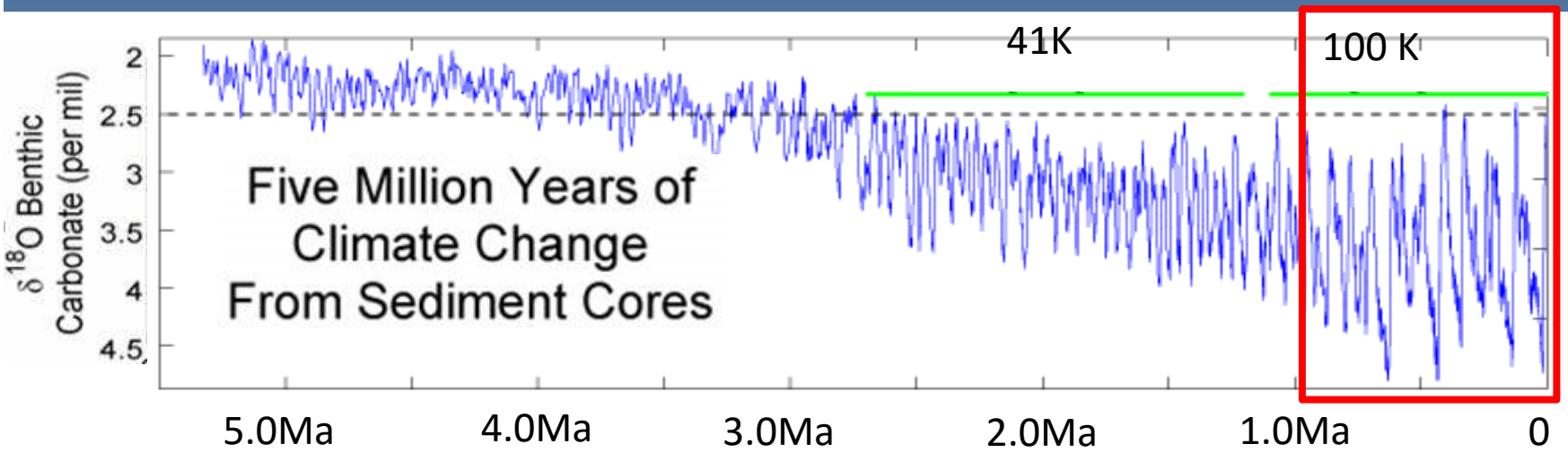
180ppm



Glacial-interglacial change. Over the course of the past 24,000 years, CO_2 concentrations have risen (black curve) (*1*) as Earth emerged from glaciation, as shown by climate records from Greenland and Antarctica (blue curves) (*14*, *15*). Schmitt *et al*. (*2*) report a record of the change in the $^{13}C/^{12}C$ ratio of CO_2 during this time (red curve). The isotopic ratio is expressed in delta notation, where $\delta_{13}C$ is the deviation of a sample ratio from that of an internationally expected standard, expressed in parts per thousand. Comparison of the CO_2 record with the isotopic record provides insights into the mechanisms behind the CO_2 rise.

/ http://www.sciencemag.org/content/early/recent / 29 March 2012 / Page 1/ 10.1126/science.1219710

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



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Paleocene/Eocene Thermal Maximum
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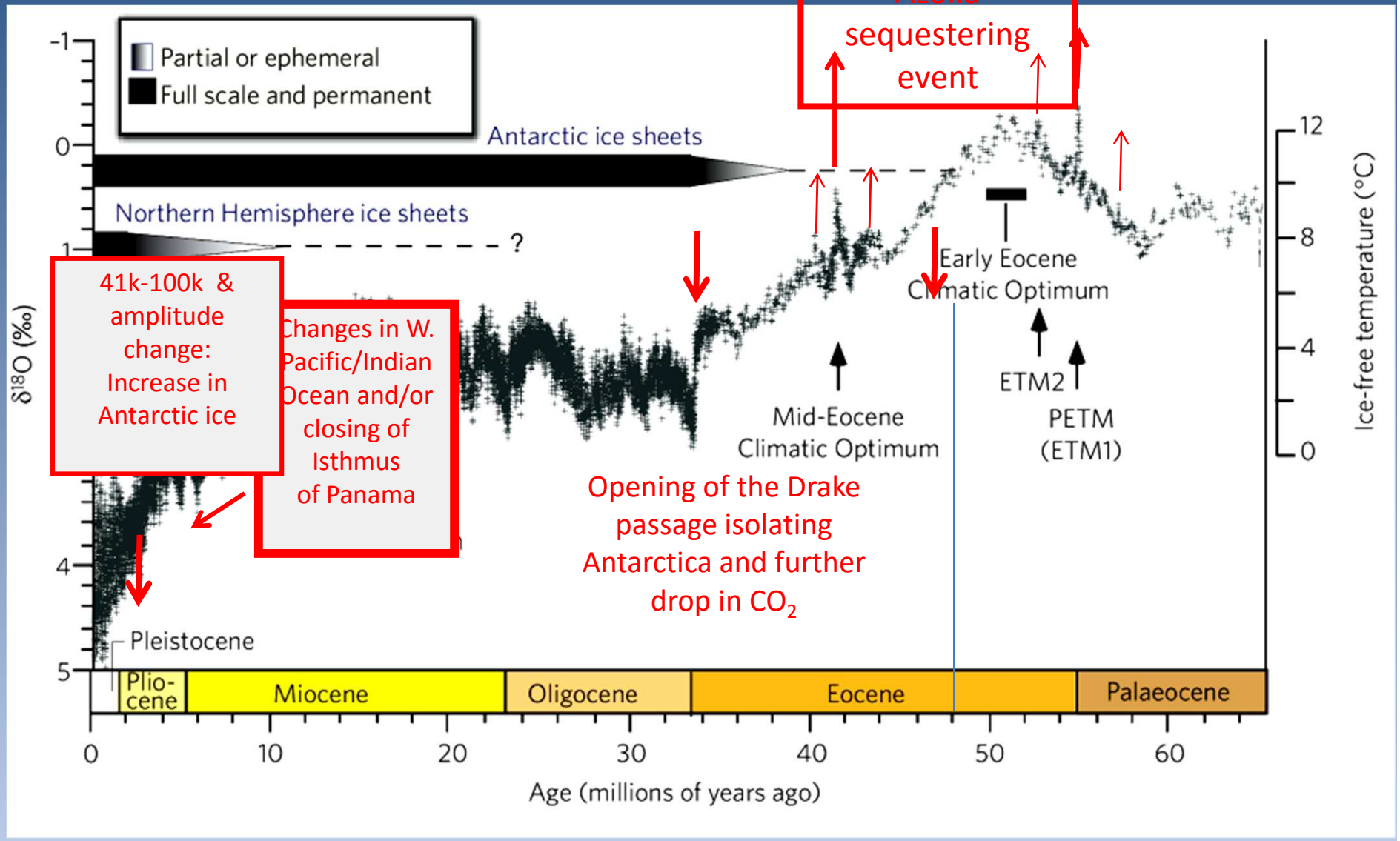

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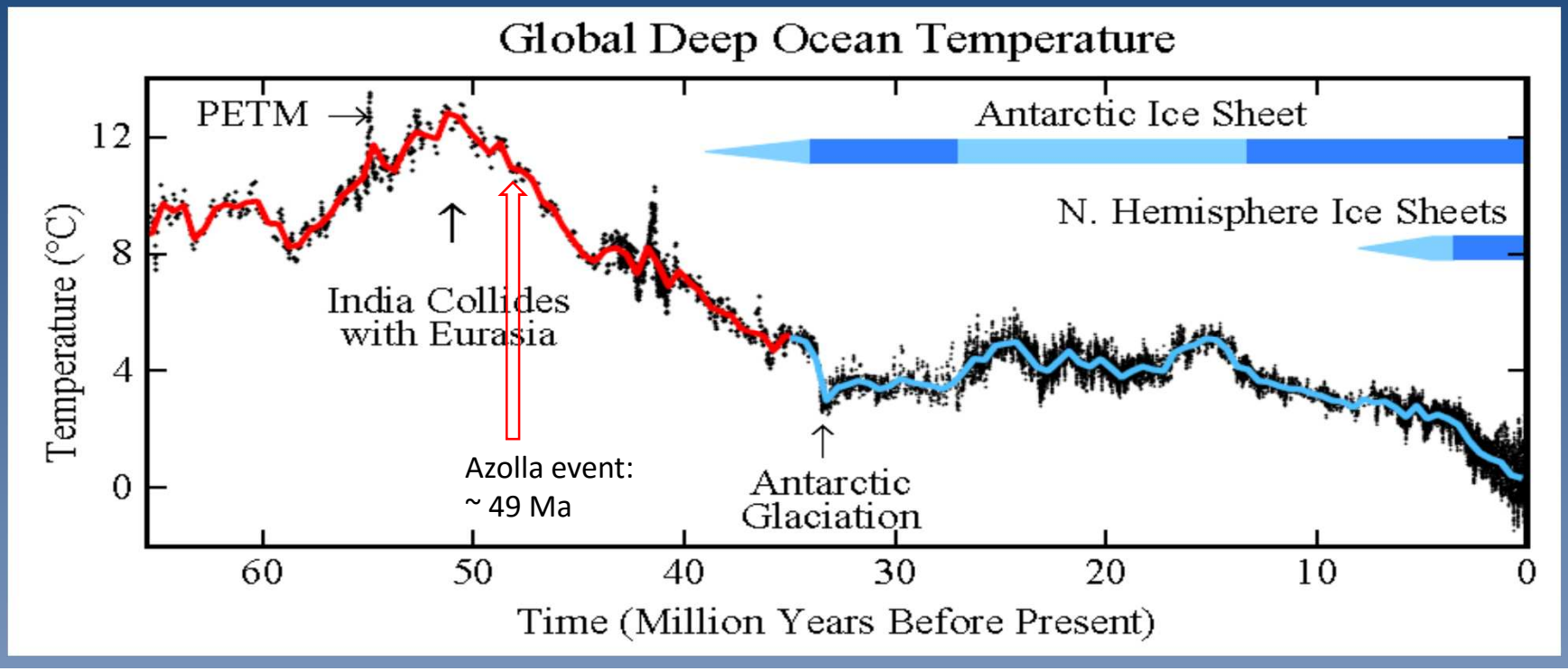
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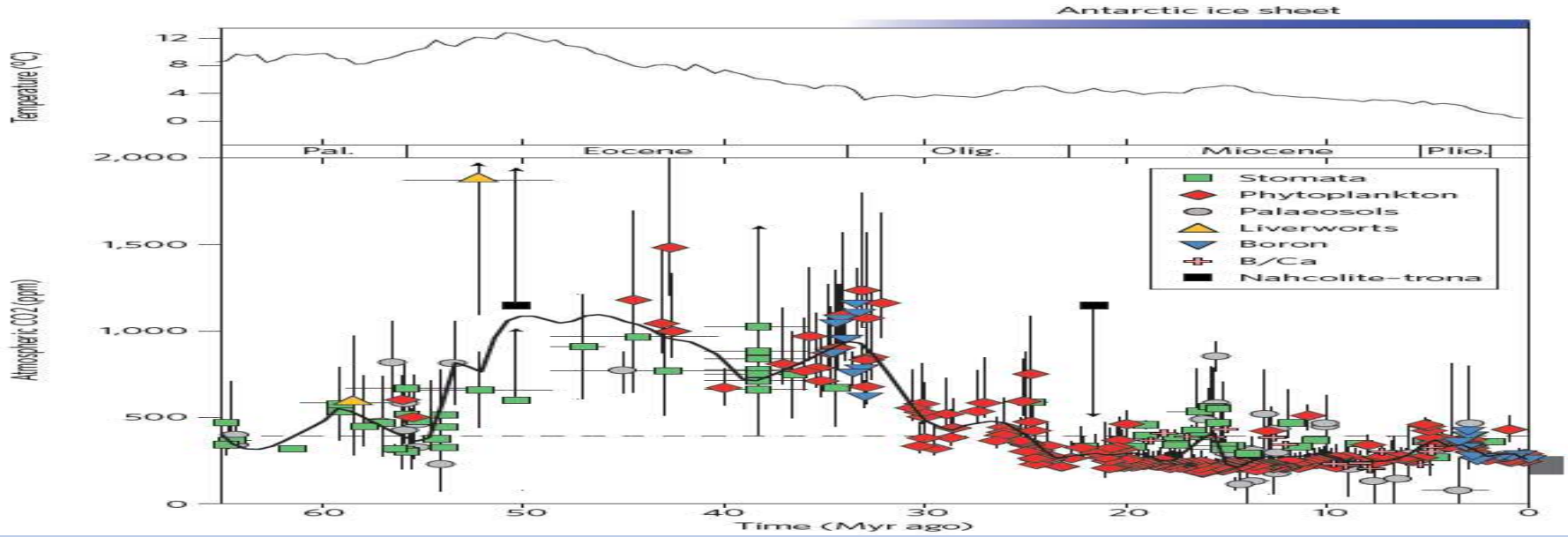
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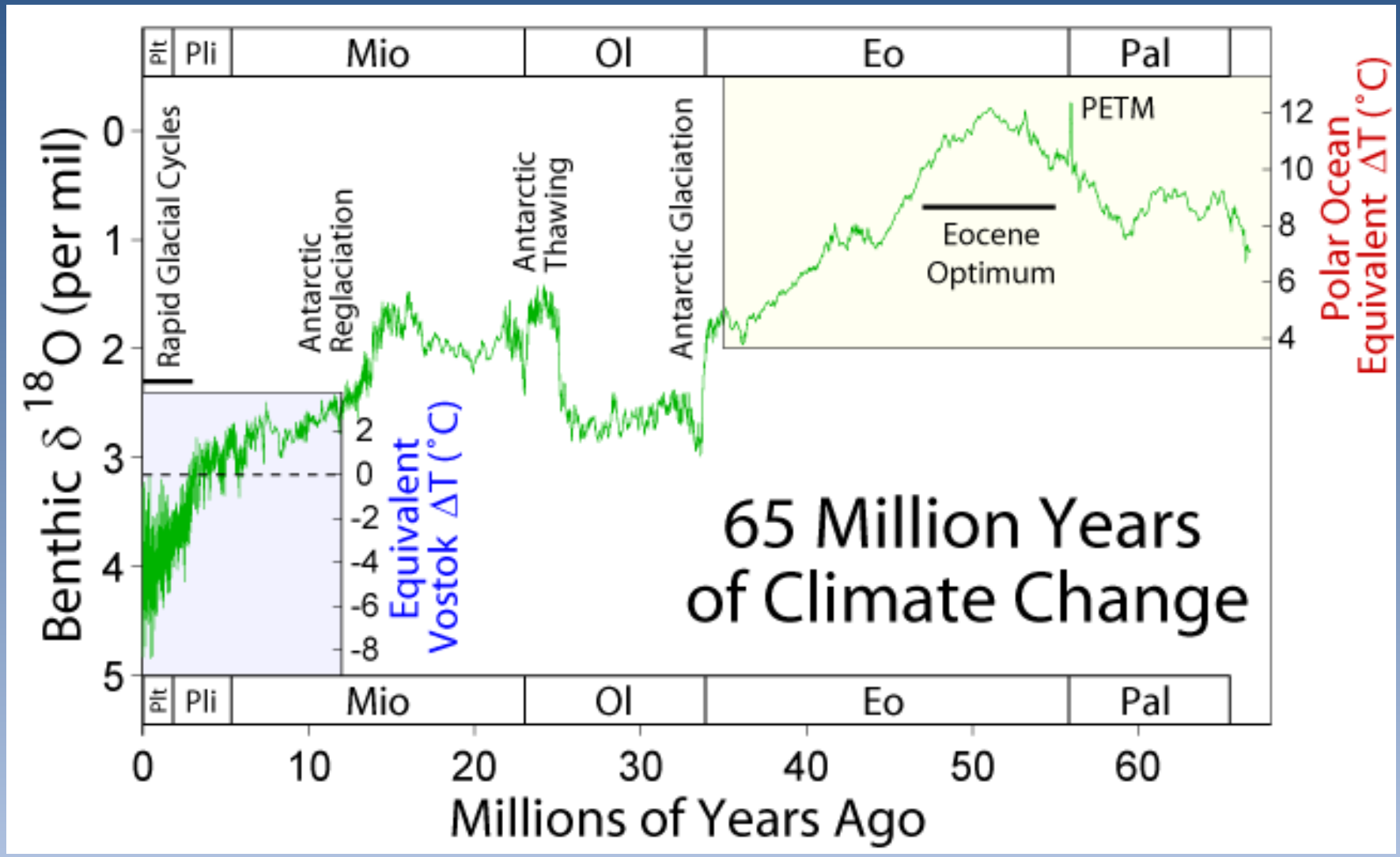
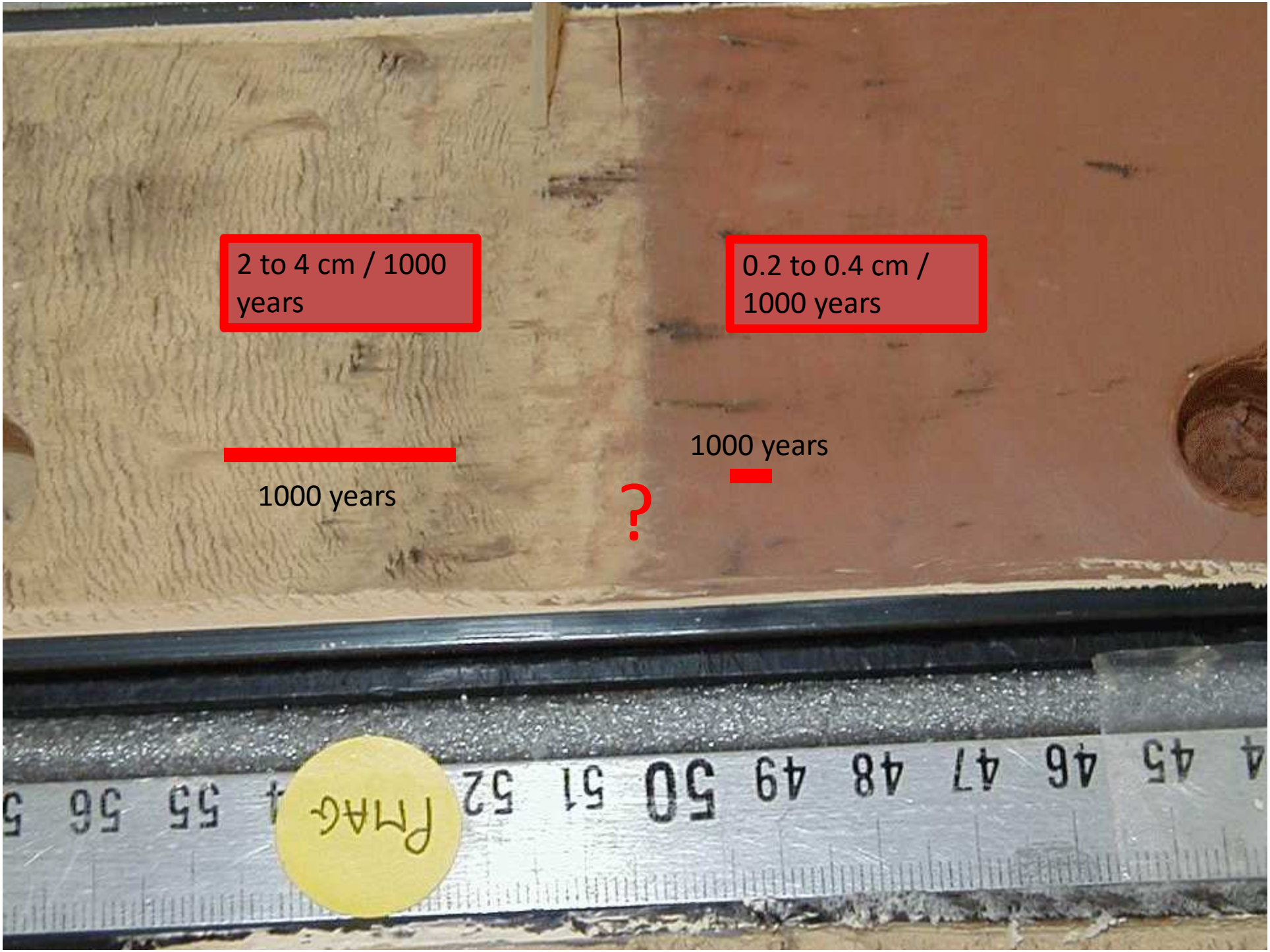
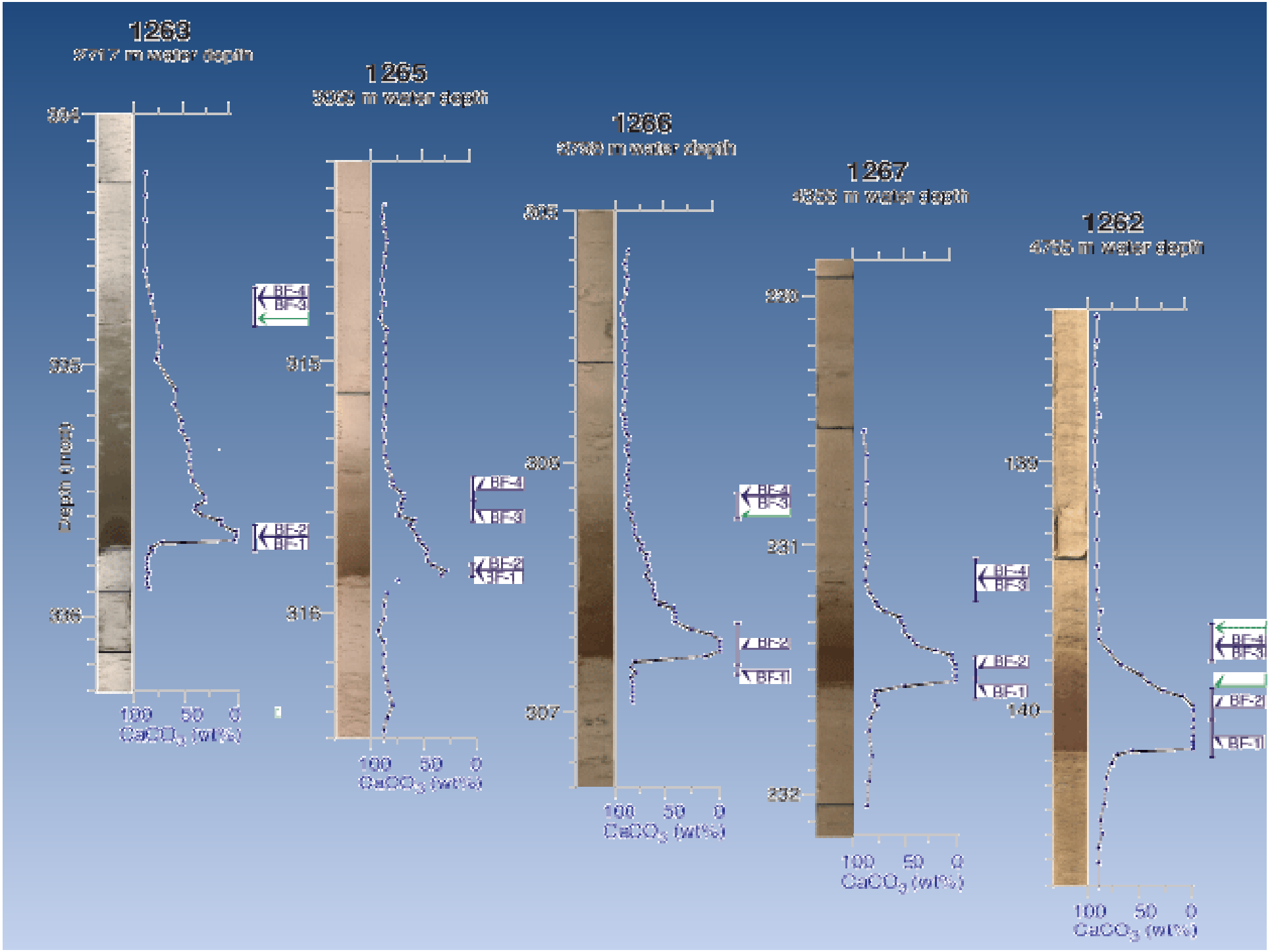
Proxy data: stable isotopes



Wikipedia


2 to 4 cm / 1000 years
0.2 to 0.4 cm / 1000 years
1000 years
1000 years
?


1263
1265
3362 m water depth
1266
1267
4355 m water depth
1262
4755 m water depth
Depth (mcd)
334
335
336
315
316
307
231
232
139
140
100 50 0
CaCO3 (wt%)
BF-4
BF-3
BF-2
BF-1

It took a long time to recover

The Azolla event

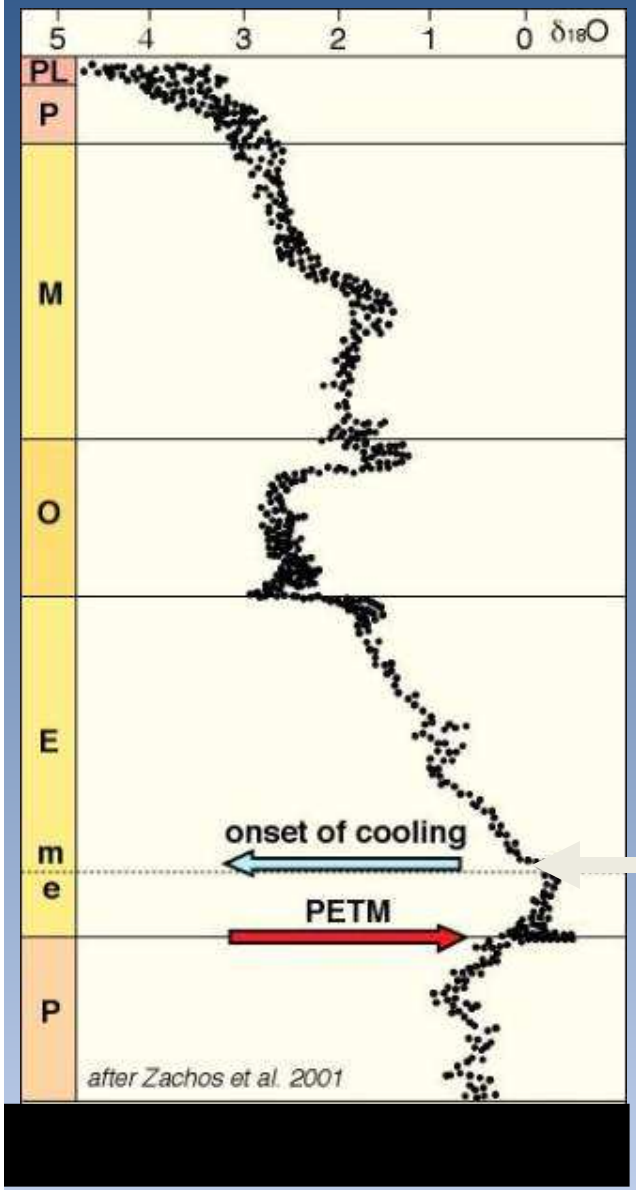
The Arctic Sea 50 million years ago

ACEX Azolla core

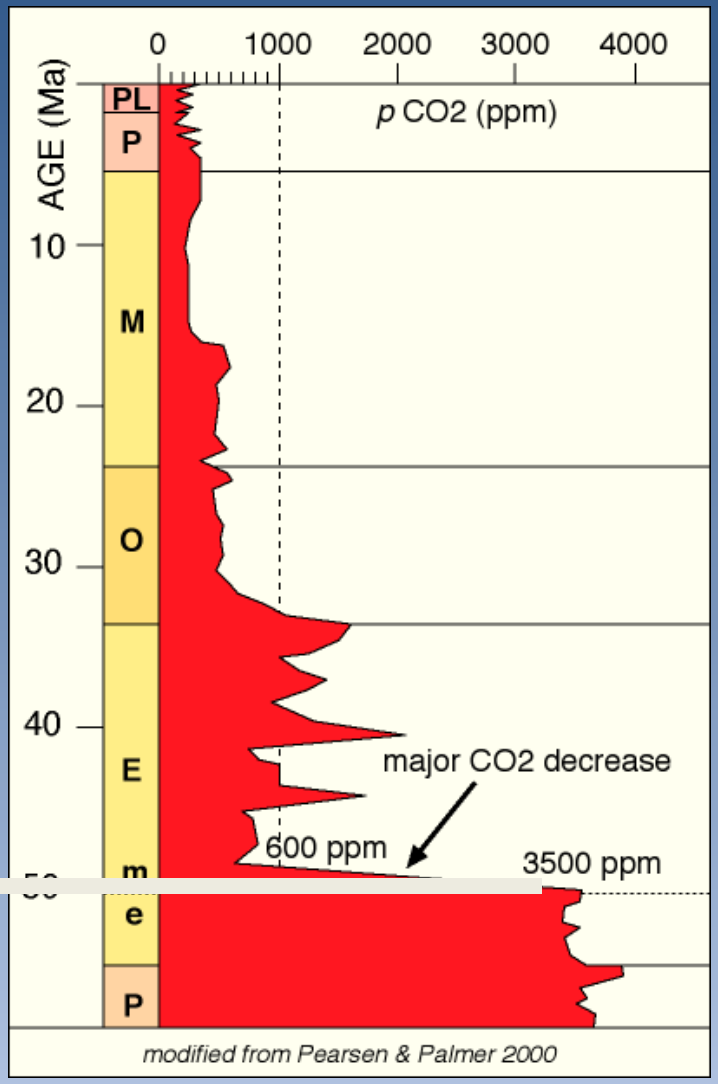
- >8 meter ACEX core with 90% Azolla
- Azolla occurs as laminated layers
- indicates Azolla deposited in situ
- bottom-water anoxia at ACEX site

Bujak, pers. Comm.

UNPRECEDENTED DROP IN CO_2



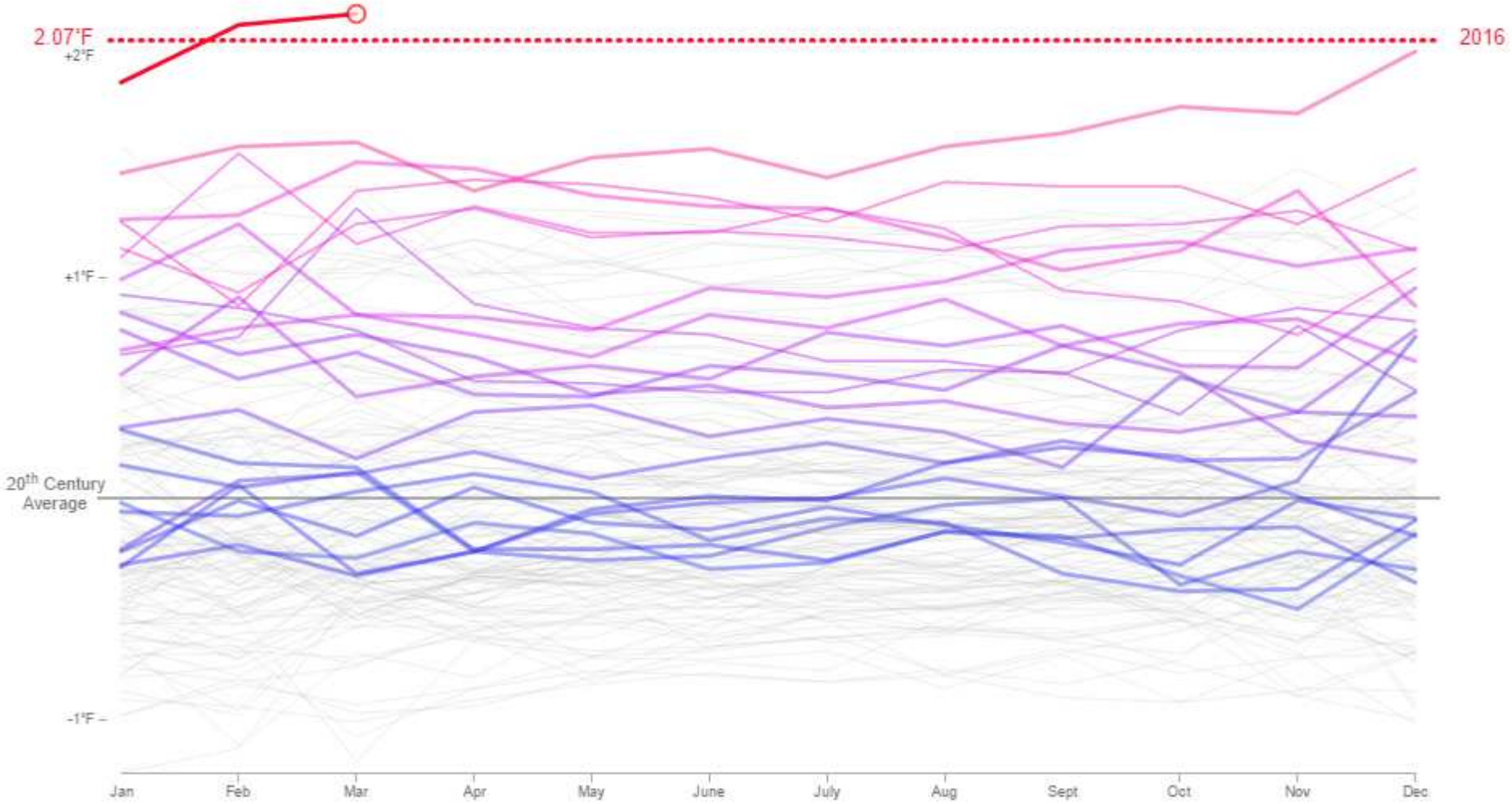
the massive decrease in atmospheric CO_2?

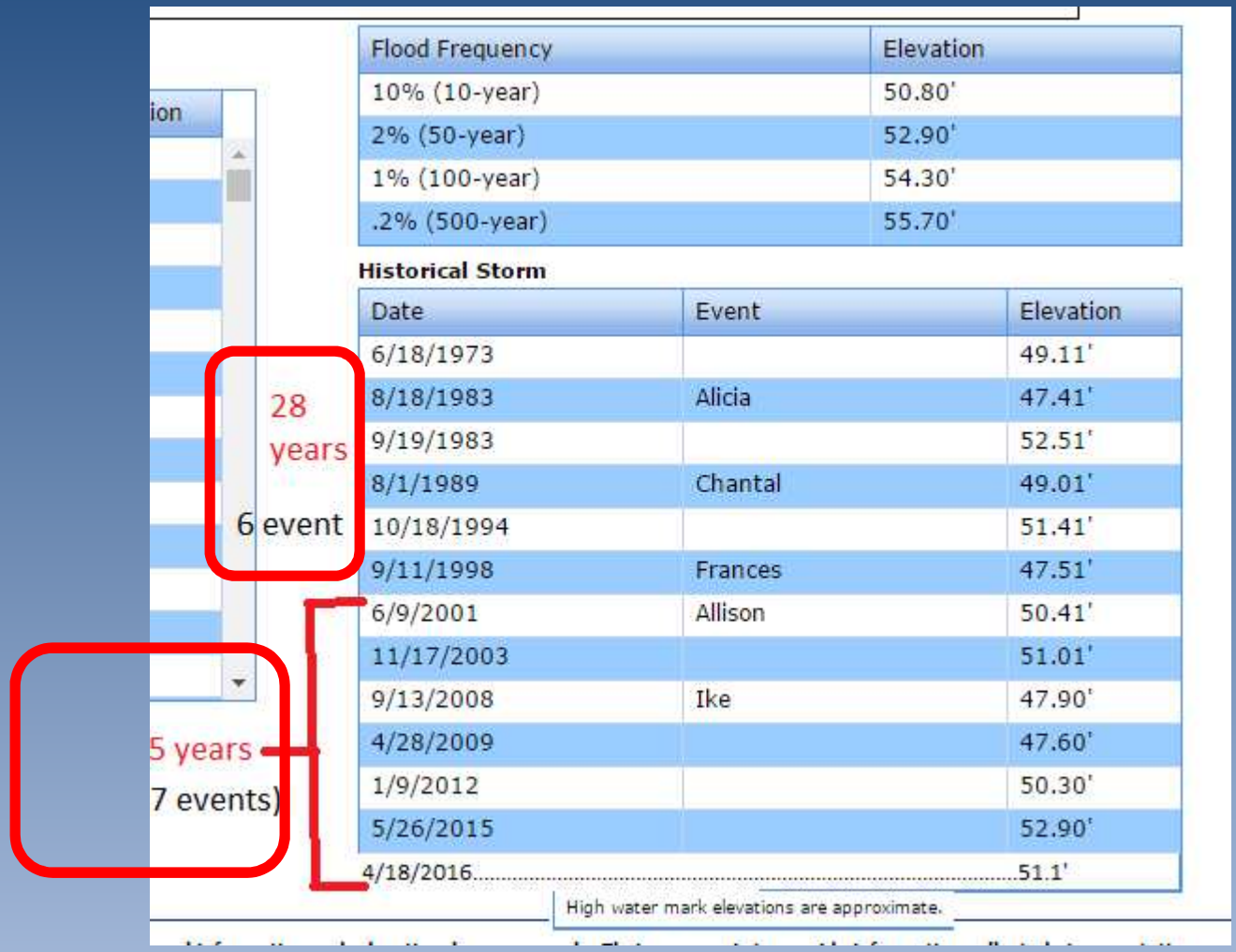


Bujak, pers. Comm.

Click To Start Animation

http://www.bloomberg.com/news/features/2016-04-19/earth-s-temperature-just-shattered-the-thermometer





Flood Frequency	Elevation
10% (10-year)	50.80'
2% (50-year)	52.90'
1% (100-year)	54.30'
.2% (500-year)	55.70'

Historical Storm

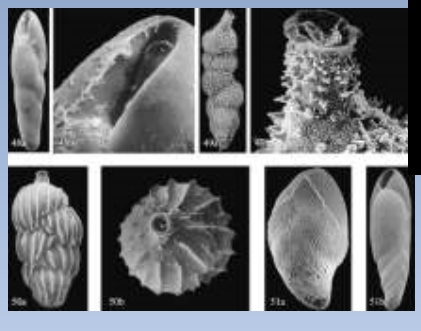
Date	Event	Elevation
6/18/1973		49.11'
8/18/1983	Alicia	47.41'
9/19/1983		52.51'
8/1/1989	Chantal	49.01'
10/18/1994		51.41'
9/11/1998	Frances	47.51'
6/9/2001	Allison	50.41'
11/17/2003		51.01'
9/13/2008	Ike	47.90'
4/28/2009		47.60'
1/9/2012		50.30'
5/26/2015		52.90'
4/18/2016		51.1'

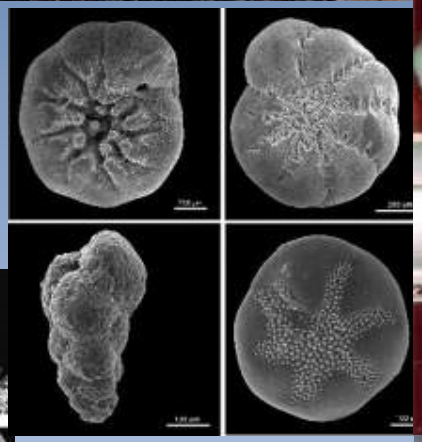
High water mark elevations are approximate.

http://www.harriscountyfws.org/GageDetail/Index/440?r=1&span=7#stream

3. Proxies that tell us of climate records

Scientific History of Climate change – 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

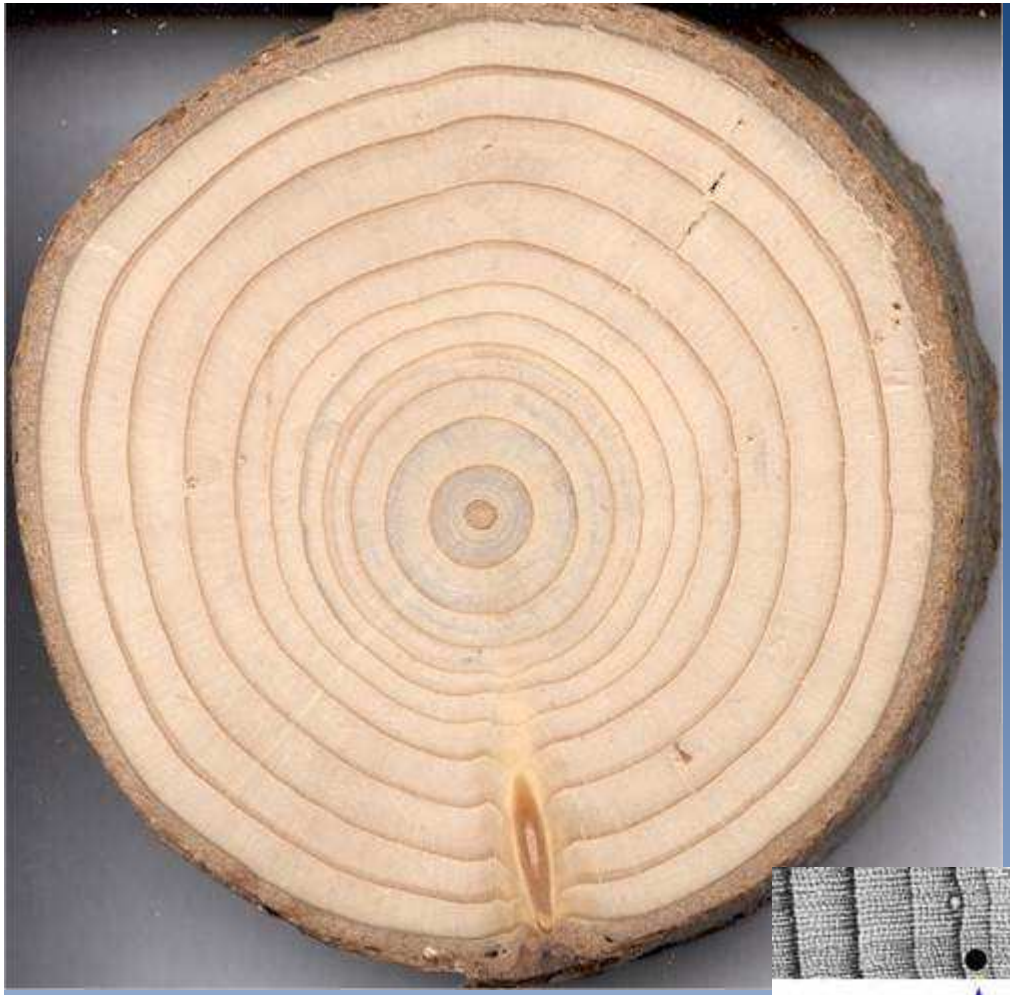
Louis Agassiz

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

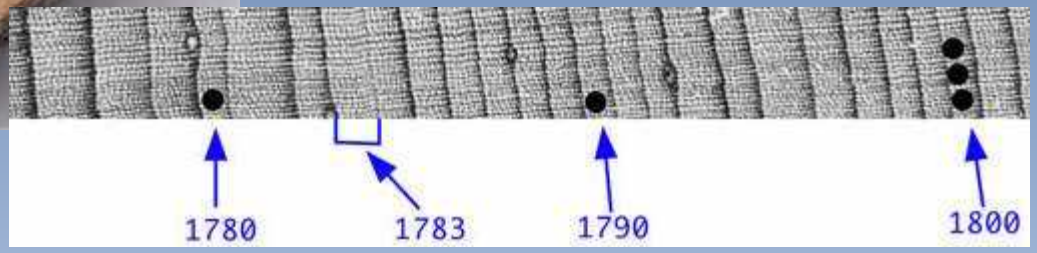
- **Jean Louis R. Agassiz**
- **"Father" of Glaciology**
- 1807-1873
- Paleontologist
- Glaciologist

Photographic proxy data/evidence

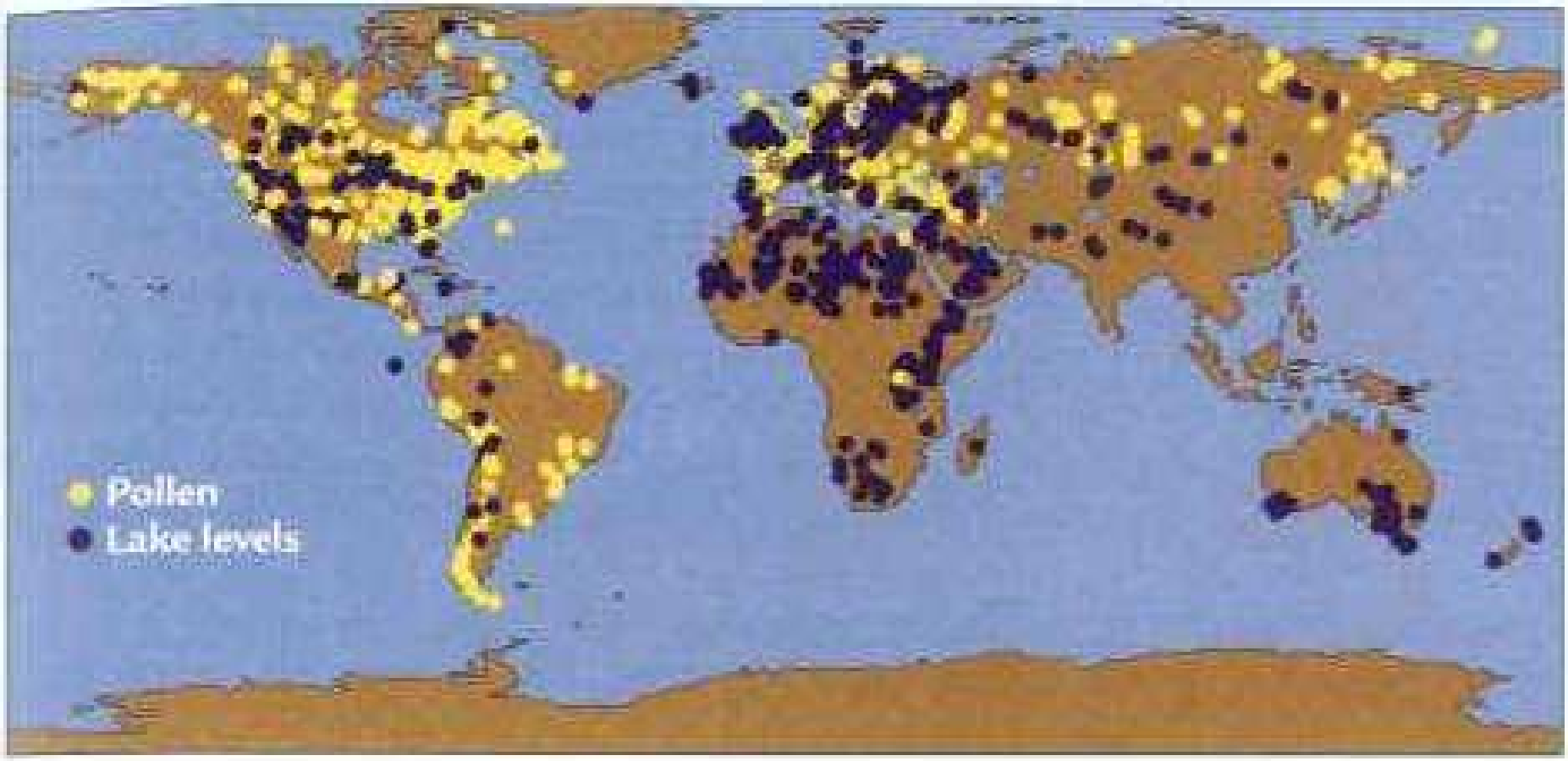
Ruddiman, 2008



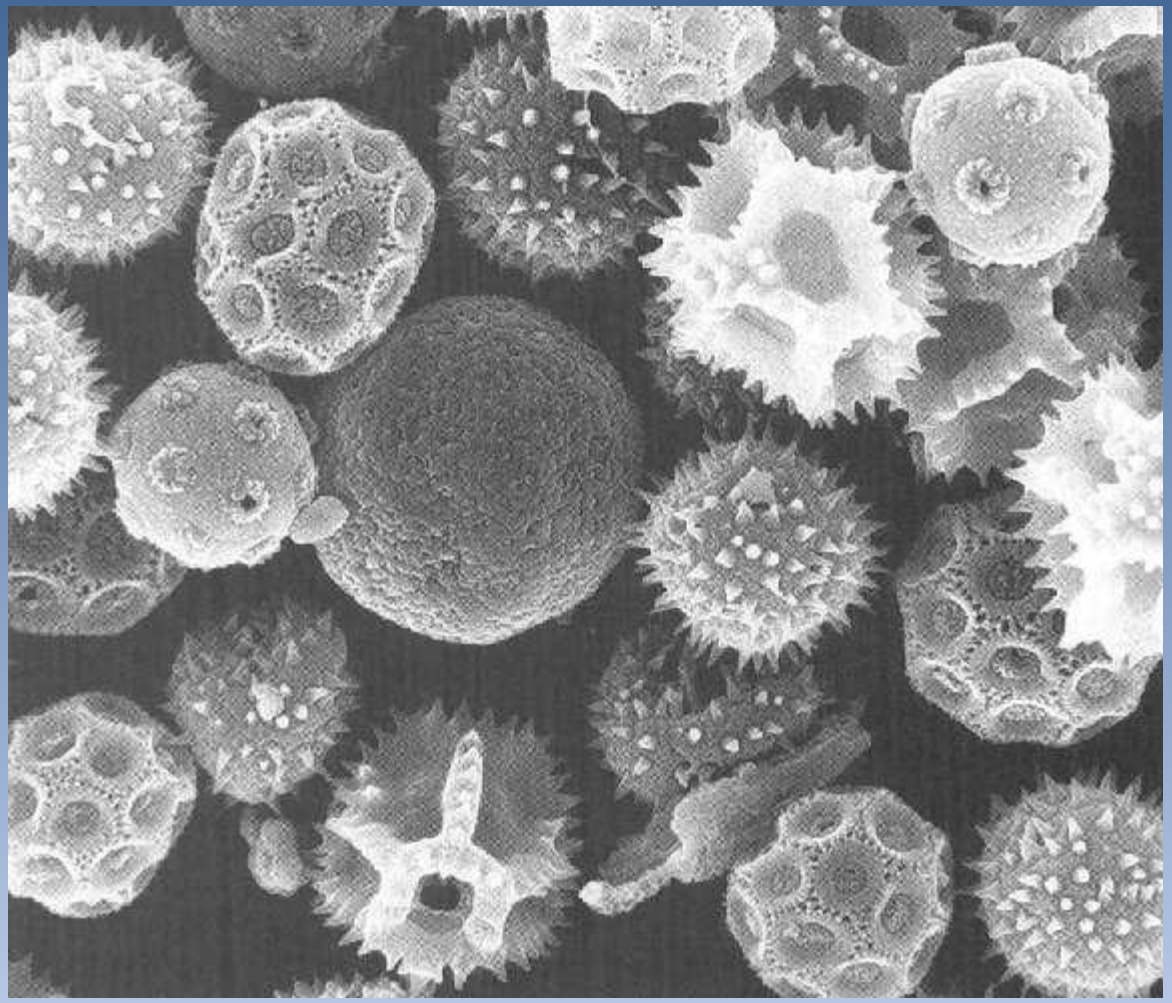
EARLY PROXY DATA: TREE RINGS



Pollen & Lake core data

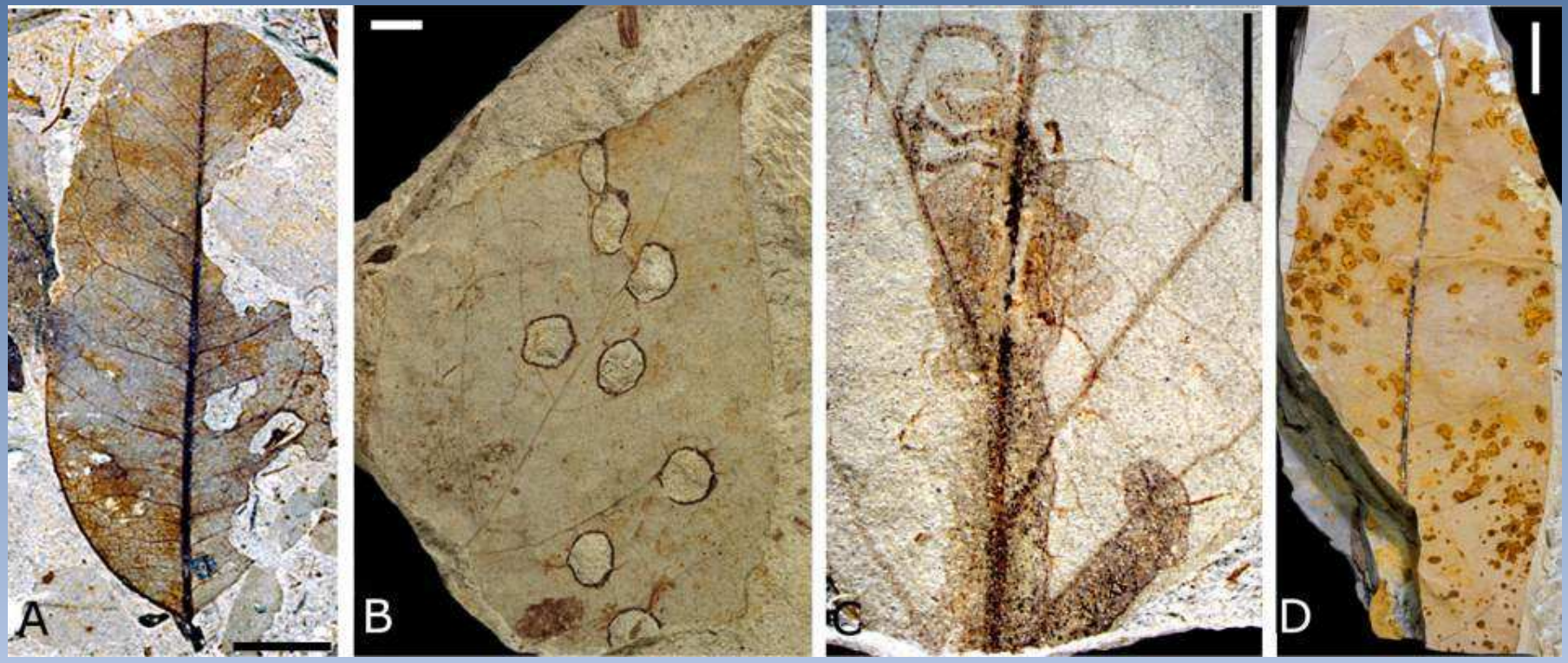


Ruddiman, 2008

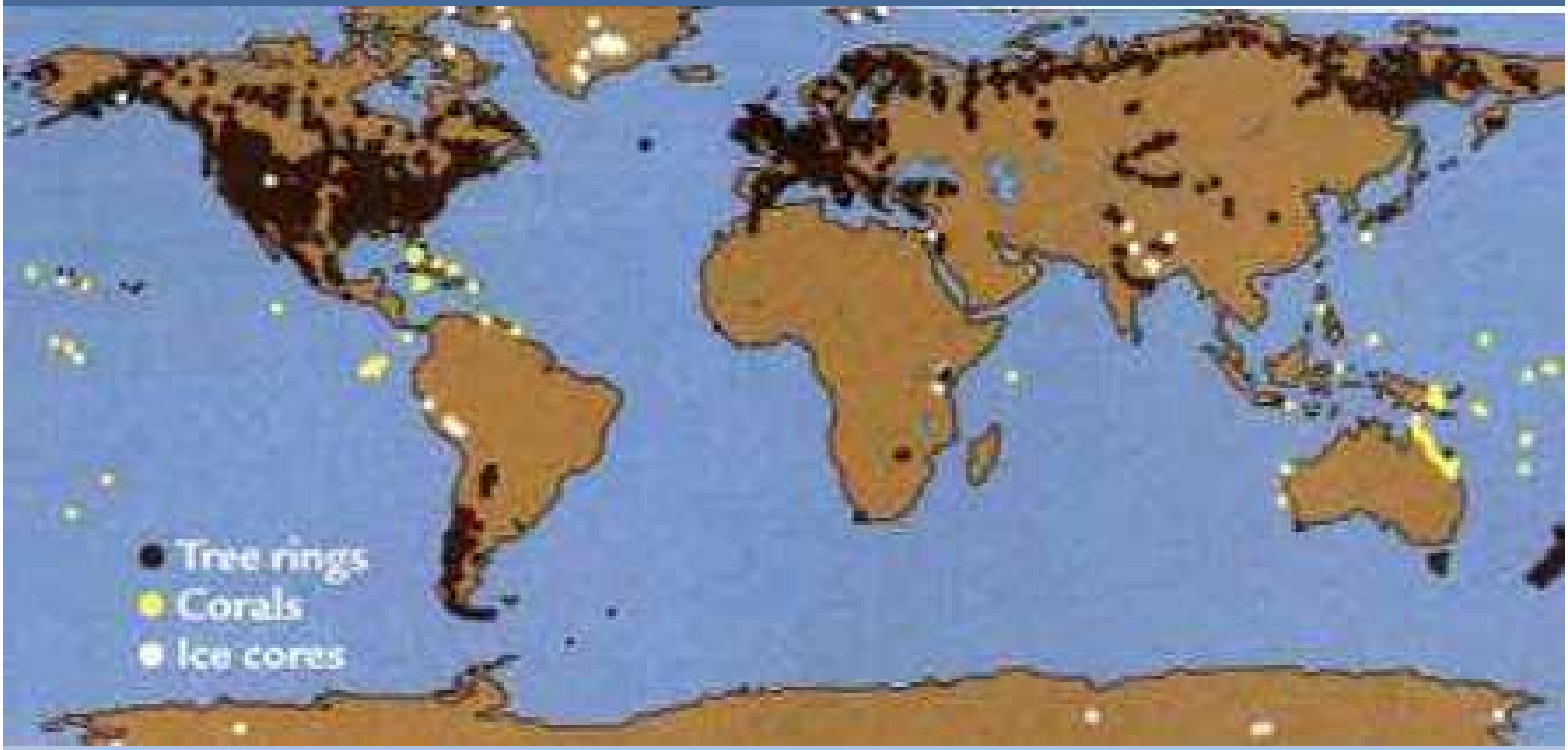


PROXY DATA: POLLEN DATA

PROXY DATA: LEAVES

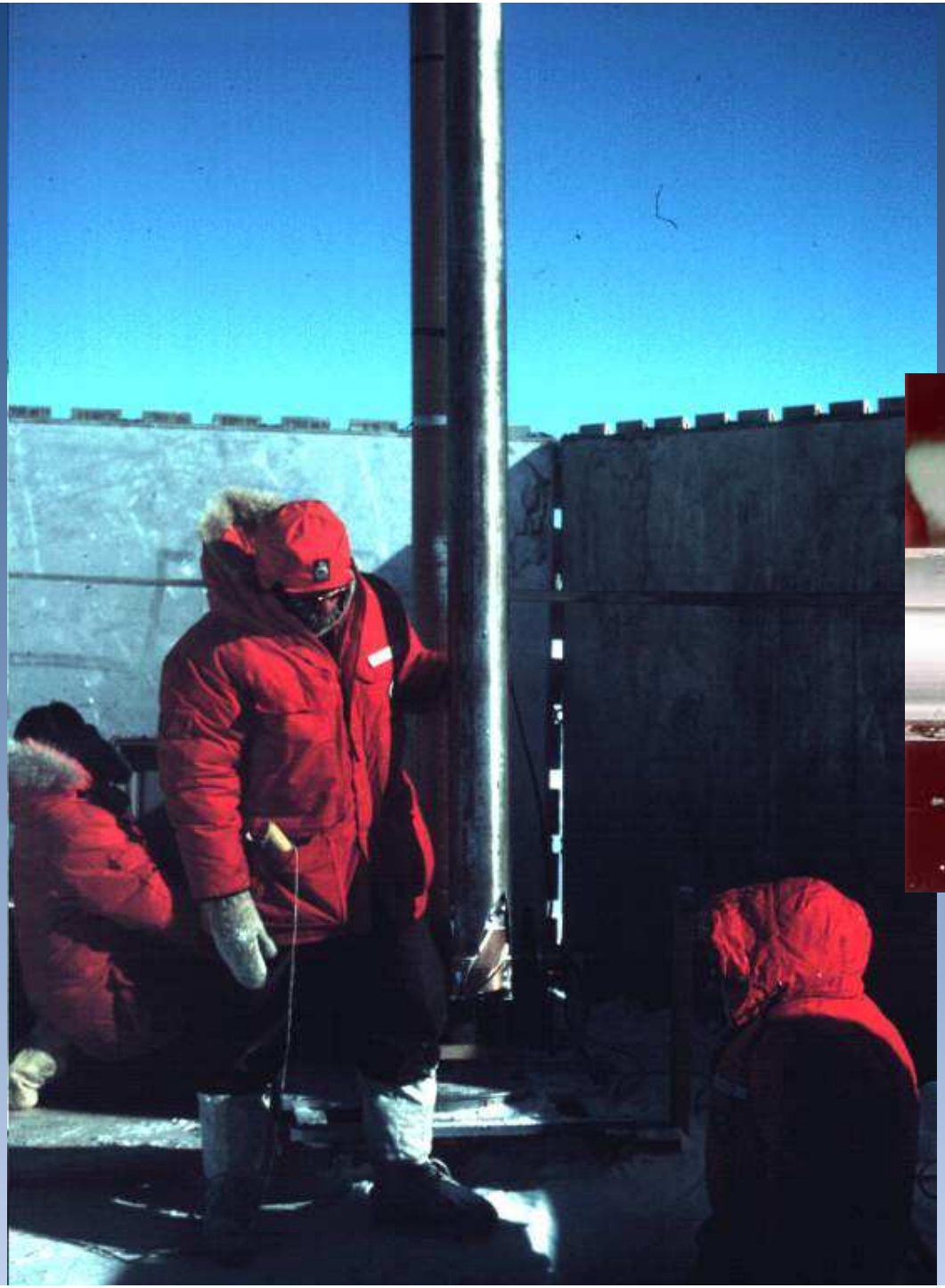


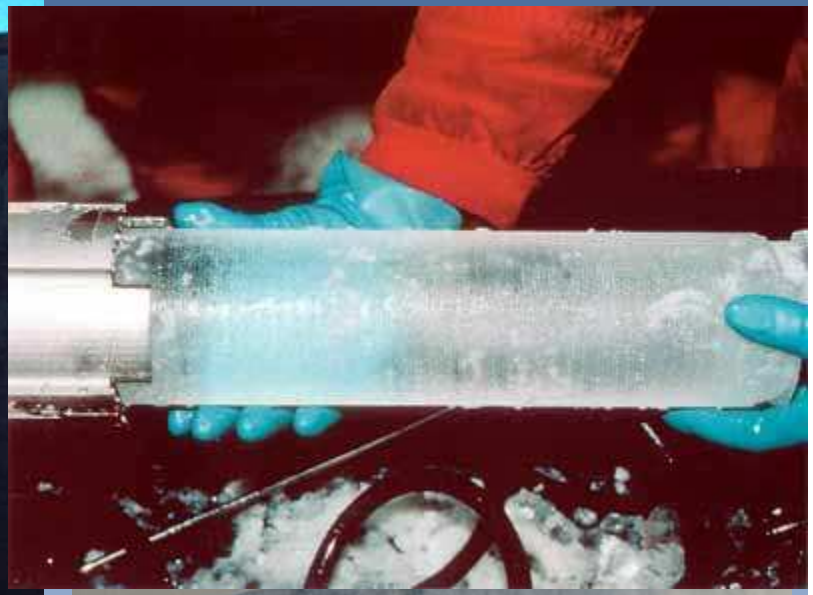
Tree rings, corals, ice cores



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).

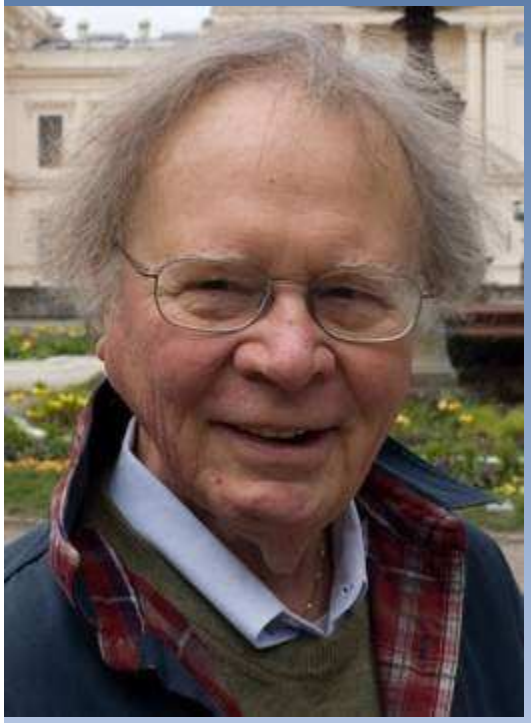
Cesare Emilani:

Paleontologist, Chemist

Father of Paleoceanography

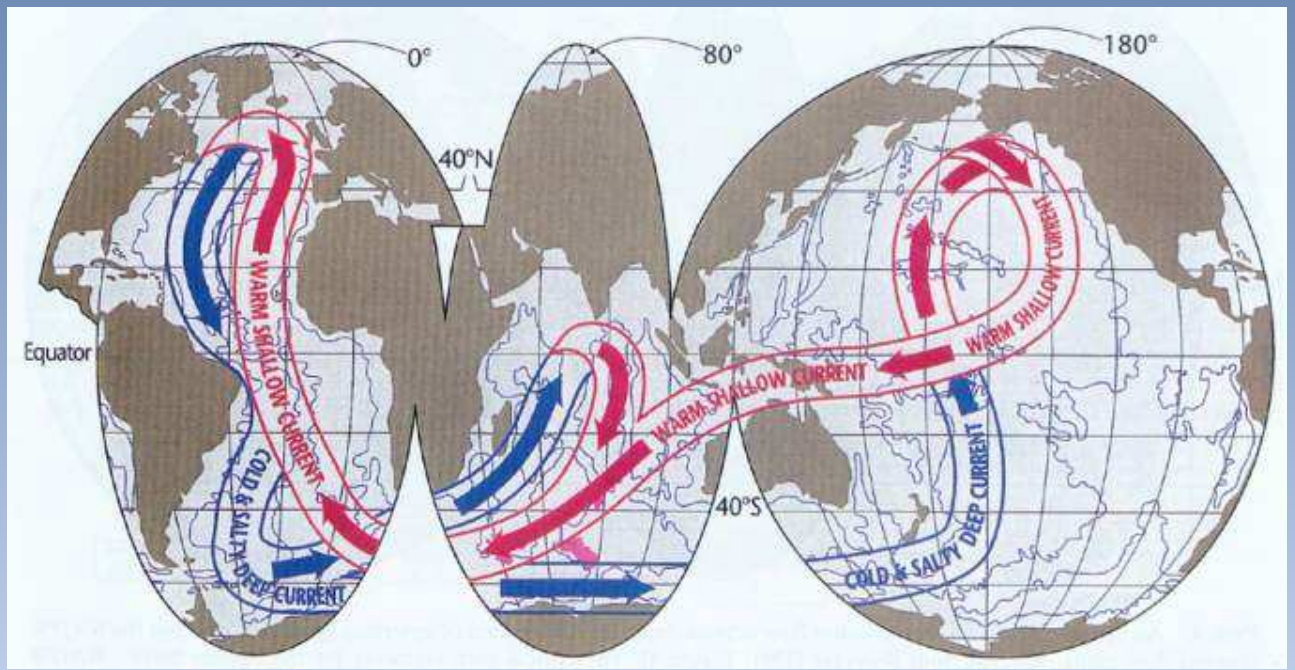
Other Paleoceanographers

Wally Broecker



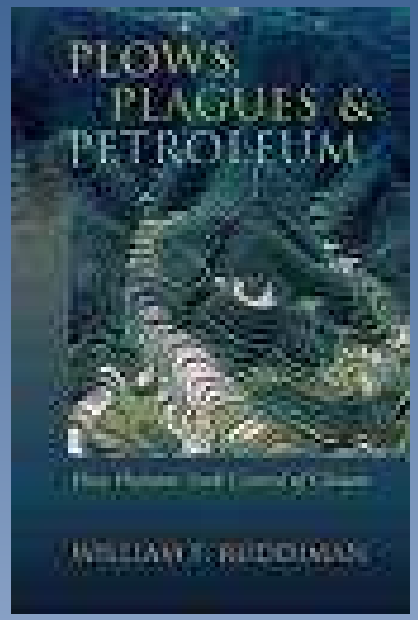
Thermal-haline

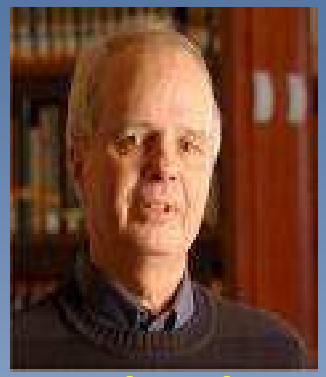
"conveyor" belt of circulation



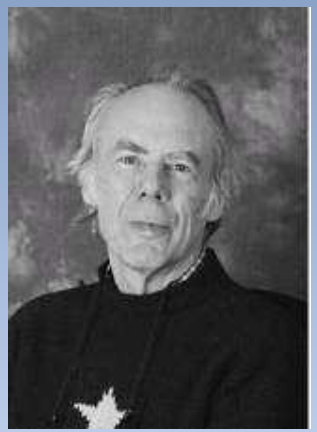
Other Paleoceanographers

Bill Ruddiman





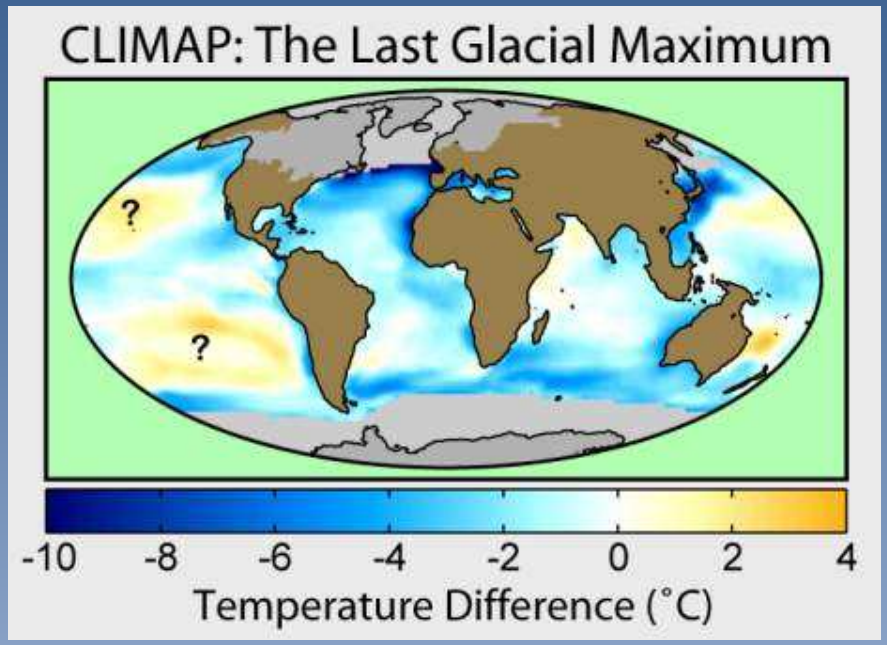
Nick Shackleton

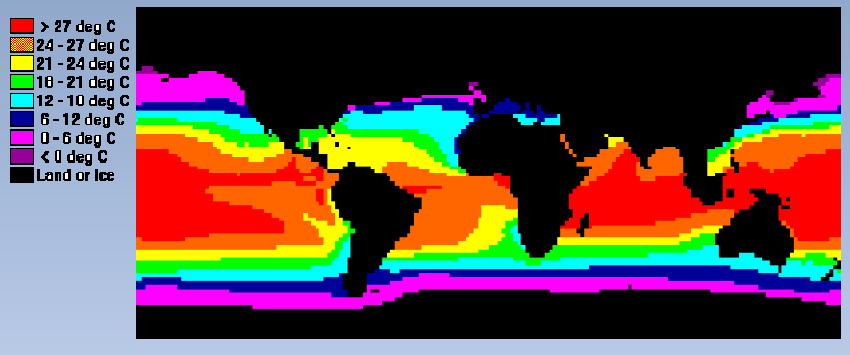


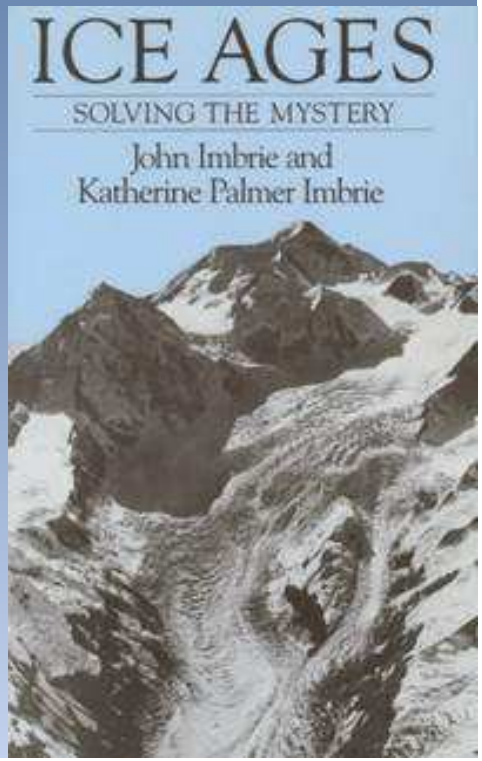
Other Paleoceanographers

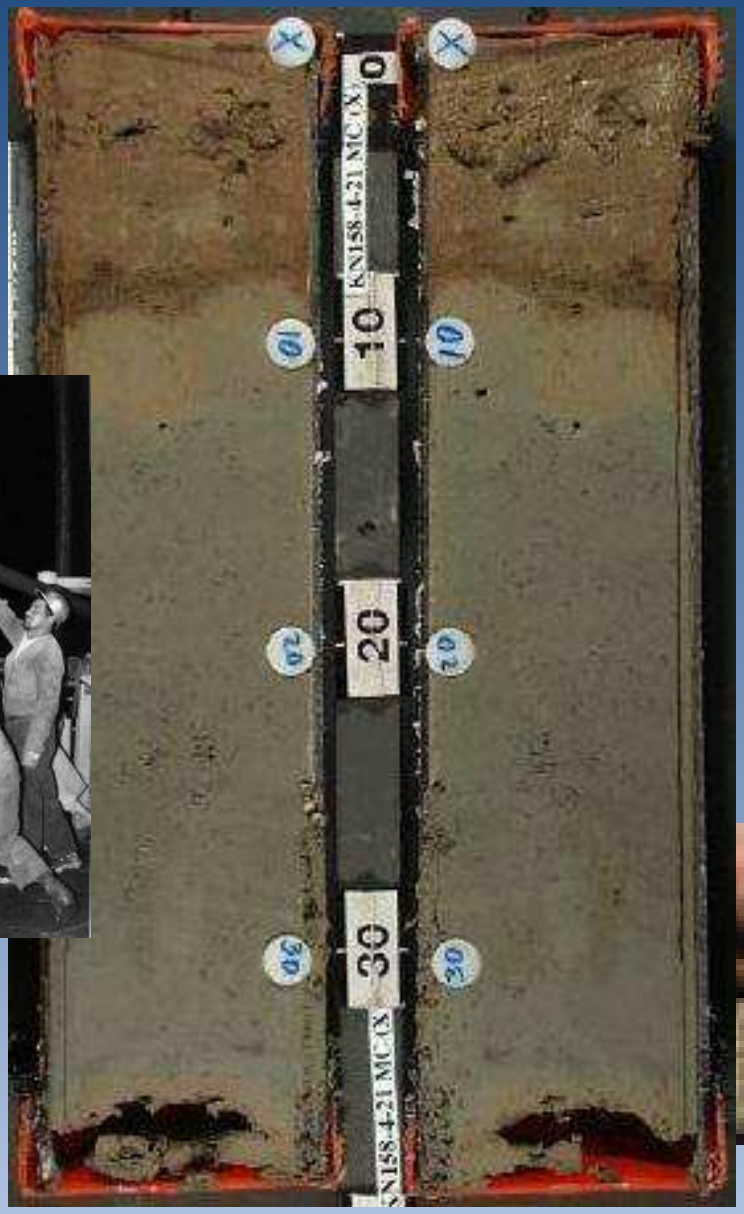
John Imbrie:

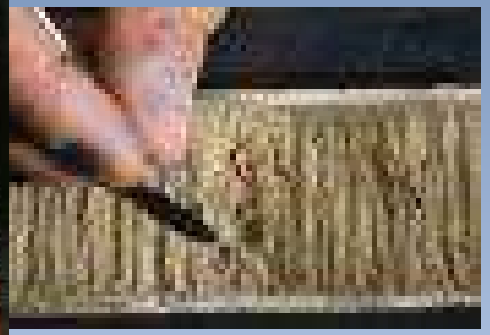
CLIMAP





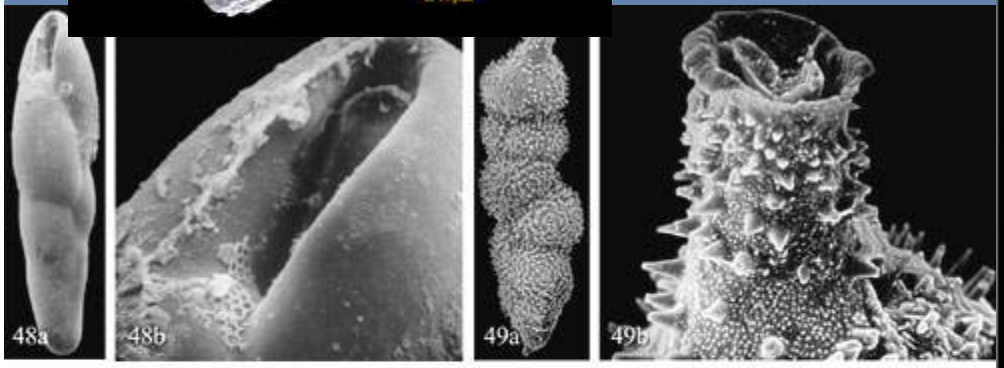


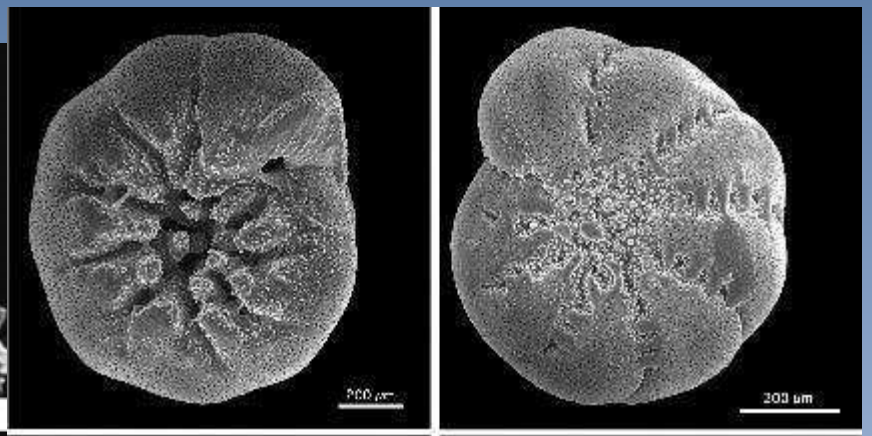


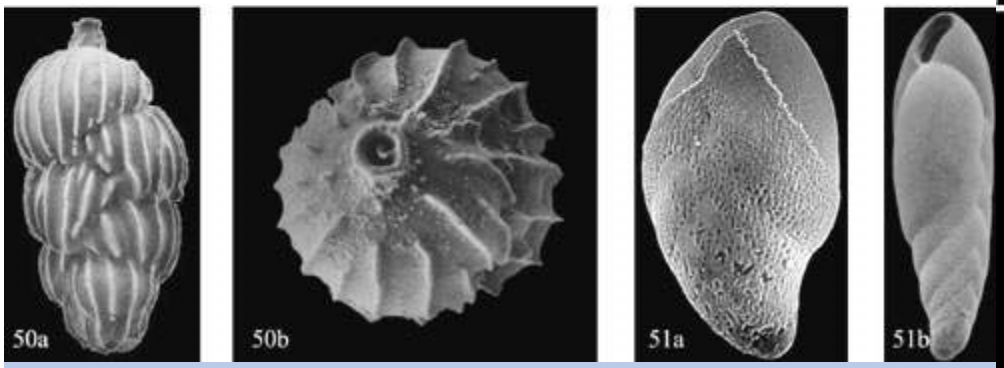


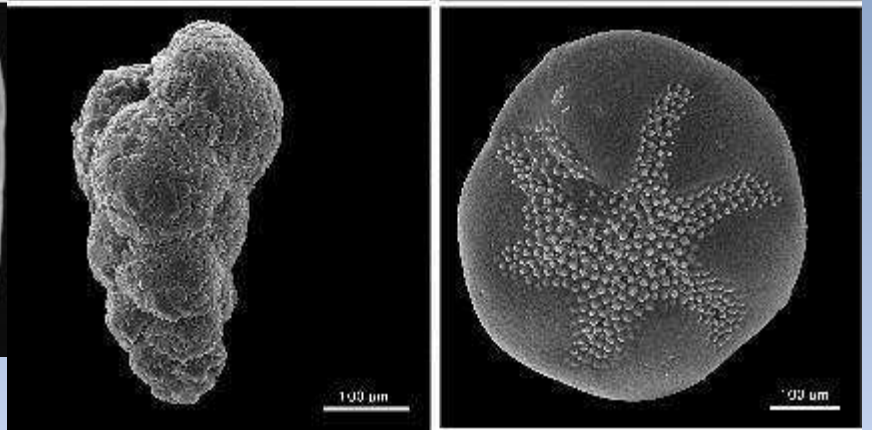
PROXY DATA: CORE DATA

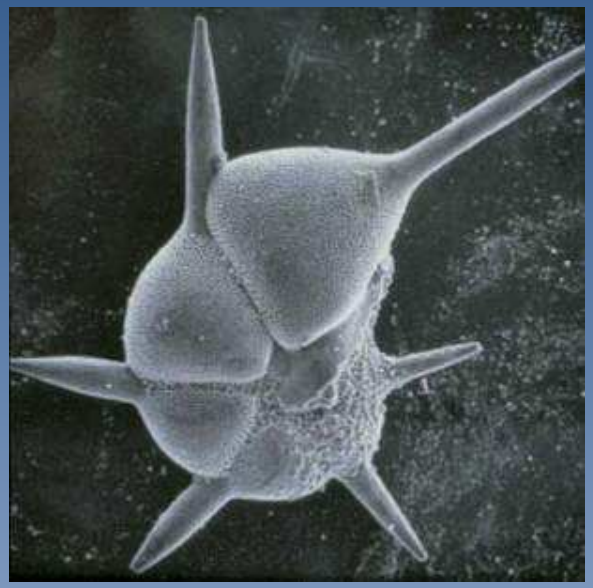
PROXY DATA: BENTHIC FORAMS





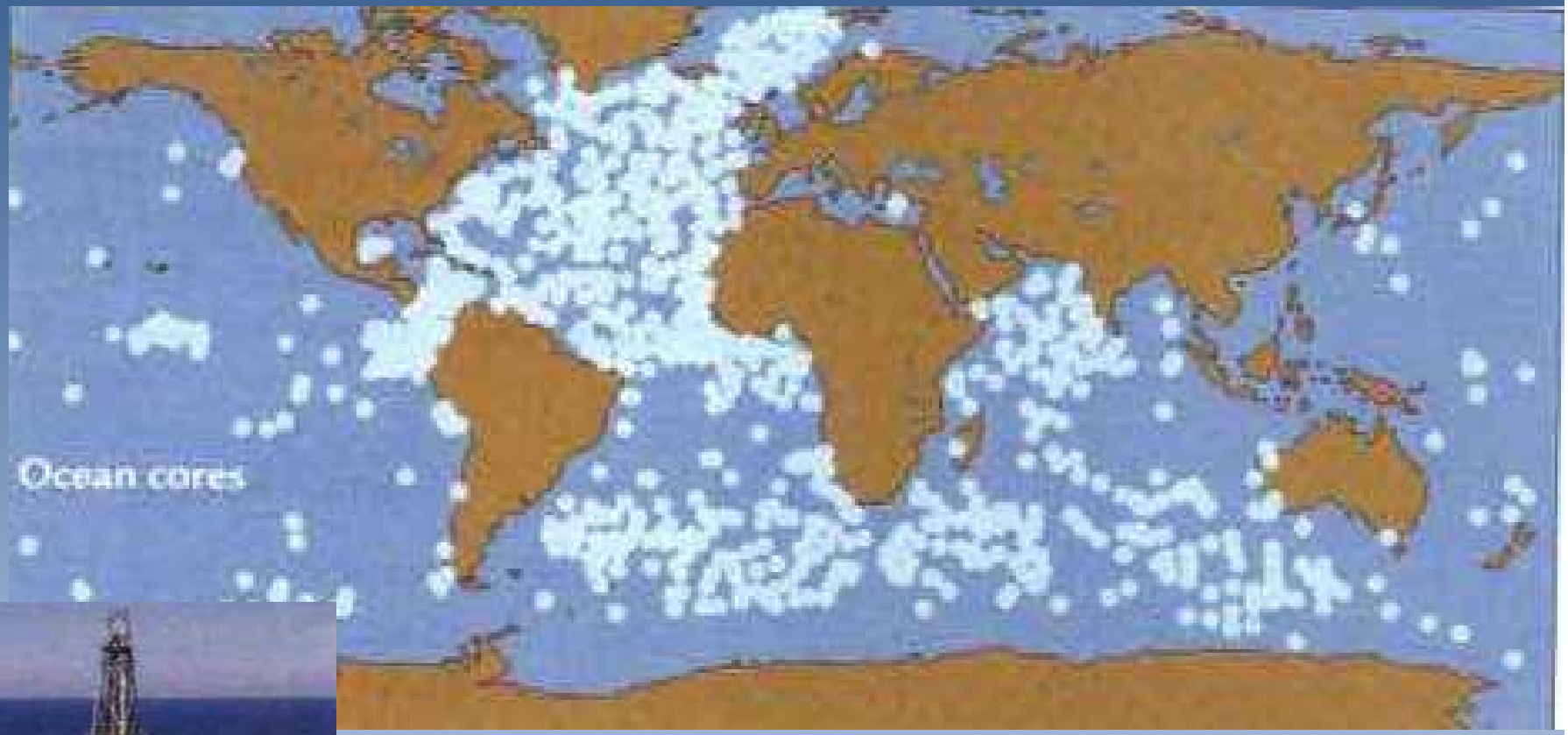






PROXY DATA: PLANKTONIC FORAMS

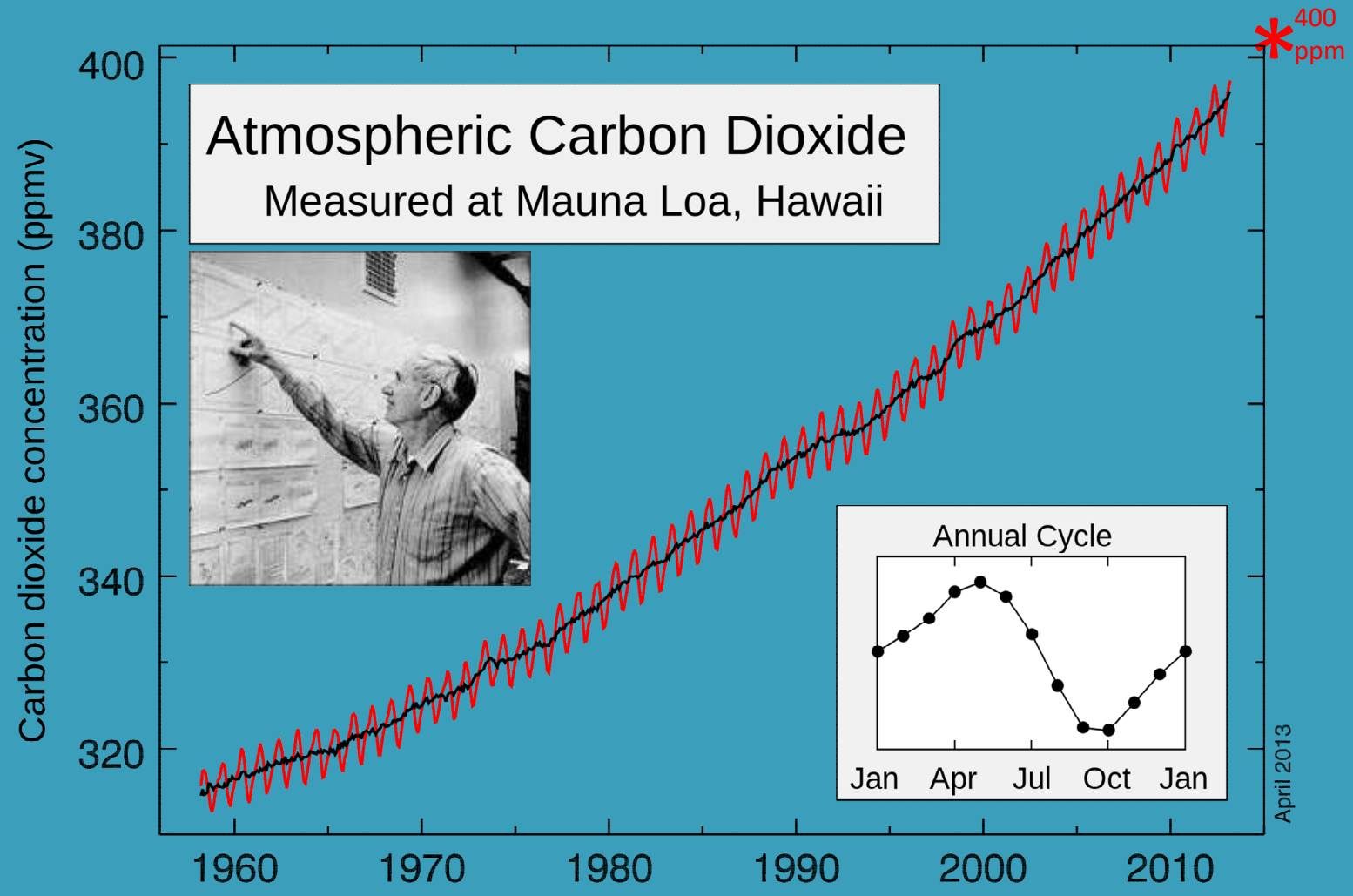
Deep Sea Coring



Ruddiman, 2008

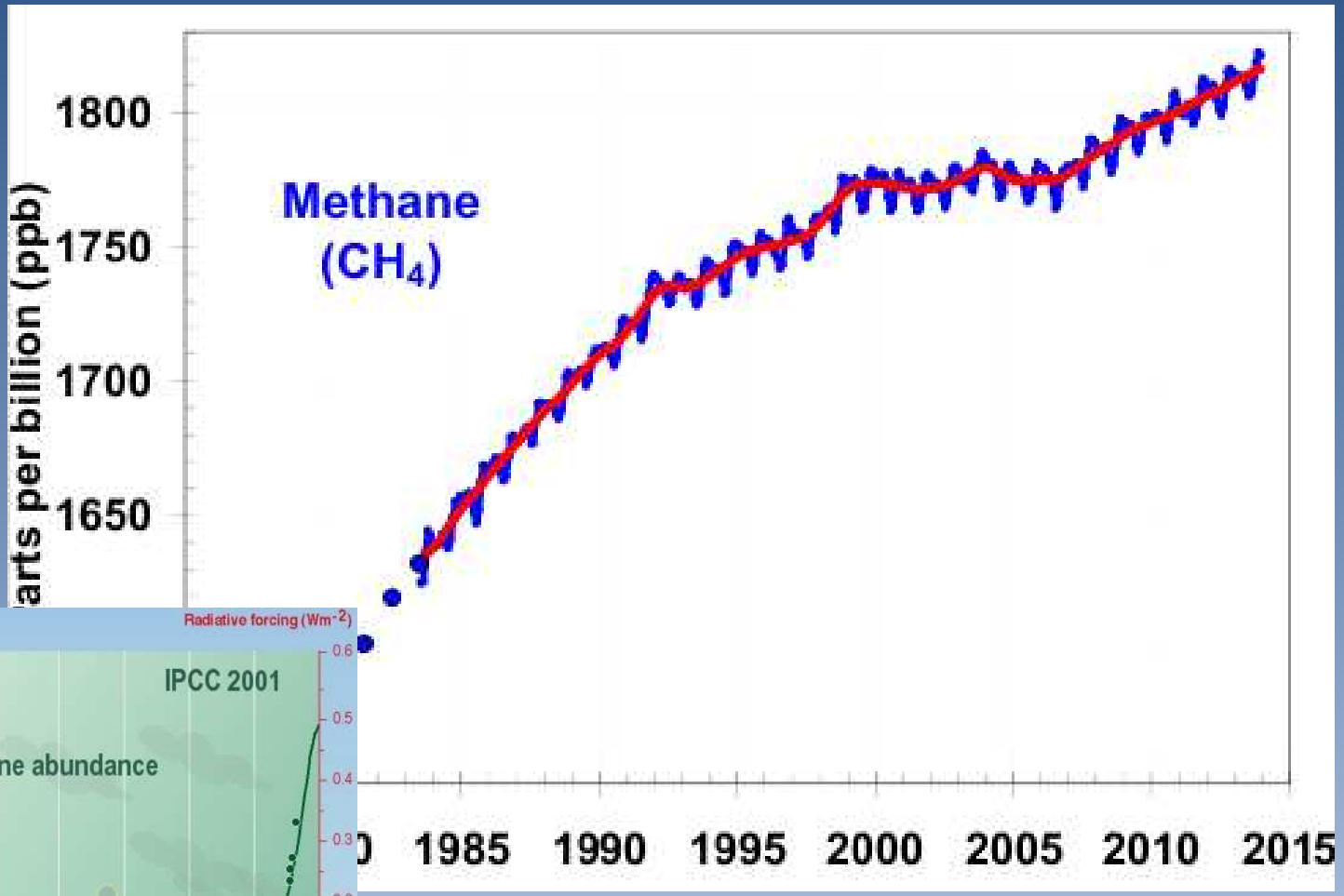
Empirical: real measured data

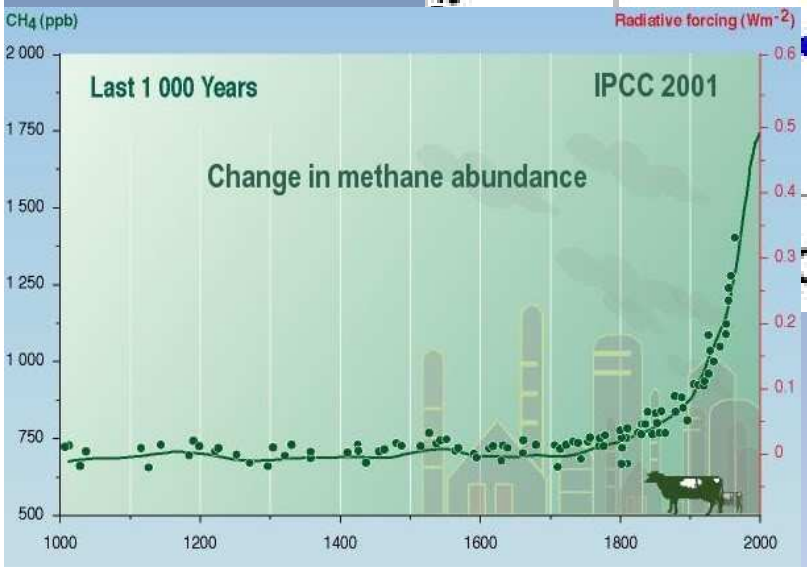
Lest we forget: CO_2 is still going up



http://en.wikipedia.org/wiki/Keeling_Curve

What about Methane?

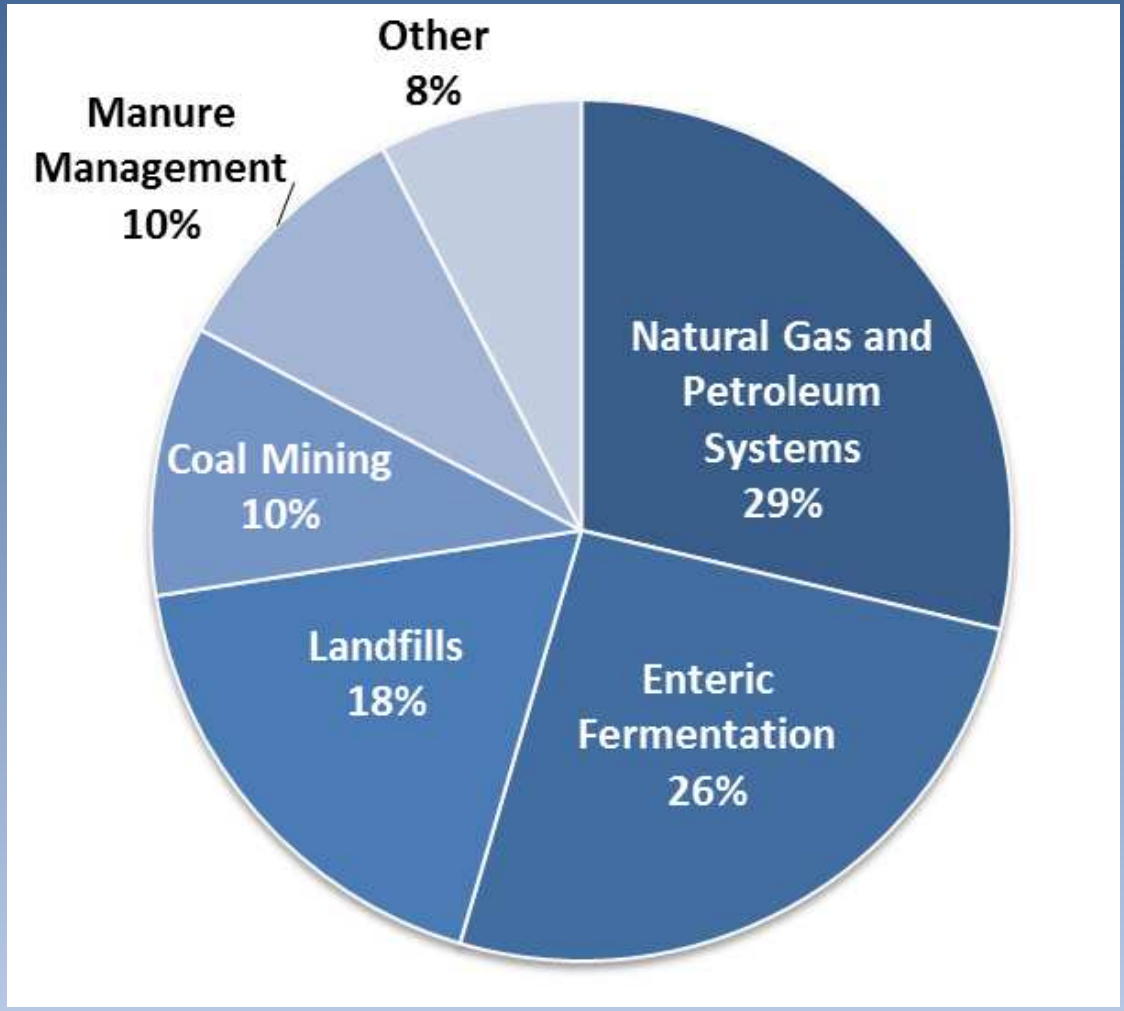




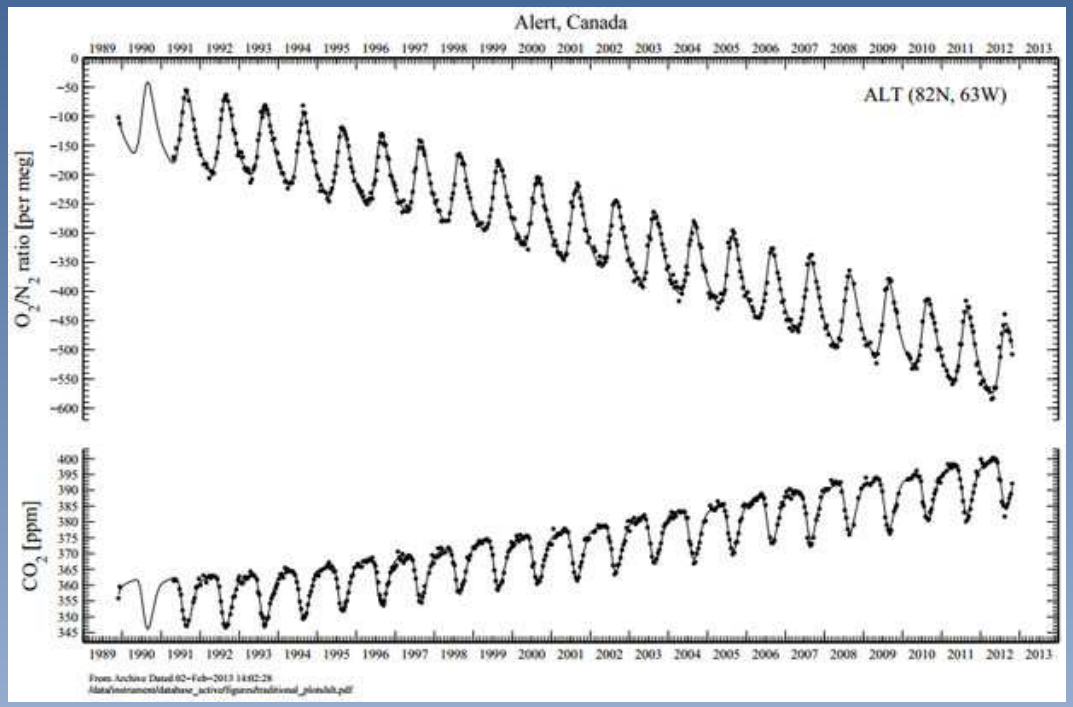
http://www.esrl.noaa.gov/gmd/aggi/aggi.html

http://clathrates.blogspot.com/2012/04/threat-of-methane-release-from.html

SOURCE OF METHANE

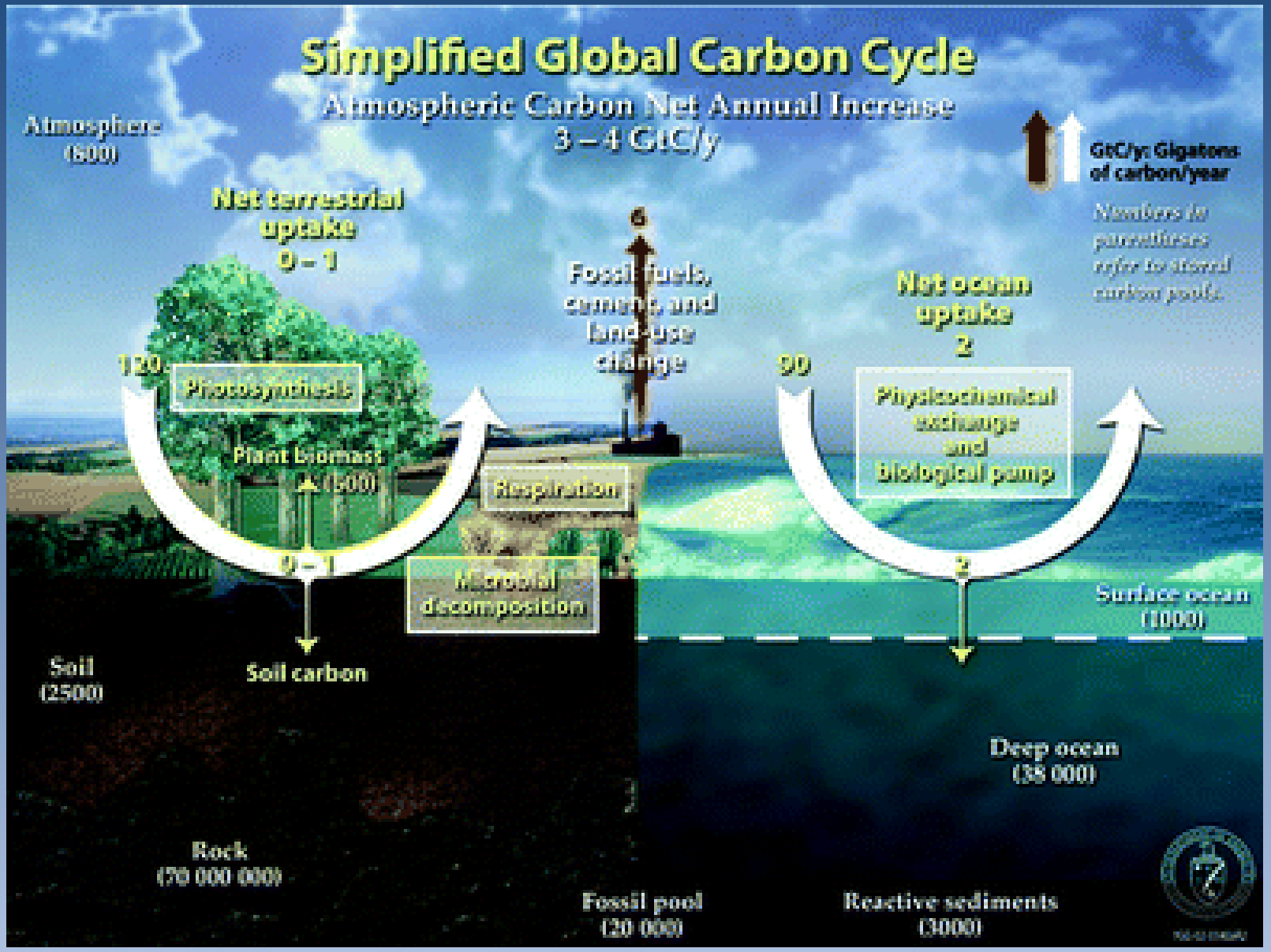


Oxygen used by burning



The observed downward trend is 19 'per meg' per year. This corresponds to losing 19 O_2 molecules out of every 1 million O_2 molecules in the air/year.
http://scrippso2.ucsd.edu

4. Ocean Acidification



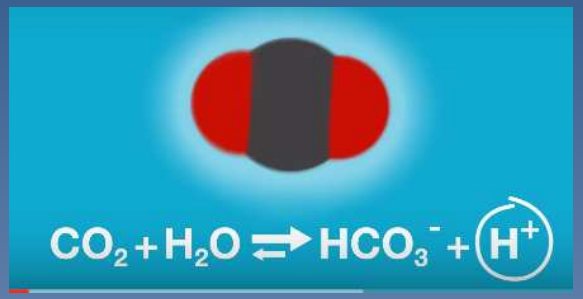
http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Uptake

Ocean acidification

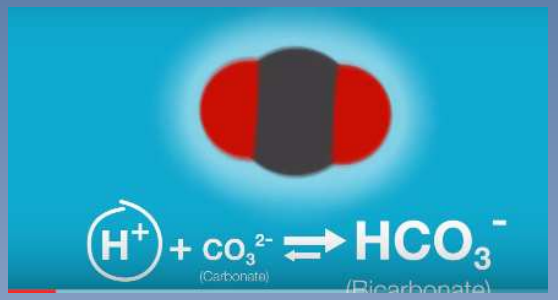
- Web page post Monday October , 2015 (and fb)
- Let's start with a video: https://youtu.be/W1TZ8g8JYVU from http://www.skepticalscience.com/ocean-acidification-global-warming.htm

VIDEO HIGHLIGHTS: Ocean acidification

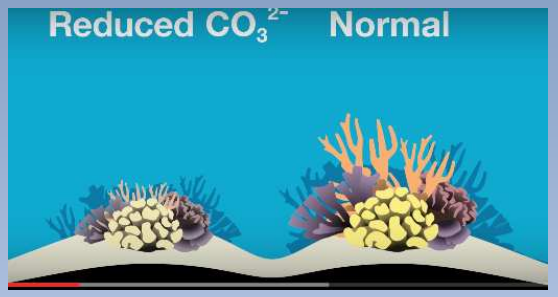
- Adding CO_2 adds H^+ ions making water more acidic (lowers pH)



- This in turn reduces CO_3^{-2} ions



- reducing CO_3^{-2} makes it more difficult for organisms to make their shell – especially aragonitic ones



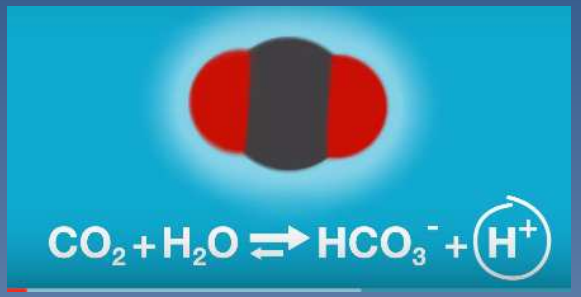
http://www.skepticalscience.com/ocean-acidification-global-warming.htm

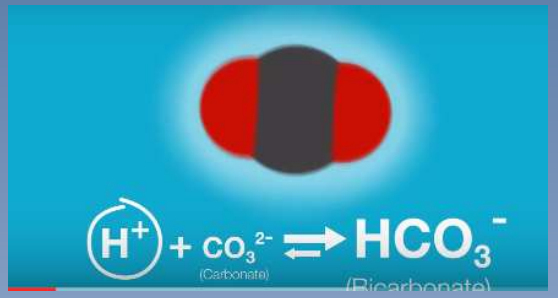
Continued

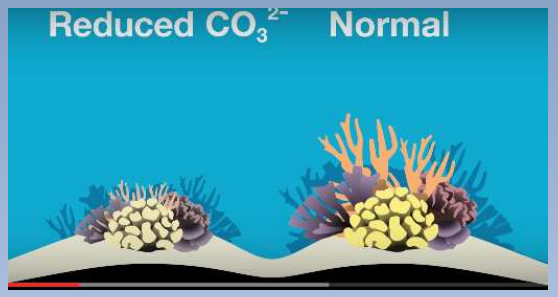
- Takes hundreds of years to equilibrate from weathering – or buffering from the deep sea carbonates as we saw in the PETM

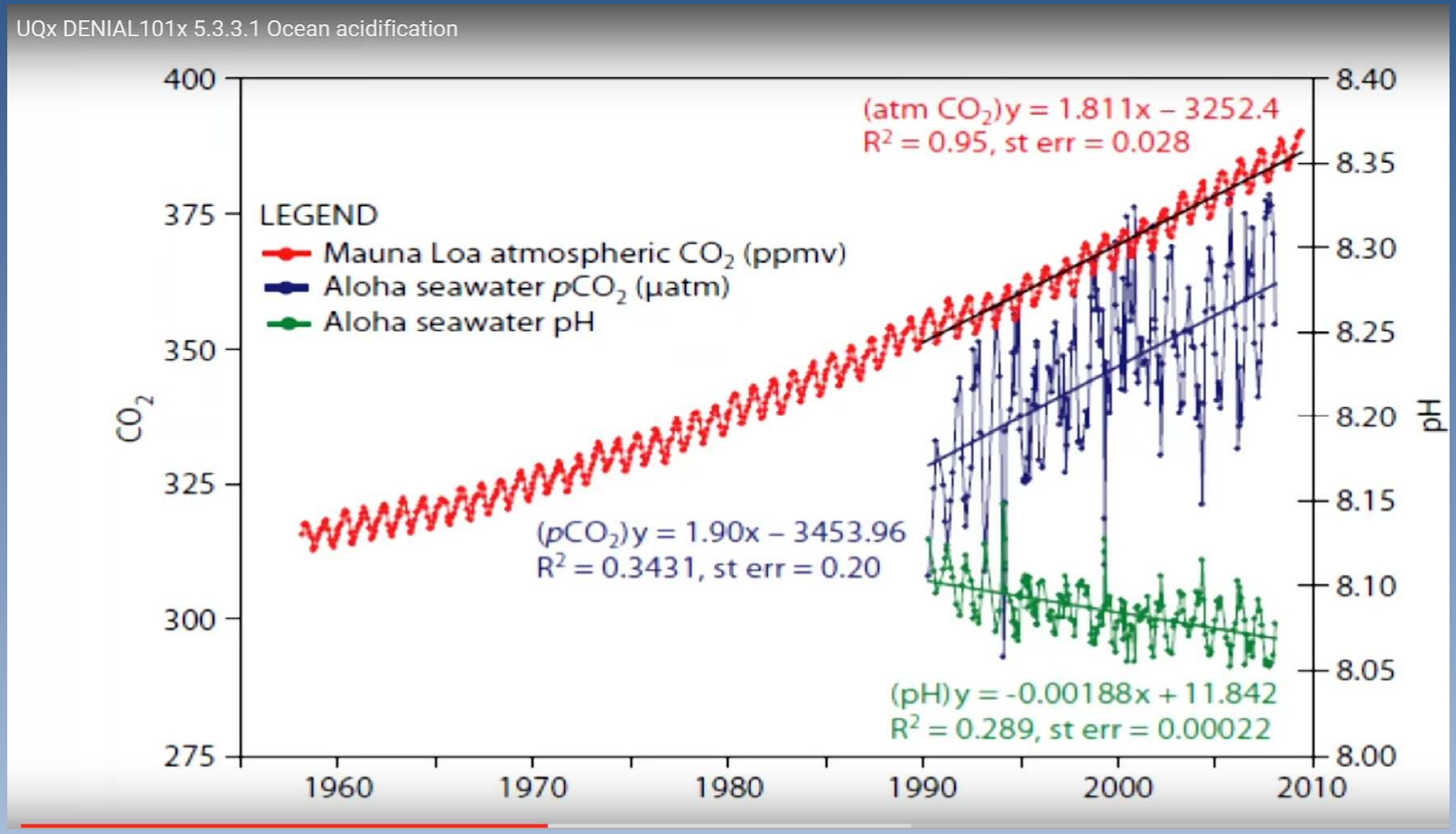
- 0.1 decrease in pH = 26% CO_3^{-2} ions

- reducing CO_3^{-2} makes it more difficult for organisms to make their shell – especially aragonitic ones

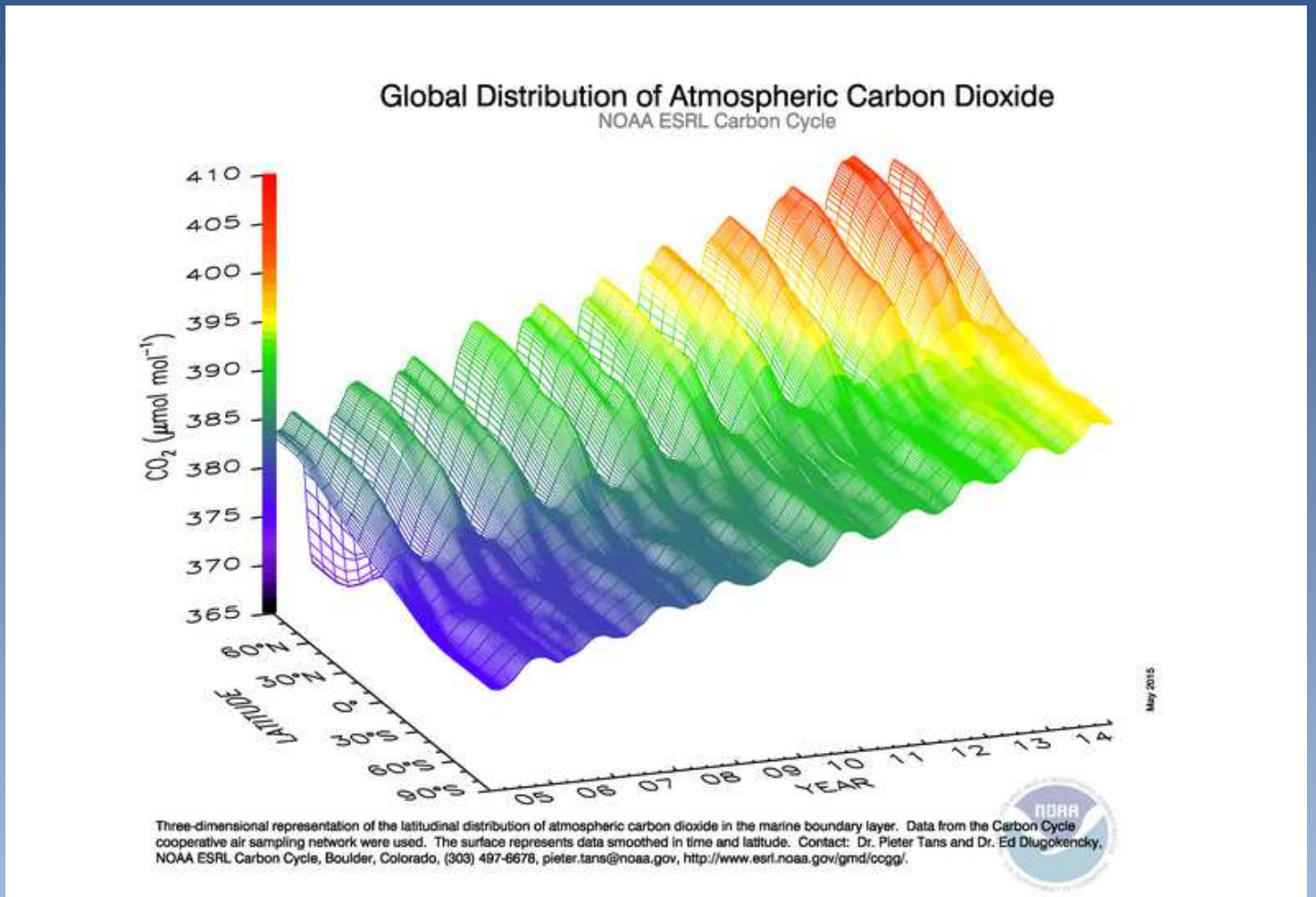




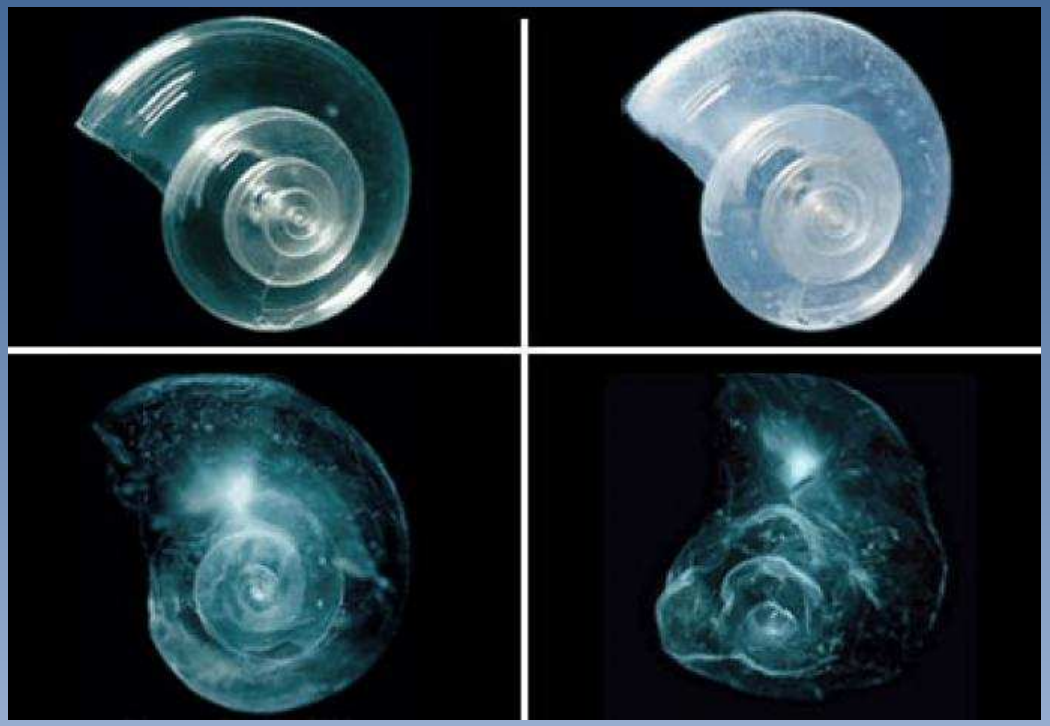




http://www.skepticalscience.com/ocean-acidification-global-warming.htm


Global Distribution of Atmospheric Carbon Dioxide
NOAA ESRL Carbon Cycle
410
405
400
395
390
385
380
375
370
365
CO_2 (μmol mol^{-1})
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
05
06
07
08
09
10
11
12
13
14
YEAR
May 2015
NOAA
Three-dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the Carbon Cycle cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Contact: Dr. Pieter Tans and Dr. Ed Dlugokencky, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

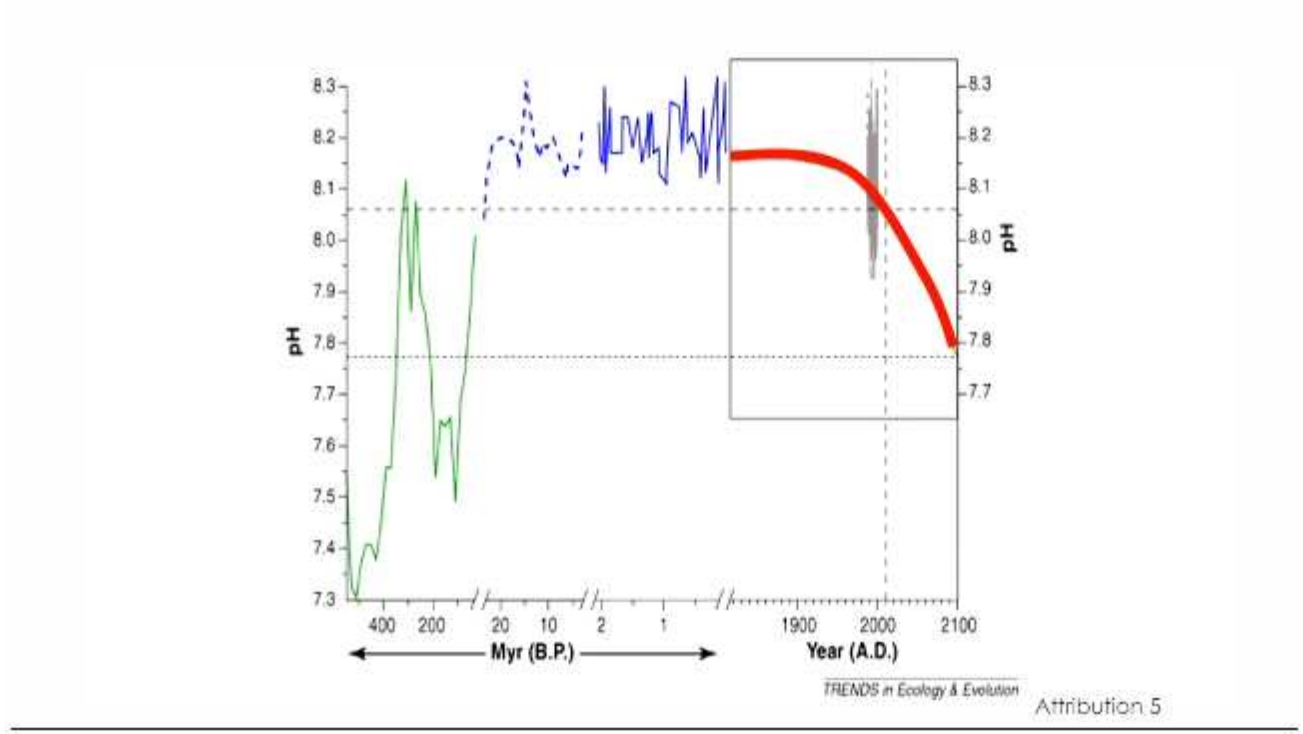
Pteropods



http://ocean.si.edu/ocean-acidification?gclid=Cj0KEQjw-b2wBRDcrKerwe-S5c4BEiQABprW-CHiUm54_8lcDb8ns9yN_W-5pYHfqqSf7QUb6MFohssaAmCM8P8HAQ

pH through time

Here is a related lecture-video from Denial101x - Making Sense of Climate Science Denial



Attribution 5

Ocean acidification

- $CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO^{-}_3$ [1]
- H_2CO_3 is carbonic acid - a relatively weak naturally occuring acid that forms by the reaction between water and carbon dioxide: $H_2O + CO_2 = H_2CO_3$ [2]
-

Unprecedented rates of change

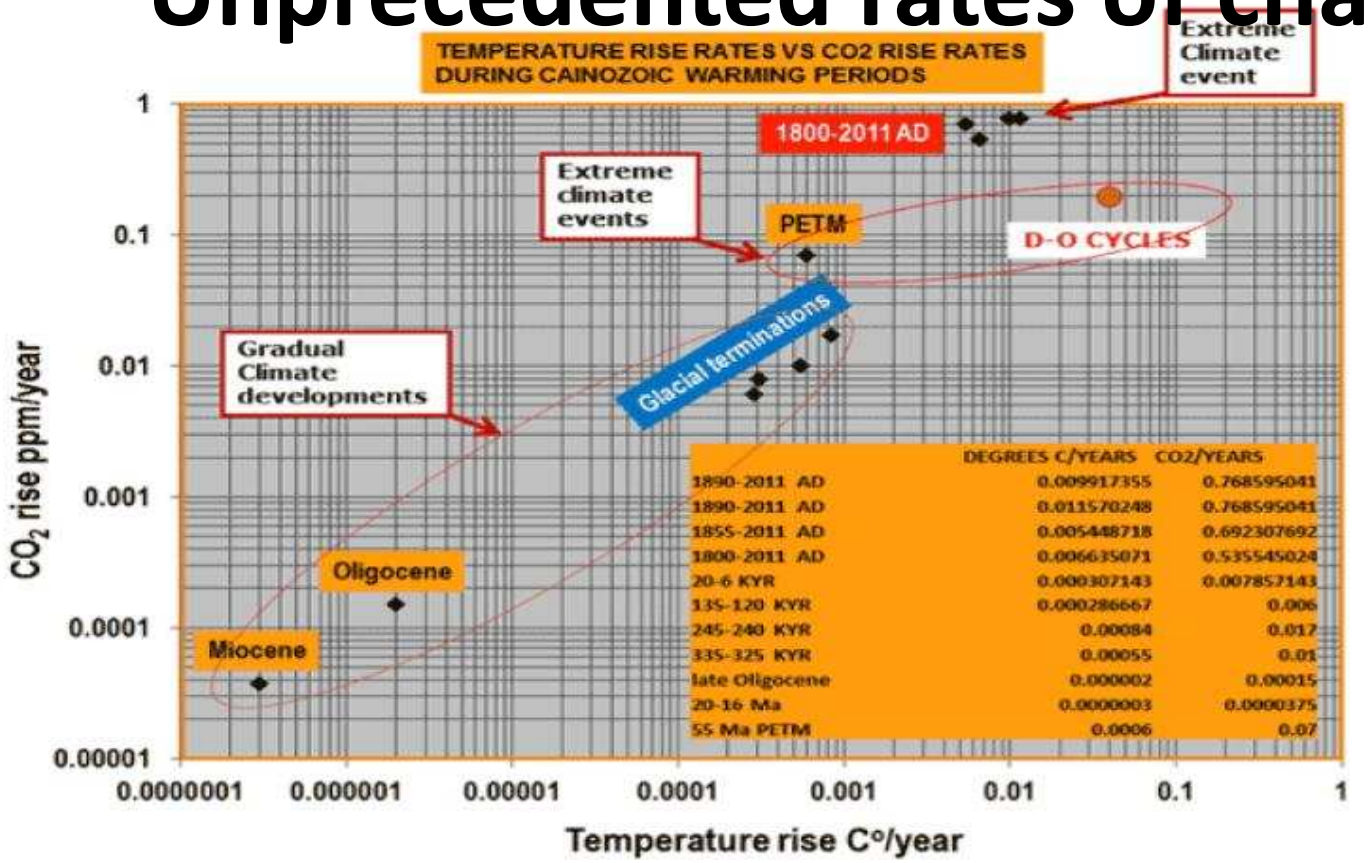


Figure 2: Relations between CO_2 rise rates and mean global temperature rise rates during warming periods, including the Paleocene-Eocene Thermal Maximum, Oligocene, Miocene, glacial terminations, Dansgaard-Oeschger cycles and the post-1750 period.

Past and present; future estimates

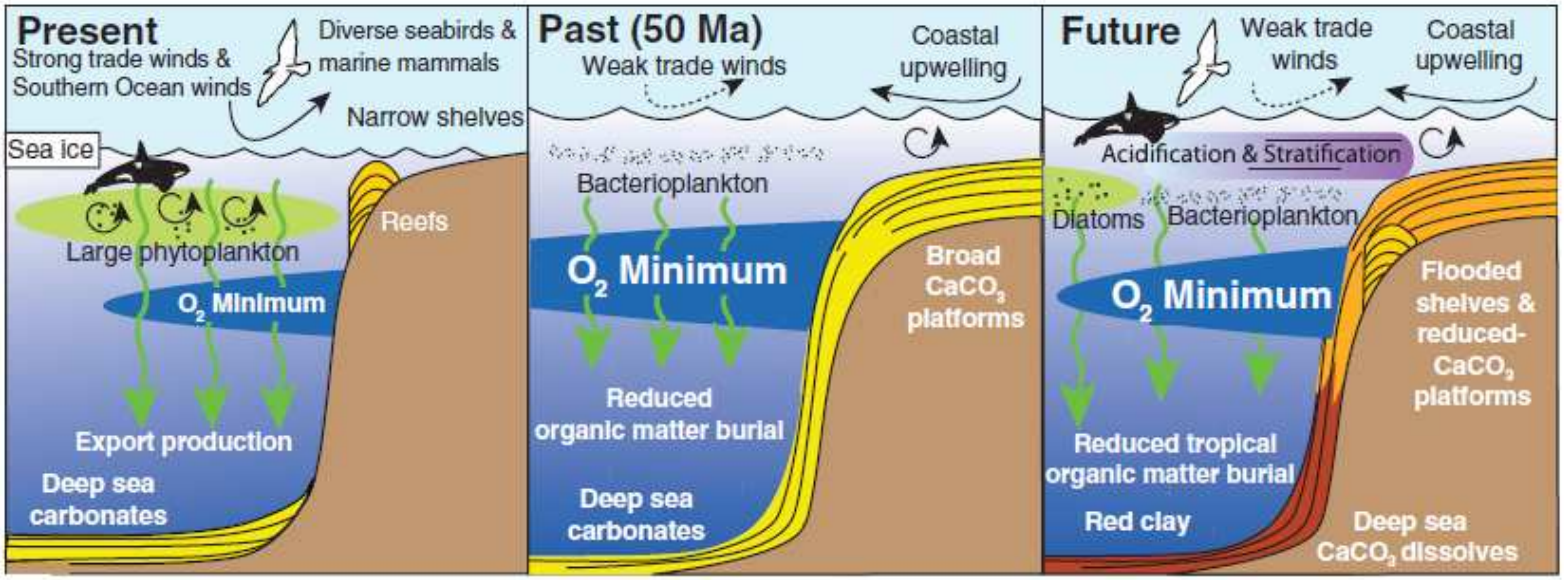
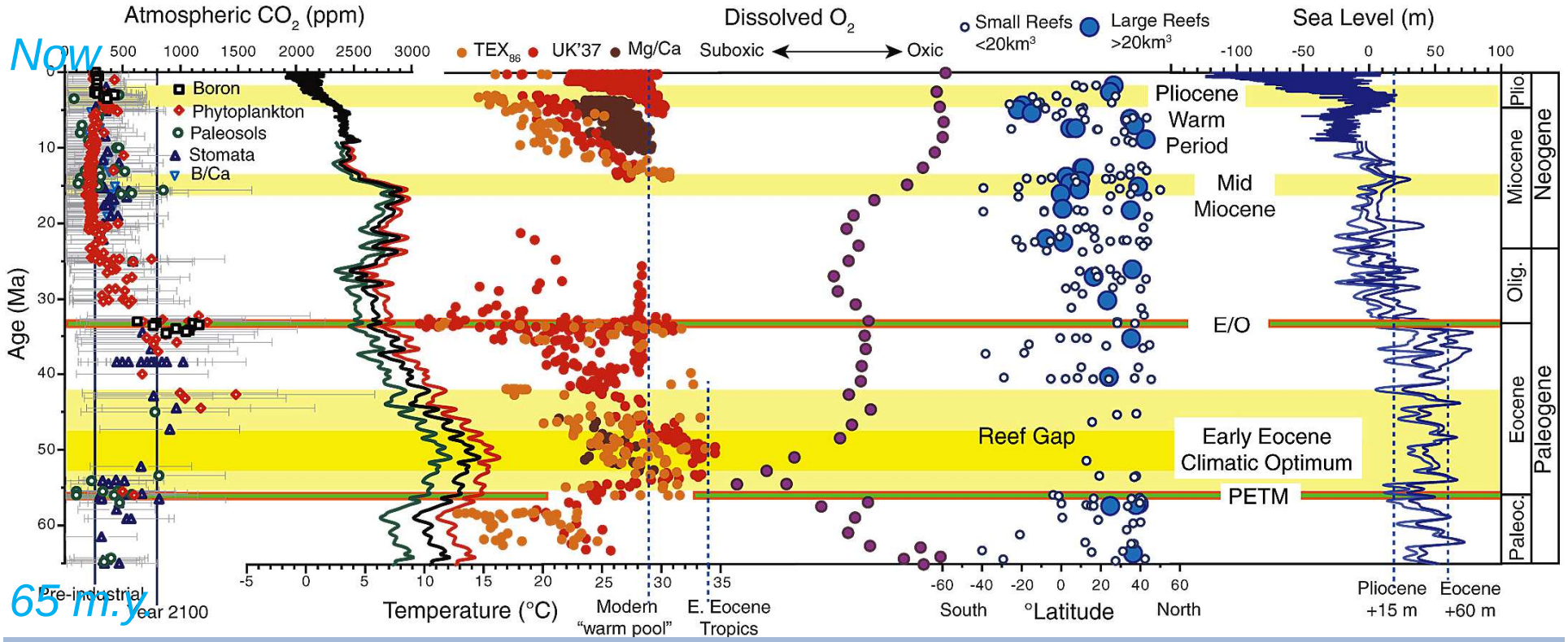


Fig. 1. Comparison of present, past, and future ocean ecosystem states. In the geologic past (middle panel), a warmer, less oxygenated ocean supported longer food chains based in phytoplankton smaller than present-day phytoplankton (left panel). The relatively low energy transfer between trophic levels in the past made it hard to support diverse and abundant top predators dominated by marine mammals and seabirds, and also reduced deep-sea organic matter burial. Equilibration of weathering with high atmospheric pCO_2 allowed carbonates to accumulate in parts of the deep sea. Reef construction was limited by high temperatures and coastal runoff even as high sea level created wide, shallow coastal oceans. In the future (right panel), warming will eventually reproduce many features of the past warm world but will also add transient impacts such as acidification and stratification of the surface ocean. Acidification will eventually be buffered by dissolving carbonates in the deep ocean, which create carbonate-poor "red clay." Stratification and the disappearance of multiyear sea ice will gradually eliminate parts of the polar ecosystems that have evolved in the past 34 million years and will restrict the abundance of short–food chain food webs that support marine vertebrates in the polar seas.

R. Norris et al., Science, 2013

History of oceans for last 65 m.y.

We know a great deal about past CO_2 , temp., etc.

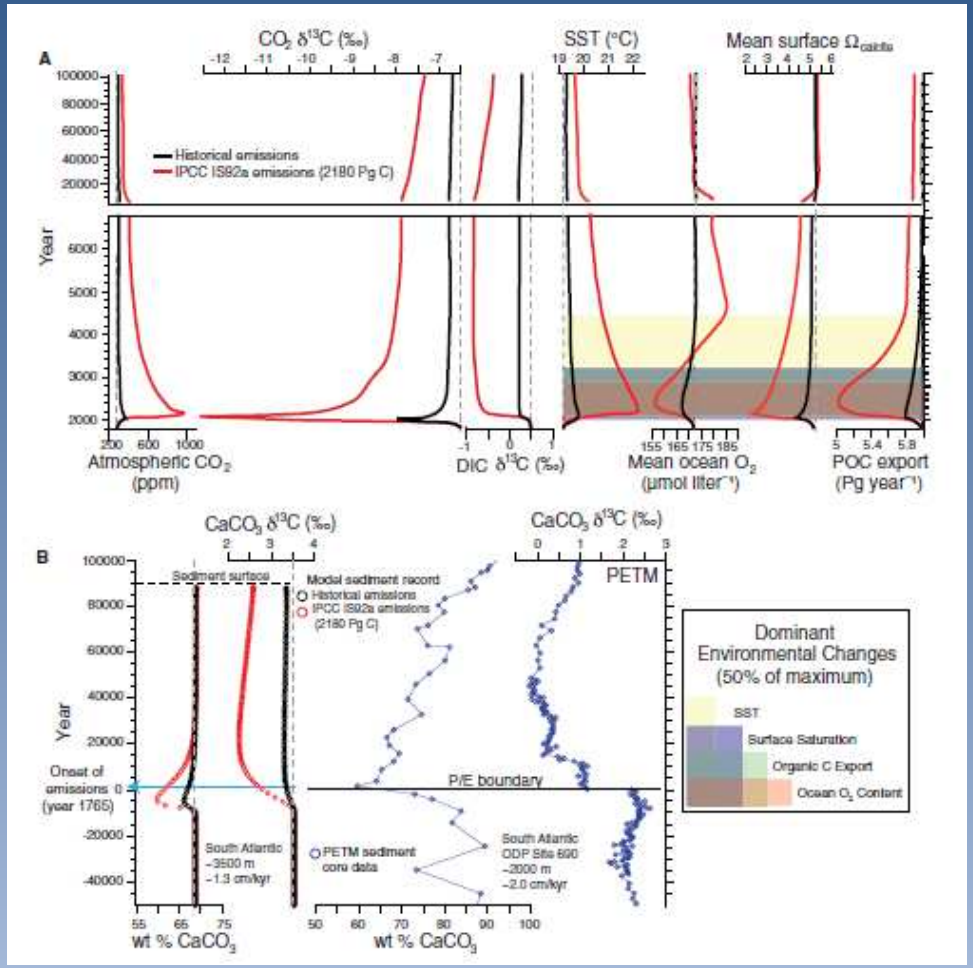


R. Norris et al., Science, 2013

History of oceans for last 65 m.y. and 100,000 year projections into the future

Using the past to model the future

…and a SEGWAY to Modeling



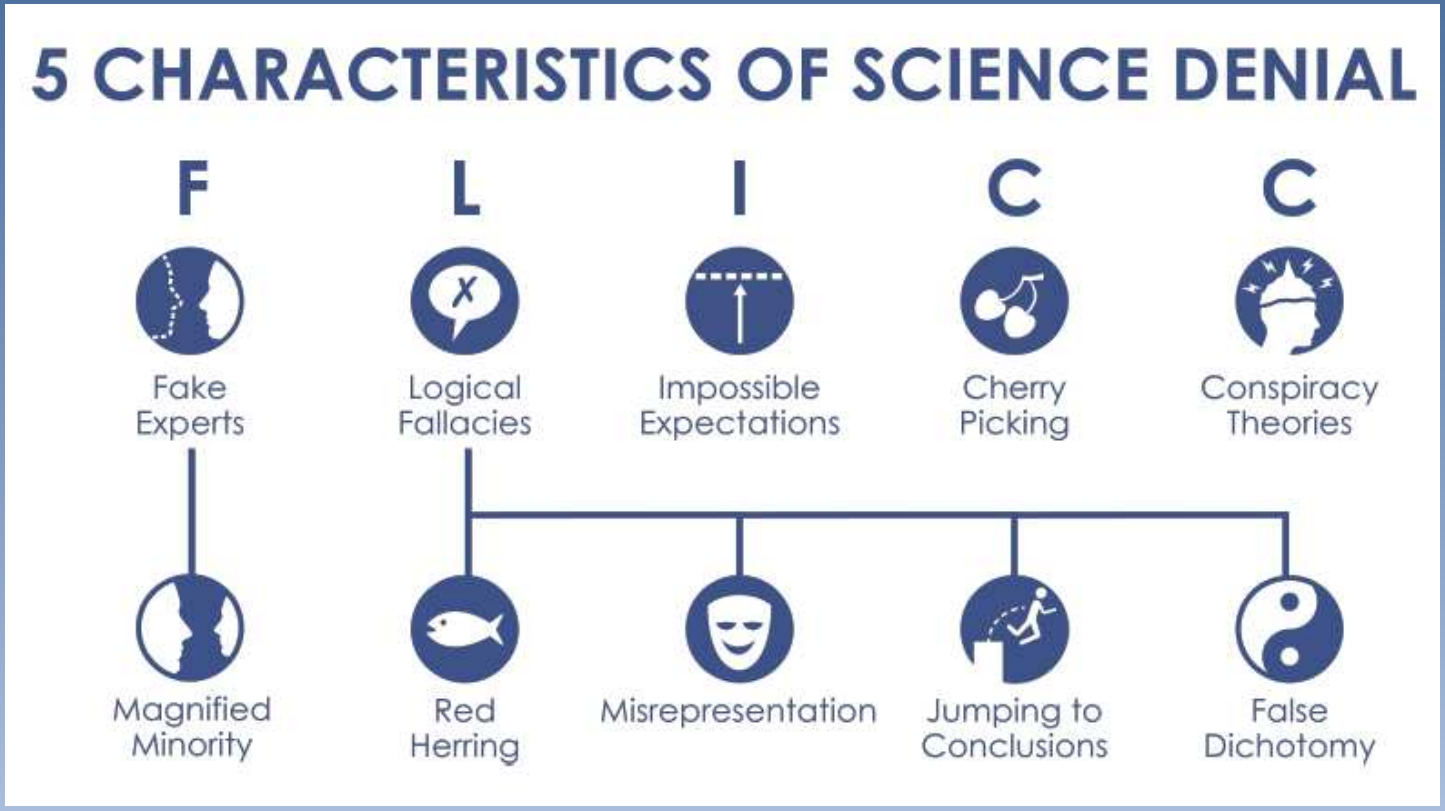
R. Norris et al., Science, 2013

Full list of Videos from Skeptical Science

http://www.skepticalscience.com/denial101x-videos-and-references.html

5. Modeling

But first – terminology you'll see being used regarding misrepresentation



Models – 2 videos

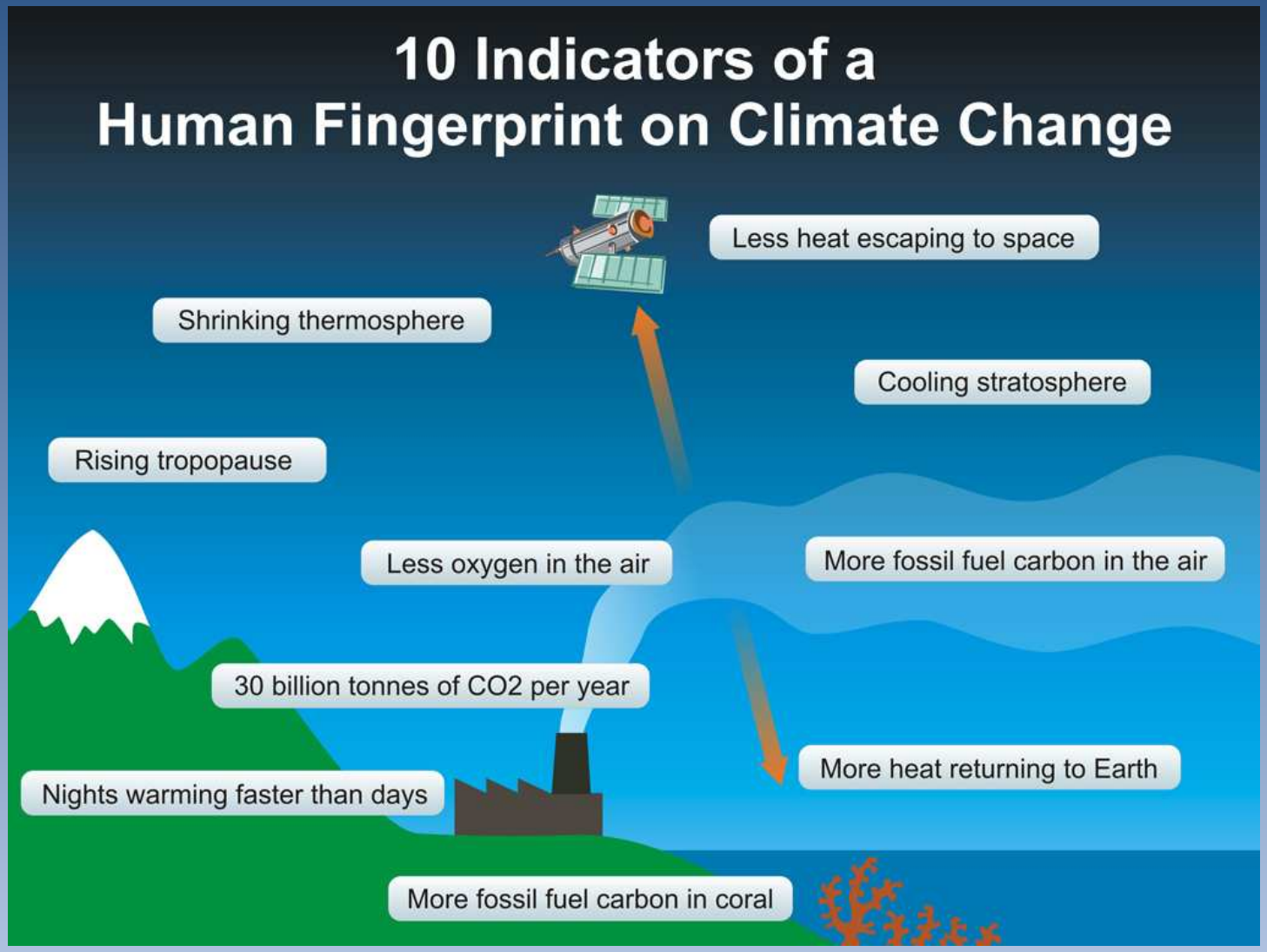
Principles that models are built on – view today
https://www.youtube.com/watch?v=mYU2uawYPlE&feature=youtu.be

From the experts: Climate models – leaving it for you to view at your leisure:
https://www.youtube.com/watch?v=PZo1TYpsy2U&feature=youtu.be

NOAA's Science On a Sphere (SOS) http://sos.noaa.gov/What_is_SOS/index.html ; used at DMNS where I've been co-developing a climate change playlist, soon to be released. In the meantime see http://spaceodyssey.dmns.org/exhibitsprograms/interactives-exhibits/sos.aspx

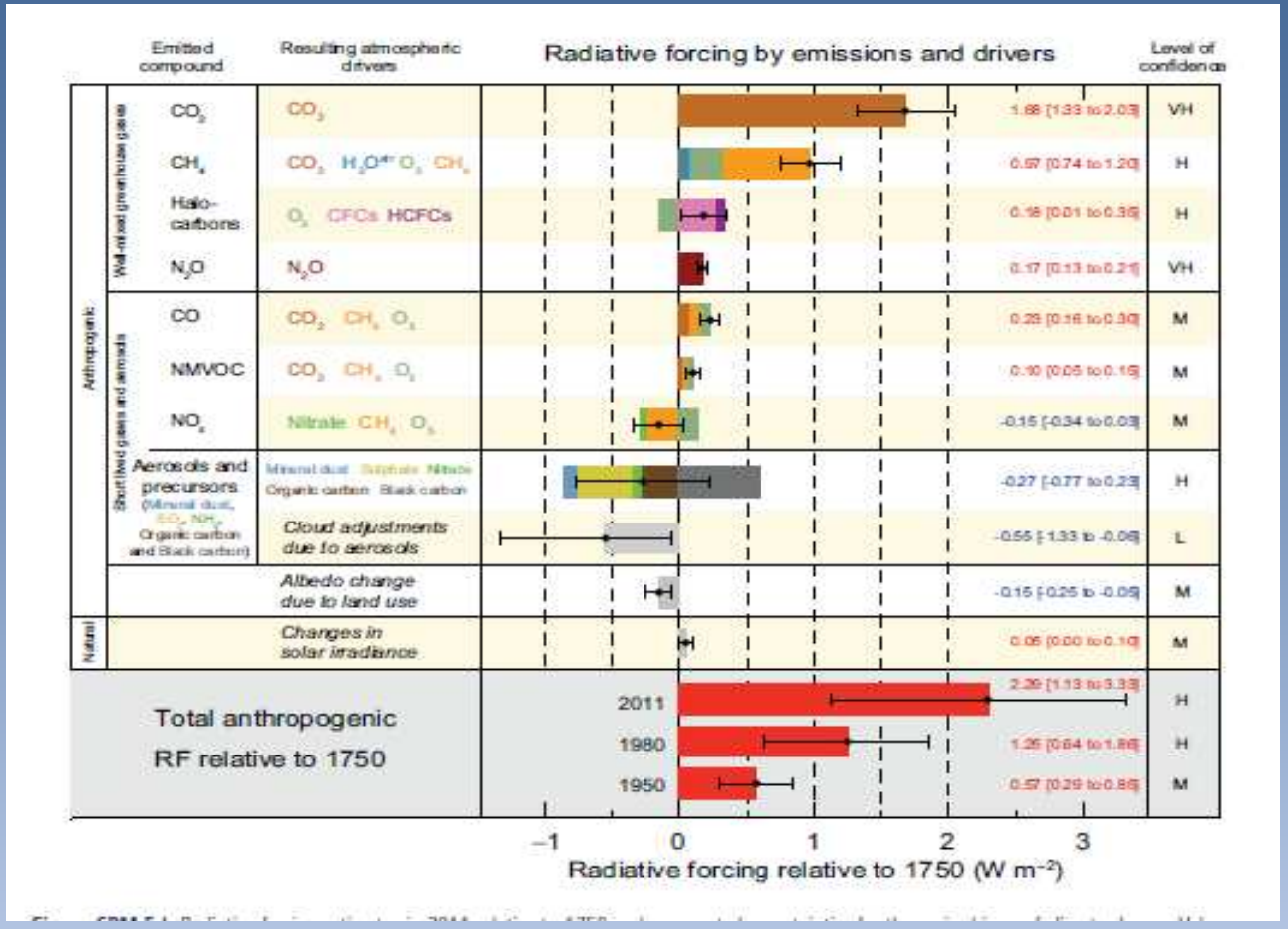
Full list of Videos from Skeptical Science

http://www.skepticalscience.com/denial101x-videos-and-references.html


10 Indicators of a
Human Fingerprint on Climate Change
Less heat escaping to space
Shrinking thermosphere
Cooling stratosphere
Rising tropopause
Less oxygen in the air
More fossil fuel carbon in the air
30 billion tonnes of CO2 per year
More heat returning to Earth
Nights warming faster than days
More fossil fuel carbon in coral

1: THE CLIMATE IS WARMING

- **Drivers, aka forcings (causes)**



Intergovernmental Panel on Climate Change
IPCC

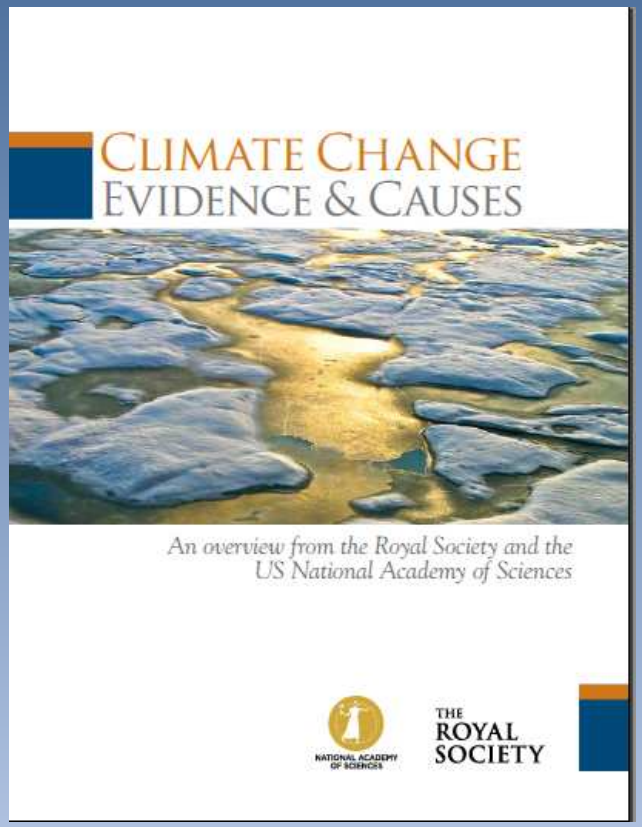
- http://www.ipcc.ch/report/ar5/ - three working groups:
  1. WG I: Physical Science Basis – what we've been dealing with thusfar
     - Especially headlines for policy makers and chapters 5 (paleoclimate), 6 (Carbon) and 9 (models) that can be found at http://denverclimatestudygroup.com/?page_id=63
  2. WG II: Impacts, Adaptations and Vulnerability; Part A: Global and Sectoral Aspects
  3. WG III: Mitigation of Climate change – in coming weeks

- Synthesis report – my other PowerPoint based on http://www.ipcc.ch/report/ar5/syr/

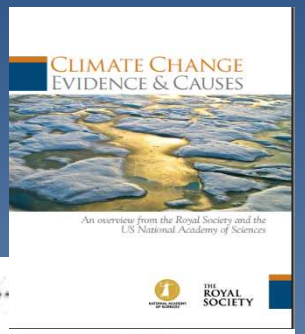
Joint U.S. National Academy of Science and Royal Society 20-point summary:

- OR: *Joint U.S. National Academy of Science and Royal Society 20-point summary: 20-point Climate-Change Summary (pdf) – summarized in the following 3 slides*

Joint U.S. National Academy of Science and Royal Society 20-point summary:



20
Q/As
to follow
this slide



1 Is the climate warming? .....

2 How do scientists know that recent climate change is largely caused by human activities? .....

3 CO_2 is already in the atmosphere naturally, so why are emissions from human activity significant? .....

4 What role has the Sun played in climate change in recent decades? .....

5 What do changes in the vertical structure of atmospheric temperature—from the surface up to the stratosphere—tell us about the causes of recent climate change? .....

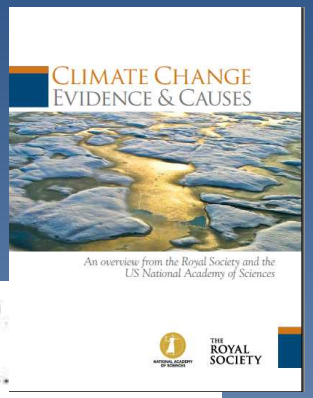
6 Climate is always changing. Why is climate change of concern now? .....

7 Is the current level of atmospheric CO_2 concentration unprecedented in Earth's history? .....

8 Is there a point at which adding more CO_2 will not cause further warming? .....

9 Does the rate of warming vary from one decade to another? .....

10 Does the recent slowdown of warming mean that climate change is no longer happening? .....



Joint U.S. National Academy of Science and Royal Society 20-point summary:

- FOR ANSWERS SEE MY OTHER PowerPoint

Joint U.S. National Academy of Science and Royal Society 20-point summary:

- OR: *Joint U.S. National Academy of Science and Royal Society 20-point summary: 20-point Climate-Change Summary (pdf) – summarized in the following 3 slides*

- If we are so concerned about leaving a national debt to our children and grandchildren, and BTW we should be, shouldn't we put the costs of climate change as part of that equation?
- For those that don't accept climate change maybe it would be a good thing to limit CO_2 into the atmosphere anyway, especially at the rates we are putting it into the atmosphere – BECAUSE OF OCEAN ACIDIFICATION issues and the law of unintended consequences!

A Climate knowledge quiz:

- http://www.csmonitor.com/Environment/2014/0827/Climate-change-Is-your-opinion-informed-by-science-Take-our-quiz/